NIAB TAG



Cover Crops

A practical guide to soil and system improvement

2016/17

In association with

Kellogg's ORIGINS

Kellogg's Origins™
Natural Heritage

Introduction

This NIAB TAG and Kellogg's Origins™ publication is a practical guide to the use of cover crops for soil and system improvement. It provides information on the selection and management of cover crop options. Cover crops can (among other things) help to increase resource use efficiency, improve system management/resilience, benefit environmental goals and increase yield/economic returns. Origins™ farmers are working with NIAB TAG to translate research into practice and to quantify the delivery of key benefits.

The guide provides information based on current understanding on how to select, deploy, manage and make the most of specific cover crops against identified end uses. Guidance has been generated from a range of sources including research, grower feedback and other expert opinion. There may be a need to amend specific practices for individual farm situations.

It also serves to support and inform on-farm decision making and will be developed further in collaboration with field activities and feedback from the Origins™ farmers.

The focus is primarily on the use of autumn sown cover crops used ahead of spring sown crops, but also features some aspects of cover crop use in wider scenarios. To use the document select the cover crop goal which best describes your objective; then use the decision guides to select an appropriate cover crop species or mix. The cover crop options are suggestions and further ingredients or particular agronomy and management inputs may be required to help tailor the selection to a particular circumstance on farm.

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Costs and returns

Cover crops can provide benefit across the rotation (e.g. mitigating pollution, reducing erosion and improving soils/habitat), but direct financial benefit is most easily gauged against yield improvement in following crops. While some variation is expected, the following is a provisional guide based on research, farm feedback and expert opinion.

This section gives an indication of both yield and potential margin changes that would be needed to deliver a financial benefit.

Response

Benefits from cover crops accrue through improvements in nutrient cycling, water retention, soil structure, soil biology and other parameters. Finding positive changes in these areas is a useful indication of a direction of travel and is often detectable before yield responses. However, yield is the best absolute measure and is often seen in crops following cover crops, but also frequently in subsequent crops across the rotation; responses may require repeated cycles of cover crop use to become fully apparent.

Yields

Findings from longer term studies at NIAB suggest:

- Yield response in the crop following the cover crop will vary with cover crop, following crop type, season and management. Some following crops have shown little response and others more consistent yield improvements.
- Research examining the yield response in spring barley following an autumn legume cover crop was assessed in NIAB TAG National Agronomy Centre research at Morley in Norfolk over four years (i.e. the trial was repeated in each of four seasons). While responses in individual seasons varied, a mean yield response of c. 0.3 t/ha was seen in spring barley following use of a legume cover crop. This response was achieved with a 'farm standard' nitrogen (N) dose (150 kg/ha) applied to the spring barley. Similarly UK trial data from Shah *et al.* (2015), demonstrated a yield response of c. 0.6 t/ha in a spring barley crop where 150 kg/ha N had been applied following an autumn brassica cover crop, and field strip research at The Allerton Project (Loddington, Leicestershire) by the Game and Wildlife Conservation Trust (GWCT) demonstrated mean yield responses in spring oats of c. 0.5 t/ha following brassica based cover crops (compared to an over-winter stubble).
- Longer term NIAB TAG New Farming Systems research at Morley (running since autumn 2007) has also shown responses in wheat crops behind the crop following the cover crop (i.e. a rotational scenario of autumn sown cover crop, spring sown break crop and then autumn sown winter wheat). The response will again vary with cover crop type, season, repeated use and management; however, studies have suggested yield responses of the order of 0.3 t/ha. (at standard N doses) following legume and brassica cover crops can be detected.
- Linking these research findings together gives an estimate of potential cumulative grain return of c. 0.5-0.75 t/ha over cereal crops following the use of a cover crop.
- In addition to the direct financial benefits, cover crops can also provide wider value on farm (e.g. reduced soil erosion risk and improved surface drainage) and potentially contribute to longer term 'climate smart' improvements to soil (e.g. improved workability, moisture retention and soil organic matter) and the overall farm system (e.g. greater resilience).

Grain value

The value of 0.5 t/ha of grain depends on the mean grain price over the two crops. Examples of value against a range of prices are set out in Table 1; this indicates what cover crop cost would cover the gain (i.e. a break even point). Table 2 sets out the yield increase needed to break even at a range of potential cover crop costs.

Table 1. The value of grain yield margin response (£/ha) for a range of mean grain prices (£/t) at a series of anticipated yield benefits (t/ha).

Grain value per tonne (£)	80	100	120	140	160	180
Yield benefit expected (t/ha)						
0.3	24	30	36	42	48	54
0.4	32	40	48	56	64	72
0.5	40	50	60	70	80	90
0.6	48	60	72	84	96	108
0.7	56	70	84	98	112	126

Table 2. Yield response required (t/ha) for a range of sample cover crop costs (£/ha) at specimen grain prices (£/t).

Grain price (£/t)	80	100	120	140	160	180
Sample cover crop cost (£/ha)						
20	0.25	0.20	0.17	0.14	0.13	0.11
40	0.50	0.40	0.33	0.29	0.25	0.22
60	0.75	0.60	0.50	0.43	0.38	0.33
80	1.00	0.80	0.67	0.57	0.50	0.44
100	1.25	1.00	0.83	0.71	0.63	0.56

Costs

These can vary substantially but, in work undertaken at The GWCT Allerton Project in Leicestershire and at NIAB, seed costs have varied from £15-60/ha. Costs of establishment and management systems also vary and should be guided by condition and requirement. Establishment systems range from £15-30/ha for broadcasting/direct drilling based systems to over £40/ha for combi-drilled systems.

Input costs are generally low but may range from £0-30/ha including application costs (e.g. where starter fertiliser and pest protection are needed). Growers should calculate sample costs based on their own systems, but specimen costs would often be £50-70/ha with a potential range of £30-130 at the system extremes.

Wider benefits

The financial returns listed here do not include any wider benefits (soils, weeds, habitat, soil organic matter (SOM) etc). While there is a clear benefit, for example, to improvements in soil organic matter or reduced soil erosion, the financial implications of this are difficult to resolve and are likely to vary with season and circumstance. In addition, financial benefits against the use of cover crops can also be accrued though environmental schemes; the additional benefits are also not included in these calculations.

Case study

Kellogg's Origins™

Phil Jarvis is Head of Farming for the Game and Wildlife Conservation Trust's Allerton Project, based at the Loddington Estate in Leicestershire. The estate is also a LEAF Innovation Farm and the Defra SIP mixed arable and livestock Study Farm.

Size	319 ha – as part of a 900 ha joint farming venture
Soil	Clay soil (Hanslope and Denchworth series with a small amount of Banbury)
Cropping	Winter beans, winter wheat, winter oilseed rape, winter and spring oats
Livestock	280 mule ewes and, through a grazing agreement with a neighbour, a South Devon suckler herd
Staff	Two staff
Machinery	NH 9080 Combine, Caterpillar 765, 7530 John Deere tractor, Dale 4m eco drill, Kuhn fertiliser spreader

The Allerton Project, in association with the Game and Wildlife Conservation Trust (GWCT), was set up in 1992 to carry out public, private and charitably-funded research on the interaction between farming, the environment and wildlife, and to advance industry and public education on these issues. A commercial farming operation runs alongside research and demonstration studies on the effect of farming systems on wildlife, soil conservation, water and environmental habitats.

Since 1992 the soil management strategy on the farm has moved progressively toward non-inversion tillage and more recently single pass (direct) drilling. The next chapter in the farmland research includes resource protection, reducing fuel and energy consumption and increasing soil resilience and organic matter with the aim of working towards a sustainable farming blueprint. This means maximising the value of agrochemical inputs and using more biological inputs from natural processes; our move to include cover crops in our rotation encompasses many of these points. We currently grow oil and tillage radish with some oats, but have been experimenting with other mixes as well.

The cover crop captures nutrients, making them available for following crops and the soil; this improves the soil structure, reduces our erosion risk and there is some evidence that the right sort of cover crop may help with our overall black-grass management strategy. We are following this up with a range of practical trials and demonstrations on farm particularly through the Kellogg's Origins™ project, but also other initiatives such as the Defra SIP platforms.

However, from our experience growing cover crops is not a quick and easy option. When planning a cover crop, especially if direct drilling, we have learnt to take into account the previous cropping and spray regime, particularly with sulfonylureas such as Atlantis which can have a residual effect. Slugs, trash from the previous cropping, and dry conditions can also reduce establishment. You also need to give thought to cover crop destruction and the establishment systems for your following crops.

The economics must also be considered. We often talk about soil resilience, with a robust rotation and soil biology, but we are in the business of profitable food production. Interest in cover crops will be dictated by the gross margins, fixed costs and general profitability of the system. Our aim is also to put some costs on these farming systems; are the additional establishment costs, including an extra drilling, affordable and worthwhile and how does the cover crop compare to other methods of intervention, for example agrochemicals for weed control? Our trials include different crop species, varieties, and seed rates with costs ranging from £20 to £50/ha. We want to look at the impacts of these approaches in the following crops and across the rotation so we can get a better idea of the value as well as the cost.

Selecting your ingredients – choosing your cover crop

Where the cover cropping objective features black-grass, increasingly, it is considered that the use of cover crops as a trap crop (to help deplete the seed bank and improve soil condition) prior to spring cropping can provide a useful and complementary management tool.

Managing weeds and pests

The use of cover crops to help manage weed and pest populations is a developing area; it is in need of further research and may not be suited to all cover crop circumstances. This section will focus ostensibly on weed management scenarios, but will include detail on pest management where appropriate.

There are a number of potential approaches to the management of grass-weeds through the use of cover crops, but essentially, cover crops can be used for short term benefit or longer term strategic weed management; these systems are not necessarily compatible.

AHDB funded research (RD-2012-3789) being delivered through Rothamsted Research and NIAB examines the relative merits and interactions of these options in greater detail.

