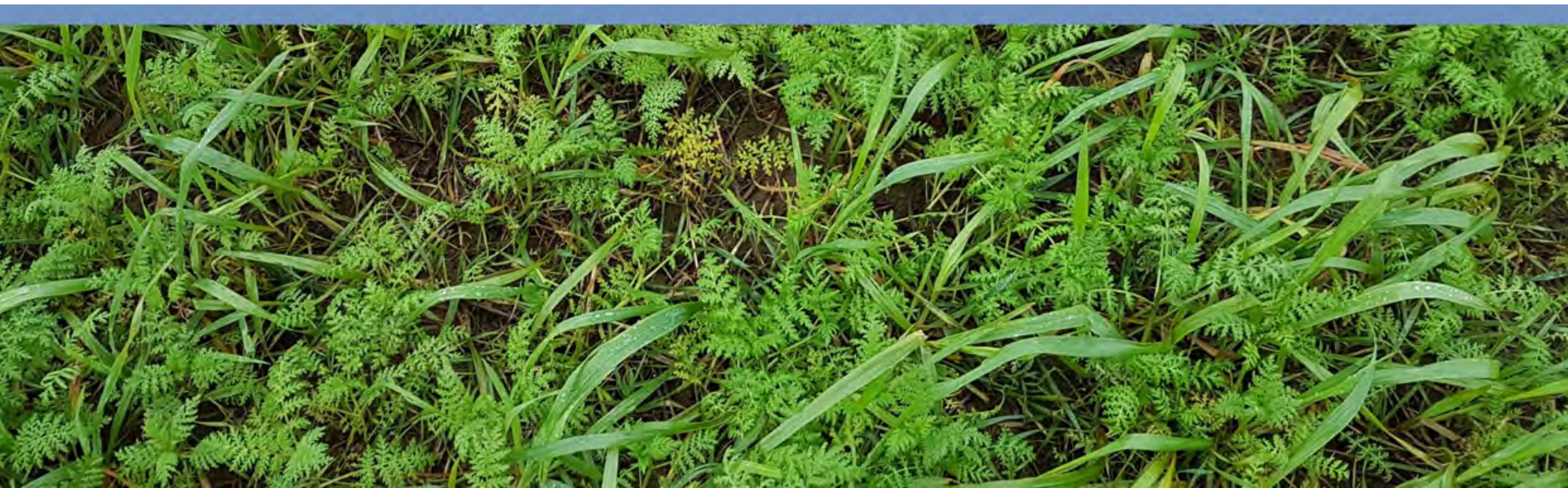
Investigating the integration of cover cropping into vining pea rotations

Summary report for trials 2017-2019

Processors & Growers Research Organisation
Green Pea Company



Investigating the integration of cover cropping into vining pea rotations.
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Tom Jelden & Dr. Lea Herold, June 2020.
Processors and Growers Research Organisation
in partnership with
The Green Pea Company.

Contents

1 Introduction

The United Kingdom is a leading producer of high-quality vining peas. Like any other crop, peas are vulnerable to numerous pests, diseases and environmental stresses. In particular, they suffer from soil-borne root pathogens, extremes of soil moisture and poor soil environments caused by compaction/over-cultivation. These issues can decimate a crop in some circumstances and persistently depress yield for growers in the UK. There are no simple fixes for these problems, thus tools that may assist long term agronomic solutions are required.

A healthy soil is well structured, biologically diverse and resilient to environmental extremes and disease pressures. These criteria are sought by the vining pea grower, rendering cover crops a potentially useful agronomic tool. Cover crops can be used to protect and restore soil. Their ability to retain nutrients and improve soil health is well documented, plus they are becoming increasingly relevant in the context of sustainable agricultural practice and environmental protection.

The agronomy of vining peas is under constant review and refinement by PGRO in order to sustain long term production in the UK as challenges to the industry mount. PGRO conducts research to provide growers with tools to successfully grow vining peas whilst also reducing negative impacts on the environment. Existing knowledge on cover cropping before vining peas was very limited, therefore GPC and PGRO aimed to close this knowledge gap. This study was launched to investigate the suitability of using cover crops in vining pea rotations. General effects of cover crops on soil health were examined. Resulting impacts on overall crop performance were monitored with particular attention given to the effects on soil-borne pathogens.

It is important to note that this is not a general guide or summary of cover cropping, rather a report on a series of trials that specifically focused on the compatibility of cover crops preceding vining peas. This text presents an overview of three years of trials discussing the cover crop options, benefits/drawbacks and conclusions from these studies. It accompanies supplementary technical documents that detail all trial findings (see section 8).

This work was sponsored by PGRO, GPC, Birdseye and the EIP-AGRI scheme. Trials were hosted and established by GPC members. Seed was generously provided by Elsoms.

2 Trials

Nine field trials were conducted over three years covering the vining pea seasons of 2017, 2018 and 2019. Cover crops were planted in the autumn prior to vining peas and catch crops followed vining peas in summer prior to following winter cereals. Trials were hosted on various soil types in commercial vining pea crops ranging from early sown peas on sandy loam to late sown on clay loam, all in the East Riding of Yorkshire. Foot rot pressures and cultivation practices differed between sites. A simple strip trial layout was employed with four cover crop and three catch crop options investigated alongside control measures. Selected combinations of cover and catch crops were also trialled. The species chosen for cover crop mixes were winter vetch, oil radish, black oats (with berseem clover) and phacelia (with black oats). Additionally, the hosts own mix was assessed which could include linseed, mustard, barley or borage. Catch crop mixes had phacelia as a base in combination with either oil radish or buckwheat or berseem clover.

Field operations were carried out by Green Pea Company (GPC) members. PGRO made numerous assessments of soil and plant criteria over the duration of the trials. All soil and foliar analyses were performed by Hillcourt Farm Research.

Soil factors measured included:

- Soil mineral nitrogen
- Soil nitrogen supply
- Phosphorus, potassium and magnesium
- Soil organic matter
- Soil moisture
- Compaction
- Soil structure
- Risk from pea foot rot pathogens

Crop responses measured included:

- Severity and incidence of foot rot infection in peas (*Fusarium solani, Didymella pinodella, Aphanomyces euteiches*)
- Yields and haulm biomass in peas
- Grain and straw yields in following cereals

Detailed findings of all assessments are available in technical documents accompanying this publication (see section 8). Conclusions of data analyses from combined trials are given throughout this text. Details of statistical procedures are given in the technical reports.

3 Species

3.1 Black oats

Avena strigosa (aka Bristle, Sand, Japanese, Lopside, Forage, Saia oat)

Black oats make a good foundation to a cover crop mix. They have a good balance between above and below ground biomass. Foliage is similar to cereal oats and a diverse range of varieties are available. Reasonably priced, EFA compliant and reliable to establish. Frost sensitive varieties are available which facilitates destruction, useful if leafy biomass is extensive. C:N ratio is lower than that of other cereals.

Oats have proven themselves as the best candidate cover crop before vining peas throughout these trials. Mixes dominated by black oats have shown the most positive effects on soil structure, foot rot development and yield in vining peas. In these trials, black oat based mixes resulted in better topsoil structure compared to no cover or competing species. Compaction was also moderately relieved with the use of black oats. These physical soil improvements were frequently found to be important dictators of yield, haulm biomass and foot rot development (discussed in section 4.1). When compared to conventional practice, employing a predominantly black oat based cover crop increased pea yield in five out of six trials where yield was measured. On three of those occasions, a yield increase of approximately 1.5 t/ha was achieved.

Foot rot was subdued by black oat cover crops in a few trials and never exacerbated. Pre destruction assessments of foot rot risk showed that there were no significant differences in *Fusarium* or *Didymella* pathogen loadings in black oat cover crops compared to the controls. The occasionally reduced incidences of foot rot attributed to black oats are therefore unlikely to be a consequence of active suppression by oats in the case of *Fusarium* and *Didymella*. *Aphanomyces* inoculum was not assessed in these trials but it has been demonstrated that compounds released by oats can be detrimental to *Aphanomyces* encystment [6–8, 12]. Significant structural soil improvements due to oats reduced foot rot disease by facilitating root development and improving soil moisture retention. Additionally, the biological legacy of the black oat cover crop may also have been important. Third party studies have shown that oats foster a beneficial soil microbiome. Oats support a greater population of *Bacillus spp.* and *Pseudomonas spp.* bacteria that are antagonistic to pea root pathogens[18]. Some publications have shown that antagonistic saprophytic fungi *Trichoderma spp.* and *Penicillim spp.* were better fostered by oats compared to vetch and phacelia whilst also simultaneously supporting lower populations of pathogenic fungi relevant to peas including *Nectaria haematococca* (*Fusarium solani* anamorph), *Fusarium culmorum* and *Fusarium oxysporum*[17]. This influence on the soil microbiome may also partially explain the ability of black oats to subdue levels of foot rot in peas.

Growers using cover crops often ask whether spring oats are an acceptable substitute for black oats. Black oats are probably a superior cover crop option, however, there are testimonies of spring oats improving pea performance in accordance with observations from these trials. Assessments of root length in glasshouse tests showed that black oats do extend slightly deeper than spring oats, but the difference was minimal. The similarities (general root architecture and chemical composition) are far greater than the differences.

Figure 2: Comparison of root extension and seed between black oat (left) and spring oat (right).

Figure 1: Crown rust on oat.

Black oats are not typically hosts for the most common cereal foliar diseases but are instead affected by crown rust and powdery mildew specific to oats. They are shared hosts for eyespot, *Fusarium sp.* and BYDV. Unlike other cereals, oats are not susceptible to the common strain of take-all, and thus do not multiply it. The resistance of oats to this pathogen is attributed to the presence of Avenacin, an anti-fungal saponin present in all oat tissues. Avenacin has been shown to compromise zoospores of *Aphanomyces sp.* and *Pythium sp.* which cause pea foot rot and damping-off, respectively[6]. There are also suggestions that saponins may confer resilience to *Fusarium species*[5]. Incorporated oat residues therefore may help to depress pea root pathogens. This effect is illustrated in Figure 23.

3.2 Winter vetch

Vicia villosa

Winter vetch was included in these trials to determine whether it would increase foot rot pressures. Vetches and clovers are legume species and it was hypothesised that they might be hosts for pea foot rot pathogens. These trials did not find any evidence that winter vetch proliferates either *Fusarium solani*, *Didymella pinodella* or *Aphanomyces euteiches*. At this stage, the project findings would suggest that it is safe to include winter vetch in rotations with vining peas and work will continue to further detail these findings. However, these trials have tested straight winter vetch immediately before peas which is not recommended. A winter vetch cover crop was usually an improvement on no cover crop in these trials, but as a cover crop before peas vetch was not the best candidate. It has low biomass above and below ground, doing little in terms of soil carbon contribution and structural conditioning. Vetch makes nitrogen contributions by fixation but is often less effective in accumulating nitrogen than other species which capture nitrogen exclusively. That said, the C:N ratio of its biomass is superior to other options, with a relatively quick release of early season nitrogen. These trials have demonstrated however, that this additional spring nitrogen is rarely beneficial to peas. The suitability of a vetch mix in distant parts of the rotation remains un-quantified. Very expensive and sometimes tricky to destroy it is perhaps best to use vetch as minor component of a cover crop mix. Winter vetch is EFA compliant and can provide total ground cover where successfully established, partnering well with rye if late drilling or late destruction is unavoidable.

