Investigating the integration of cover cropping into vining pea rotations

Technical report for 2nd round of trials, 2017-2019.

Processors & Growers Research Organisation
Green Pea Company

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Contents

This report details all findings from three cover crop trials beginning August 2017 as part of a greater project investigating the compatibility of cover and catch cropping in vining pea rotations. The project was launched in 2016 sponsored by PGRO, Birdseye and The Green Pea Company, with funding awarded by the EIP-AGRI scheme and seed provided by Elsoms. All work was carried out by PGRO and GPC members Chris Byass, Tamara Hall, Andrew Falkingham and Richard Boldan.

1 Background

Vining peas are vulnerable to poor soil conditions and soil borne pathogens. Cover crops can be used to improve soil structure and health. They also have the potential to mitigate disease risk from soil borne pathogens. These attributes in addition to the growing recognition of cover crop's environmental benefits render them a potential agronomic tool in vining pea production.

Cover cropping is a complex niche subject and their use in vining pea rotations is poorly documented. The purpose of this project is to investigate the effects of cover crops on vining pea development with reference to soil health and foot rot. Additionally, the effect of catch crops on following cereals is studied. Here cover cropping is defined as over-wintering vegetative cover (preceding peas) and catch crops as a fill between vining peas and the following crop.

This document presents the findings and analysis of three trials (out of nine) hosted by GPC growers. It is the second report in a series of three technical reports. The trials have assessed the use of a selection of common cover crops with numerous soil and plant criteria monitored. Cover crops were sown in 2017 prior to the 2018 vining pea season with 1st wheats assessed in spring 2019.

The ultimate objectives of these trials are to determine the suitability of cover cropping in vining pea rotations, to show how and where they may be employed with particular focus on improving our understanding of foot rot management.

2 Trial methods

Four cover crop mixes and three catch crop mixes were trialled alongside control measures and the field standard (Custom). The mixtures are detailed in table 2. The trial adhered to a simple strip trial layout. Cover crop strips were drilled parallel to then be partially overlapped by perpendicular catch crop strips later on (see figure 1). This resulted in field areas that had overlapping treatments. Where only catch crops are drilled, the treatments will be abbreviated with the prefix "*Post*" in this document (see table 2 for further clarification). It is important to note that this layout cannot completely distinguish field effects from treatment effects in some cases. The trials were repeated at three sites in the East Riding of Yorkshire with different soil types, foot rot pressures and drilling dates.

Table 1: Trial sites

Field name	Location	Drilling window	Foot rot pressure	Soil type
Molescroft 96	Beverley	Late drilled	High foot rot risk conferred by *Aphanomyces* and *Didymella*	Poorly drained clay loam
Eastfield Kilnwick	Bainton	Mid season	Light foot rot risk from *Fusarium*	Medium sandy clay loam with cover cropping and min-till history
Vicarage Hills	Asselby	Early drilled	Medium risk from *Fusarium* and *Didymella*	Free draining sandy loam with poor inherent structure

Table 2: Treatments / Species mixes

Name in text	Species mix	Rate
Control	Stubble	n/a
Vetch	100% Winter vetch (*Latigo*)	30kg/ha
Oat + Radish	20% Oil radish (*Defender*), 80% Black oat (*Codex*)	50kg/ha
Oat + Clover	87% Black oat, 13% Berseem clover (*Otto*)	40kg/ha
Oat + Phacelia	95% Black oat, 5% Phacelia (*Angelia*)	40kg/ha
Post control	Stubble	n/a
Post radish	90% Phacelia, 10% Oil radish	18kg/ha
Post buckwheat	10% Phacelia, 90% Buckwheat (*Hajnalka*)	20kg/ha
Post clover	38% Phacelia, 62% Berseem clover	12kg/ha
Control:Control	"Control" "Post control" overlap	-
Radish:Radish	"Radish" "Post radish" overlap	-
Phacelia:Buckwheat	"Oat + Phacelia" "Post buckwheat" overlap	-
Clover:Clover	"Oat + Clover" "Post clover" overlap	-

*Note - The clover in the "Oat + Clover" mix had emerged poorly, therefore it is better to consider the mix to be mostly black oat. In "Oat + Radish", oil radish dominated despite the high oat constituent. Cover and catch crops at the Molescroft 96 site had not established well and thus only data for a few treatments are presented in this report. Some assessments were impossible due to ground conditions (Compaction and VESS).

Numerous soil and plant parameters were assessed at various times throughout the rotation. Samples and assessments were made before cover crop drilling, prior to cover crop destruction, prior to vining, shortly before catch crops were destroyed, and in the late spring in 1st wheats. Throughout the text these points are referred to as Pre-cc, Cover crop, Vining pea, Catch crop, and 1st wheats respectively.

Soil properties examined included;

- SMN (soil mineral nitrogen) at various depths
- Macronutrients including phosphorus, potassium and magnesium
- Soil organic matter (LOI) and pH
- Soil moisture
- Compaction (penetrometer resistance)
- Assessment of soil structure (VESS)
- Inoculum pressure for foot rot pathogens *Fusarium solani* and *Didymella pinodella*

Assessments of crop health and responses included;

- Vining pea biomass
- Vining pea yield
- Severity of foot rot development
- Estimates of straw and cereal yields

There were three relevant foot rot pathogens. *Fusarium solani*, *Didymella pinodella* and *Aphanomyces euteiches* which are referred to by their genus thought the text. *Fusarium* and *Didymella* were frequently monitored with *Aphanomyces* levels determined to be considered in analysis.
Details on methods, timings, analysis and replication are given in the appendix. All chemical analysis of soil samples was performed by Hillcourt Farm Research.

Weather

The weather in 2018 was difficult and extreme at times. The December to January period saw 51mm more precipitation than the previous year, after which very cold conditions and significant snowfall occurred. Soil conditions hadn't righted themselves for drilling until the end of March at the earliest, consequently a lot of sub-standard seedbeds had to be contended with. After good weather in April-May, no significant rainfall was seen through-out the growing season. Simply put, a very cold wet start followed by drought. Rainfall was lacking in August and into September after which weather conditions returned to normal/dryish.

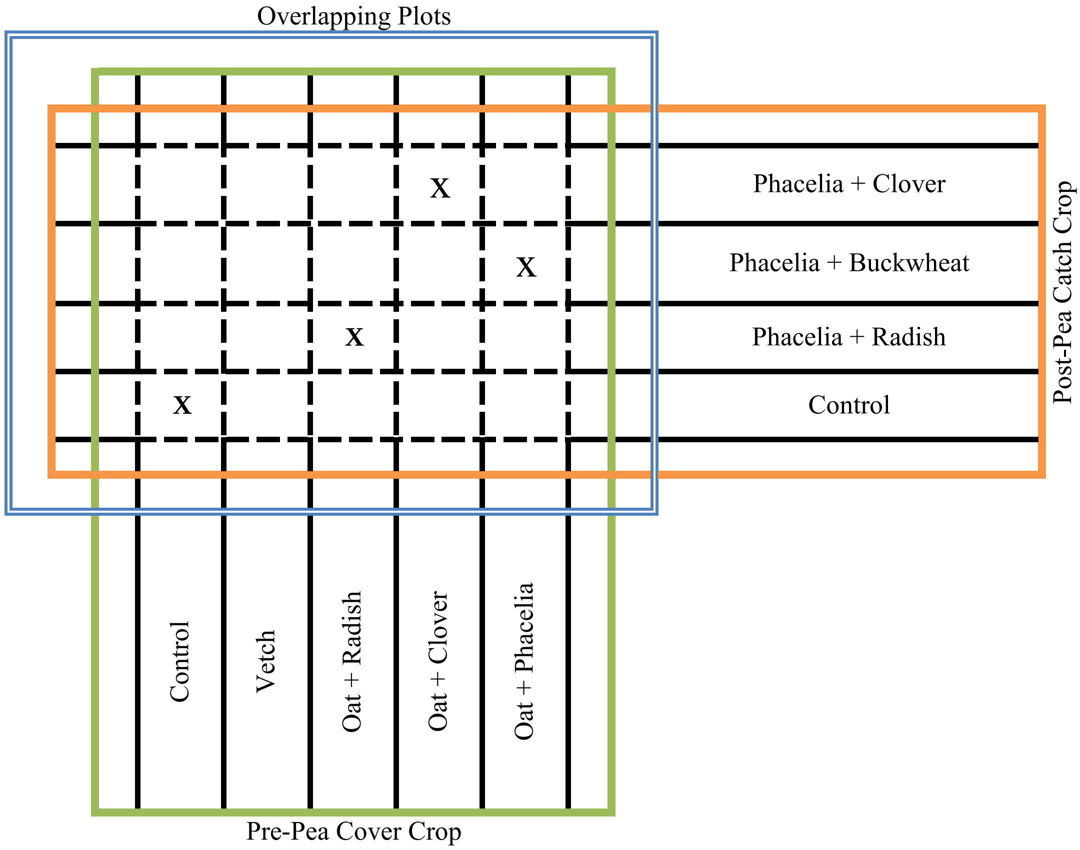


Figure 1. Experimental layout of field trials.

Figure 1: Trial plot layout. Crosses denote overlapping plots.

3 Results

3.1 Soil mineralisable nitrogen (SMN)

3.1.1 Cover crop

There was little confidence in any treatment effect on soluble nitrogen at Molescroft 96. Concentrations varied considerably at both depths measured. Only three treatments were sampled due to underdevelopment of the cover crops at the time of sampling which would also explain the lack of differences. At Eastfield Kilnwick, SMN was generally lower in the Custom and Radish treatments at both depths. This is probably due to high nitrogen demand of oil radish and mustard (Custom mix). SMN in the 30-60cm range was by far greatest in the control measure, demonstrating the expected downward leaching of nitrogen. The figures for SMN at Vicarage Hills were similar to those of Eastfield Kilnwick albeit slightly more variable. The highest value of SMN in the Oat + Clover 0-30cm depth could not have been caused by clover fixation as it had emerged poorly.

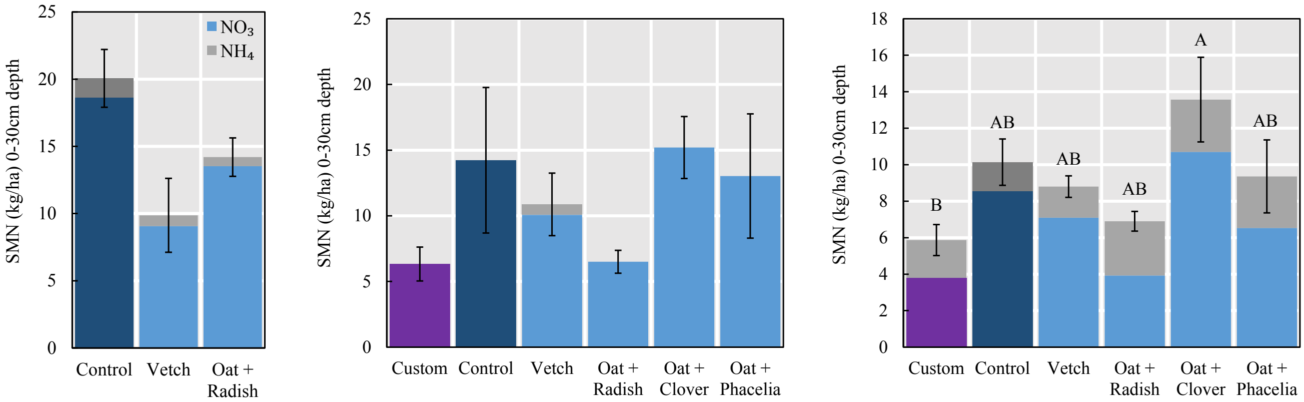


Figure 2: Mean soil mineral nitrogen to 30cm depth at cover crop stage (January 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

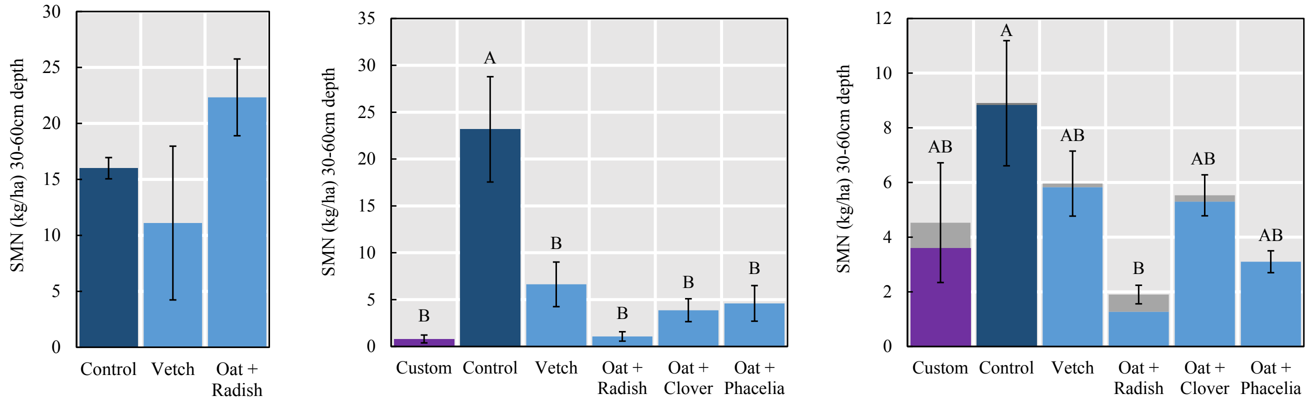


Figure 3: Mean soil mineral nitrogen from 30 to 60cm depth at cover crop stage (January 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.1.2 Vining pea

There were no significant treatment effects at Molescroft 96 at harvest although Vetch plots remained the lowest in SMN reflecting the observations in the winter. Overall quantities of SMN remained largely unchanged at Molescroft 96 since the winter. In contrast, levels of SMN had increased at both Eastfield Kilnwick and Vicarage Hills, around 2 to 3 fold in the 0-30cm soil and roughly 4 fold in the deeper soil. There were notable exceptions, for example, the 10 fold increase in Custom plots at Eastfield Kilnwick and the very small changes to SMN in the Control plots at 30-60cm. The failure of Control plots to accrue SMN in the deeper soil was likely a result of early season leaching and lack of nitrogen release from decaying cover crop.