For longer term strategic management the cover crop is fundamentally a trap crop; the pest, in this case black-grass, is encouraged to establish and thrive, and then, before the pest can reproduce, the pest and the cover crop are destroyed together. The grass weed population is reduced over time by a combination of seed removal from the seed bank, germination and establishment in the cover crop, and natural process of seed death in the soil.

For a shorter term approach, the cover crop can essentially be used to suppress weeds ahead of a following crop. While this can deliver benefit to a following spring crop (perhaps where herbicide options may be more limited) any effect of the cover crop on reducing the number of black-grass plants that germinate and establish, potentially leaves a higher number of seeds in the seed bank, to carry over to the following crops in the rotation.

Current research is comparing the effectiveness of the underlying cropping strategy (e.g. the inclusion of spring cropping or fallows) with the effectiveness of the same system including various cover crop approaches. This will enable the effects of the cover cropping approaches, over and above the underlying strategy, to be demonstrated and quantified. While research remains ongoing, findings and field experience to date suggests that the underlying system changes (e.g. inclusion of a spring crop), along with the wider merits of cover crop use (e.g. use as a trap crop and improvement of soil condition), are delivering the more consistent benefits.

With regard to cultural control of black-grass; if the strategy is to exhaust the seed bank prior to planting a crop (whether that is a spring crop or an autumn drilled crop following a year-long fallow) do not use deep cultivation that will mix the soil profile and reduce the effectiveness of that strategy. If spring cropping is the underlying approach and grass population levels have become a real challenge, pick a spring crop where the weed can be managed effectively. Use of non-selective weed control, both to destroy the weeds before they can set seed and (if relevant) to remove any weed seedlings that are present before the crop is drilled, is essential. In extremely heavy black-grass population sites, consider other options as well as cover cropping; the route may not be appropriate in all scenarios.

A cover crop can act as a trap crop for grass-weeds such as black-grass, but both pest and cover crop must be destroyed before seed dispersal

WEEDS AND PESTS

KEY TO SELECT A SUITABLE COVER CROP/MIX COMPONENT

Managing weed populations (weeds)		Sanitising cover crops (weeds and pests)		Other biological routes (weeds and pests)	
Trap crops (weeds)	**Crop competition**	**Bio-fumigation**	**Trap crops (pests)**	**Allelopathic effects**	**Habitat creation (pests)**
A cover crop that facilitates weed establishment and is then destroyed before the weed can reproduce.	Cover crops that outcompete weeds in some circumstances can help to provide a clean seedbed for the following crop.	Some brassica species have high levels of isothiocanate; this can sterilise soil. Such cover crops can be used against weeds and soil pests.	Some cover crops (notably brassicas) can promote egg hatch in some pest species e.g. this can be effective against certain nematode types.	Some cover crops (e.g. clovers, rye and oats) can have allelopathic activity; inhibiting the germination of weed and other species.	Pest management can also be delivered through improving predator habitat.
Suggested options/ingredients					
A wide range of cover crops can be used for this purpose. Mixtures are common and components could include brassicas, cereals or legumes.	Brassica species (e.g. radish and mustards) that can cover the ground are common; but a range of cover crops could be used.	Choose a specific variety (usually radish or mustard) that is sold for this activity. Research is ongoing in this area and there is a need for more impartial comparative data between types.	Select a variety sold for this activity. Variety choice should be guided by recent research based comparisons (e.g. current levy body research outputs as available).	There is limited current UK field information and further research is needed in this area. Consult specialist cover suppliers for options.	There is potential to use cover crops strategically on farm to provide habitat or even to use companion crops for wide row species.
Other comments (also see agronomy guidance pages for specific suggestions)					
This approach is used frequently and is increasingly thought of as one of the stronger approaches. Mixes need to be open enough to allow weed germination. Origins™ research has also shown starter fertiliser can increase weed populations in cover crops.	This approach needs good, even ground coverage in the field and rotational conflicts can be an issue where brassicas are used. Give particular attention to destruction (to remove weeds in the cover crop) and minimising soil disturbance when drilling to maintain benefits accrued.	Methods of production, destruction and incorporation are important; follow seed supplier guidelines.	Methods of production, destruction and incorporation are important; follow seed supplier guidelines.	Academic research has shown effects but there is little impartial field information on magnitude or comparison between types. Effects can be variable and potentially may impact on weeds and following crops.	Data and farm experience supports the value of predators and French companion crop data has shown changes in pressure with some pests in OSR. Further UK based research is needed in this area.

Environmental goals

Habitat creation: Cover crops provide winter cover and a habitat for birds, mammals and insects as well as grazing opportunities for livestock and wildlife. Predator habitat generation through cover crops can also potentially augment pest management.

A wide range of cover crops can be used for wildlife habitat provision, although some may be better suited to specific goals than others. Selection can be guided through expert advice (e.g. via GWCT www.gwct.org.uk).

Cover crops provide winter cover and a habitat for birds, mammals and insects

Nutrient loss: A range of research projects have shown that nitrogen uptake by cover crops reduces the risk of nitrate leaching losses over winter. Reduced soil run-off also lessens the loss of phosphate attached to soil particles. Recent research carried out on Origins™ sites over two seasons has suggested mean N leaching reductions of c. 43% (2015 mean c. 40% or c. 38 kg/ha N and 2016 mean c. 46% or c. 25 kg/ha N). This is in keeping with other findings in this area. This N will be retained to benefit crops and the wider soil system. A range of cover crops are suited to this purpose, but fast growing non-legume species (e.g. brassicas) are typically used.

The environmental benefits of cover crops can be diverse, although common objectives include habitat provision, the protection of water quality and mitigation of soil erosion.

Soil erosion and water quality: Cover crops provide ground cover during risk periods for soil erosion by wind and/or water. Losses are more likely to occur in autumn and winter when soil moisture and rainfall levels are high. Reducing these losses can benefit the environment by lessening losses of sediment, soil, nutrients and pesticides, which can impact on water quality and habitats. Cover crops help to reduce erosion losses mainly through the provision of ground cover at critical risk periods.

Cover crops can help to reduce erosion losses

As a general guide, once more than a third to one half of the ground is covered, there is a substantial reduction in run-off and erosion risks. Species mixtures, such as oats and brassicas, which grow rapidly in the autumn and provide good ground cover, can be a useful simple tool in such scenarios to help reduce erosion risk. Other mixes can be used to suit circumstance, as long as they provide the required ground cover. These mixes can also often be used to achieve other objectives (e.g. habitat provision).

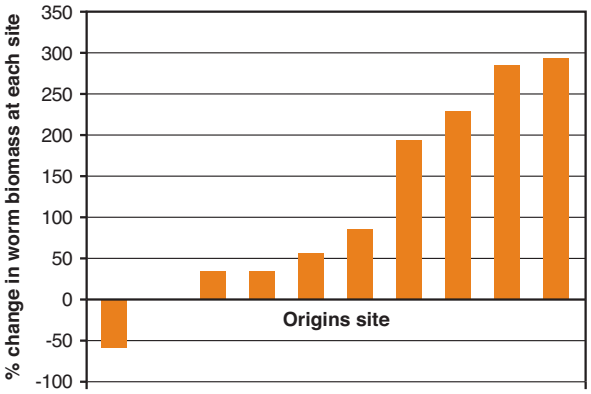
Other considerations: Think about potential conflicts with other crops in the rotation and the management of volunteers in following crops. Where wind erosion is the main issue a cereal cover crop or companion crop (sown with the main crop and then destroyed) can be beneficial. Also consider other methods of erosion management; for example, tramline management (to reduce direct water flow) or strip tillage (leaving stubble between the rows) can also reduce erosion risk.

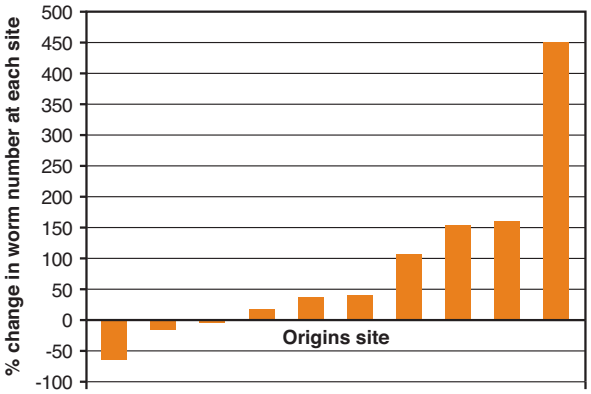
Soil fertility building and nutrition

Cover crops can be used as green manures to add organic material back to the soil. This will help to stimulate and feed biological activity in the soil and, in the longer term, regular use of cover crops can raise soil organic matter content. In the NIAB TAG New Farming Systems programme the use of fertility building cover crops has demonstrated rotational yield and margin (over N dose) improvements from the use of specific approaches.

Chopping a mustard cover crop

Figure 1. The impact of cover crop on earth worm numbers and biomass on Origins™ sites in 2016. Figures above the line are an improvement in worms due to the cover crop. Sites include partial, split and paired field sites.





Field evaluation carried out on Origins™ farms has also shown the use of cover crop to improve earthworm numbers and biomass; a useful indicator of soil biological activity (Figure 1).

Cover crops can also help capture N; this is then potentially available to both following crops and other elements of the soil system and biology. The amount of N released by a cover crop depends on a range of factors, but is influenced by cover crop type, growth, the environment as well as C:N ratio (the carbon to nitrogen ratio in the material) and other biological compounds. Broadly, if the C:N ratio is less than c. 13, net mineralisation is observed and N can become available to plants, but as it increases this availability reduces; as the ratio extends past 26 a net immobilisation can occur (for example N is retained elsewhere in the systems by micro-organisms). The extent to which N contributes to crop yield depends on time of the release as well as amount; this can be too early (may contribute to growth but not yield) or too late (could increase grain protein or still give a yield response in later crops in the rotation).