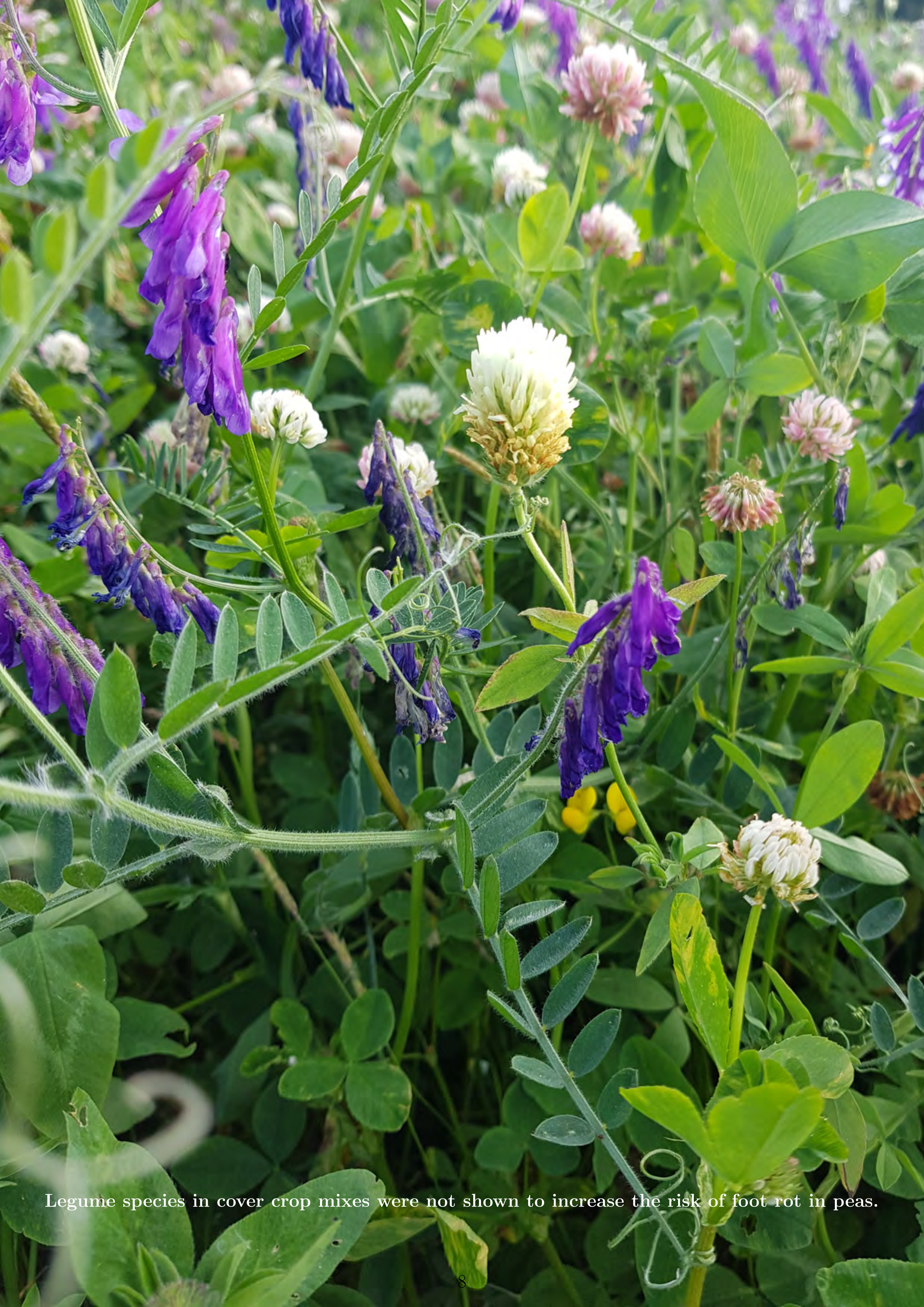
Figure 3: Vetch can be difficult to destroy. Not an aggressive weed but a potential contaminant.

3.3 Berseem clover

Trifolium alexandrinum

The merits of berseem clover are predominantly in nitrogen fixation. These trials have shown little advantage of that additional nitrogen to vining peas. That said, berseem clover was not observed to be detrimental to peas and foot rot issues have not been exacerbated by the overwintering clover. Berseem clover has a low biomass and minimal soil conditioning capacity, doing little to alleviate the soil structure and compaction pressures in a short overwinter period. Clover can make a contribution however, when used alongside a strong partner like a cereal. Berseem clover is relatively difficult to establish, easily out-competed, vulnerable to weevils and it is not recognised under EFA. Successful establishment of clover was dependant on independent shallow drilling of clover and adequate soil moisture. Drilling clover too deep led to disappointing emergence, thus casting seed ahead of the drill is often proposed to avoid separate drilling passes. Detrimental effects of residual herbicides were often observed. Some have hypothesised that clover may prime the soil microbiome in anticipation of peas. For example, fungal diversity in soil after clover was dominated by arbuscular mycorhizza, far more than oat, phacelia and vetch[3]. Oil radish does not form mycorhizzal associations. This study would only recommend using berseem clover as a minor component of cover crop mixes before vining peas.

Figure 4: Residual clomazone damage?



Legume species in cover crop mixes were not shown to increase the risk of foot rot in peas.

3.4 Oil radish

Raphanus sativus

Oil radish is a cheap, reliable and fast growing cover crop. It has a long taproot with a reputation for breaking deep compaction and can amass very large quantities of strong woody biomass, accruing vast quantities of nitrogen in the process. Varieties are diverse with ample clubroot and nematode resistant options available. Oil radish is quite competitive and when well established is very effective at soil drying. Unfortunately, it is particularly attractive to slugs and cabbage stem flea beetle.

Figure 5: Oil radish remnants at vining.

On paper, oil radish seems to be an ideal cover crop offering many agronomic merits. This work has repeatedly demonstrated the advantages of oil radish in alleviating deep compaction, improving spring drainage and mopping up nitrogen. Oil radish improved moisture retention in dry periods and yields were generally an improvement on no cover crop.

However, the findings of this work generally align with testimonies that say ”radish is bad for peas”. The C:N ratio of oil radish is high and despite the large quantities of nitrogen assimilated, the lock up effect is strong and may actually hinder following crop development. Oil radish did little, if anything, to improve topsoil structure in these trials, which as discussed in section 4.1, was observed to be the most critical factor in determining vining pea health. Haulm lengths were often reduced following an oil radish cover crop, though this had no impact on haulm biomass or yield.

Oil radish leaves behind a lot of trash which is woody, can take years to decompose, and is hard to fully incorporate. Consequences include non uniform seed beds, trash accumulating around coulters, harbouring slugs and bean seed fly. The trash is a nuisance to the harvesting apparatus of viners, plus the fine residue on the threshed product can potentially lead to quality implications thus risking penalties or rejection at harvest. This is a potential risk of all cover crops but definitely greatest with species like oil radish. As a catch crop it is able to form roots of considerable size. Good for assorted soil macrofauna but a problem for subsequent drill passes.

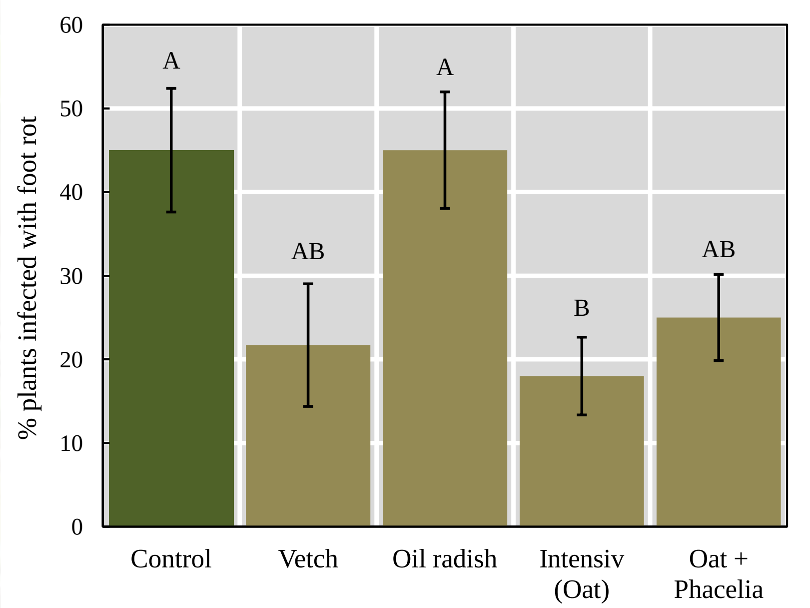


Figure 6: Percentage of pea plants infected with *Aphanomyces* and *Didymella* in late spring 2017 (Molescroft 61B).

Of most concern is the unusual connection of oil radish with pea foot rot. Oil radish showed no ability to lessen foot rot severity or incidence compared with other cover crops or even control measures. Also, lab tests determining the abundance of foot rot fungi *Fusarium solani* and *Didymella pinodella* in soil showed that oil radish often significantly increased the inoculum pressure. This phenomenon could be observed regardless of whether oil radish was used as a cover crop or catch crop (Figure 22). One third party study has demonstrated that *Raphanus sativus* can be a host for *Fusarium solani*[4], the species responsible for most cases of pea foot rot in the UK. It is also a host for *Fusarium culmorum*, a minor cause of foot rot. However, this is an isolated report (to the best of the authors knowledge) and no details on pathogen races or cross compatibility with peas are detailed.

These trials would conclude that oil radish is probably best omitted from cover crop mixes preceding vining peas due to issues concerning trash and foot rot propagation. Inclusion is less risky where oil radish proportions are kept low (<20%) in late sown cover crops, where foot rot risk is known to be low or absent, or where residues are of less concern (i.e. combining peas).

On one occasion an oil radish cover crop had a serious deleterious impact on winter wheat following peas. Demonstrated in the image above with wheat displaying straw discolour, depressed vigour and low yield. Comparative treatments appeared as below.