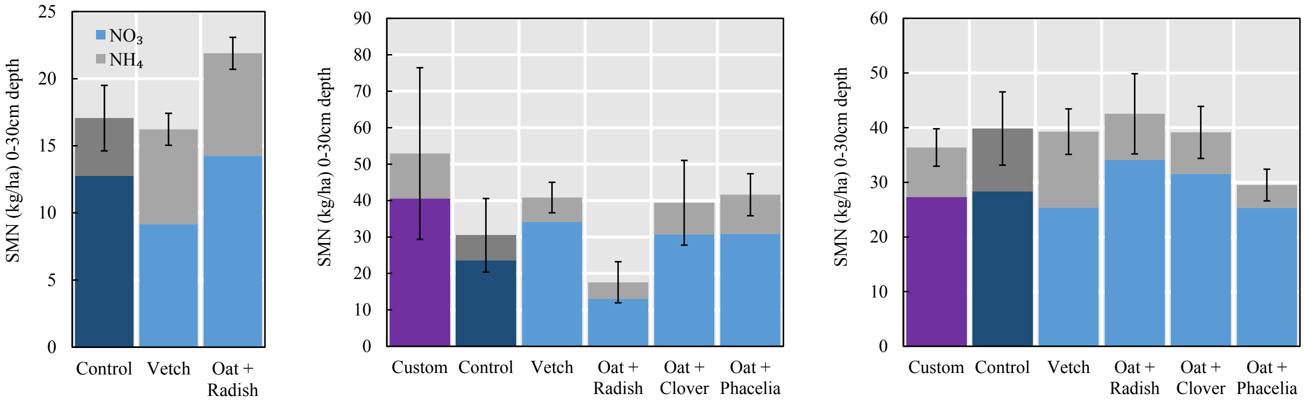


Figure 4: Mean soil mineral nitrogen to 30cm depth at vining pea stage (July 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

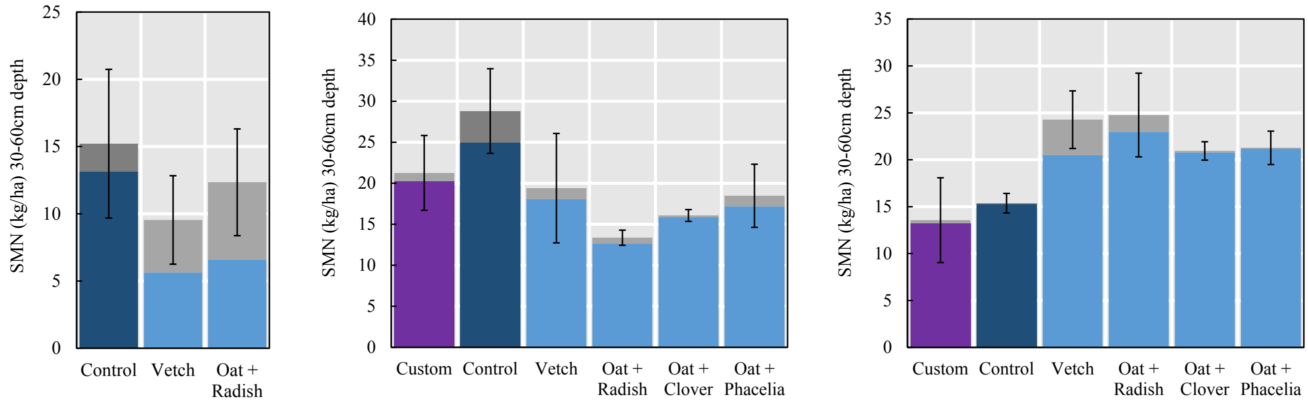


Figure 5: Mean soil mineral nitrogen from 30 to 60cm depth at vining pea stage (July 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.1.3 Catch crop

Between vining pea harvest and the catch crop, SMN had increased by roughly 40kg/ha at Molescroft 96 as haulm decayed. Perhaps the only observation here is that the previously vegetated treatments with no catch crop are the highest in SMN, as expected (Figure not shown).

At Eastfield Kilnwick, vining peas appear to have added about 30-40 kg SMN per hectare. The only significant difference was seen between Post Control and Radish:Radish treatments. This comes as no surprise given the high nitrogen demand of oil radish removing soluble nitrogen from soil. Other than that, differences are likely present between cover crop, catch crop and cover + catch crop regimes in general, where SMN reduces in the respective order.

Levels of SMN at Vicarage Hills generally mirrored the effects seen at Eastfield Kilnwick although slightly less SMN had accrued, about 30 kg/ha. Little to no rain fell in the period between vining and catch crop sampling so leaching of SMN cannot explain this difference, but the slightly better development of catch crops at Vicarage Hills than at Eastfield Kilnwick might. Regardless, control measures and cover crop treatments showed more SMN than other treatments.

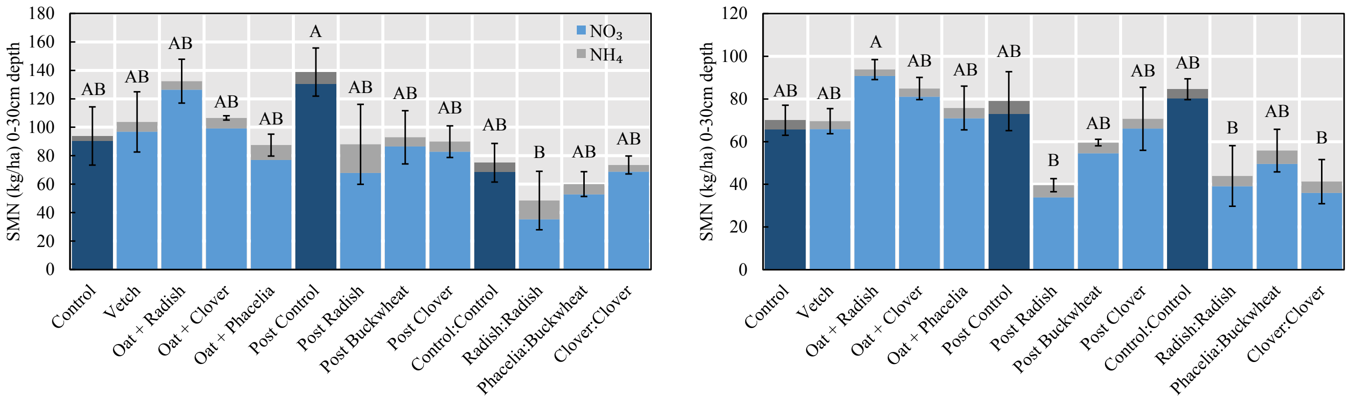


Figure 6: Mean soil mineral nitrogen to 30cm depth at catch crop stage (September 2018), Eastfield Kilnwick (left), Vicarage Hills (right).

3.1.4 1st wheats

There were no significant differences in SMN at either Eastfield Kilnwick or Vicarage Hills. There were spikes in the Post clover treatments but they were too variable to draw solid conclusions from, plus the poor establishment of the clover at both sites would rule out SMN contributions by fixation.

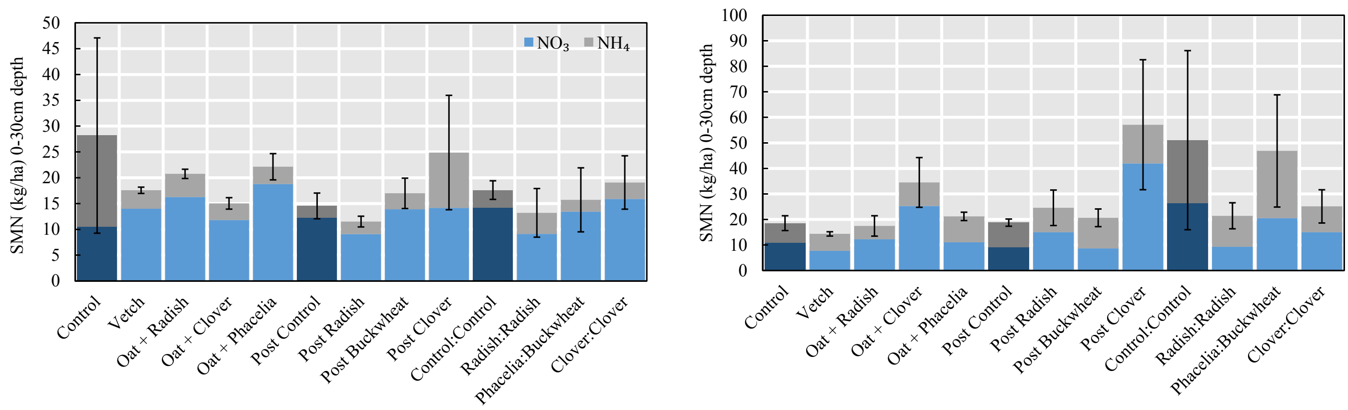


Figure 7: Mean soil mineral nitrogen to 30cm depth at 1st wheats stage (May 2019), Eastfield Kilnwick (left), Vicarage Hills (right).

3.2 Soil nitrogen supply (SNS)

3.2.1 Cover crop

Molescroft 96 showed no differences in SNS, a consequence of very little cover crop growth. The levels of SNS were lowest in the Controls at both Eastfield Kilnwick and Vicarage Hills due to no nitrogen contribution from vegetation. The Vetch treatments at both these sites were highest in SNS due to the decent nitrogen contributions from well developed vetch.

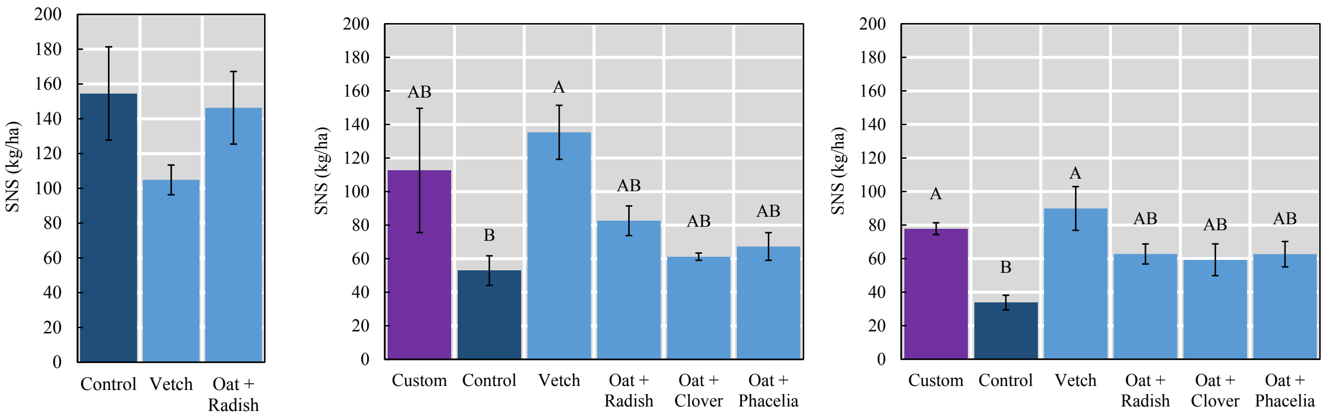


Figure 8: Mean SNS at cover crop stage (January 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.2.2 Vining pea

Values for SNS at Molescroft 96 reflected those observed in the previous sampling period. There were no significant differences in SNS at neither Eastfield Kilnwick nor Vicarage Hills at this time.