Cover such as fodder radish can help improve the soil structure

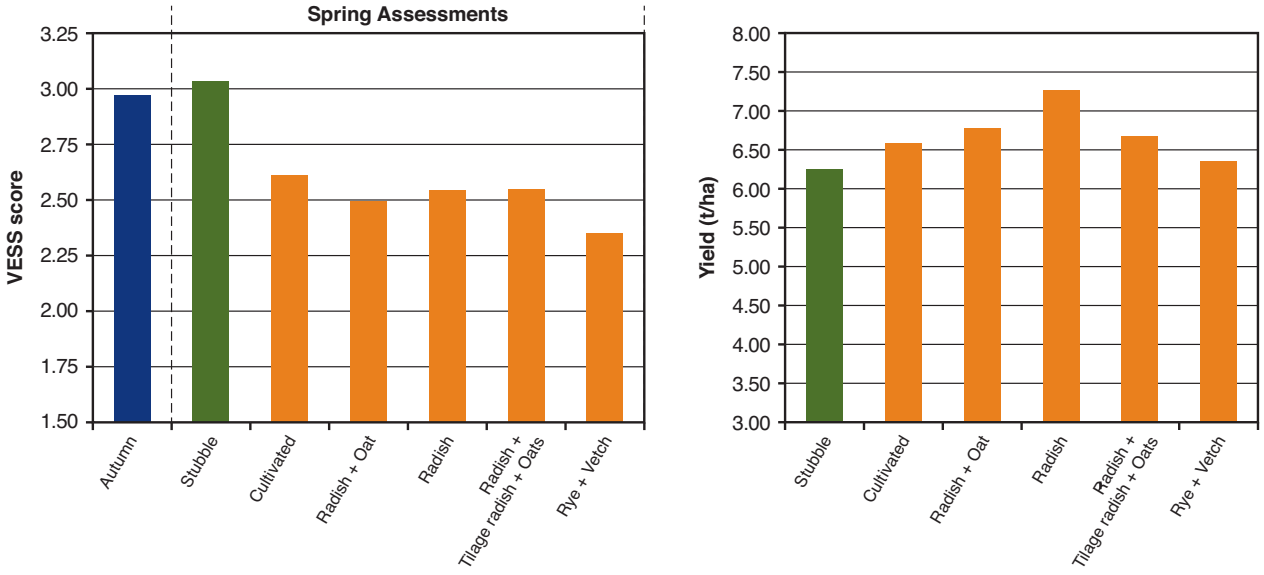
Improving soil structure

Cover crops with a vigorous and active root system can help open up soil, to improve structure. Field evaluation carried on a range of Origins™ farms has shown improvements in both soil structure and reduced variability following the use of cover crops. The VESS (Visual Evaluation of Soil Structure) system has been a useful tool to assess structure quickly and efficiently on farm; a lower VESS score is indicative of a better soil structure. NIAB TAG's Nathan Morris and Hazel Fielding provide further video guidance on this technique at **http://bit.ly/2asXQEt**

Findings from an Origins™ site in 2015 (Figure 2) indicated, in a stubble area, structure remained similar over winter, but that cover cropping improved structure to a similar level to that achieved with an autumn cultivation (potentially lessening the need for cultivations). Mean yield responses of c. 0.5 t/ha (*cf.* stubble area) were also recorded in direct drilled spring oats following cover crop use. When selecting a cover crop for improving soil structure it is important to assess the structural issues and know the extent and depth of any impediments.

Soil improvement through the use of cover crops is a common goal and cover crop choice will be guided by the objective. Goals often feature the use of cover crops as green manures, to exploit organic material additions; benefiting soil biology like earthworms. Alternatively, using root growth to improve soil structure is a common target; in this scenario it is important to assess the structural issues and know the extent and depth of any impediments.

Figure 2. The impact of a range of cover crops compared to an overwinter stubble on VESS (Visual Evaluation of Soil Structure – a lower VESS score is indicative of a better soil structure) pre and post winter and final crop yield (spring oats t/ha) on a Kellogg's Origins™ farm in 2014/15.



The following key highlights potentially suitable options.

SOIL FERTILITY KEY TO SELECT A SUITABLE COVER CROP/MIX COMPONENT

Green manure	Nitrogen (N)	Phosphate (P)	Other nutrients	Improved rooting
Range of cover crop types are suitable as 'green manures' to trap N and add organic material to the soil.	A range of legume species can be used to fix N and in many cases also improve soil structure.	Potential from some polygonums (P scavengers) and legumes (with P cluster rooting).	Cover crops with active rooting can potentially help mine and cycle nutrients.	Improved ability of roots to explore the soil can be of benefit (e.g. lower critical P values).
Suggested options/ingredients				
Oats, phacelia and brassicas (such as mustard or radish) and legumes (faster growing species sown early are more likely to fix N).	Black medick, a range of clovers (e.g. crimson clover), as well as other legumes such as vetch and lucerne. Use of species mixtures is often well suited here.	Buckwheat and lupins are possible options. Certain mycorrhiza can also benefit some species (not brassicas).	Consider species with extensive root systems or mixtures with complementary rooting.	See section on improving soil structure.
Other comments (also see agronomy guidance pages for specific suggestions)				
Growth and biomass are important, but consider incorporation issues. Fast growing species also tend to trap more autumn N.	Early autumn legume sowing is needed to fix N. Legume cover crops can provide some N availability to following crops.	Buckwheat is better suited to spring sowing although autumn use in mixes is possible. Lupins typically need pH <7.	There is little published UK research in this area and further field information is needed.	

SOIL STRUCTURE

KEY TO SELECT A SUITABLE COVER CROP/MIX COMPONENT

Period for cover cropping: Autumn (to be followed by a spring crop)			Spring			Full season fallow		
Where is the main impediment?								
Shallow (c. 0-20 cm)	Deep (c. 20-40 cm)	Very deep (> 40 cm)	Shallow (c. 0-20 cm)	Deep (c. 20-40 cm)	Very deep (> 40 cm)	Shallow (c. 0-20 cm)	Deep (c. 20-40 cm)	Very deep (> 40 cm)
Range of suitable types including cereals, brassicas, legumes and other broadleaf species.	Brassica cover crops (and possibly other deep rooted broadleaf cover crops).	Short duration cover crops are not well suited to this scenario.	Range of suitable types including cereals, brassicas, legumes and other broadleaf species.	Brassica cover crops (and possibly other deep rooted broadleaf cover crops).	Short duration cover crops are not well suited to this scenario.	Range of suitable types including cereals, brassicas, legumes and other broadleaf species.	Brassica cover crops and some legume species.	Potentially brassica and certain legume species.
Suggested options/ingredients								
Oats, phacelia and brassicas such as radish (or possibly mustard) but consider use of mixtures.	Brassicas such as radish (or possibly mustard) but consider use of mixtures particularly if other depths are of interest.	None.	Cereals (rye or oats), legumes (e.g. trefoil, vetch and others) and broadleaf crops (e.g. phacelia or brassicas).	Brassicas such as radish (or possibly mustard) but consider use of mixtures particularly if other depths are of interest.	None.	Oats, legumes (such as trefoil or crimson clover), phacelia and brassicas such as radish (or possibly mustard); potentially in mixtures.	Brassicas such as radish (or possibly mustard) or perhaps some clovers or other deep rooted species.	Lucerne or clover (perhaps sweet or red clover) may be suited (and potentially some brassicas).
Other comments (also see agronomy guidance pages for specific suggestions)								
Think about soil incorporation and rotational conflicts. Brassicas in particular can also reduce autumn nitrate leaching.	Consider brassica bolting and biomass issues. Brassica crops can also be very effective at reducing nitrate leaching.	Timeframe is too short.	Think about incorporation, rotational conflicts and crop duration.	Consider duration/rooting potential as well as seed set and volunteer risk.	Timeframe is too short.	Mixes including legumes would be relevant.	Research with legumes in this role is limited.	While research suggests this approach has potential, there is little UK field data in this area.

SUMMARY TABLE

EFFECT OF COVER CROP TYPE

Cover crop	Crop type	Sowing (autumn)	Example sowing rates (single species)	Main uses/comment
Beans	Broadleaf (pulse)	Late Aug – Sept	100-200 kg/ha	Mainly used in fertility building as part of mixtures or single species. Better suited to later sowing than many legumes, but consider rotational conflicts.
Black medick (trefoil)	Broadleaf (legume)	August	8-10 kg/ha	Mainly used in fertility building mixes, faster growing than some clovers, and can improve soil structure. Consider rotational conflict with pulses.
Buckwheat	Broadleaf (polygonum)	August	70 kg/ha	Used around fertility building and particularly scavenging phosphorus. Buckwheat is not frost tolerant and is probably best used in mixtures.
Chicory	Broadleaf (Asteraceae)	August	15 kg/ha	Deep rooted cover crop (delivering soil structure benefits) better suited to longer term use especially where grazing is of interest. Can be used in mixtures.
Crimson clover	Broadleaf (legume)	August	10-15 kg/ha	Mainly used in fertility building mixes, faster growing than some other clovers, and can improve soil structure. Consider rotational conflict with pulses.
Lucerne	Broadleaf (legume)	August	20 kg/ha	Mainly used in fertility building mixes and can be better suited to droughty soils than some other legumes. Consider rotational conflict with pulses.
Mustard	Broadleaf (brassica)	Mid Aug – mid Sept	5-15 kg/ha	Competitive crop with benefits for soil around management of erosion, leaching and structure. Consider rotational conflict with oilseed rape.
Oats or Rye	Grass (cereal)	Mid Aug – mid Sept	30-100 kg/ha	Competitive crop with benefits around shallower soil management, leaching reduction and erosion mitigation. The sowing rate will depend on specific use.
Oilseed Rape (OSR)	Broadleaf (brassica)	Mid Aug – mid Sept	5-15 kg/ha	Competitive crop with benefits for soil around management of erosion, leaching and structure. Consider rotational conflict with oilseed rape.
Peas	Broadleaf (pulse)	Late Aug – mid Sept	200-400 kg/ha	Mainly used in fertility building as part of mixtures or single species. Better suited to later sowing than many legumes, but consider rotational conflicts.
Phacelia	Broadleaf (boraginacae)	Mid Aug – mid Sept	c. 10 kg/ha	Competitive crop with benefits for soil around management of erosion, leaching and structure. Not entirely frost tolerant but unlikely to senesce fully over winter.
Radish	Broadleaf (brassica)	Mid Aug – early Sept	4-12 kg/ha	Competitive crop with benefits for soil around management of erosion, leaching and structure. Consider rotational conflict with oilseed rape.