3.5 Phacelia

Phacelia tanacetifolia

Phacelia has a high biomass. Frost sensitive and readily decomposed, negligible amounts of trash remain. The rooting structure is fine and chaotic, confined mostly to the topsoil complementing deeper rooting species like oat or oil radish as both root and canopy architecture do not conflict. It has no rotational nor pest concerns and qualifies for EFA. Phacelia is not cheap and would not be ideal as a dominant species in a mix, 30% overwinter before peas being sufficient. It prefers a firm seed bed and does not thrive in dry conditions. Phacelia performs well as a catch crop in the right conditions, with a good nitrogen appetite and rapid biomass accumulation. It also provides a good quality food source for pollinators. The fast and easy destruction of phacelia makes it an ideal catch crop to fill the space between vining peas and following cereals.

Phacelia was an acceptable component of cover crop mixes before peas. In these trials, it has frequently scored best in terms of soil structuring which was critically important in crop health (see section 4.1). Neither foot rot severity nor pathogen loadings were increased by phacelia. With regards to soil chemistry, there were indications that phacelia could cause the greatest temporary pH shifts compared to other species, although this is not thought to have been detrimental to peas.

Table 1: Abundance of ammonium to 90 cm soil depth (kg/ha) and ratio of nitrate to ammonium. Eastfield AR, February 2017.

Treatment	NH_4 0-90cm	NO_3:NH_4
Control	2.2	32.5
Vetch	1.5	13.6
Oil radish	1.2	13.0
Intensiv (Oat)	2.0	13.2
Oat + Phacelia	7.5	4.4

One particularly interesting effect of phacelia was that on ammonium abundance. Where phacelia was grown, occasionally the soil has been observed to have greater quantities of ammonium. This effect was not seen with any other cover crop species trialled. Given that the effect could sometimes be observed months after the phacelia had been destroyed suggests that the higher levels of ammonium have a persistent microbial origin. The authors are unaware of any other published results aligning with these observations. Other studies have shown that phacelia supports a distinct microbiological community different from those of black oats, oil radish and clover[1], which may impact nitrogen mineralisation.

3.6 Buckwheat

Fagopyrum esculentum

Used as a short season break crop in some parts of the world, buckwheat establishes very quickly and has strong allelopathic properties making it a popular choice for weed suppression. It is easily destroyed, extremely frost sensitive and residues deteriorate rapidly. A slightly expensive option, its merits are in weed management and reputed phosphate scavenging. Buckwheat does not have an extensive root network for soil conditioning and contributions to soil carbon are modest.

In these trials, buckwheat was investigated exclusively as a catch crop. It is better suited to short, warm growing periods, plus its fast establishment and degradation are useful properties for catch cropping. Buckwheat was a relatively poor scavenger of nitrogen compared to phacelia and oil radish due to lesser rooting and biomass. Despite its known qualities for phosphate scavenging, no effect on phosphorus availability was observed in these trials.

The main comment on buckwheat concerns the apparent alleleopathic effects on winter wheat. In one year, straw yields were significantly depressed following buckwheat although the grain yields were unaffected. This was not observed the following year but in that case the catch crop had grown poorly, amassing much less foliar material than the previous year. It could therefore be suggested that alleleopathic compounds present in incorporated buckwheat tissues suppressed winter wheat in early development. Other studies have observed similar phenomena[11,13]. Although not measured, the buckwheat is suspected to have suppressed the phacelia growth in its catch crop mix.

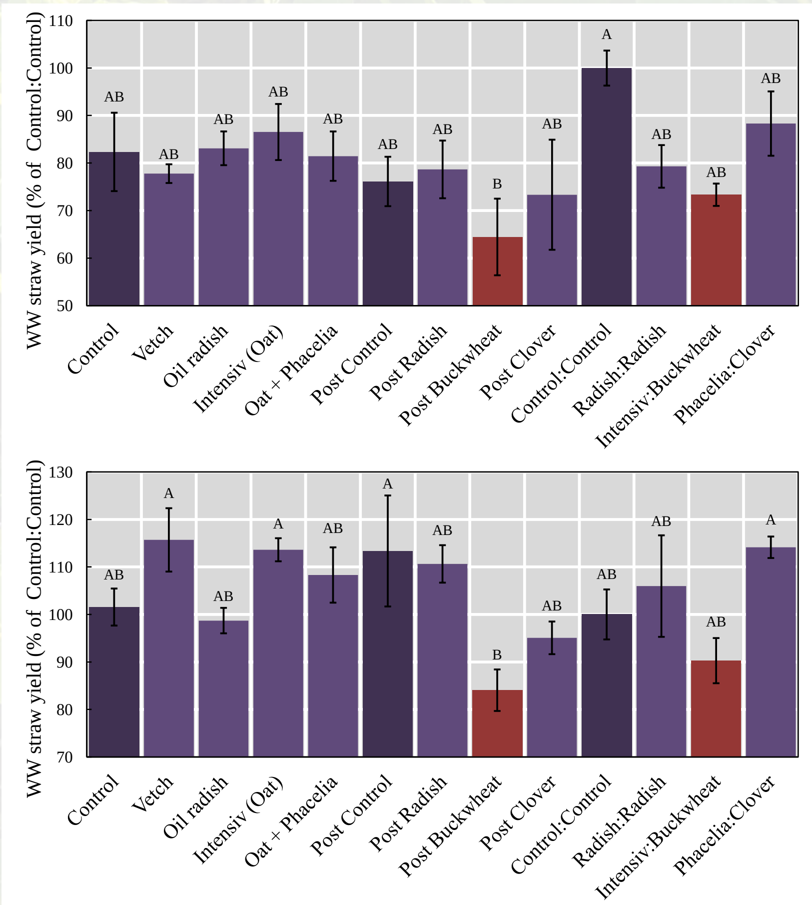


Figure 7: Winter wheat straw yields (as % of Control:Control). Straw biomass reduced following catch crop mixtures containing buckwheat. Molescroft 61B (top), Eastfield AR (bottom), May 2018.

Figures on next page. Top - Phacelia growing normally alongside oil radish. Below - In contrast, phacelia vigour depressed by accompanying buckwheat.


3.7 Linseed

Linum usitatissimum

Linseed is not the obvious choice for a cover crop component given its modest biomass and rooting. However, seed is readily available, plus there are few concerns about pests or rotational conflicts. It was not observed to be detrimental to peas when deployed in some custom mixes by our trial partners who advocate its use. Foot rot incidence has been shown to be low after linseed regardless of pathogen spore pressure[16]. Total destruction is critical to avoid contamination in vining peas.

Figure 8: Linseed can generate good soil structure despite its modest rooting.

3.8 Mustard

Sinapis/Brassica sp.

Mustard was briefly investigated in a single trial. No detriment to peas was observed nor any obvious benefit. Mustard is a cheap option. Its reliable vigour would probably out-compete most other cover crop species if drilled very early. No further comment can be made given the lack of data. Work investigating mustard as a cover crop candidate before peas is due in 2020. The mixed observations of Brassicaceae cover crops on foot rot require mustard be examined further.

Figure 9: Consider variety in order to avoid propagating clubroot.

4 Responses

4.1 Soil structure

Pea roots must occupy a well structured soil matrix in order to maintain correct function. Where peas are under pressure from drought, nutrient stress or foot rot pathogens, a greater root mass helps to support the plant on the surface. This is best achieved through providing decent soil structure. Cover crops have repeatedly shown their ability to improve soil structure, even after cultivation passes. This conditioning has been demonstrated to protect yield and haulm development and is believed to be the most important factor in determining these criteria. It is thought that the benefits are chiefly due to enhanced moisture retention at times of water stress, providing the critical resource for growth, particularly when roots are compromised by foot rot. The best VESS scores (a score of soil structure) resulted from cover crop mixes that were dominated by black oats or phacelia. These mixes consistently performed the best with regards to improving vining pea development. Oil radish rarely did anything to improve topsoil structure, mostly affecting deep compaction. Species with low root abundance (i.e. vetch or buckwheat) displayed a poor ability to improve soil structure in these trials.

Figure 10: Worm channel, crumb and some fine roots discovered at 70 cm soil depth after years of commitment to cover cropping and minimal tillage.

Figure 11: Legacy of cover cropping on soil structure 5 months after cover crop destruction. Standard practice left, oat + phacelia cover crop right. Large differences in porosity, root penetration and moisture retention. Boxtree Bubwith, June 2017.

4.2 Compaction

Peas do not perform well in compacted soil. Avoiding soil compaction can be achieved through careful consideration of tillage and traffic. However, cover crops can also be employed here. Their far reaching roots can cleave and restructure soil, even at depth. This ability is quite dependant on species. For example, the tap root of oil radish breaking deep layers of compaction compared to the fibrous shallower roots of phacelia reducing compaction in the topsoil. These trials have repeatedly shown that cover crops affect soil compaction. Compaction is sometimes very obviously directly detrimental to peas but in these trials compaction was seldom directly implicated in yield depression. However, soil compaction was often strongly coupled to increased foot rot development and *Didymella pinodella* spore abundance, which then led to modest yield decreases. Catch crops following vining peas were also generally effective at relieving compaction, perhaps more so than overwintering cover.