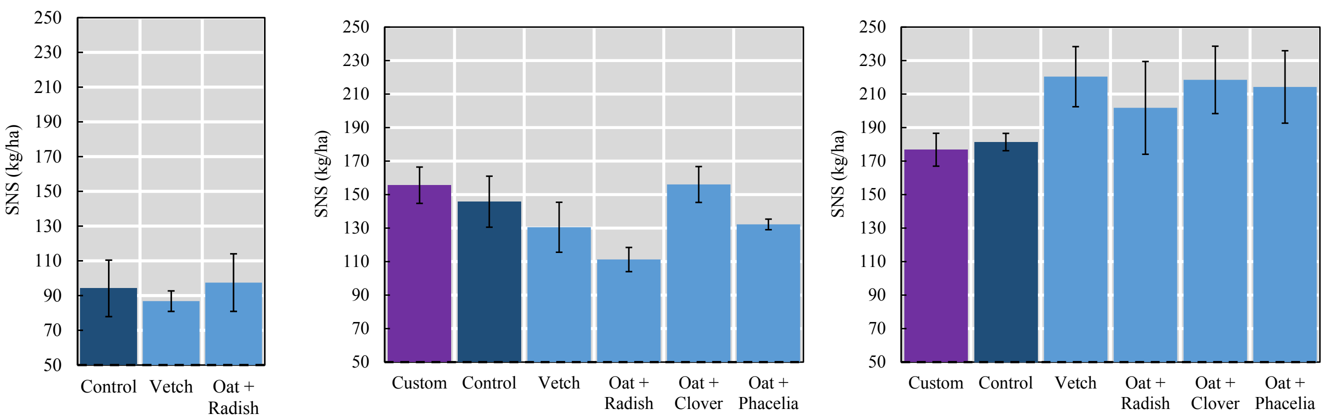


Figure 9: Mean SNS at vining pea stage (July 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.2.3 1st wheats

At Eastfield Kilnwick some differences in total nitrogen were observed. No clear pattern was discernible. The range was quite large with treatments differing by more than 100kg/ha of SNS.

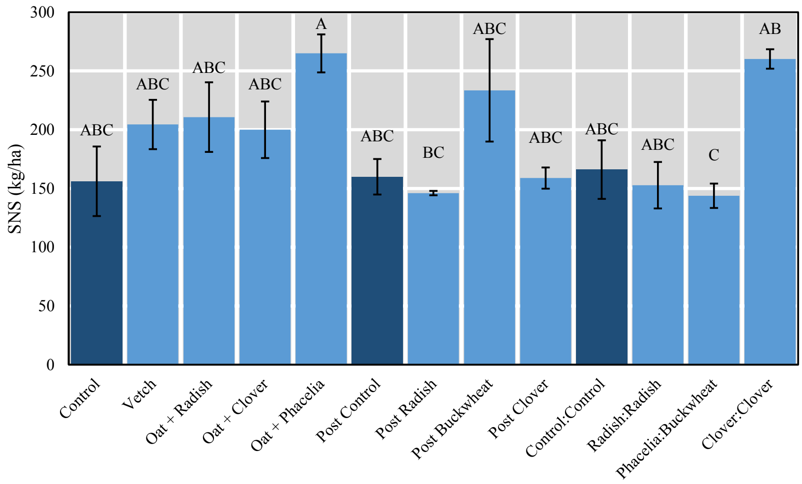


Figure 10: Mean SNS at 1st wheats stage (May 2019), Eastfield Kilnwick.

There was only one significant difference in SNS at Vicarage Hills between Post Buckwheat and Phacelia:Buckwheat. This was quite odd considering that they had very similar recent management and yet the difference in SNS was nearly 150kg/ha. Post Buckwheat had given low yields but no depression of straw (see section 3.6.4).

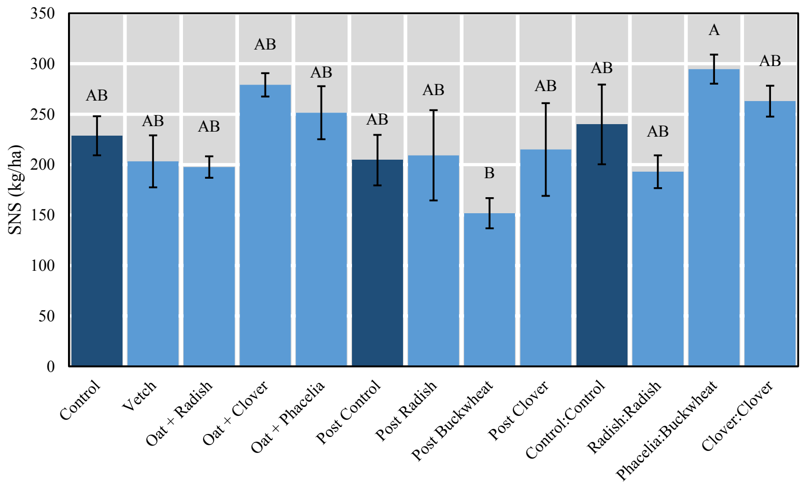


Figure 11: Mean SNS at 1st wheats stage (May 2019), Vicarage Hills.

3.3 Nutrient data

3.3.1 Cover crop

Phosphorus, Potassium, Magnesium

There were no significant differences in macronutrient availability at Molescroft 96 or Eastfield Kilnwick. However, the greater variability in values at Eastfield Kilnwick, where cover had developed far better than at Molescroft 96, suggests that cover crops do affect macronutrient availability to some extent. However, the significant differences at Vicarage Hills were probably due more to field effects than cover crops. The levels of phosphorus and potassium at Vicarage Hills correlated very strongly which is an improbable consequence of the cover crops, rather a legacy of distant fertiliser applications were P & K may have accompanied each other.

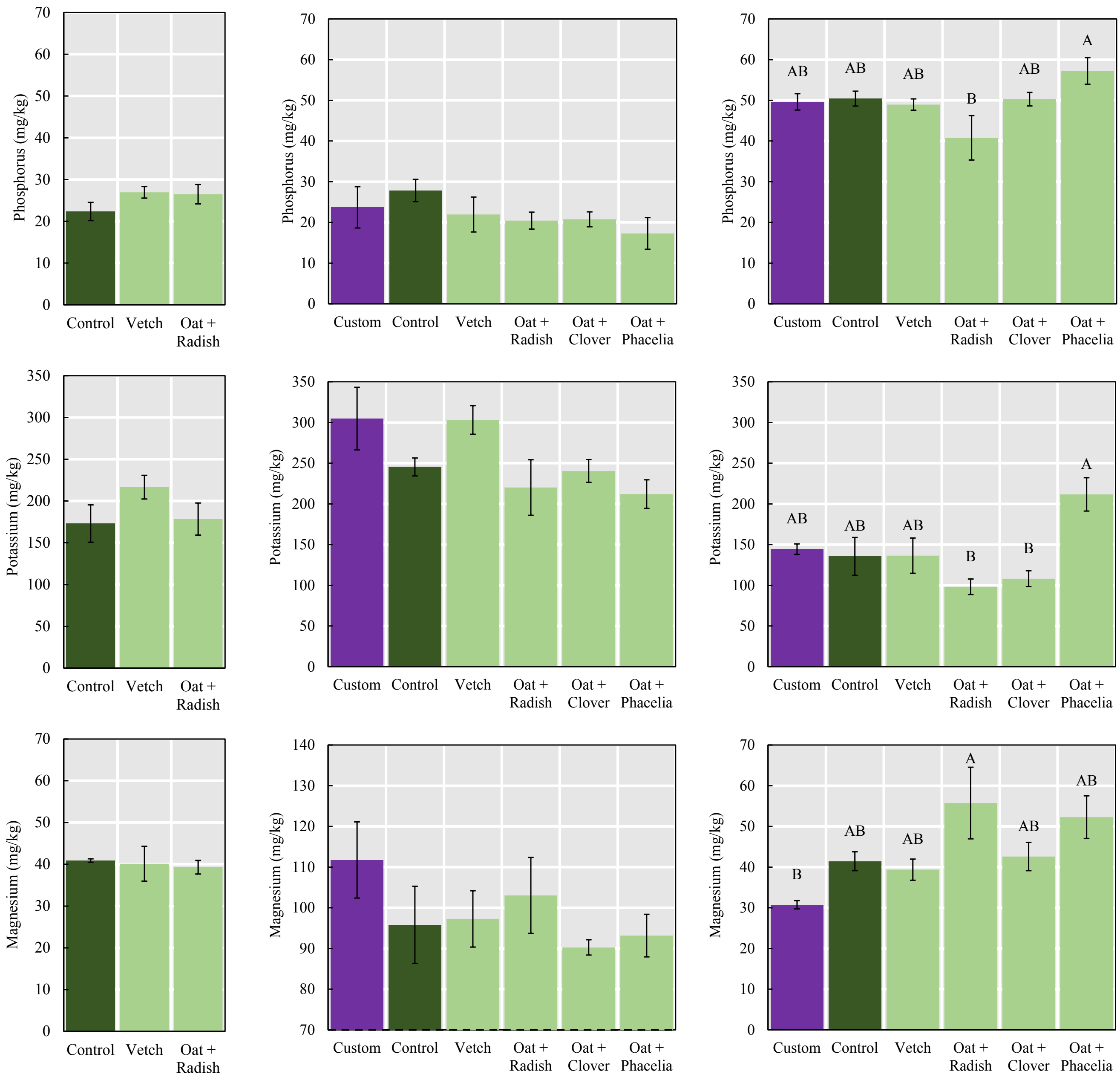


Figure 12: Mean macronutrient availabilities at cover crop stage (January 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.3.2 Vining pea

Phosphorus, Potassium, Magnesium

At all sites the levels of macronutrient availability were consistent. The only exception was seen Vicarage Hills where magnesium levels in Oat + Radish were roughly double that of other treatments. This was probably a consequence of soil pH at the cover crop stage. Magnesium availability and soil pH have been tightly coupled in these trials.

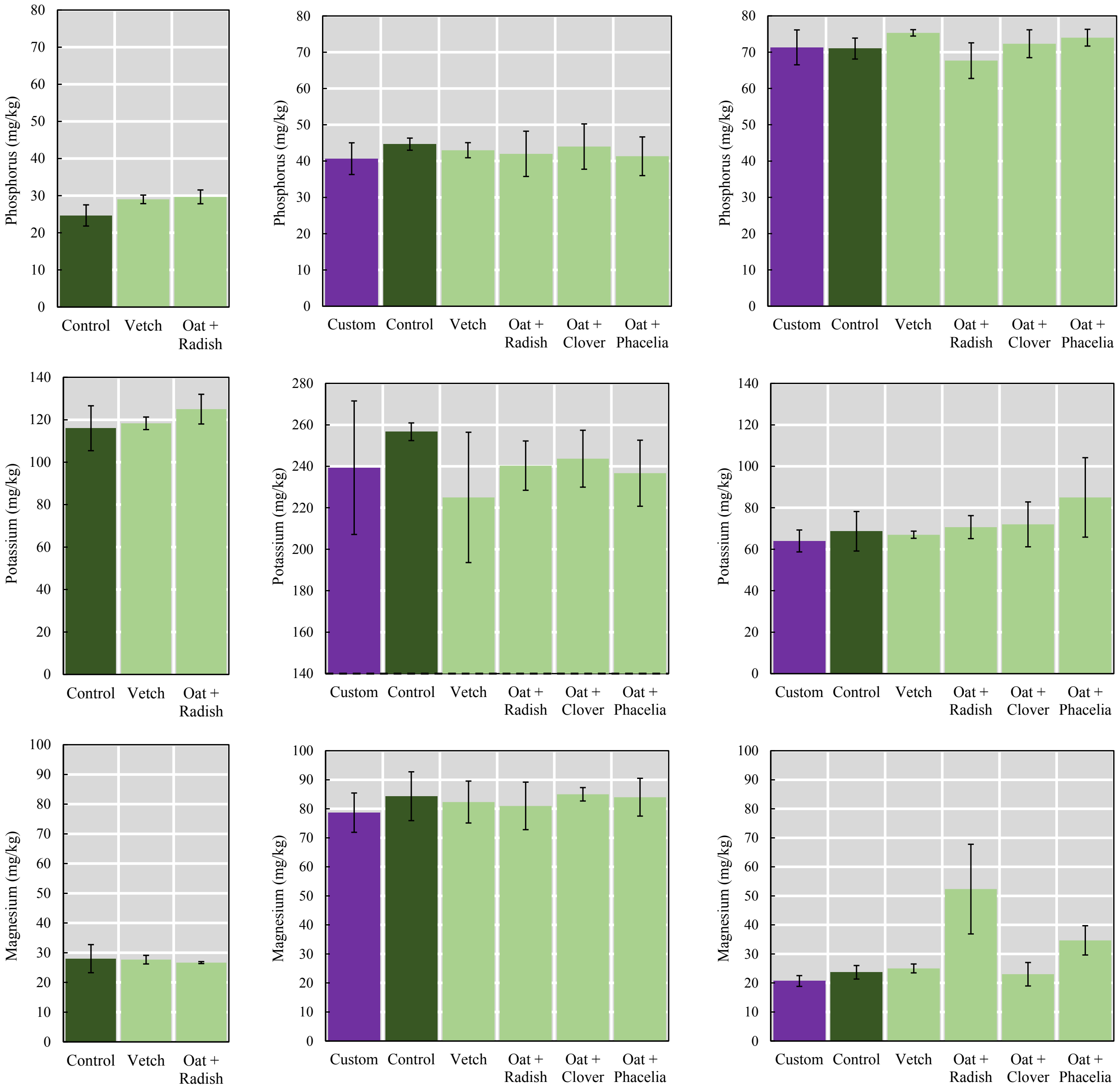


Figure 13: Mean macronutrient availabilities at vining pea stage (July 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