Continued overleaf

Cover crop	Crop type	Sowing (autumn)	Example sowing rates (single species)	Main uses/comment
Ryegrass	Grass (Lolium)	Typically August - Sept	25-35 kg/ha	Competitive crop with benefits around shallower soil management, leaching reduction and erosion mitigation.
Sanfoin	Broadleaf (legume)	August	70 kg/ha	Mainly used in fertility building and grazing mixes but is less well suited to droughty soils than some other legumes. Consider rotational conflict with pulses.
Sweet clover	Broadleaf (legume)	August	10-15 kg/ha	Mainly used in fertility building mixes, quite slow growing but can improve soil structure (from longer residence). Consider rotational conflict with pulses and malting barley.
Vetch	Broadleaf (legume)	August - Sept	80 kg/ha	Quite a competitive legume and mainly fertility building mixes and can be later sown than some other legumes. Consider rotational conflict with pulses.
White clover	Broadleaf (legume)	August	10-15 kg/ha	Mainly used in fertility building mixes, quite slow growing but can improve soil structure (from longer residence). Consider rotational conflict with pulses.

The ingredients – cover crop components

Brassica types

FIVE POINTS ABOUT BRASSICA COVER CROPS

1. *Can grow quickly and give rapid ground cover in the autumn.*
2. *Quick growth means brassicas are generally good at capturing nitrogen.*
3. *Deep rooting brassicas can be particularly useful to help with soil structural issues.*
4. *Brassicas can offer a wider range of autumn sowing dates than most legume options.*
5. *Be cautious of use where you have a high oilseed rape inclusion in the rotation.*

Mustard

(*Brassica* and *Sinapsis* species e.g. *Sinapsis alba*).

Mustard is widely used and can be a competitive crop that grows rapidly, quickly covering the soil surface and developing a strong rooting system. The crop can also reduce nitrate leaching, help to manage soil erosion and improve soil structure.

Sowing: for autumn sowing mid August - early September is suggested (although conditions are more important than calendar date). Typically sown at c.10 kg/ha (5-15 kg/ha); but this varies with establishment conditions, method, mix used and seed size (thousand seed weights are often typically around 3-5 g). Seed costs vary substantially depending on mustard type but costs of £2-10/kg may be typical.

Management: Sowing depths and establishment are similar to oilseed rape, so mustard can be established either through broadcast or drilled routes depending on factors including seedbed conditions and equipment available. In a similar manner to oilseed rape, mustard cover crops should be managed for pigeons, slugs and flea beetles.

Typically, no other inputs are required through the growing period. While some growers favour using small amounts of starter N fertiliser, recent Origins™ research, has questioned the value of these applications on cover crop growth and the yield response in following crops. Starter fertiliser should only be used where directed by FACTS qualified advice. Some mustard types will bolt more readily than others; as plant stems and other biomass develops it can become increasingly fibrous which can impact on destruction and breakdown. A range of mustard types are available and while impartial information on specific varieties/types is limited, breeder/supplier information can be useful and help support selections.

Notes: Mustard is related closely to oilseed rape and other veg brassicas. This can impact on disease carry over, volunteers and other weed issues in the rotation. Where mustard is being used as part of a programme for improving soil condition, use in conjunction with soil amendments can be complementary. This section refers ostensibly to autumn sown mustard; in some instances mustard may also be a spring sown cover crop (although generally this is less common).

Radish

(various types, but usually *Raphanus* sp).

Radish types tend to be competitive and quick growing with strong deep tap roots. As cover crops, or components in mixtures, they can reduce nitrate leaching, help to manage soil erosion and improve soil structure (radish can be particularly deep rooted from an autumn sowing compared to other cover crops).

Sowing: for autumn sowing mid August - early September is suggested (although conditions are more important than calendar date). Typically sown at c. 8 kg/ha (range 4-12 kg/ha); this varies with establishment conditions, method, mix used and seed size (thousand seed weights are often typically around 3-5 g). Seed costs vary substantially depending on type but costs of £4-10/kg may be representative.

Management: Sowing depths and establishment are similar to oilseed rape, so radish can be established through broadcast or drilled routes depending on factors including seedbed conditions and equipment available. In a similar manner to oilseed rape, radish cover crops should be managed for pigeons, slugs and flea beetles (although some types are less susceptible than others). Often no inputs are required through the growing period, and while some growers favour using small amounts of starter N fertiliser, recent Origins™ work has questioned the value of these applications on cover crop growth and the yield response in following crops. Starter fertiliser should only be used where directed by FACTS qualified advice. Both rooting type (e.g. the size and nature of the tap root) and the propensity for bolting will vary with variety; but some radish types will stay as a vegetative rosette over the autumn, consequently radish can often present less biomass to deal with in the spring compared to mustard. A range of radish types are available and, while impartial information on specific varieties/types is limited, breeder/supplier information can be useful and help support selections.

Notes: Radish is related closely to oilseed rape and other veg brassicas. This can impact on disease carry over, volunteers and other weed issues in the rotation. Where radish is used as part of a programme for improving soil condition, its use in conjunction with soil amendments can be complementary.

Brassica 'sprinkles'

In addition to the key ingredients above there is a range of 'sprinkles' (other brassica types) that could complement these ingredients; they may serve well as additions to mixtures or are perhaps suited for sole use in some circumstances. In general, comments on sowing, management and rotational conflicts would be similar to those described previously. Options are often selected around root characteristics e.g. stubble turnips (can be particularly useful where grazing provision is an objective) or tillage radish (which has a larger deep tap root) or types with trap/bio-fumigant activity (often used alone; see managing weeds and pests section).

Legume species

FIVE POINTS ABOUT LEGUME COVER CROPS

1. *Legume cover crops can fix their own nitrogen given suitable growth and conditions.*
2. *Within NIAB TAG long term research, some of the most consistent yield responses have been associated with legume cover crops.*
3. *Legume cover crops often need to be sown earlier than other types for best effect.*
4. *Legume cover crops can be associated with improved mycorrhizal associations.*
5. *Be cautious of use where you already have a high legume inclusion in the rotation.*

Clovers

(various types, but often *Trifolium* sp).

Like all legumes, clovers have the ability to fix N from the air and can also offer useful improvements to soil structure; collectively this can confer fertility building benefits. N is more likely to be fixed during spring rather than autumn growth, however from early sowing some nodulation and N fixing may be expected. From spring sowing levels of up to 150 kg/ha N pa are cited for a range of types. Clovers are commonly used in species mixtures.

Sowing: White clover, sweet clover and crimson clover can all be spring (March onward) or autumn (late July - mid August) sown. Where crops are autumn sown chances of establishment will diminish as sowing dates move toward September. Seed rates will vary with circumstance, but often rates for white clover (*Trifolium repens*) (10 kg/ha, with thousand seed weights often around 0.5 g), sweet clover (*Melilotus officinalis*) (15 kg/ha, with thousand seed weights often around 2 g) and crimson clover (*Trifolium incarnatum*) (15 kg/ha, with thousand seed weights often around 2.5-3.5 g) could be considered representative for use as single species. A range of other types of clover could also be sown. White clovers are often slow growing, but can be beneficial in mixtures and low input systems, crimson clover is faster growing and potentially more suited to use in shorter (autumn sown) leys (or in mixes) and sweet clovers can produce a deep tap root if left for longer periods (e.g. full season cover crops), but is not well suited for grazing. Seed costs vary substantially with type, but costs of £6-10/kg may be representative.

Management: Clover species should generally be broadcast or drilled into firm, moist seedbeds at a shallow depth (a few mm) and rolled to improve establishment; in some cases an inoculant may be needed to aid root nodulation. White clover seed can be purchased as pelleted seed (with a clay coating to effectively increase the seed size). This can be useful and help to improve uniformity of distribution if seed is to be broadcast; some producers will recommend a slightly reduced seed rate here as well. As with most legumes, some pest protection can be required (e.g. beetles, weevils, slugs and pigeons) and inputs should be targeted as necessary. Depending on the type/mix being grown, topping (or grazing) may be beneficial during the season.

Notes: Clovers are legumes and as such rotational intensity needs to be considered where other legumes or pulses are grown in the rotation (e.g. for disease carry over). Clovers tend to be slow to establish and initially can be uncompetitive with weed species; however once established they will be more competitive. The N fixed by clover does not necessarily all become available to a following crop or at the time of requirement. Use of some mixtures of species can help with the fertility building benefits and research suggests species such as crimson clover can be better suited to autumn ley use.

Black Medick

(*Medicago lupulina*, often referred to as yellow trefoil).

Black medick is typically a short-lived N fixing annual legume with a low growth habit; it tends to be faster establishing than white clover (similar to crimson clover). This can offer both fertility building and soil structure benefits in autumn leys. Black medick has been used both alone and in mixtures and in research has performed relatively well from early August sowings. There are also some perennial types of medic, although these tend not to be used in cover crops.