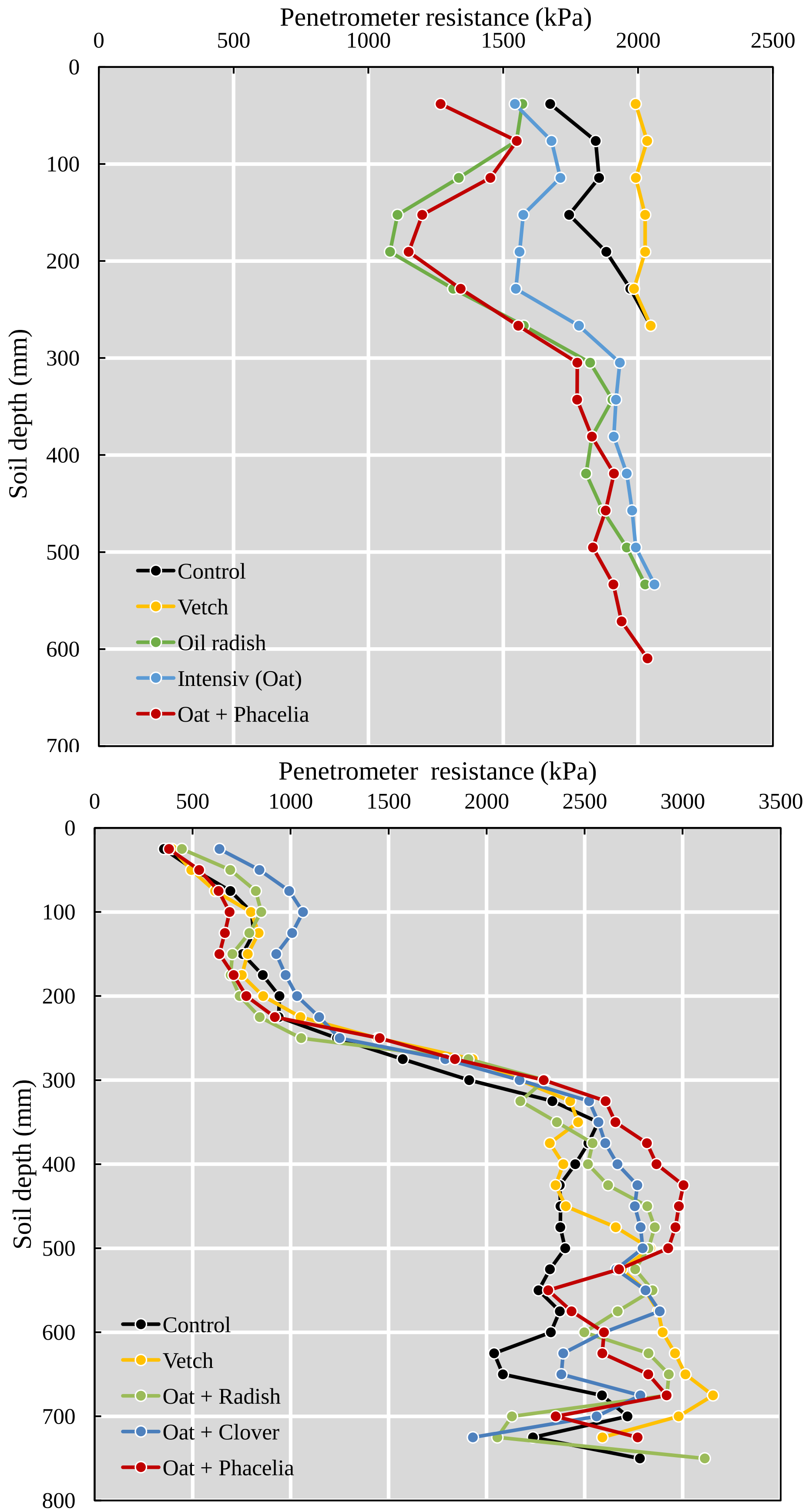


Figure 12: Soil penetrometer resistance profiles. Boxtree Bubwith (top) showing lesser compaction after certain cover crop mixes (June 2017). Vicarage FS (bottom) after heavy rainfall, plough pan obvious at 250-300mm (June 2019).

4.3 Soil moisture

Peas are particularly vulnerable to extremes of soil moisture. Where conditions are wet, imbibing vining pea seed can leak significant quantities of sugars and salts important for early development. Also, wet conditions are conducive to foot rot development. Too dry, and peas will struggle to achieve adequate root development and thus have little to draw on at the critical stage of pod fill. In these trials, cover cropping altered soil moisture relations often benefiting peas. Specifically, enhanced rates of drainage after heavy rainfall and moisture retention through dry periods have been observed. Deep rooting cover crops repeatedly demonstrated the ability to alleviate deep compaction and, as a consequence of this, accelerate drainage after heavy spring rainfall. Figure 13 (top) shows the change in soil moisture 48 hours after a spring rainfall event. Cover cropped treatments showed improved drainage capacity of soils, reducing water stress to developing peas which are very sensitive to water-logging. The oil radish was most effective at improving drainage capacity compared to other treatments. Retention of soil moisture through dry periods was also a common consequence of cover cropping. This was most likely a result of structural amendments (which were consistently observed) rather than increased soil organic matter content (which was not always observed). Figure 13 (bottom) shows the contrast between cover cropping and stubble (control) on moisture retention after important summer rainfall. The control started with the lowest soil moisture and fluctuated considerably compared to cover cropped treatments, which in comparison displayed better soil moisture retention and buffering against soil moisture change.

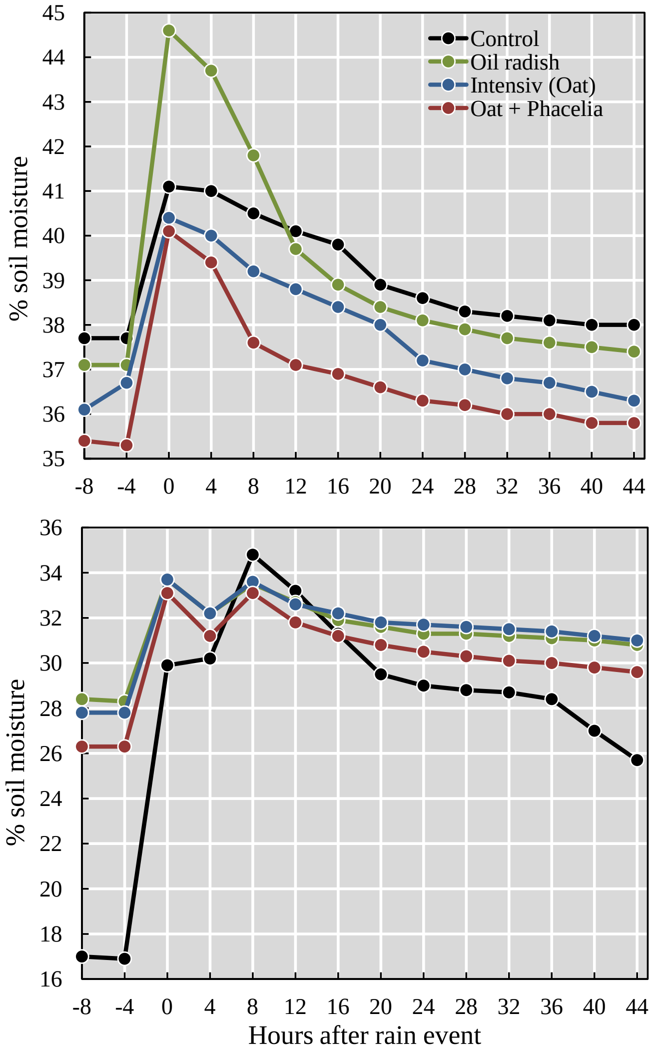


Figure 13: Soil moisture change at Eastfield AR (top) 3rd March 2017, Boxtree Bubwith (bottom) 3rd June 2017.

	Eastfield FNW		Vicarage FS
soil moisture at	Establishment	Pod fill	Establishment
Pearson-r	0.845	0.836	0.600
p-value	0.034	0.038	0.039

Table 2: Pearson correlations of yield and soil moisture at approximate growth stages. Eastfield FNW and Vicarage FS, 2019.

Retaining soil moisture in dry periods was shown to protect yield. For example, in Figure 15 the 3-5% extra soil moisture recorded in early April, a difficult dry spell of spring 2019, was a significant predictor of yield. As can be seen in the figure, an oat + clover cover crop helped maintain soil moisture at this time. A similar phenomenon was observed at another trial site in the same year (Figure 14), with soil moisture at critical growth stages correlating strongly with yield (Table 2). Water retention by the structuring legacy of black oats helped to increase yield by up to 1.5 t/ha. Figure 15 also demonstrates how cultivations and cover cropping interact to affect soil moisture. Ploughing resulted in greater moisture loss in the early spring compared to shallow cultivations. However, where cover crops were employed, no difference in soil moisture between cultivations was observed. Again, this was likely due to the residual structuring that survived the cultivations.

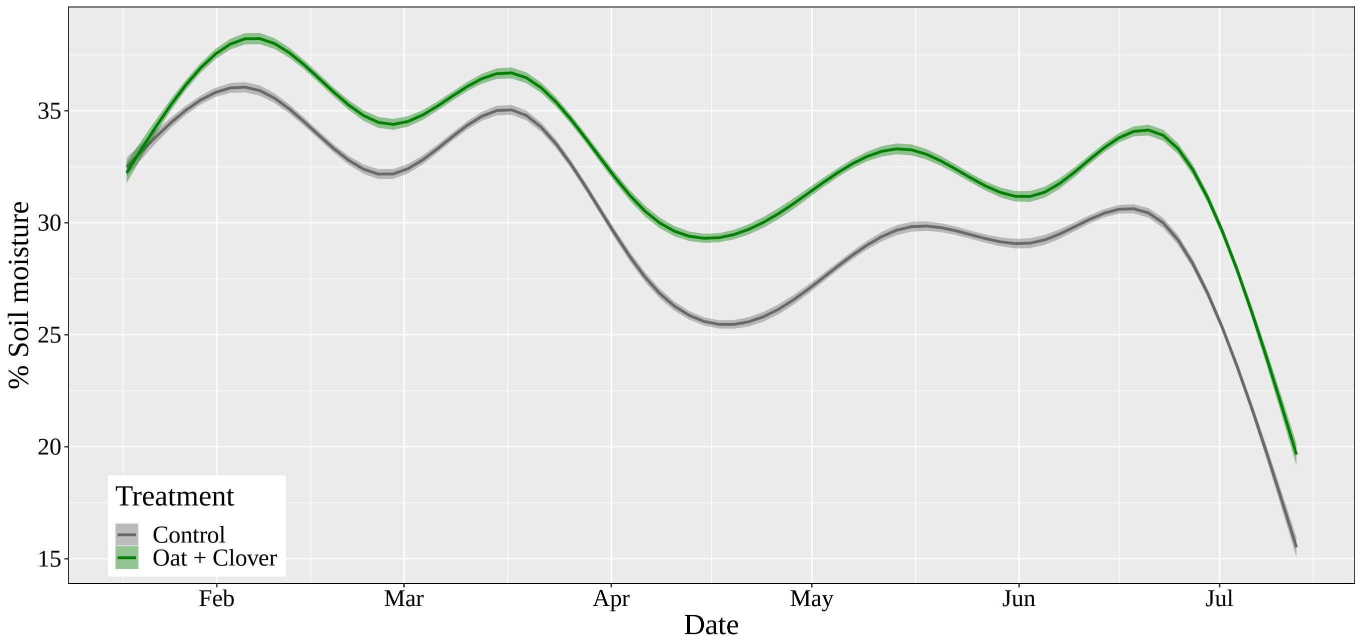


Figure 14: Soil moisture change from cover crop destruction to vining pea harvest. Eastfield FNW 2019.