Cover crop soil pH

Soil pH was not affected by cover crop treatments at either Molescroft 96 or Eastfield Kilnwick. At Vicarage Hills, Oat + Radish plots had higher pH than adjacent treatments Vetch and Oat + Clover.

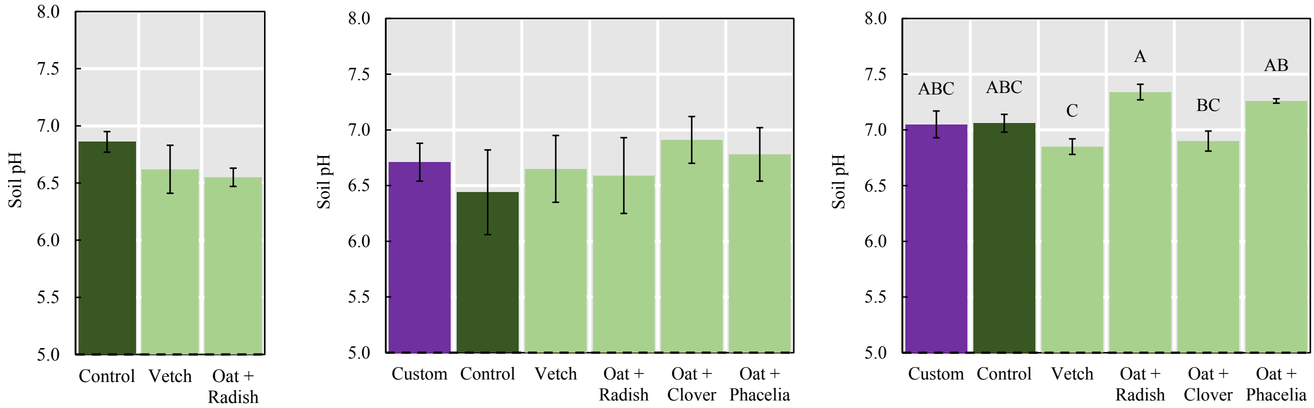


Figure 14: Mean soil pH at cover crop stage (January 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

Vining pea soil pH

At Molescroft 96 little had changed in terms of soil pH. At Eastfield Kilnwick soil pH had dropped by approximately 1 pH across all treatments except the Control which dropped only slightly. Soil pH at Vicarage Hills had climbed slightly since the winter, with the Oat + Radish treatment having significantly higher pH than Vetch, Oat + Phacelia and Control treatments.

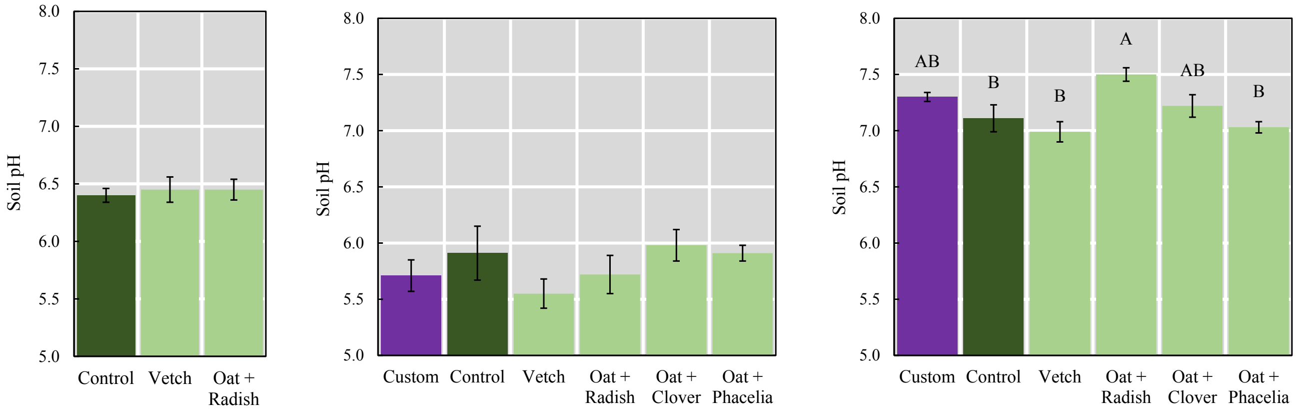


Figure 15: Mean soil pH at vining pea stage (July 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.3.3 1st wheats

Phosphorus

At Eastfield Kilnwick phosphorus was lowest in the Post Control treatment, roughly half the quantity compared to Post Buckwheat and Post Clover. In contrast, soil phosphorus was highest in the Post Control at Vicarage Hills. The lowest value was observed in the Oat + Radish treatment which also yielded the poorest wheat (see figure 32).

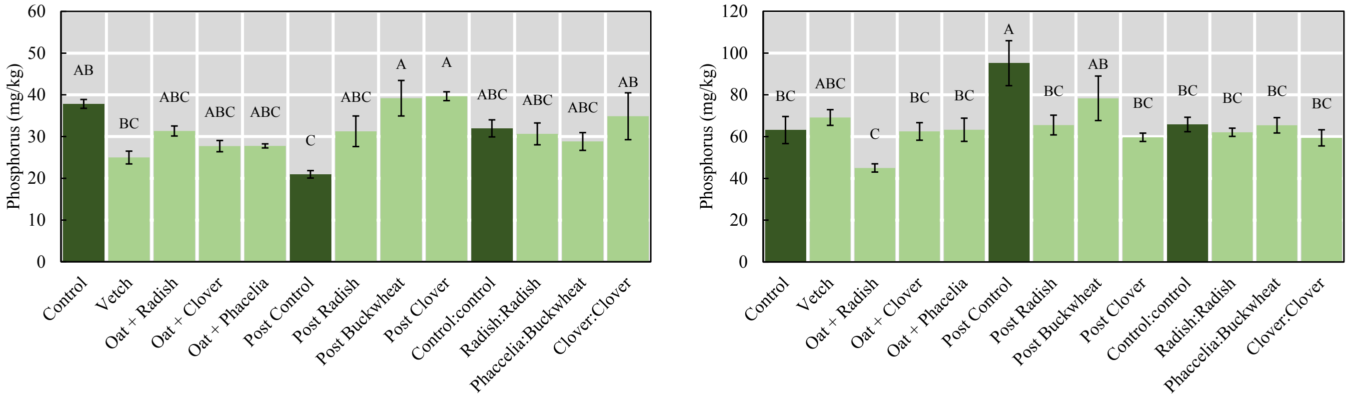


Figure 16: Mean phosphorus availability at 1st wheats stage (May 2019), Eastfield Kilnwick (left), Vicarage Hills (right).

Potassium

At Eastfield Kilnwick, available potassium was generally higher in the catch cropped treatments, although the control measures were an anomaly. There were significant differences at Vicarage Hills though there was no obvious explanation as to why.

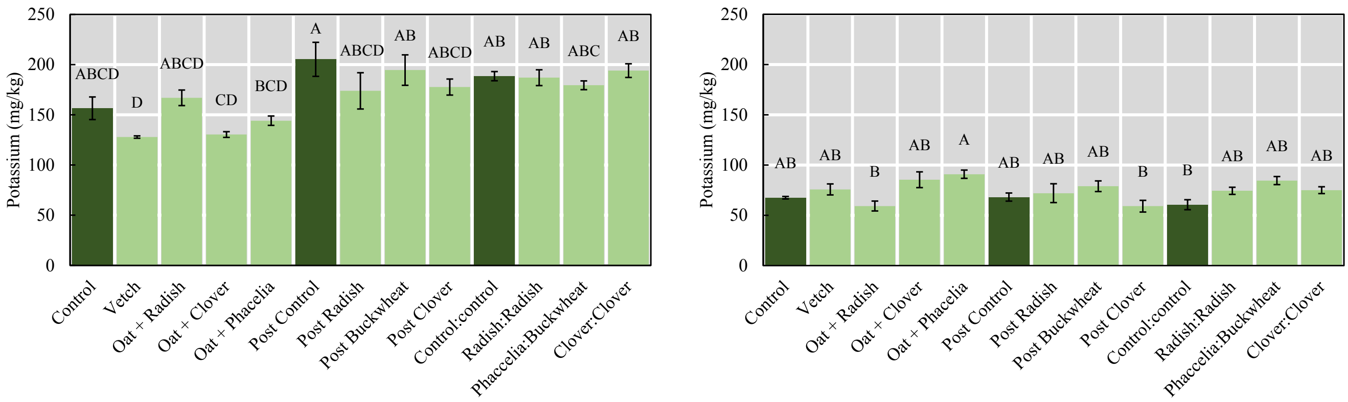


Figure 17: Mean potassium availability at 1st wheats stage (May 2019), Eastfield Kilnwick (left), Vicarage Hills (right).

Magnesium

Magnesium levels were overall higher in the control measures at Eastfield Kilnwick. The levels roughly correlated with the levels of potassium. At Vicarage Hills, the Post Control had the lowest magnesium level by a considerable margin.

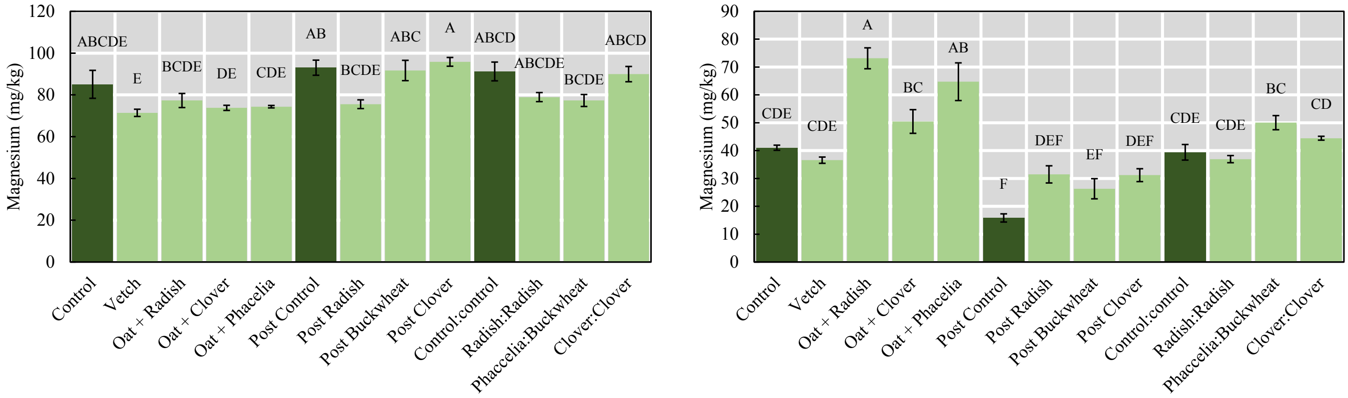


Figure 18: Mean magnesium availability at 1st wheats stage (May 2019), Eastfield Kilnwick (left), Vicarage Hills (right).