Sowing: Black medick can be spring (March onward) or autumn (late July - mid August) sown; the chances of good autumn growth decline as dates tend to September. Sowing rates vary with establishment conditions/method and seed size (with thousand seed weights often around 1.5-2.0 g), but c. 8-10 kg/ha are common where the species is used alone. Seed is cost likely to be c. £10-12/kg.

Management: Black medick is typically broadcast or drilled into firm, moist seedbeds at a shallow depth (a few mm) and rolled to improve establishment. As with most legumes, some pest protection and other inputs may be required (e.g. beetles, weevils, slugs and pigeons) but are not always necessary. In limited research at NIAB sites black medick has remained prostrate from autumn sowing; this has provided benefits around the following crop establishment and has not required topping over the autumn.

Notes: Black medick is a legume and as such rotational intensity needs to be considered where other legumes or pulses are grown in the rotation (notably for disease carry over). The N fixed by a legume does not necessarily all become available to a following crop or at a time of requirement; use of some mixtures of species can help in these situations. Black medick seems to be generally well suited for use as a component of mixtures.

Vetch

(*Vicia sativa*, also known as 'tares').

Vetch is a N fixing annual legume that is commonly used in cover crop mixtures (although it could be used alone). There are a number of types of vetch available, with differences in vigour and frost susceptibility.

Sowing: Vetch can be spring (March onward) or autumn sown. For autumn sowing vetches can be sown later than clovers and medick species (August through to early September). Seed is also larger then clovers (with thousand seed weights often of 40-80 g) and rates of 75-100 kg/ha are common when used alone. Cost is around £1-2/kg.

Management: Vetch needs to be deeper sown then clovers; possibly 2 cm into some tilth and moisture, consolidation can also be beneficial. Pest protection and other inputs may be required (e.g. for sitona weevils and sometimes pigeons), but is not always needed. Vetch can produce a lot of biomass for a legume cover crop but field accounts suggest it does not respond well to topping.

Notes: Rotational intensity should be considered where vetches are grown in rotation with other legumes. As with many legumes vetch is often used as a mix component and this can work well as the seed size and sowing requirements tend to be more in keeping with non-legumes compared to small seeded legumes. It should be noted, the N fixed does not necessarily become immediately available to following crops, but is typically retained in the soil system.

Legume 'sprinkles'

The legumes described previously are only a sub-set of those that could be used as key ingredients, and there are a range of possible 'sprinkles' that could be added to mixtures to complement these ingredients. Specific agronomic guidance on these additions will vary with crop type, although the rotational considerations would generally be common to all legumes.

Suggestion of other novel options to consider are:

Beans and peas

These can be relatively cheap and farm available ingredients where there is frequently on-farm production expertise. Larger seeded legumes they can be sown later than many other smaller seeded legumes, but appreciable N fixing is more likely to occur from earlier sowing. Autumn seeding rates of 100-400 kg/ha may be appropriate if used alone (lower end generally for beans and higher end for peas), but these options are perhaps most likely to be used within mixtures rather than as stand-alone species.

Lucerne

(*Medicago sativa*, also known as alfalfa)

This may be August sown as an autumn cover (often at c. 20 kg/ha as a single species). The crop will develop a tap root and can be suited to droughty soils. Over winter it often defoliates, but will generally recover. Lucerne usually needs to be destroyed in short-term leys and can require topping. Seed costs vary but are often around £10/kg.

Lucerne (Alfalfa)

Sainfoin

Traditionally a spring sown legume, but can be grown as a summer (August) sown legume (at c. 70 kg/ha as a single species for autumn cover). The species tends not to like droughty soils, is highly frost tolerant (so will need to be destroyed in short term leys) and has excellent grazing potential (can be suited to use in longer leys and where it is not grazed it can need topping). Seed costs vary but can be around £2-3/kg.

Sainfoin field

Other options

FIVE POINTS ABOUT OTHER COVER CROP TYPES

1. *Grasses and cereals, such as oats or rye, can often be a cost effective inclusion also offering good vigorous surface rooting.*
2. *Consider using wider species that are unrelated to anything in the rotation; e.g. phacelia is a boraginacea.*
3. *Some species can offer novel potential in a mix; for example buckwheat is very frost sensitive and has been noted as a phosphate scavenger.*
4. *Make sure choices help meet objectives and complement the cover crop function.*
5. *Why not use ingredients where you have existing knowledge, such as beans or oats?*

Grasses: oats (*Avena* sp.), rye (*Secale* sp.), rye-grass (*Lolium* sp.) and others.

Graminacious species typically give rapid ground cover from autumn sowings, often have relatively well understood agronomy and can be easy to grow compared to some other cover crop types (e.g. legumes). While growth is rapid and rooting can be vigorous, grass species are more likely to root more actively at shallow depths compared to those achieved with brassica roots (for example). However grasses are useful at opening up surface soil structures and commonly tend to be used in mixtures, but in some cases can be used alone.

Sowing: Oats and rye: can be spring or autumn sown and seed rate will depend on conditions and use, but rates of c. 35 kg/ha (when used within autumn mixes for erosion management) up to 80-100 kg/ha (where stands are needed as a single species for example for weed competition) are common; seed costs are often around £1-2/kg and thousand seed weights of 30-50 g can be representative.

Italian (and Perennial) ryegrass can be sown in April or August/September with seed rates (from thousand seed weights often around 1.5-2.5 g) typically around 30-35 kg/ha (perennial ryegrass is suited to longer term stands); seed costs are £2-4/kg. Westerwolds ryegrass can be drilled later than other rye-grass, potentially into October for cover crop use, and is again typically drilled at 25-35 kg/ha in the autumn; seed costs are £2-4/kg (although can be very vigorous).

Management: Oats and rye can be established via drilling (at a similar depth to cereal crops) or through broadcasting and rolling routes, provided there is adequate tilth. Ryegrass should generally be drilled into firm seedbeds at 1-2 cm and rolled to improve establishment. Post establishment, frequently no other inputs are required through the growing period, however, sites may need to be managed for pest damage should this occur. Ryegrasses can provide grazing opportunities or may need to be topped during the autumn.

Notes: A range of oat types (e.g. winter/spring oats, black oats, bristle oats) are available at a range of prices, and while impartial information on specific types is limited, breeder/supplier information can be useful and help support selections. Practically, many farmers using oats will often use a spring oat variety in the autumn. While consideration should also be given to carry over or increased disease pressure to cereal crops, volunteer management in following crops is likely to be the greater immediate practical conflict. In this respect the management of volunteer oats, in particular, can often be less problematic in following spring crops than many other cover crop choices.

Phacelia
(*Phacelia tanacetifolia*)

Phacelia is fast to establish, highly competitive and the purple flowers provide a source of nectar and seeds beneficial to insects and other wildlife.

Sowing: For spring sowing phacelia can typically be sown March onwards, but it is also suitable for early autumn sowing (e.g. a similar window to oilseed rape of mid August to early September). Seeding rate varies with establishment conditions/ method and seed size (with thousand seed weights of 2-3 g), but c. 8-10 kg/ha is suitable where it is used alone; seed costs vary but £8-10/kg is typical.

Management: Phacelia can be shallow drilled (perhaps 1-2 cm) or broadcast to suit conditions and equipment. Phacelia is generally relatively pest resistant and frequently no other inputs are required through the growing period, however, sites may need to be managed for pest damage should this occur. Autumn sowings do not tend to get overly tall and topping is not usually required. Some canopy management/topping could potentially be required from spring sowing to prevent seed set in certain scenarios. From autumn sowing phacelia is not fully frost tolerant, but the degree of winter senescence depends very much on the season and crop destruction is often needed.

Notes: Phacelia is a boraginaceae and unrelated to most other crops grown commonly in UK rotations (although is related to borage, echium, buglossoides etc). Unless seed set is an objective (e.g. for environmental goals) growers should seek to remove the crop before seeds set to limit volunteer problems in following crops. Should phacelia set seed there can be a requirement to manage volunteers in following crops, although this is more likely to be an issue where herbicide choice is limited. NIAB TAG research has indicated positive, but variable, yield responses in spring barley crops following phacelia.

Other 'sprinkles'

There are a range of options that can be used as cover crops and finding species that are outside legumes, brassicas or cereals can be a good way to minimise rotational conflicts. In addition to the key ingredients described previously there are several possible 'sprinkles' that could be added to complement seed mixtures. Two possible options to consider are as follows:

Buckwheat
(*a Polygonaceae*)

This typically fast growing species often does better from spring establishment, but can be summer sown (August); buckwheat can be useful at scavenging phosphorus (potentially improving availability), but is short-lived and not frost tolerant. Buckwheat is probably best used as a component of mixtures. Seed rates are up to 70 kg/ha (used as a sole species) and typical costs are often £2-4/kg.

Chicory
(*an Asteraceae*)

Can be spring (March onwards) or autumn sown (typically August). The species produces a very deep and vigorous tap root, but is slow growing and is often suited to longer term leys, however can be used as a component of mixtures. Chicory is frost tolerant and can fit well with grazing use. Seed rates are up to 15 kg/ha (used as a sole species) and typical costs are often £10-15/kg.

Buckwheat (a Polygonaceae)

The mixing bowl – combinations of components in a cover crop

FIVE POINTS ABOUT COVER CROP MIXES

1. *There are no hard and fast rules about the right mix; it depends on your situation!*
2. *Think about what you include in the context of objectives, systems and budget.*
3. *As well as the functional traits of the species in a mix, also think of the range of seed sizes and whether this is likely to cause seeding issues.*
4. *Consider the potential problems around species use, notably potential rotational conflicts and issues around volunteer management.*
5. *Find out what other people are using, discuss the options and be prepared to evaluate different mixes or components.*

There are no hard and fast rules about selecting cover crop mixtures and the selections should be governed by the primary objective of the cover crop as well as other factors including budget, potential rotational considerations and farm equipment or scenario. In some cases this may require a bespoke mix or the generation of simple mixes on farm through the collection of various ingredients, but in others, pre-formulated mixes sold though a range of seed merchants will serve well.