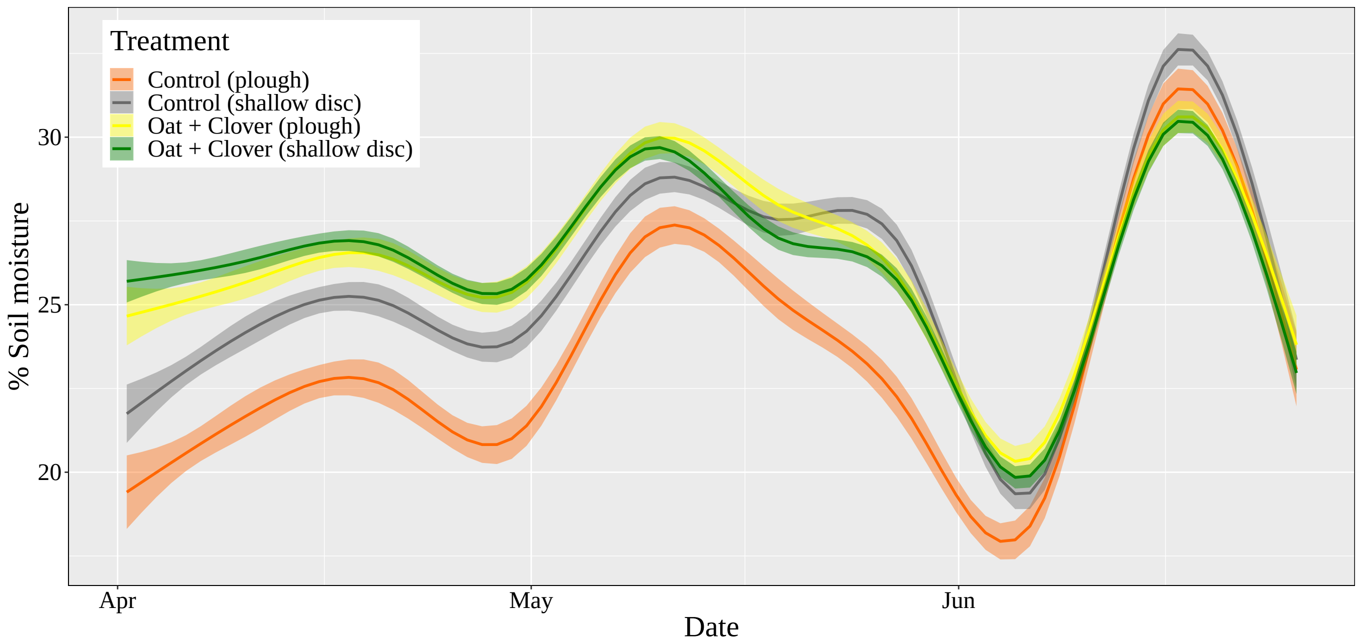


Figure 15: Soil moisture change from sowing to vining pea harvest. Vicarage FS 2019.

4.4 Vining pea yield

The motivations for using cover crops are not necessarily in the cash return, but yield responses in the following crop are important to investigate. The financial returns in the long term are difficult to quantify and were not investigated here, but immediate yield effects were observed in most trials. In three out of six trials where yield was assessed, cover cropping increased pea yield regardless of species choice, by up to 1.5 t/ha. In the remaining three trials assessed, yield responses were species dependent or absent. Mixes that were predominantly black oat resulted in higher pea yields on five out of six occasions. Yield increases were chiefly the consequence of better soil structure, improving resilience to foot rot and water stress. Positive financial returns are therefore certainly possible and not difficult to achieve. A modest yield boost of approximately 0.25-0.5 t/ha will generally cover the cost of establishing a cover crop, which may also contribute to longer term rotational returns. Quality and consistency is very important in vining peas. A crop must have uniform maturity and minimal contaminants. This work has shown that cover cropping has no effect on pea maturity. On one occasion crop contamination was assessed by the processor who commented that no discernible difference in contaminants was observed between cover cropped land that had been ploughed (trash buried) or shallow disc cultivated (residual surface trash present).

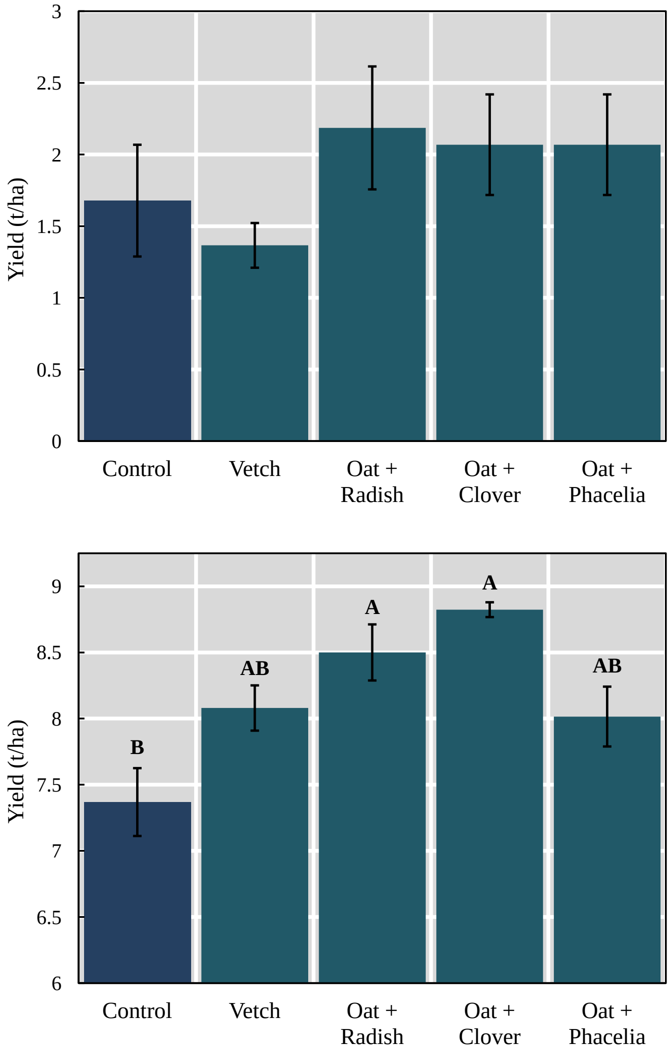


Figure 16: No vining pea yield response to cover cropping at Eastfield Kilnwick 2018 (top). Strong vining pea yield response at Eastfield FNW 2019 (bottom). Similar soil types and management.

Table 3: Mean vining pea yields (t/ha). Molescroft 29 expressed as % of control. Kilnwick and Hills 2018 trials, remaining trials 2019.

Mix	**Molescroft**	**Eastfield**		**Vicarage**		
	29	Kilnwick	FNW	Hills	FS-PH	FS-PL
Control	100	1.7	7.4_{b}	1.3_{c}	5.2	4.4
Vetch	99.6	1.4	8.1_{ab}	2.1_{b}	3.8	5.4
Oil radish	111	2.2	8.5_{a}	2.3_{ab}	5.0	5.7
Oat + Clover	91.0	2.1	8.8_{a}	2.7_{a}	6.5	5.6
Oat + Phacelia	89.7	2.1	8.0_{ab}	2.5_{ab}	4.9	6.1

4.5 Pea haulm

There were few consistent effects of cover cropping on pea haulm development. Oil radish tended to decrease haulm length very slightly, but did not decrease mass of haulm. Only in one trial did cover cropping affect haulm development where biomass was increased by at least 75% after cover crops, although this was observed only where shallow cultivations were employed. No effect was seen in the ploughed counterpart. Soil structure and foot rot were shown to be significant predictors of haulm biomass. Additionally, spring SNS was occasionally linked to increased haulm but this was not the case for yield.

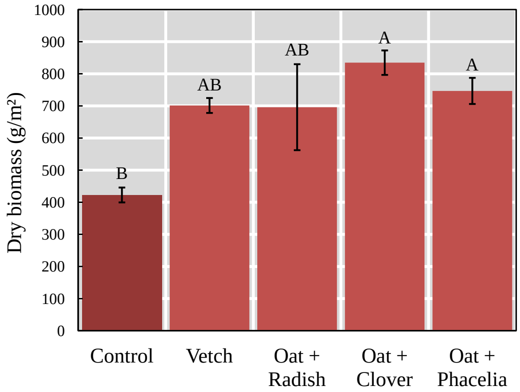


Figure 17: Pea haulm biomass accrued at Vicarage FS (2019) after shallow disc cultivation.

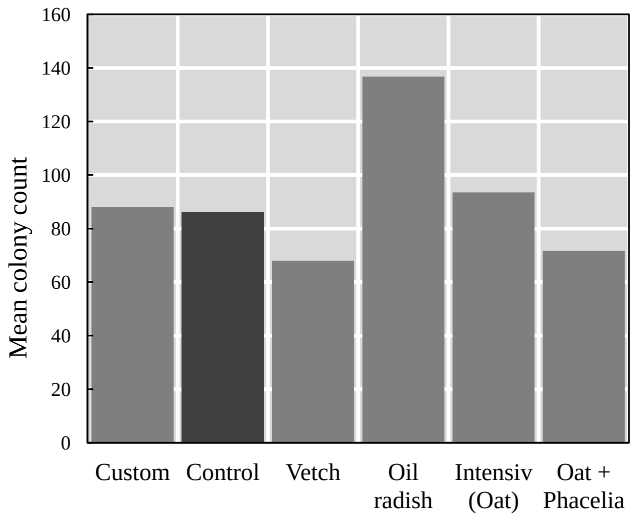
4.6 Winter wheat

These trials have also investigated the combined effects of cover crops and catch crops on winter wheat development following vining peas. The residual nitrogen from legumes is known to benefit following cereals. Catch crops can be used to hold nitrogen and give a delayed, gradual release of this nitrogen. No single combination of cover and/or catch crop proved to be significantly advantageous to winter wheat development. There were, however, a couple of instances were catch crop choices appeared to depress winter wheat development. Buckwheat suppressed straw yields but not grain yields (discussed in section 3.6). An oil radish cover crop (a year prior to winter wheat establishment) was also occasionally observed to be detrimental to winter wheat yields. Further evaluation of these effects is required. Full details on winter wheat responses are available in the accompanying technical reports.

Figure 18: Skeletons of oil radish amongst the winter wheat following a catch crop.

4.7 Foot rot

Foot rot infection is a serious persistent cause of pea yield losses, leading to impaired root functioning caused by (in Britain) fungal pathogens *Fusarium solani*, *Didymella pinodella* and oomycete *Aphanomyces euteiches*. These pathogens can infect roots individually but more commonly infect simultaneously resulting in a foot rot complex that is extremely hard to control. Management is predominantly achieved by extending rotations. However, cover crops can be used to partially mitigate the harmful effects of foot rot. The severity of foot rot infection is mostly determined by the abundance of pathogen resting spores in soil and weather conditions during the growing season. Very wet conditions (particularly in spring) facilitate spore mobility and germination success, enhancing disease development and ultimately decreasing yields. Additionally, foot rot is exacerbated by poor soil structure and compaction. Therefore, foot rot may be limited by management practices that reduce pathogen abundance, improve soil moisture relations and soil structure. Cover crops are a tool that can be used to help realise these objectives.