Soil pH

The soil pH at Eastfield Kilnwick was highest in the control measures. Some plots had decreased in pH to below pH 5.5. The values for the overlapping plots seemed to be a clear product of the effect of both cover and catch crops (i.e. the value of Radish:Radish falls between the values of Oat + Radish and Post Radish for example). At Vicarage Hills there were considerable differences between treatments. The overlapping plots had similar values to the cover crop treatments, suggesting that the catch crops had little effect on soil pH.

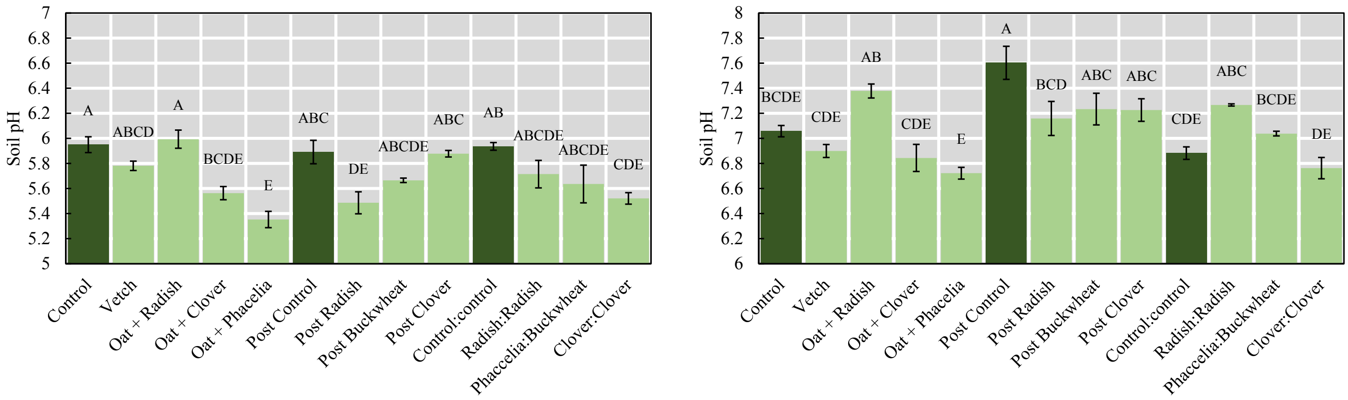


Figure 19: Mean soil pH at 1st wheats stage (May 2019), Eastfield Kilnwick (left), Vicarage Hills (right).

3.4 Soil organic matter

3.4.1 Cover crop

There were no treatment effects on soil organic matter at Molescroft 96 or Eastfield Kilnwick. The organic matter had not changed in the time since drilling. At Eastfield Kilnwick, soil organic matter had decreased in all treatment since drilling (initially 4%) except Custom which had slight head start in terms of drilling. At Vicarage Hills, there were some significant treatment effects with Oat + Clover and Oat + Phacelia treatments having risen slightly in organic matter (0.5%) since drilling.

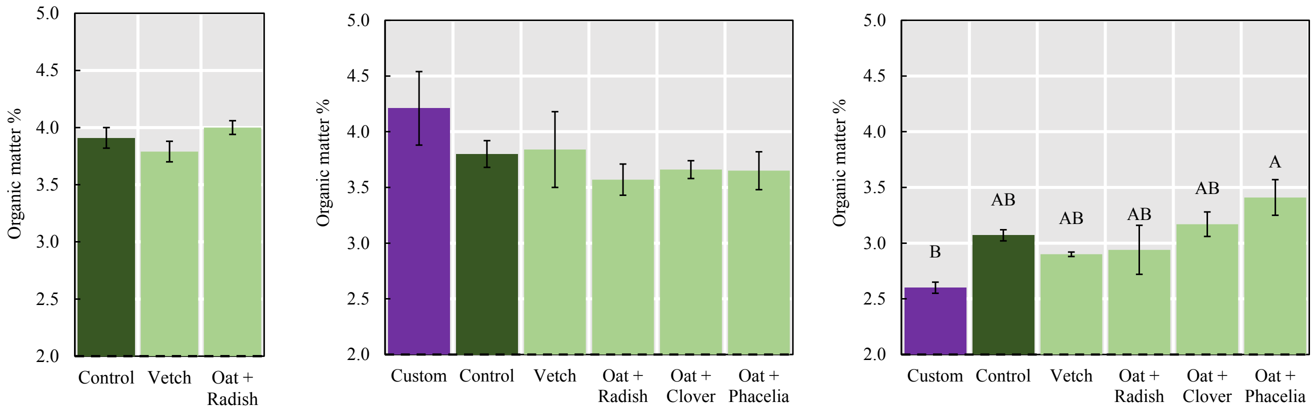


Figure 20: Mean soil organic matter % at cover crop stage (January 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.4.2 Vining pea

Soil organic matter at Molescroft 96 had decreased since the cover crop stage, and no treatment effects were present. There were no treatment effects at Eastfield Kilnwick and soil organic matter hadn't changed much since the cover crop stage. Oat + Clover and Oat + Phacelia treatments at Vicarage Hills maintained an organic matter content just above 3% with other treatments declining closer to 2.5%.

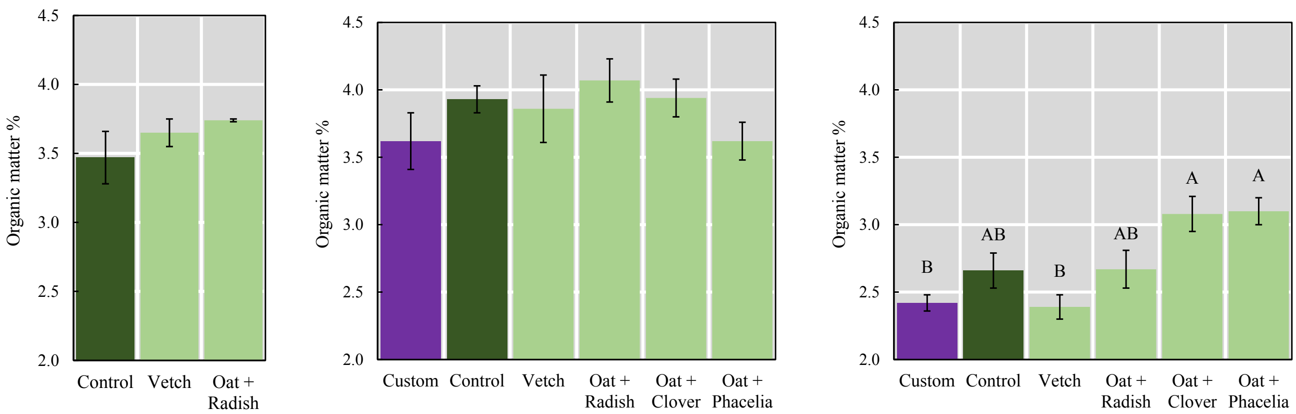


Figure 21: Mean soil organic matter % at vining pea stage (July 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.4.3 1st wheats

Soil organic matter at Eastfield Kilnwick measured around 3.5%, little change since the previous year. Some treatments were found to be significantly different. At Vicarage Hills, organic matter had settled to around 2.6%. Again differences were identified with no clear explanations to their cause. Overall, soil organic matter has declined across the board at both sites from starting points of 4% at Eastfield Kilnwick and 3% at Vicarage Hills.

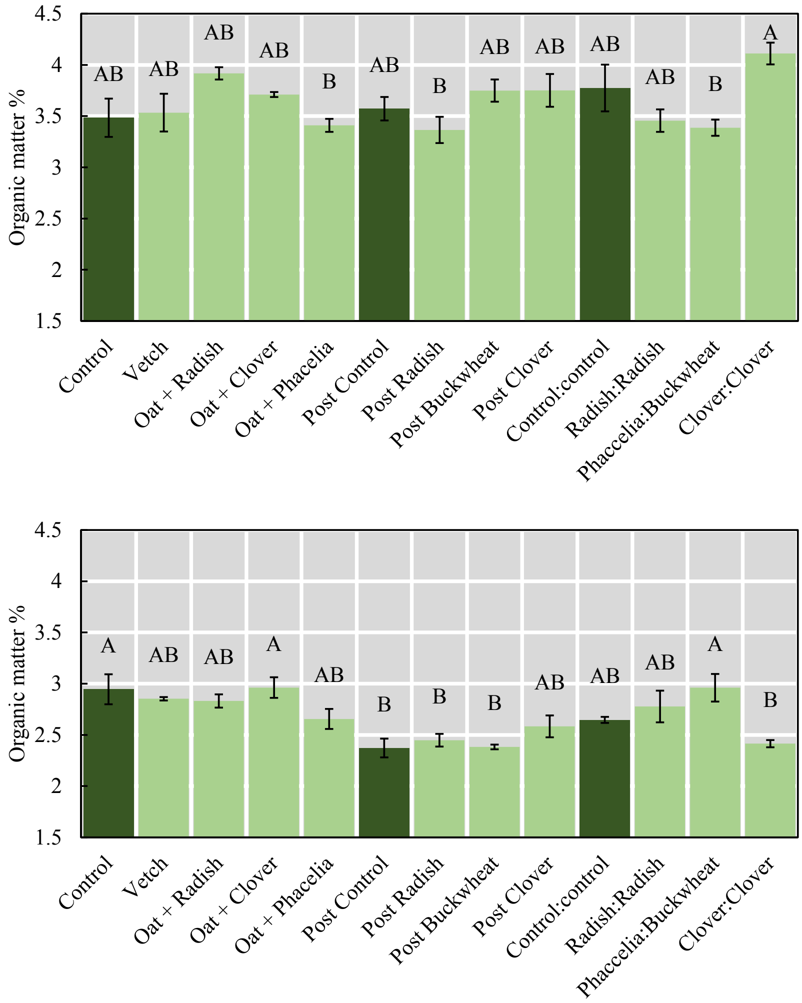


Figure 22: Mean soil organic matter % at 1st wheats stage stage (May 2019), Eastfield Kilnwick (left), Vicarage Hills (right).

3.5 Foot rot risk

3.5.1 Cover crop

There were no significant differences detected in foot rot risk at any of the sites at the cover crop stage. There was a medium burden of foot rot at both Molescroft 96 and Vicarage Hills, and low risk at Eastfield Kilnwick. *Didymella pinodella* was the dominant pathogen though *Aphanomyces euteiches* was detected at Molescroft 96 and Vicarage Hills (data not shown).

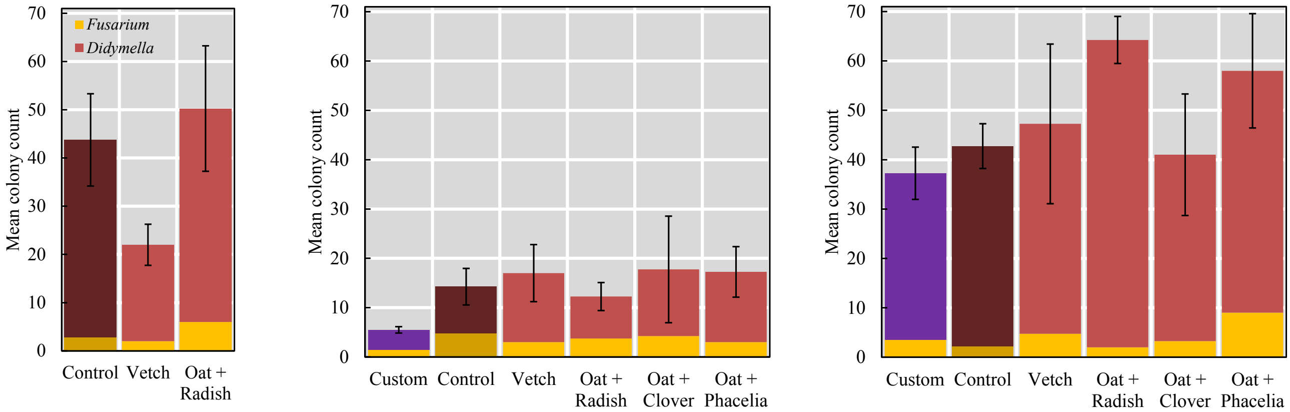


Figure 23: Foot rot risk assessment at cover crop stage (January 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.5.2 Vining pea

The *Didymella* inoculum pressure at Molescroft 96 had decreased considerably although there were no differences in relative terms between treatments since 6 months prior. Pathogen inoculum remained low at Eastfield Kilnwick with no treatment effects present. However the *Didymella* counts had diminished whilst the *Fusarium* abundance had increased by a small amount. At Vicarage Hills, the pathogen abundance had increased slightly since the cover crop stage but treatment effects didn't show.