For further information formulating and growing mixes see the section 'Cooking – growing the cover crops' and consult your seed supplier or other specialist guidelines.

The suggested mixes presented in this section are some that may be used commonly on farm, have worked well in field research or have been suggested through consultation. However, these are only examples and growers are encouraged to experiment with mixes suited to their own goals and situations; why not try some split field areas or field strips of different cover crops, and remember to leave an untreated area for comparison.

The simple mixes listed in the following section are ostensibly for use in soil management (e.g. erosion, leaching reduction or soil structure situations). However, these mixes would also potentially provide other benefits around green manure use, habitat provision and weed competition. These mixes could also be extended to include other species to provide a wider range of root types (e.g. try oil and tillage radish with oats rather than just a two way mix) or add other species to widen objectives (e.g. consider adding in vetch as a fertility building legume).

Cover crop mixes

Oilseed rape and oats

(use: soil management, particularly erosion mitigation)

This is often used as a relatively inexpensive mix to manage soil erosion (providing vigorous, effective ground cover at key periods); although will also provide some soil conditioning, nutrient retention and green manure benefits.

Seed rates: will vary with circumstance but rates of around 30-50 kg/ha for the oats and 3-10 kg/ha for the oilseed rape can be suited to a range of situations.

Sowing dates: typically mid August to mid September (depending on conditions).

Complementary species: this simple two way mix could be extended by adding in other components. For example, addition of vetch or crimson clover would introduce a faster growing legume for autumn sowing. In addition rye could be used instead of oats.

Other comments: use of oilseed rape as a cover crop and closer brassica rotations are a common cause of concern with this mix, in addition oilseed rape is potentially shallower rooting than a radish from autumn growth.

Radish and oats

(use: mainly for improving soil structure and erosion management)

The root depths and structures of the two species complement each other well and can be useful at developing soil bio-pores over a range of depths. This simple competitive mix will also provide useful erosion mitigation, nutrient retention and green manure benefits.

Seed rates: will vary with circumstance but rates of around 30-50 kg/ha for the oats and 3-8 kg/ha for the radish can be suited to a range of situations.

Sowing dates: typically from mid August to early September.

Complementary species: this two way mix could be extended by adding in other components. For example, phacelia would add a third species with a different rooting habit (to aid soil structuring) or legumes such as vetch or crimson clover would introduce a nitrogen fixing species. In addition, rye could be used instead of oats.

Other comments: close rotations are a common cause of concern with this mix.

Phacelia and oats

(use: potentially suited to soil conditioning and improving structure)

Where additional brassica use in a rotation is a concern phacelia can also be a vigorous rooter and the combination with oats again would give complementary root depths.

Seed rates: there is less field experience with this mix, but rates of 30-50 kg/ha for the oats and 3-6 kg/ha for the phacelia may be suited depending on circumstance and goal.

Sowing dates: typically from mid August to early September.

Complementary species: as with previous mixes other components such as this two way mix could be extended by adding in other components. For example, legumes such as vetch or crimson clover to added (to introduce nitrogen fixing species). In addition, rye could be used instead of oats.

Other comments: the mix will not conflict with brassica crops in the rotation, but equally probably will not root to the same depth as brassica species. Phacelia has a more fibrous root system, compared to the deep tap root system of a brassica.

The following are simple mixes ostensibly for fertility building and include legumes to fix/capture nitrogen in a way that is potentially more available to the crop. These mixes could also provide wider benefits around habitat provision, leaching reduction and soil condition improvements. In addition to the suggested mixes also consider simple approaches, such as the use of beans as a cover crop (or part of the mix) or more adventurous approaches with multi-way mixes (e.g. potentially adding other ingredients to improve deep soil conditioning).

Legume (e.g. black medick) and phacelia

(use: mainly for habitat (insects) and fertility building benefits)

This mix is a combination of an active rooting phacelia cover and one of the faster developing, nitrogen fixing, legume species. Phacelia is also very attractive to bees and other pollinators.

Seed rates: as a guide seed rates of around 3-5 kg/ha for the medick and 3-8 kg/ha for the phacelia, depending on circumstance, may be suited to this mix.

Sowing dates: typically from mid to late August (the legumes tends to do less well from September sowing).

Complementary species: vetch (at c. 30 kg/ha) is another common legume choice rather than black medick in this mix. Other choices could include crimson clover or beans.

Other comments: this mix provides an option that will not conflict with brassica crops in the rotation, although with a legume the proximity of pulse crops in the rotation should be considered. The medick and phacelia components have performed well individually in research trials, but there is a need for more field experience and data with the mix.

Legume (e.g. black medick) and oats

(use: mainly fertility building benefits)

This mix is combination of the vigorous root and canopy development of oats and options for the faster developing, nitrogen fixing, legume species.

Seed rates: as a guide seed rates of around 3-5 kg/ha for the medick and 30 kg/ha for the oats and vetch. This mix will depend on circumstance and goal.

Sowing dates: generally from mid to late August (the legumes tends to do less well from September sowing).

Complementary species: other choices of N fixing legume species for use in the mix, either as well as or instead of black medick/vetch could include crimson clover or beans. The use of vetch, perhaps at 20-40 kg/ha, is an option which may cope better with slightly later sowing. In this mix crimson clover (possibly at 5-8 kg/ha) would perform similarly to black medick/vetch and is also a relatively faster growing legume (albeit with a different growth habit), but field observation suggests it may be more attractive to certain pollinators. Beans or peas could also be added as a relatively cost effective legume mix component. Alternatively a multi-way mix with several of these components could also be considered.

Other comments: this mix provides an option that will not conflict with brassica crops in the rotation, although with a legume the proximity of pulse crops in the rotation should be considered. The black medick and crimson clover components have performed well individually in trials and there is some expert opinion to support the mix, but there is a need for more field experience and data.

The following are a couple of examples of possible wider mixes. These suggestions are by no means exhaustive but are illustrative of potential multiway mixes.

Legume species mixture

(use: mainly fertility building but also soil condition benefits)

The mix (white clover, black medick, lucerne and crimson clover) is based on one developed and tested in Defra LINK project LK09106 (using legume-based mixtures to enhance the nitrogen use efficiency and economic viability of cropping systems). This mix has been used by NIAB TAG and others and estimates of return from research vary, but margin over nitrogen improvements of around £50-75/ha have been recorded in NIAB trials.

Seed rates: the total rate tends to be 10-15 kg/ha with rate ranges for the components as follows: white clover (2-4 kg/ha), black medick (2-4 kg/ha), lucerne (3-5 kg/ha) and crimson clover (3-5 kg/ha). Of the mix components white clover is the slowest growing and could be omitted in some situations.

Sowing dates: generally in early to mid August (and tends to do less well from a September sowing).

Other comments: while this legume mix provides an option that will not conflict with brassica crops in the rotation the proximity of pulse crops in the rotation should be considered. Due to the range of seed sizes in the mix, care should be taken to ensure uniformity of seed distribution during sowing.

Radish, crimson clover, oats and buckwheat

(use: mainly for improving soil structure and nutrient availability)

The root depths and structures of the species complement each other well and can be useful at developing soil bio-pores over a range of depths. In addition there is some suggestion from research that buckwheat can be effective in sequestering phosphate. This competitive mix will also provide useful erosion mitigation.

Seed rates: will vary with circumstance but rates of around 30-50 kg/ha for the oats and 3-8 kg/ha for the radish and crimson clover and (perhaps) 10-20 kg/ha of buckwheat.

Sowing dates: typically from early August to early September.

Complementary species: if a legume was not required in the mix phacelia could be added as well as or in place of the crimson clover. In addition rye could be used instead of oats. If used as a full season mix, white or sweet clover can be a useful addition.

Other comments: close brassica and pulse rotations could be a cause of concern with this mix.

Phacelia mustard mix

‘Cooking’ – growing the cover crop

FIVE POINTS ABOUT COVER CROP PRODUCTION

1. *Think about the objective of your cover crop and how this will fit with your time, equipment and budget.*
2. *Have a plan for the season; what might the cover crop look like at key stages and what management will be required.*
3. *Don’t start big: try a limited area and leave an untreated control strip for comparison.*
4. *Gauge progress; for example compare soil structure or worm numbers in the cover crop and control areas, look at follow crop growth and compare field area yield maps.*
5. *While this book offers a guide, be prepared to experiment with mixes and management to get it right for your situation.*

Cover crop selection

There are few hard rules with selecting cover crops, but guidance on specific choices either to use alone or in mixture begins on page 14.

Seed mixtures

The use of mixtures is common. There are a many pre-generated commercial cover crop seed mixes available, but equally growers could develop their own. While there is a need for further comparative data on mixes, the suitability of mix components and field experience can be a useful guide to their value.

The mixes and approaches suggested in this guide are provisional and based on farm practice, limited experimental data and discussion with growers. When selecting cover crops to use in mixtures, consider how the components help to achieve the overall objectives and complement each other; for example is one component likely to out-compete another, are the lifecycles, breakdown characteristics etc. suitably matched or do the functional traits help to achieve the overall goal of the mix.

There are also some practical aspects to consider around using mixtures. For example, when seed sizes differ appreciably in mixes there can be a need to mix the seed periodically in the drill to avoid separation. In addition some concession on drilling depth can be needed when mix components have markedly different requirements. In general it is advisable to select components that minimise these differences, although this is not always possible and other solutions (such as separately broadcasting and drilling some mix elements) can be used if needed.