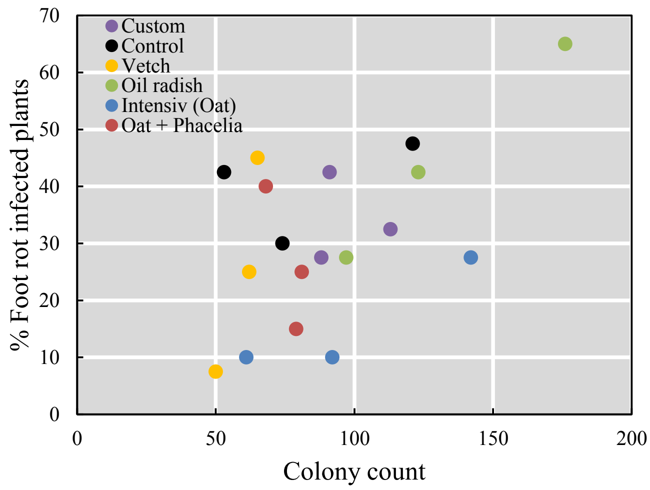
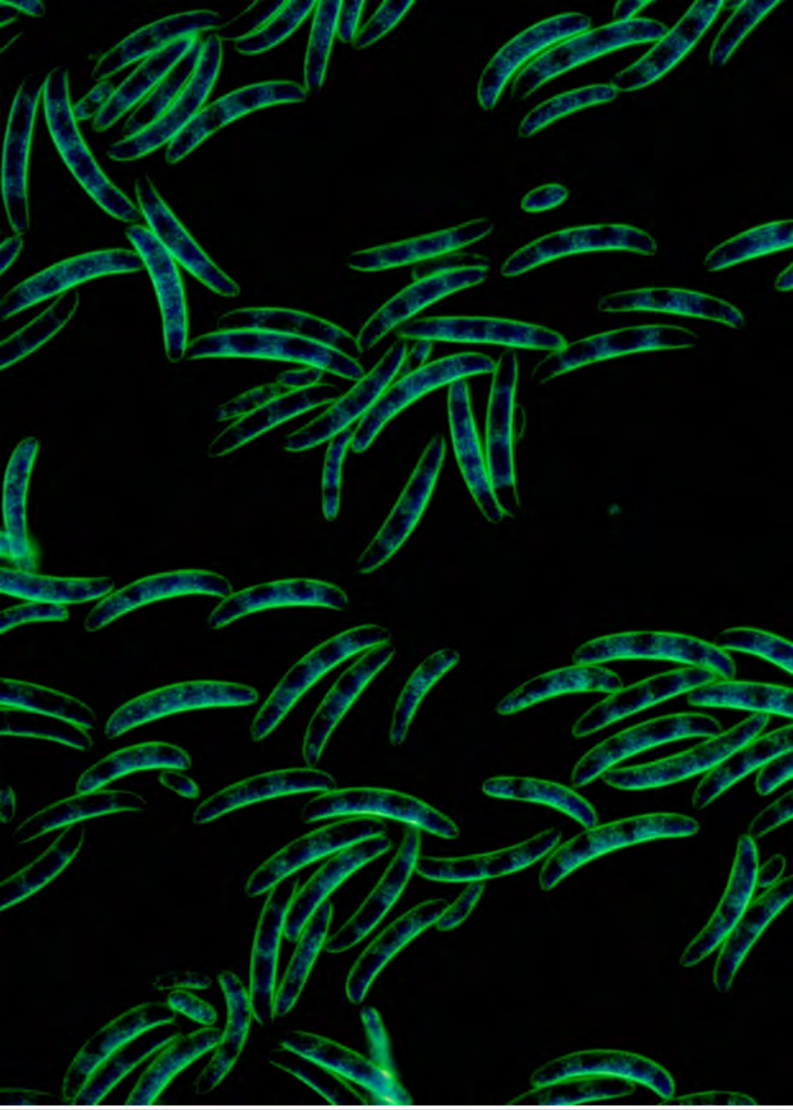
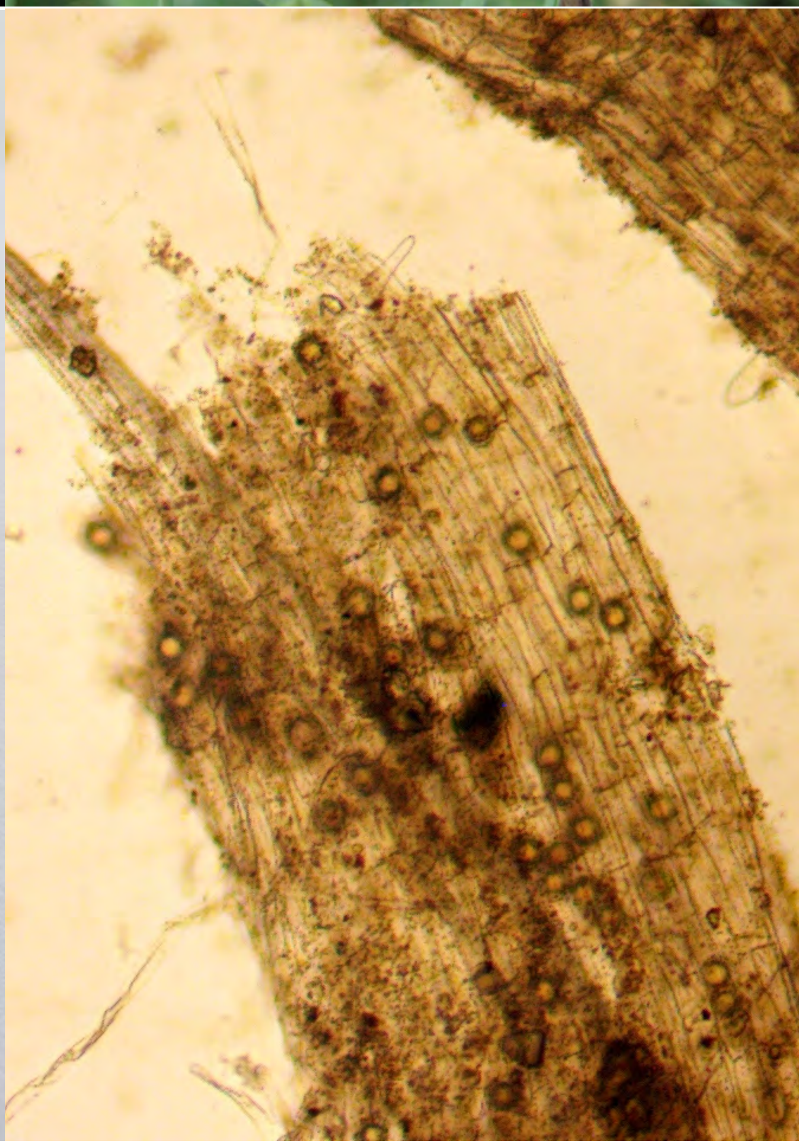


Figure 19: Pre drilling assessment of pea foot rot pathogen *Didymella pinodella* spore abundance at Molescroft 61B (left). Development of foot rot in field at Molescroft 61B (right). Oil radish seemed to increase the risk of *Didymella* infection. The additional presence of foot rot pathogen *Aphanomyces* complicates the situation.

Figure 20: Severe foot rot infection caused by a combination of *Aphanomyces euteiches* and *Didymella pinodella*.

Figures opposite page: *Fusarium solani* macroconidia (top left), *Fusarium* symptoms in pea (top right), severe *Aphanomyces* infection in pea (bottom left), *Aphanomyces* resting spores in pea root (bottom right).



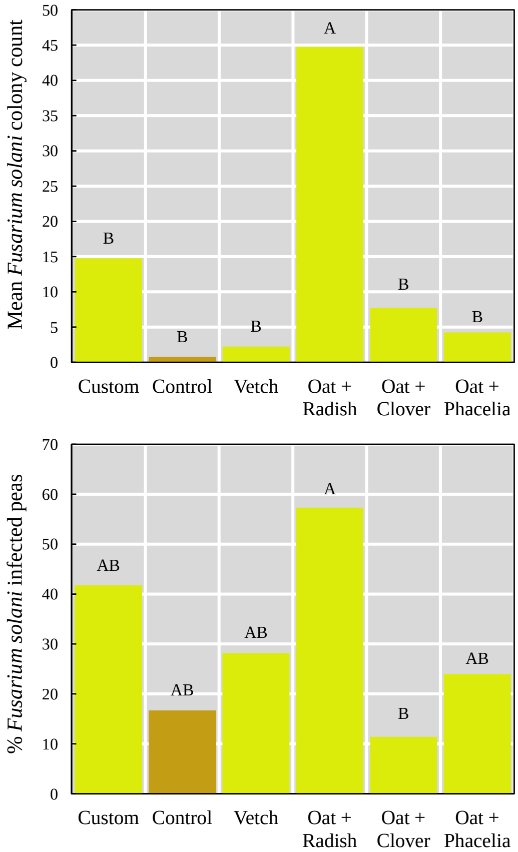


Figure 21: Pre drilling assessment of pea foot rot pathogen *Fusarium solani* spore abundance at Eastfield FNW (top). Incidence of *Fusarium* infection in field at Eastfield FNW (bottom).

Soil compaction makes foot rot infection worse. Root development is impaired leaving peas poorly equipped to survive and yield well when infected. Compaction also slows drainage after heavy rainfall leading to water-logging, favouring foot rot pathogens (especially *Aphanomyces*). Soil compaction was significantly implicated in foot rot development in almost all trials. Most cover crop species were shown to alleviate soil compaction (section 4.2) thus helping to reduce foot rot severity. Similar comments can be made with respect to soil structure. Preserving and improving soil structure through the use of cover crops was particularly important in preserving adequate soil moisture, which in turn protected yield when roots were compromised by foot rot. Maintaining good soil structure also helps to support large and diverse microbial communities in soil which are known to be antagonistic to soil borne pathogens. Moisture retention and microbial diversity can also be enhanced by increasing soil organic matter. Although not necessarily observed in these trials, cover crops are often used to raise levels of soil organic matter in the long term. Cover cropping generally reduced foot rot severity. The effect was normally quite subtle unless foot rot was extreme, where cover cropping made a considerable difference to foot rot infection. As discussed in section 3.4, oil radish tended to make foot rot infection worse. *Didymella* inoculum was often greatest following oil radish in these trials, regardless of whether it was used as a cover or catch crop. The effect was observed only once with *Fusarium*. The higher levels of infection after oil radish could be partially explained by poor topsoil structuring but the high inoculum pressure is likely to have a complex explanation which remains unknown.

Figure 22: Glasshouse demonstration of the residual effect of an oil radish catch crop on *Didymella* severity (control left, oil radish right) one year after peas. Could this effect endure an entire rotation?

Figure 23: Oat residues can have a powerful suppressive effect on *Aphanomyces euteiches* root rot. This is believed to be a consequence of anti-fungal saponins present in oat tissues. Right shows a moderate level of infection of *Aphanomyces euteiches* compared to a far healthier plant that occupied the same soil with incorporated spring oat residues (left).