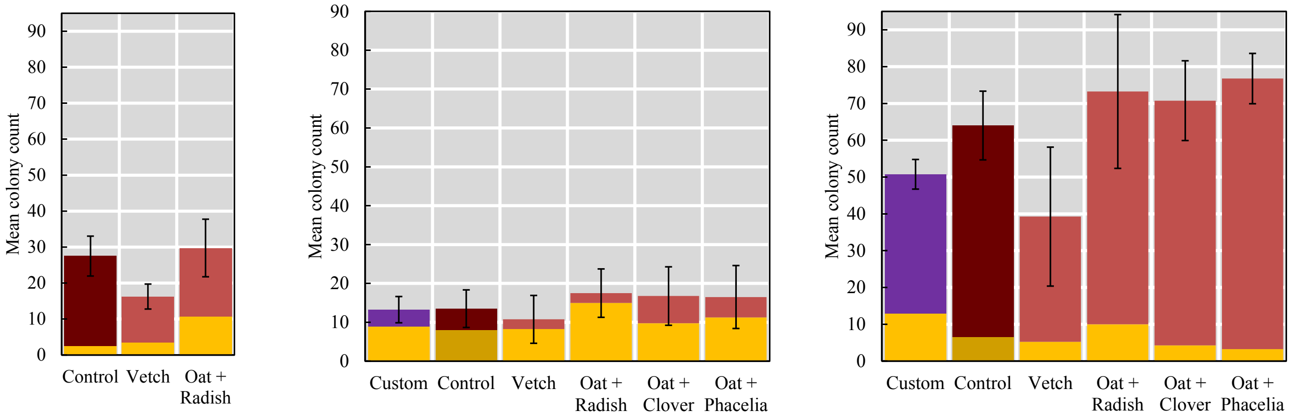


Figure 24: Foot rot risk assessment at vining pea stage (July 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.5.3 Catch crop

At Eastfield Kilnwick *Didymella* inoculum was found to be practically absent at the catch crop stage. *Fusarium* levels varied widely (though not significantly between treatments) but remained low in relative terms.

Extremely high *Didymella* pressure was observed in some treatments at Vicarage Hills (see figure bottom right). The data were accordingly variable too, meaning that statistical support of the differences cannot be confirmed but the figures are quite clear. An explanation however is not.

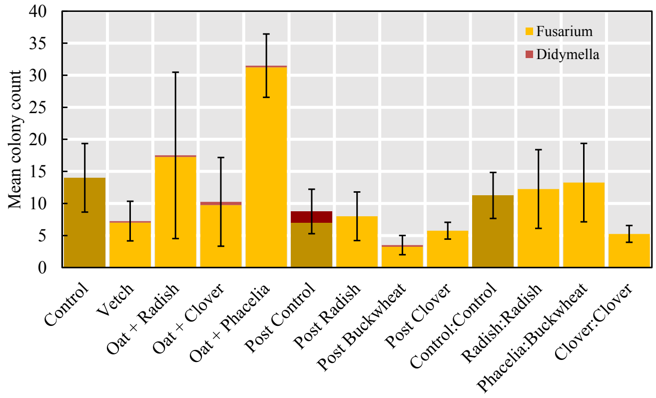
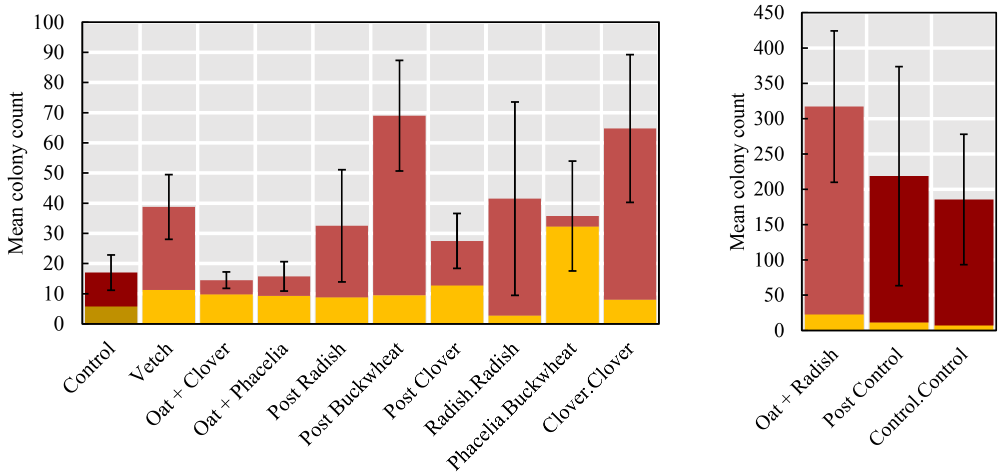


Figure 25: Foot rot risk assessment at catch crop stage (September 2018), Eastfield Kilnwick (above), Vicarage Hills (below).



3.5.4 1st wheats

By the spring in the first wheats *Fusarium* pressure had increased by a small but not negligible amount at both sites. There were no significant treatment effects and the data did not reflect those in the catch crop stage. At Vicarage Hills the extreme *Didymella* values had declined since the previous sampling period but the worst scoring treatments remained the worst here with Vetch scoring poorly too.

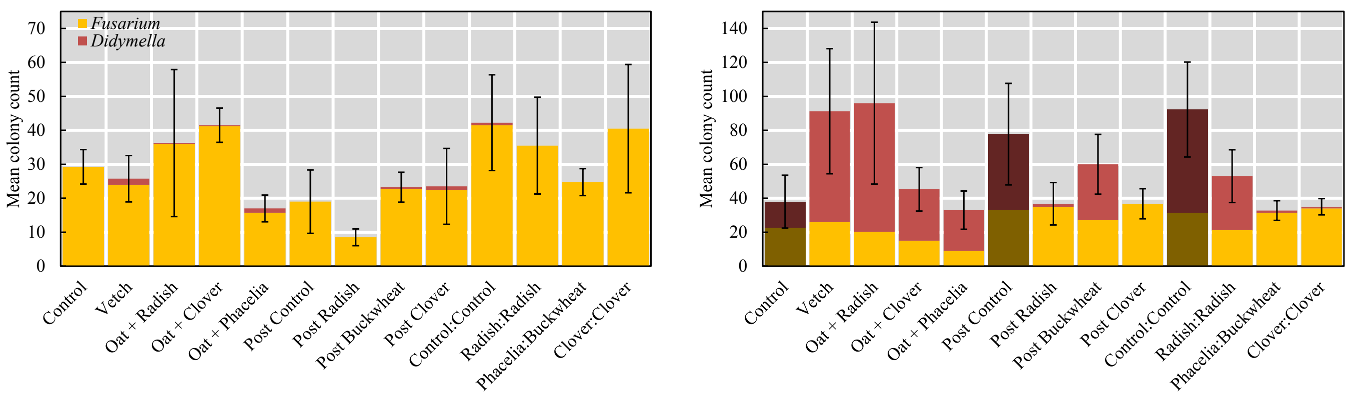


Figure 26: Foot rot risk assessment at 1st wheats stage (May 2019), Eastfield Kilnwick (left), Vicarage Hills (right).

3.6 Crop health and development

3.6.1 Foot rot development

Foot rot severity was greatest in the Oat + Radish treatment at Molescroft 96. This was a surprising result given that the radish had not established well. The Oat + Radish treatment also performed the worst in terms of foot rot at Eastfield Kilnwick, although this was not a statistically significant observation.

At Vicarage Hills, the Control showed the worst foot rot symptoms. This may have been due, in part, to a greater moisture deficit in that treatment which may have increased vulnerability to foot rot. The Oat + Clover treatment scored the lowest foot rot score which later became apparent in yield.

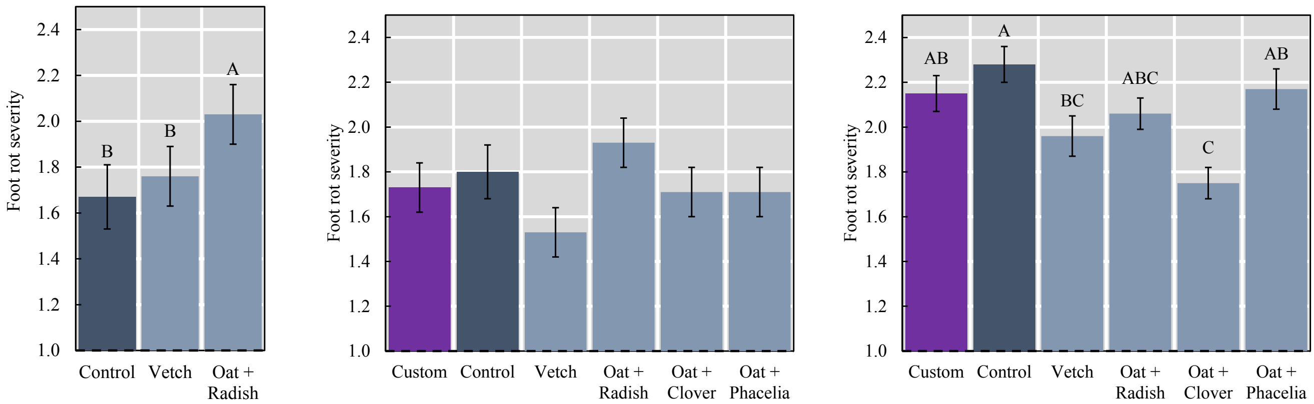


Figure 27: Foot rot severity in vining peas (June 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.6.2 Yield

There were no significant differences in yield at Eastfield Kilnwick. The oat based mixes did yield about a third more than other treatments, but was not statistically supported. The yields here were also very poor due to drought.

There were very clear differences in yield at Vicarage Hills. The Control plots yielded approximately one tonne per hectare less than cover cropped treatments. This was due to the effects of cover cropping on foot rot, plus the improved water retention in cover cropped treatments is also believed to have protected yield. Overall, yields were still low (difficult season).

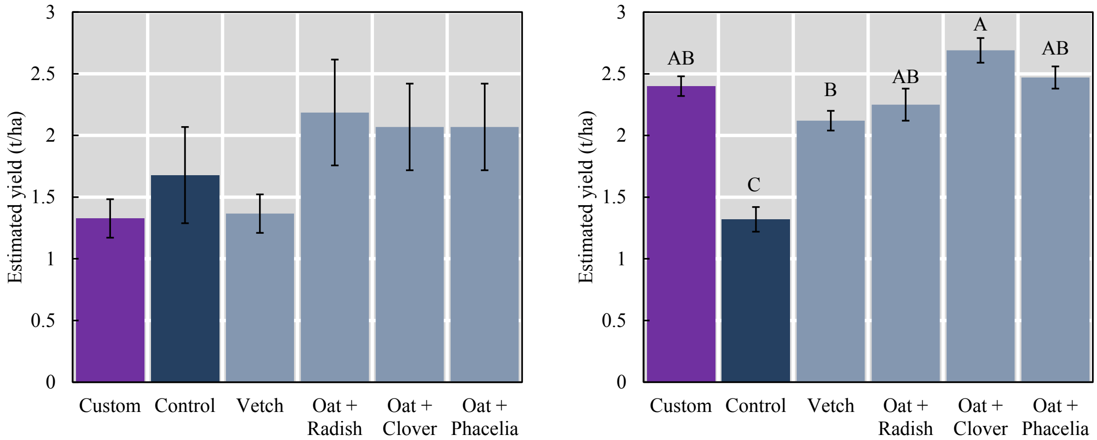


Figure 28: Vining pea yield (July 2018), Eastfield Kilnwick (left), Vicarage Hills (right).

3.6.3 Haulm length, biomass and emergence

Cover cropping had no significant effect on emergence at any site. That said, Control did have the lowest emergence at all sites. Emergence for Custom at Molescroft 96 scored the same as Vetch (not shown in figure, see appendix). Haulm biomass did not respond significantly to cover cropping at any site. Haulm lengths did vary at Eastfield Kilnwick and Vicarage Hills. However, the differences at Eastfield Kilnwick may have been the consequence of an inherent field gradient.