Sowing date

This will be guided by the specific components of a mix, but broadly autumn sown mixes tend to be established in early August - mid September. Most legumes need to be earlier in this window (by mid August) but other cover crops (e.g. brassicas and cereals) can often be sown later. In general, earlier sowing tends to show greater growth over the autumn, however, good soil/seedbed conditions are more important than specific date. For many cover crop species, seed should ideally be established into surface tilth in a firm, moist seedbed and rolled to improve moisture conservation and establishment. The relationship between sowing date and autumn cover crop growth from Origins™ farmers in autumn 2014 is presented in Figure 3 while some examples of autumn growth (measured as Green Area Index (GAI)) are presented in Figure 4. Later sowing on Origins™ sites in 2015/16 (generally early September sowing) compared to 2014/15 (generally mid-late August sowing), due to seasonal conditions, reduced overwinter biomass by around a third on average across sites.

Figure 3. The impact of sowing date on mean autumn cover crop green area index (GAI) in Kellogg's Origins™ sites from assessments made in October 2014.

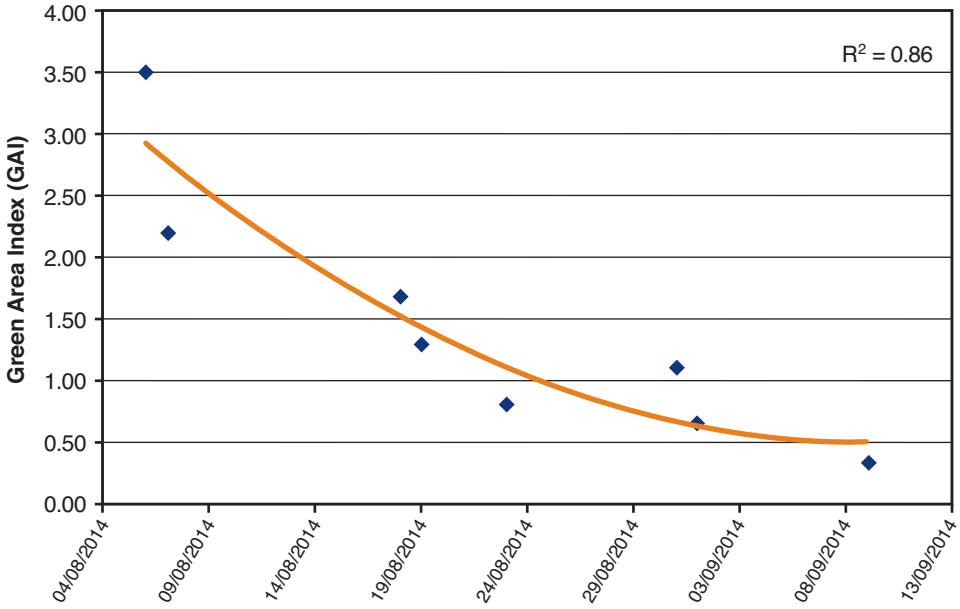
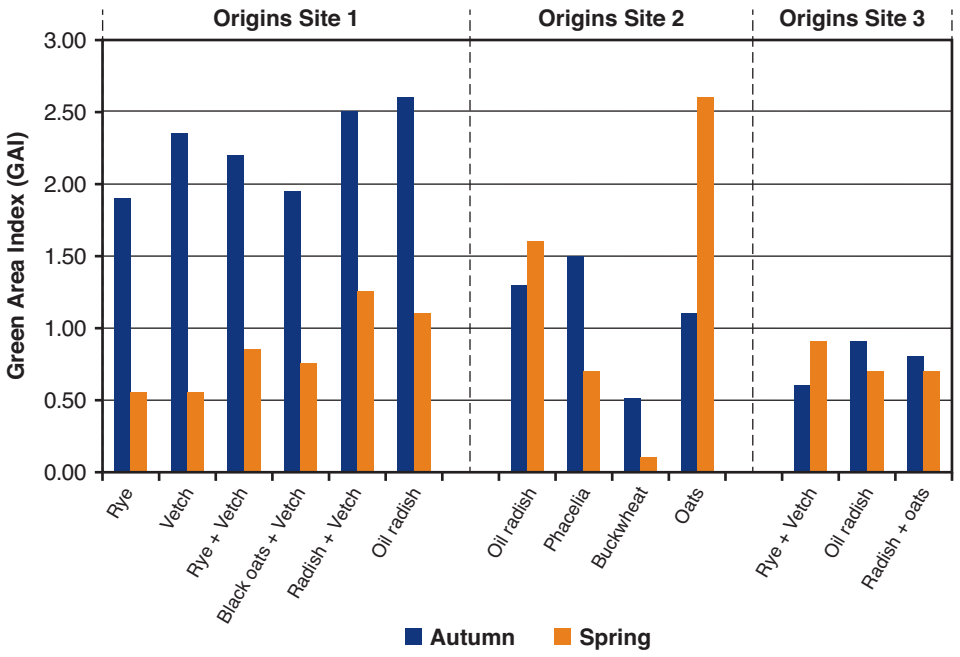


Figure 4. Autumn (October) and spring (February) cover crop green area index (GAI) in selected sites over the Kellogg's Origins™ programme (2014). Sowing dates were site 1 (07/08/14), site 2 (31/08/14) and site 3 (23/08/14). Green Area Index (GAI) is a measure of the ratio between the total area of all green tissues and the area of ground from which they come.



Sowing rates

Specific seed rates will depend on the inclusions and specific mix. Further information on seed rates can be found on page 12, but as a broad steer in multi-way mixes, it is often common to sow at less than full rate. As a guide perhaps quarter to up to a half of the rate (*cf.* that would be used for that cover crop grown alone) would be typical of the main components in several mixes; but this will also be guided by the objective, the number of components in the mix and the overall budget for the cost of the mix.

Establishment

The method of establishment varies with cover crop type, equipment available, field conditions, soil type and farm scenario. However, generally, a cover crop is drilled or broadcast followed by seedbed consolidation; often broadcasting is used on light to medium soils and drilling over a range of soil types. Establishment with broadcasting (possibly trash raking to distribute straw and generate tilth, followed by broadcasting and rolling) tends to be cheaper, but can be more variable and seed distribution uniformity should be considered. When drilling seed mixes, a range of drill types can be used; single pass systems are often adopted to improve timeliness and reduce cost. Thought should also be given to row width/seed spread; the 'floating' drill method (either over or just engaging with soil) has been employed by a number of growers.

Management and inputs

This will be guided by the specific mix components. While monitoring autumn sown cover crops for input requirements is recommended, in some situations there may be no need for any inputs. However, in other situations pest protection could be needed for grazing by pigeons, slugs or insect pest damage.

While a need for autumn starter N fertiliser is sometimes suggested, recent UK research has failed to show strong benefits. Starter fertiliser should only be used where directed by FACTS qualified advice. The use of starter N was assessed in the Wensum DTC project in 2013/14 (www.wensumalliance.org.uk); in a brassica cover crop receiving 30 kg/ha N this study suggested foliar biomass increases of c. 15%, but without any comparable increase in root biomass (numerically a 5% decline in root growth). In addition starter N fertiliser was assessed in 15 cover crop field strip comparisons at (two) Origins™ sites in 2014/15 (N dose c. 30 kg/ha N). While use did result in some increased growth, differences were small (c. 10-20%, Table 4), but N also tended to increase autumn weed populations. Work within Origins™ has seen some interaction with cover crop type, however, in general growth benefits appear to be limited, and by the spring any differences due to starter N were difficult to detect. On one Origins™ site, yields in the spring barley crop following the cover crop were recorded for with and without starter N areas. Across each of 10 cover crop comparisons the use of starter N fertiliser in the cover crop reduced the yield of the spring barley crop; mean reduction of 0.6 t/ha (loss range 0.02-1.06 t/ha). The reasons for this are not clear, but is has been speculated it may be related to cover crop root growth; NIAB TAG research work is currently examining this area further.

Table 4. Mean data from 15 cover crop comparisons with, and without, starter fertiliser carried out over two sites in the Kellogg's Origins™ programme during 2014/15. Comparison of plant counts (per m²) and green area index (GAI; as a measure of canopy size).

Treatment	Autumn assessment			Spring assessment		
	Cover crop		Weed	Cover crop		Weed
	Count (plants/m²)	GAI	Count (plants/m²)	Count (plants/m²)	GAI	Count (plants/m²)
Without N	61	1.6	24	29	1.1	21
With N	60	1.8	51	30	1.2	27

Cover crop destruction/following crop establishment

Methods of destruction vary markedly and will depend on soil type, growth (canopy size and type of growth), available equipment and objectives. Autumn-established covers can be killed off by frost action, grazing/destroyed mechanically or sprayed off with glyphosate early in the year (while other herbicides could be used glyphosate tends to be used most commonly).