4.8 Nitrogen

Cover crops were very effective at assimilating nitrate that would otherwise been leached over the winter. It was common to see over 50 kg of nitrogen per hectare recovered over winter or after peas in catch crops. Species with the greatest biomass were typically more effective at capturing nitrogen. Oil radish was the best in this regard, intercepting most of the nitrogen available to it. Shallow rooted vetch was least effective at mopping up nitrogen. Capture was also far greater when cover crops had properly established. In the 1^{st} and 3^{rd} years of trials, mixes containing phacelia were often found to have the highest amounts of ammonium compared to other cover crop options. This could be observed months after destruction and into deeper soil. As discussed in section 3.5 this is thought to be a consequence of phacelia's effect on the soil microbial community. SMN is a partial component of SNS (soil nitrogen supply). SNS is a better reflection of the total available nitrogen reserves. Cover cropping was very effective at building/maintaining SNS. This was mainly achieved by the assimilation of SMN into plant tissue and occasionally through nitrogen fixation. Vetch and clover contributed significantly to SNS only where they had established well and attained high biomass. SNS in the harvested vining pea crop was partially a reflection of the SNS status at cover crop destruction. The amount of haulm accrued also strongly determined SNS at this stage which in itself was affected by the multifaceted legacy of cover crops. SNS was not shown to be a predictor of yield in vining peas. Increased SNS from cover crops did affect haulm biomass on two occasions but did not have any impact on yield. This is perhaps an unsurprising result considering that peas attain nitrogen via fixation unlike other spring crops which are dependent on external nitrogen inputs.

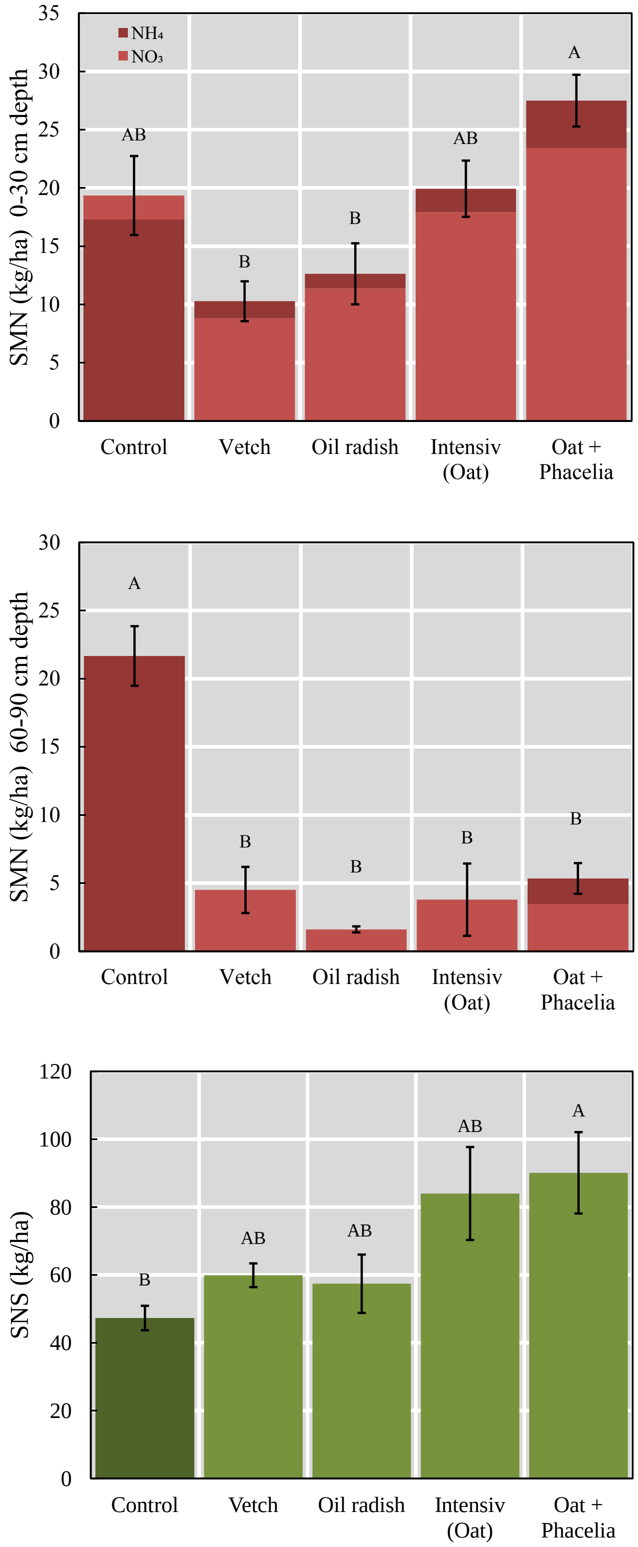


Figure 24: SMN in top 30 cm soil depth (top) and 30-60 cm soil depth (centre) at cover crop stage Eastfield AR 2017. SNS at vining pea stage Molescroft 61B 2017 (bottom).

4.9 Nutrients and organic matter

Cover crops are known to assist nutrient availability. Macronutrients are assimilated into plant tissues and then released into topsoil in readily available forms once destroyed, particularly important in the case of phosphorus[9,19]. These trials did not show any consistent effect on macronutrient availabilities after cover or catch crops, though there were certainly effects that seemed to be site dependant. Soil pH was often affected by species choice which was very strongly linked to nutrient availabilities, but again, no consistent patterns emerged. Whilst species-specific effects remain un-deciphered, the data have proven to be important in modelling foot rot and yield outcomes. Potassium availability in the early summer was often a strong model parameter predicting foot rot development and yield. Earlier season potassium and magnesium availabilities were also implicated. PGRO has observed this in other studies investigating foot rot development. It is still unknown as to whether this is a direct consequence of nutrition or a reflection of soil mineralogy.

Raising levels of soil organic matter is a common objective of cover cropping. Soil structure, moisture retention and nutrient holding capacity are improved by increasing soil organic matter. In some trials, a brief minor lift in soil organic matter was observed after cover or catch cropping. However, these effects did not persist into cereals following peas. Species selection had no consistent effect on soil organic matter. No impact on yield and few weak effects on foot rot development were determined. PGRO did not expect to see any significant soil organic matter responses to a single cover and/or catch crop. Raising soil organic matter occurs in the long term and requires high inputs of organic matter, either from cover crops or imports, and compatible tillage practices.

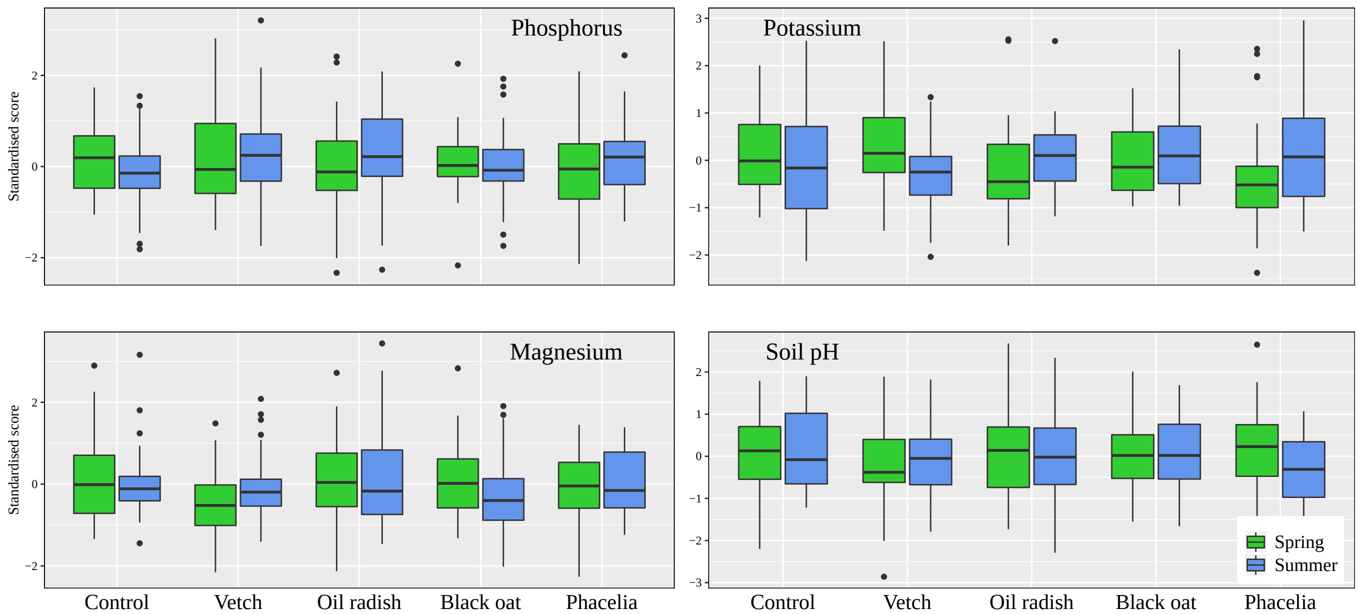


Figure 25: Standardised scores for relative abundance of soil macronutrients and soil pH, prior to vining pea drilling and prior to harvest. All trials data combined.

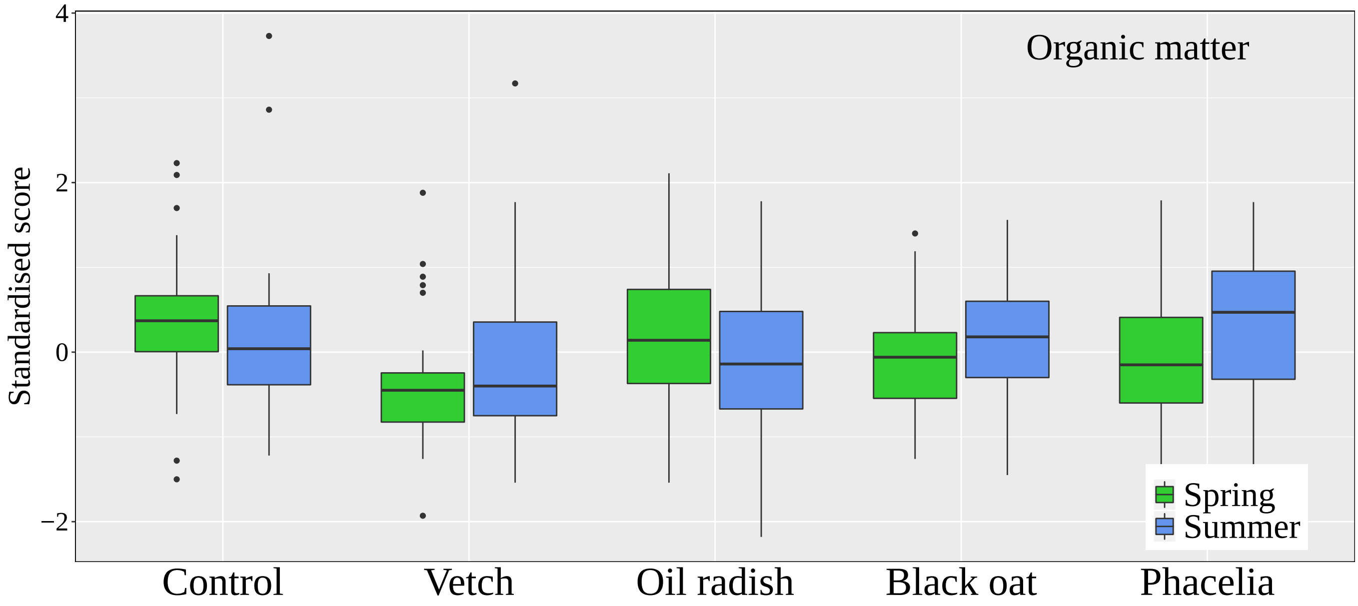


Figure 26: Standardised scores of soil organic matter compiled from all trials prior to drilling (Spring) and prior to vining (Summer). No individual species had any consistent prolonged effect on soil organic matter content.