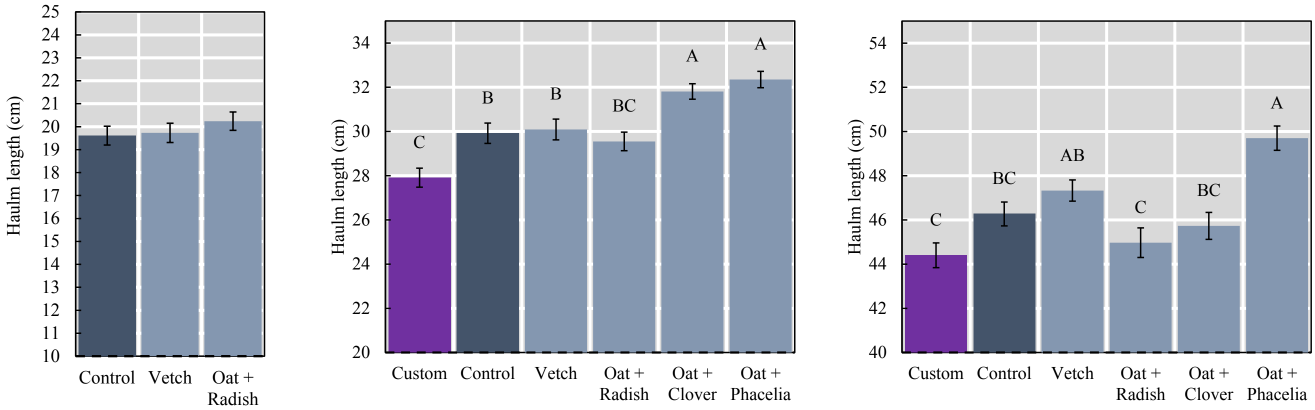


Figure 29: Mean haulm lengths (June 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

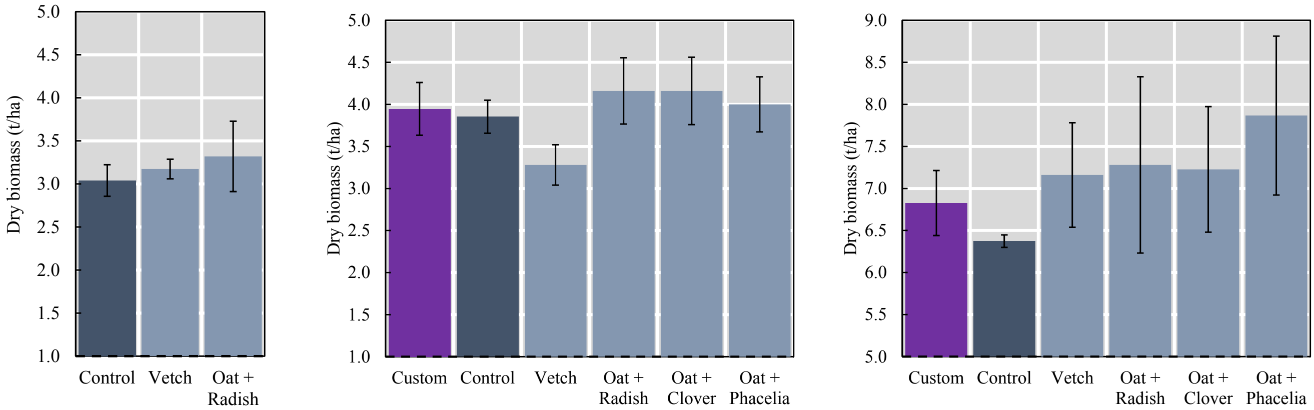


Figure 30: Mean haulm biomass (July 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

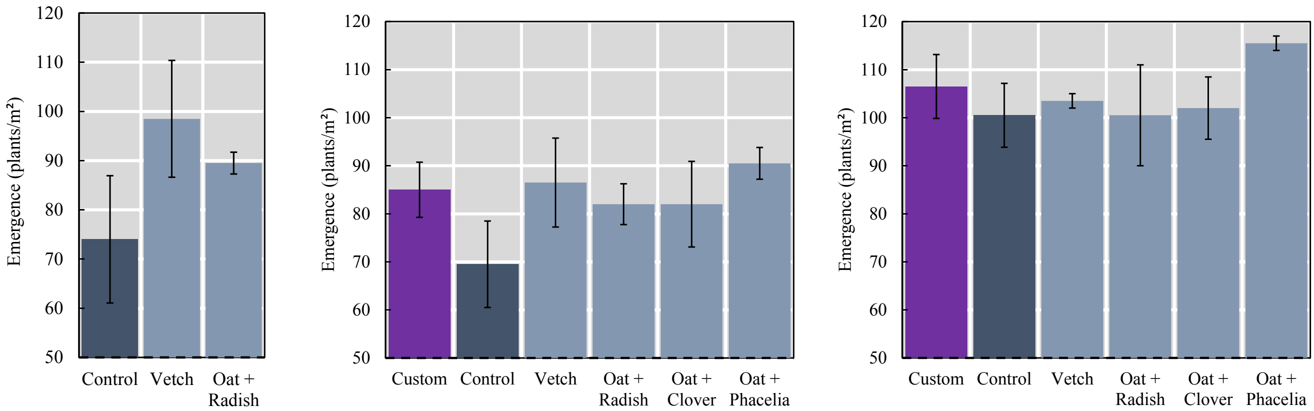


Figure 31: Mean seedling emergence (Spring 2018), Molescroft 96 (left), Eastfield Kilnwick (middle), Vicarage Hills (right).

3.6.4 Wheat-straw and yield

The wheat straw weights at both Eastfield Kilnwick and Vicarage Hills showed no significant treatment effects and did not correlate with yields. The only significant difference in yield at Eastfield Kilnwick was that between Control and Oat + Radish treatments which is suspected to have been influenced by a drilling anomaly, thus possibly not credible. That said, the Oat + Radish and Post Radish treatments at Vicarage Hills yielded the lowest where a treatment effect was certainly at play. Most notable in the Oat + Radish treatment was a poor vigour and accelerated maturity of winter wheat (see figures 33, 34).

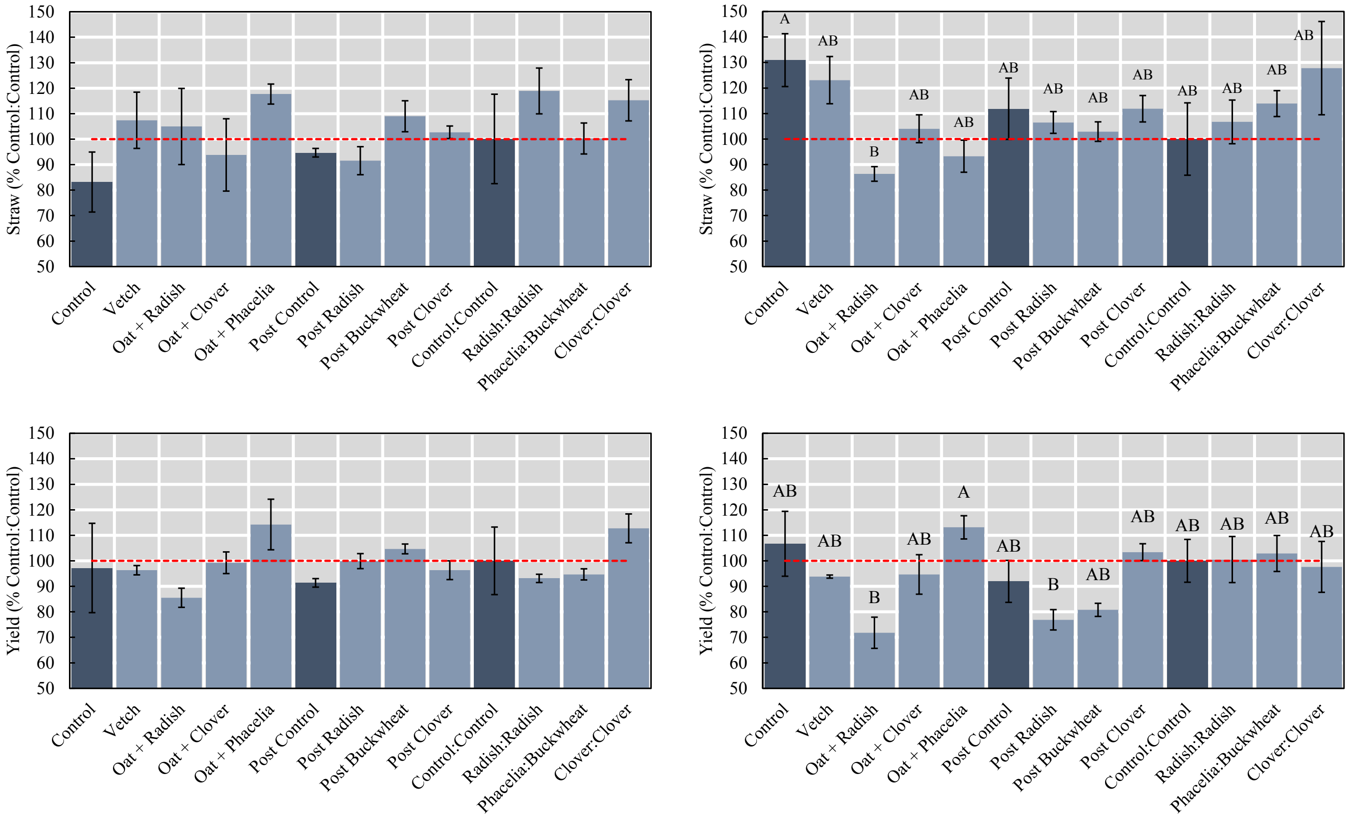


Figure 32: Estimated straw and crop yields in first wheats (May/July 2019), Eastfield Kilnwick (left), Vicarage Hills (right).

Figure 33: Contrast in crop status at Vicarage Hills (July 2019). Early maturity and low vigour in Oat + Radish treatment (left), better development in Oat + Clover treatment (right).

Figure 34: Vicarage Hills (July 2019). Pale/pink straw and foliar discolour in Oat + Radish treatment (left), generally healthier in adjacent Oat + Clover plot (right).

3.7 Soil health

Assessment of soil structure and earthworm abundance were made at the cover crop stage. Perhaps the only discernible pattern was that SQ was generally higher in controls and that Oat + Clover treatments fostered the greatest numbers of worms. No further assessments of soil structure were possible due to the firmness of the soil during the remainder of the trial.

Treatment	**Eastfield Kilnwick**		**Vicarage Hills**	
	SQ	Worms	SQ	Worms
Custom	1.3	1.7	n/a	n/a
Control	1.7	1.3	2	0.7
Vetch	1.5	3.7	1.3	0
Oat + Radish	1.8	1	1	0.3
Oat + Clover	1.7	6	1.5	1.7
Oat + Phacelia	1.3	3	1	0.7

Table 3: VESS assessments at cover crop stage (January 2018). Mean structural quality scores (SQ) and earthworm abundance per block. Lower SQ scores denote better soil structure.

3.8 Compaction

3.8.1 Cover crop

At Eastfield Kilnwick, the Control and Oat + Radish treatments displayed the highest compaction. Custom, and predominantly oat based mixes Oat + Clover and Oat + Phacelia had similar levels of compaction, significantly lower than the Control. Vetch occupied the middle ground. This was a fairly typical result compared to previous trials.

The Control plots at Vicarage Hills displayed the lowest penetration resistance. This was probably due to a drying effect of cover crops on the readily dried soil at Vicarage Hills (sandy loam), and the greater strength of cover cropped soils compared to the Control that offered greater resistance. It was predicted that this picture of compaction would flip by the summer, however the drought made it impossible to measure. Table 5 shows that by the first wheats stage the Control treatment did indeed have the highest level of compaction.

PGRO has observed similar anomalies in penetrometer readings on lighter land where obviously compacted regions offered lower penetration resistance after heavy rain (figure 36). This highlights the fact that moisture corrections for these data would assist interpretation.