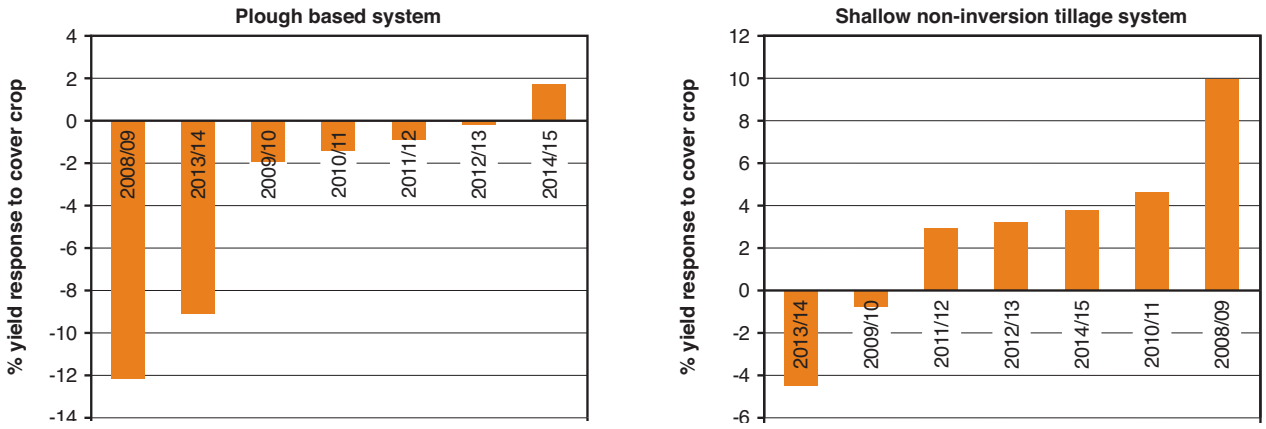
Where cover crops are being used to help manage pernicious weeds, more than one glyphosate application may be needed (as the cover may shelter some weeds). This is usually followed by some degree of spring incorporation (often a shallow a non-inversion system) prior to establishment of the following crop, although in other situations, single pass drilling through residues is used. Where cover crops are used as black-grass 'trap crops', reducing the soil disturbance will help to minimise fresh germination. In the NIAB TAG New Farming Systems project on medium sandy soils, research has been examining the interaction of cover crop use and tillage technique on rotational yield response. The research has been using brassica (oil radish) based

cover crops, ostensibly in alternate seasons ahead of spring crops (alternating with winter wheat), with objectives primarily around the improvement on soil structure. Yield responses in this study suggest a greater likelihood of a positive yield response from cover crops where shallow (<10 cm) tillage was used for follow crop establishment rather than ploughing (Figure 5). The negative yield response to shallow tillage occurred when oilseed rape was gown in the rotation (see rotational planning section).

The interaction of soil type, cover crop choice and follow crop sowing system (e.g. drill type) will all have a bearing on destruction method. Management is typically easier on light and medium soils and there are a range of options; often destroying (e.g. spraying and/or grazing off) a cover crop early in the new year and some degree of incorporation ahead of drilling a spring crop is common. On heavier soils, particularly where surface structures and drainage are poor, management can be more difficult. One common issue is that while soils can be in good condition at depth, but the surface layers remain wetter (the extent of this issue varies with soil type and scenario). There are a number of routes to help manage this and the most suitable option will depend on circumstances. Common routes might be equipment related (e.g. using single pass equipment better suited to sowing following cover crops); alternatively consider complementary strategies to improve soil surface condition (e.g. NIAB TAG farming systems work has shown how compost and other amendments can improve soil surface condition and water infiltration); or, as a starting point, often opening up cover crops early enough to allow the soil surface to dry can be useful (e.g. choosing a cover crop or mix components which will senesce over the winter or spraying off earlier are options, and as your system develops cover crop use itself can improve soil condition over time).

The specific approach used is likely to be highly farm specific; when selecting a cover crop mix it can be useful to visualise what it might look like in the spring and consider how this will integrate with your proposed destruction method and drilling equipment. Where bio-fumigant or trap crops are sown there are usually specific destruction requirements in order to attain the full benefits.

Figure 5. The effect of tillage and brassica cover crop (before spring sown break crops in the rotation) on crop yield (% response). Figures for plough based systems (left) and shallow non-inversion tillage (right); positive values are a benefit from rotational cover crop use.



Rotational planning

Potential rotational conflicts should be considered with any cover crops or cover crop mixture. For example the likely risks and impacts of shortening brassica and pulse rotations or likely issues with volunteer management in following crops.

Field research on the longer term impacts is limited, but for brassicas NIAB TAG's New Farming Systems research, over an eight year period, shows some reduction (c. 6%) in oilseed rape yield associated with short (alternate) rotations of brassica cover crops, although this is less than would be expected from a short (alternate) oilseed rape rotations (c. 12%). The research also suggests there may be some potential to further mitigate these losses if shallow non-inversion systems were used (possibly better management of cover crop volunteers). Problems with specific pathogens such as clubroot and verticillium were not apparent in this study, but could be of concern on some sites (e.g. those with a history, where local pressure is high or where field conditions are suited).

Information on the impact of legume inclusions in pulse crops is very limited and will be influenced by the pathogens in question, the legumes grown, the farm site and environmental conditions, but current thinking suggests at least a three year break before a grain legume crop may be appropriate.

Use of cover crops in EFAs

Cover choice is generally best guided by the end objective and the farming scenario, but those wishing to grow catch crops and cover crops as an Ecological Focus Area (EFA) option will need to follow a more predefined set of options. Further details can be found in the relevant Defra CAP guidance; essentially the guidance sets out a predefined list of options, suitable mixtures and key dates that need to be followed. While cover crop use within this mechanism will contribute to CAP greening, those wishing to grow cover crops outside this mechanism will have greater flexibility.

'The new Common Agricultural Policy schemes in England: October 2014 update' (page 11) states the following. Since this update radish has also been added to the list of crops that can be grown in mixes.

Growing catch crops and cover crops as an EFA

Catch and cover crops are designed to protect the soil and use available nutrients between harvest and sowing. The crops farmers can grow as an EFA are those that give the best chance of:

- establishing within the sowing period
- growing quickly
- achieving ground cover
- having different rooting depth types.

Farmers must use a sown mix of at least two different cover types (one cereal and one non-cereal). However, grass can be used as either a catch crop or a cover crop as long as it was undersown in the previous crop and is sufficiently established. Crops that farmers can grow in the sown mix are:

- Rye
- Vetch
- Phacelia
- Barley
- Mustard
- Oats
- Lucerne

This list is based on the crops that have been used successfully for Environmental Stewardship in recent years. The regulations don't allow farmers to include crops that are usually grazed, so we haven't included kale or stubble turnips. Using crops from this list will give the soil surface the best chance of protection from erosion. It will also help to make sure that available nutrients are taken up by the plants. Once the catch/cover crop is destroyed, farmers should take care to ensure that all those benefits are not lost. So, they should avoid grazing and establish the next crop quickly. Farmers can include other crops in their catch crops or cover crops, but these areas cannot count as an EFA.

Further information can also be found in the CAP updates at www.gov.uk and search for Common Agricultural Policy (CAP) Reform or scan the QR code:

RPA helps farmers by providing guidance on greening rules 2016:

Seed sourcing

There are a wide range of companies providing cover crop seed, with no particular preference these would include (among a wide range of others):

Boston Seeds: www.bostonseeds.com

Bright Seeds: www.brightseeds.co.uk

Cotswold Seeds: www.cotswoldseeds.com

DSV: www.dsv-uk.co.uk/cover-crops

Green Manure: www.greenmanure.co.uk

Kings: www.kingscrops.co.uk

Pearce Seeds: www.pearceseeds.co.uk

BSPB guidance on home saving of seed for use in cover crops

BSPB is advising farmers and their advisers that seeds regulations and farm-saved seed (FSS) rules apply regardless of whether a crop is taken to harvest, and that when sowing a cover crop mixture which includes seed of PVR protected varieties, farmers must use either new seed purchased from a licensed seed merchant or farm-saved seed produced on their own holding.

Under the FSS rules, farmers cannot sell, barter, exchange or in any other way transfer farm-saved seed between holdings.

In addition, the use of eligible varieties as FSS in cover crops must be declared to BSPB and FSS payment made according to the proportion of eligible varieties in the mixture and the area sown.

A list of eligible varieties and payment rates by crop species is available on the FSS section of the BSPB website at: **http://www.bspb.co.uk/farmsavedseed/combinable-crops-payment-rates-and-eligible-varieties.php**
Farmers can contact the BSPB helpline on 01353 653209 for advice.

Farmers purchasing new seed to use for cover crops should ensure that this is certified seed bought from a licensed seed merchant (for peas, oats and barley) or if they are buying a cover crop mixture which may include a combination of regulated and unregulated species, that the bag carries an official green label stating 'mixture of seed for green cover'.

Further information

Cotswold Seeds; 'Sort out your soils' available through the following link:
www.cotswoldseeds.com/files/cotswoldseeds/Cotswold_Green_Manures_final.pdf

Döring TF, Baddeley JA, Brown R, Collins R, Crowley O, Cuttle S, Howlett SA, Jones HE, McCalman H, Measures M, Pearce DB, Pearce H, Roderick S, Stobart R, Storkey J, Tilston EL, Topp K, Watson C, Winkler LR, and Wolfe MS (2013). Using legume-based mixtures to enhance the nitrogen use efficiency and economic viability of cropping systems. HGCA Project Report 513.

'Managing Cover Crops Profitably' from the U.S. Department of Agriculture.
See: www.mccc.msu.edu/documents/ManagingCCProfitably.pdf

Morris NL, Stobart RM and Orson JH, (2014), An appraisal of research, best practice and communication approaches for the management of soil structure, Felix Cobbold Trust review (see the member area of the NIAB website).

Shah *et al.*, (2015), Can cover crops cover their establishment costs and are their any potential benefits to following crops?, Aspects of Applied Biology 129 (Getting the Most out of Cover Crop), pp 41-50.

Stobart RM and Morris NL, (2013), Approaches to cover cropping and the impact on soils and farming systems, Aspects of Applied Biology 121 (Rethinking Agricultural Systems in the UK), pp43-50.

Stobart *et al.* (2015), Developing the use of cover crops on farm through the Kellogg's Origins™ grower programme, Aspects of Applied Biology 129 (Getting the most out of Cover Crop), pp 27-34.

Through the ARTIS cover crop e-learning training programme:
www.artistraining.com/e-learning

It is intended that the information provided in this document will continue to evolve and your feedback and suggestions for improvement are welcomed. Please email nac@niab.com or origins@kellogg.com with comments for the further development of this publication.

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Partners in Defra LINK project LK09106 (Using legume-based mixtures to enhance the nitrogen use efficiency and economic viability of cropping systems).

Other commercial sources of information including Cotswold Seeds, Kings, RAGT and other cover crop researchers.

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