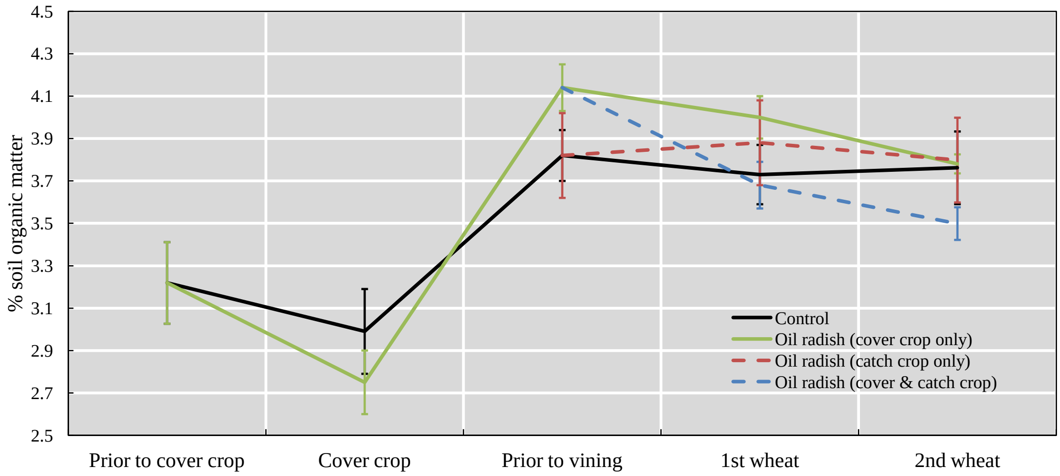


Figure 27: Soil organic matter flux from August 2016 to May 2019 (Eastfield AR). A short lived increase in soil organic matter was observed after cover cropping.

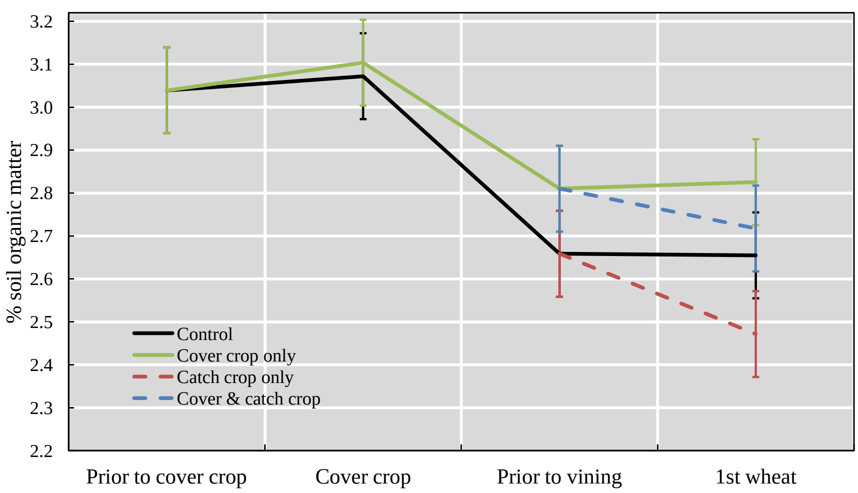


Figure 28: Soil organic matter flux August 2017 to May 2019 (Vicarage Hills). Data are averages of all control measures and cover/catch cropping treatments trialled.

5 Conclusions

These trials investigated the effect of cover crops on vining pea development with special reference to pea foot rot interactions. Major soil attributes have been assessed and their effects on peas determined. The effect of cover and catch crop combinations on following cereals was also examined.

These trials have re-inforced cover cropping's established reputation for intercepting soil nitrogen, improving soil structure and soil moisture behaviours. The often vast quantity of nitrogen assimilated by cover crops was not believed to have affected vining pea development. Improved soil structure and soil moisture retention properties that followed cover cropping were certainly beneficial to vining pea yield and resilience to foot rot. Soil compaction was affected by cover cropping in these trials. Although not directly implicated in vining pea yield, compaction relief here was demonstrated to improve soil drainage and reduce the impact of pea foot rot. Cover cropping was shown to affect levels of soil organic matter and macronutrient availabilities. However, no consistent species effect could be determined. Nonetheless, the data were useful in explaining foot rot and yield development.

Yield could be significantly increased by cover cropping, but the species selection and management were highly important in this regard. Foot rot was modestly subdued by cover cropping, primarily by protecting the crop's ability to maintain proper root function and growth via residual soil conditioning. Oil radish, a popular cover crop species, was frequently demonstrated to increase foot rot risk and incidence. Legume cover crop species winter vetch and berseem clover did not increase the risk or incidence of pea foot rot.

Positive outcomes from cover cropping were found to be dependant on species selection and timing of establishment. Vining peas responded best to cover crop mixes dominated by black oats. Phacelia, berseem clover and linseed were acceptable and probably beneficial accompaniments to the oats. Winter vetch was safe to use as a cover crop before vining peas although to little benefit as a monocrop. Winter vetch would be better suited as a minor component of cereal based mixes. Oil radish presented the greatest risks and, in most cases, it should be avoided in cover crop mixes preceding vining peas.

Figure 29: The benefit of early drilling. Leave too late and nothing will be achieved. Late drilled buckwheat left, early drilled buckwheat right.

The timing of establishment was also extremely important in determining the success of a cover crop. Best results were achieved when mixes were drilled in August. Late September drillings showed few crop, soil or pathogen responses. Destroying cover well in advance of drilling the following crop was recognised to be very important. This allowed residues ample time to deteriorate. Failing to do so can cause issues with trash/seedbeds and invertebrate pest carry over.

Figure 30: Frost will not kill hardy species like winter vetch (left) but other species like phacelia (right) will reliably die off after frost. If only the frost was reliable.

6 Unanswered questions and further trials

Legume species were included in cover crop mixes to investigate any rotational conflict with vining peas through potential disease propagation. Conventional advice is to exclude legumes because they might be shared hosts of soil borne pea pathogens, although there is little data to support this precaution in the case of vetches and clovers. For example, vetch is moderately susceptible to *Aphanomyces euteiches* whilst peas are extremely susceptible. Thus, it would seem sensible to omit vetch from the cover crop mix. However, the strains of *Aphanomyces* that primarily affect vetch are different to those that would destroy peas, and the cross compatibility of these strains is weak[14]. PGRO has also observed in glasshouse experiments that winter/hairy vetch is much less susceptible to *Aphanomyces* than common vetch, another consideration in selecting species.

Vetches and clovers are also hosts for numerous *Fusarium* species. Other studies have demonstrated that the pathogenicity of *Fusarium* species and strains is hugely variable but could not confirm that *F. solani* propagation by vetches and clovers had a significant impact on pea foot rot[20,21]. Field surveys have shown that clover root rot (*F. avenaceum*) was unaffected by legume cropping frequency in one study[10] and, in another, pea foot rot was not affected by the inclusion of white clover or lucerne into the rotation[15].

The authors are unaware of any published field studies and/or grower testimony of detrimental pea foot rot proliferation by vetch and clover. Our trial results have yielded little to no evidence that vetch or berseem clover preceding vining peas increases the risk of foot rot. The risk of foot rot propagation where legume cover crops are not rotationally adjacent to vining peas remains un-quantified. PGRO is continuing with vetch cover crop trials to further clarify its suitability.

A considerable proportion of the UK vining pea area is silt. These trials so far have not been hosted on silts, though this has now begun. It might be expected that the soil structuring abilities of cover crops are less relevant on silts, but given the prevalence of foot rot in these areas, any method of disease mitigation is certainly worth exploring. For now, the suitability of cover cropping before peas on deep silts is unknown.

Cover cropping ultimately aims to protect and rebuild soils whilst offering environmental benefits. It is often used in tandem with min/zero-till systems. Establishing decent seed beds and eliminating surface contaminants is a priority for vining pea growers. Cover crops provide the strongest long-term benefits in systems with reduced cultivations. However, in some circumstances, heavy cultivations prior to drilling vining peas are necessary. This work has shown that structural soil improvements offered by cover crops can partially survive the impact of cultivations whilst still providing benefits to the vining pea crop. Also, the soil architecture beneath the reach of implements remains undisturbed.

7 Biodiversity

Cover crops offer precious shelter for numerous animals over winter. Many harmless and beneficial invertebrates thrive beneath the canopy. However, pests including slugs, weevils and bean seed fly also enjoy the shelter and prosper on the residues reinforcing the importance of destroying the cover well in advance of drilling. One of the participating growers of this project has observed that cover crops provide excellent refuge for snipe, dormice and hares. Birds were frequent company during sampling visits, clearly drawn in by the arable oasis. Catch-crops and some early drilled cover crops were extremely popular with pollinators, acting as an important late season food source. Cover cropping did not have any consistent effect on earthworm abundance throughout these trials. Earthworms are important for healthy soil functioning and are best preserved through reduced tillage.

Figure 31: Saprophytic fungi beneath a cover crop canopy (left), butterfly on oil radish catch crop (right).

Figure 32: As demonstrated in these trials, cover crops are able to intercept large amounts of nitrogen that would otherwise leach. This in combination with their capacity to reduce soil erosion results in cleaner, less polluted waterways, benefiting the aquatic life therein.

8 Additional reading

Technical report for 1st year trials [Link]
Technical report for 2nd year trials [Link]
Technical report for 3rd year trials [Link]

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Processors and Growers Research Organisation, Great North Road, Thornhaugh, Peterborough, Cambridgeshire, PE8 6HJ.
The Green Pea Company, BGA House, Nottingham Road, Louth, Lincolnshire, LN11 0WB.