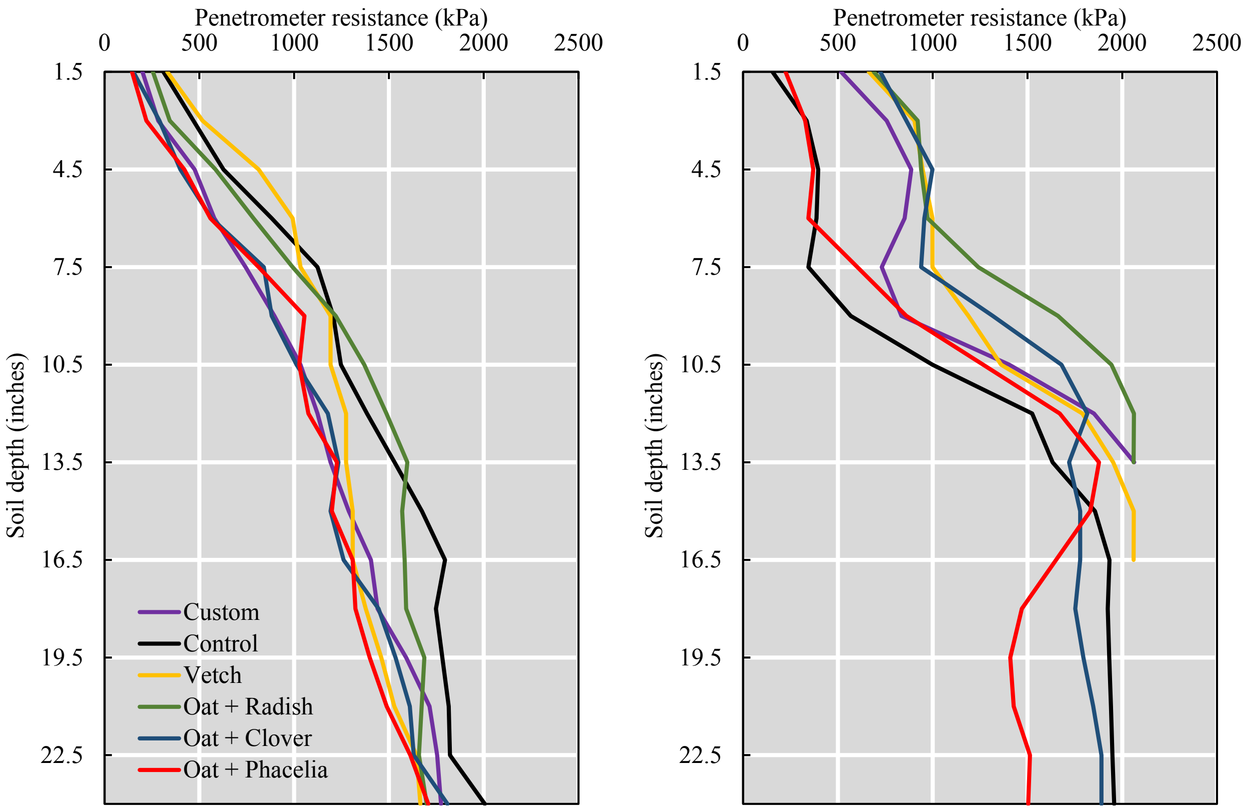


Figure 35: Compaction profiles at cover crop stage (January 2018), Eastfield Kilnwick (left), Vicarage Hills (right).

Treatment	(ls) Mean penetrometer resistance	
	Eastfield Kilnwick	Vicarage Hills
Custom	1095_{c}	1518_{c}
Control	1341_{a}	1242_{d}
Vetch	1184_{b}	1573_{b}
Oat + Radish	1258_{ab}	1684_{a}
Oat + Clover	1066_{c}	1484_{bc}
Oat + Phacelia	1037_{c}	1149_{d}

Table 4: Least square mean penetrometer resistance (kPa) through 24 inch soil profile at cover crop stage (January 2018).

Figure 36: Tractor wheelings visible at crop maturity. These compacted areas gave lower penetration resistance than the surrounding areas after heavy rainfall. Better structure, transpiration and drainage in traffic free areas are thought to be responsible.

3.8.2 1st wheats

Treatment	**(ls) mean resistance**	
	Eastfield Kilnwick	Vicarage Hills
Control	1530_{ef}	1561_{a}
Vetch	1572_{cde}	1196_{ef}
Oat + Radish	1514_{def}	1116_{f}
Oat + Clover	1638_{abc}	1300_{abcd}
Oat + Phacelia	1580_{de}	1257_{def}
Post Control	1636_{ab}	1341_{abcd}
Post Radish	1628_{abc}	1467_{ab}
Post Buckwheat	1495_{f}	1408_{bcd}
Post Clover	1709_{a}	1332_{cde}
Control:Control	1677_{a}	1424_{abc}
Radish:Radish	1614_{bcd}	1266_{cdef}
Phacelia:Buckwheat	1588_{cde}	1371_{cde}
Clover:Clover	1648_{abc}	1301_{cde}

Table 5: Least square mean penetrometer resistance (kPa) through 24 inch soil profile at 1st wheats stage (May 2019).

4 Conclusions

Nitrogen

Patterns of SMN abundance reflect what was observed in the previous round of trials. Cover crops mop up considerable amounts of nitrogen, and those amounts differ depending on species selected.

Macronutrients

Soil nutrient parameters have not reacted strongly to cover crop treatments on heavier land, but effects are noticeable on sandy loam. Catch crops too have affected nutrient availability but seemingly at random.

Soil organic matter

Soil organic matter appears to have responded in the short term to different treatments. There were however no similarities between sites or immediately intuitive responses. Soil organic matter has slightly declined after a cycle of cover and catch crops.

Foot rot

Foot rot development in crop responded to cover crop treatments at two sites, with Oat + Radish appearing to exacerbate foot rot on heavier land as was noted in previous trials. The most probable risk factor was compaction at 7.5"-12" soil depth. Extremely high *Didymella pinodella* pressure was induced by select treatments at Vicarage Hills, suggesting again that fallow and oil radish may increase risk of foot rot in peas. No negetive of legume cover crop species were observed.

Crop development and yield

Aspects of vining pea progress like haulm length, emergence, biomass and yield have in some cases responded to cover crop treatments. A very strong yield response has been observed at one site where all cover crop treatments here have increased yield (up to double) probably by mitigating the conditions imposed by the difficult weather, alleviating compaction, lowering foot rot development and improving soil structure. Wheat progress had been depressed by the Oat + Radish treatment, especially on lighter land.

Soil structure, health and moisture

The use of penetrometer readings must be treated with caution. It is perhaps best to think of the figures in terms of resistance to the probe, which does not necessarily equate to compaction. Moisture is important in this regard. In wet conditions, a lack of soil structure and rooting can lead to low resistance readings, particularly in non-cohesive soils. This pattern reverses upon drying.

Agronomy

Early establishment of cover crops is critical. Delaying drilling until October produced plants with negligible biomass or rooting density. This gives a cover crop that falls short of its potential achieving virtually nothing in terms of nutrient retention or soil conditioning.

5 Appendices

Methods

Soil mineral nitrogen (SMN) is a readily available soluble form of nitrogen. It is also easily leached. Three soil cores to various depths were taken per treatment. The cores were refrigerated to prevent mineral decay and SMN determined by laboratory analysis. Potentially mineral nitrogen was also determined from the same cores. PMN is a stable but only partially available form of nitrogen. Corresponding plant samples were taken to complement soil cores, used to quantify total nitrogen per unit area. Soil macronutrients were determined from soil samples taken from a soil depth of 5-20cm. P, K, Mg, pH and soil organic matter (loss on ignition) were determined by laboratory analysis. Three replications per treatment. Foot rot risk was determined from soil samples taken from a depth of 5-20cm replicated four times per treatments. Risk was determined by in-house methods at PGRO. Colony numbers (which reflect risk) are reported in this document. Risk is the product of both *Fusarium solani* and *Didymella pinodella*. Foot rot development in crop was measured by noting the severity of foot rot infection on 96 individual plants per treatment. Each plant was assessed on an ordinal scale ranging from 0 to 5 (no infection to completely dead). Haulm lengths were recorded shortly before vining. 75 plants per treatment were measured. Vining pea yield was determined by threshing of $8m^2$ plots replicated 3 times per treatment. The estimated yields were extrapolated by equating the mean value of "Custom" plots to the field yield. Wheat development data was extrapolated from straw samples (crop N) and yield determined by pre-harvest plot sampling replicated 3 times per treatment. Assessments of soil structure were carried out in three replicates per treatment according to VESS methods published by SRUC. SQ scores range from 1-5, where 1=excellent soil structure and 5=very poor/structure-less soil. Soil compaction was measured using an analogue cone penetrometer. Readings were taken at regular depth intervals. This showed how resistance to penetration (a measure of soil strength) varied throughout a soil profile. 8-12 insertions were performed per treatment. Later readings were taken using a digital penetrometer that achieves a similar but higher definition result. Soil moisture was recorded using SM150T probes (Delta-t technologies). Due to a limited number of probes the data were not replicated spatially. Field cultivations, drilling and crop maintenance were conducted by GPC project partners. Some details can be found in the diary. Drill specifications are not yet provided.

	Molescroft 96	Eastfield Kilnwick	Vicarage Hills
Initial sampling	17/08/17	17/08/17	17/08/17
Cover crop drilled	11/10/17	12/08/17	15/08/17
Destruction	?	Sprayed January	Sprayed January
Cultivation	Power harrow	Light power harrowing	Plough
Cover crop sampling	17/01/18	16/01/18	15/01/18
Peas drilled	19/05/18	16/05/18	20/04/18
Variety	Plover	Boston	Aloha
Crop assessments	06/06/18	07/06/18	08/06/18
Vining pea sampling	09/07/18	09/07/18	25/06/18
Harvest	23/07/18	16/07/18	01/07/18
Catch crop drilled	?	?	10/07/18
Catch crop sampling	11/09/18	11/09/18	10/09/18
1st wheats sampling	n/a	16/05/19	13/05/19

Appendix notes

Most treatment effects are confirmed (or not) by standard ANOVA methods with appropriate pairwise comparisons (Tukey's HSD, Tukey-Kramer or Games-Howell) set at a default alpha of 0.05. Occasionally these methods are not appropriate and substitute methods are employed. These exceptions are highlighted in the appendix tables. VESS assessments are analysed using chi-squared independence of fit, and foot rot severity assessed using pseudo-binomial models.

P-value - Probability that null hypothesis holds (i.e. treatment effect). Values below 0.05 are generally considered be significant.
Root MSE - Root mean squared error. Similar to standard error which applies only to group means in the text.
CoEff var. - Co-efficient of variation. The ratio of the standard deviation of the sample data and the sample mean. Values exceeding 20 are thought to be too great to yield reliable analyses.

Soil compaction. Tables in text report "least squared mean resistance". This can be effectively interporated as "average compaction" through the measured profile. The greater the LSM, the greater the penetration resistance. No moisture corrections have been made, thus penetration resistance may not reliably reflect soil compaction when soil moistures are extreme or very variable. Accumulated resistance was used to determine statistical differences between treatments. Briefly, it involves comparing the sum of all resistance readings taking soil depth into account in the analysis.

Mean soil mineral nitrogen (kg/ha). N=3. NO_3 - nitrate, NH_4 - ammonium.

	Molescroft 96			Eastfield Kilnwick			Vicarage Hills		
	NO_3	NH_4	SMN	NO_3	NH_4	SMN	NO_3	NH_4	SMN
Pre-CC 0-30cm									
	19.2	2.5	21.7	38.3	8	46.6	14.9	9.1	24
Cover crop 0-30cm									
Custom	-	-	-	6.33	0	6.33	3.8[b]	2.07	5.87[b]
Control	18.63	1.43	20.07	14.23	0	14.23	8.6[ab]	1.57	10.1[ab]
Vetch	9.07	0.8	9.87	10.07	0.8	10.87	7.1[ab]	1.7	8.8[ab]
Oat + Radish	13.53	0.67	14.13	6.5	0	6.5	3.9[b]	2.97	6.87[ab]
Oat + Clover	-	-	-	15.2	0	15.2	10.7[a]	2.87	13.57[a]
Oat + Phacelia	-	-	-	13.03	0	13.03	6.5[ab]	2.83	9.4[ab]
ANOVA									
p-value	0.16	0.35	0.1	0.27	-	0.3	0.004	0.4	0.044
Root MSE	5.67	0.61	4.33	5.47	-	5.64	1.72	1.02	2.52
CoEff.Var	34.9	62.6	29.5	50.3	-	51.2	25.4	43.7	27.7
Cover crop 30-60cm									
Custom	-	-	-	0.8[b]	0	0.8[b]	3.6[ab]	0.93	4.5
Control	16	0	16	23.2[a]	0	23.2[a]	8.8[a]	0.07	8.9
Vetch	11.1	0	11.1	6.6[b]	0	6.6[b]	5.8[ab]	0.13	5.97
Oat + Radish	22.33	0	22.33	1.1[b]	0	1.1[b]	1.3[b]	0.63	1.93
Oat + Clover	-	-	-	3.9[b]	0	3.9[b]	5.3[ab]	0.23	5.53
Oat + Phacelia	-	-	-	4.6[b]	0	4.6[b]	3.1[ab]	0	3.1
ANOVA									
p-value	0.19	-	0.19	<0.001	-	<0.001	0.034	0.3	0.11
Root MSE	6.02	-	6.02	4.05	-	4.05	2.32	0.54	2.69
CoEff.Var	36.6	-	36.6	60.6	-	60.6	49.8	162	53.8

	Molescroft 96			Eastfield Kilnwick			Vicarage Hills		
	NO_3	NH_4	SMN	NO_3	NH_4	SMN	NO_3	NH_4	SMN
Vining pea 0-30cm									
Custom	-	-	-	40.53	12.37	52.9	27.27	9.1	36.37
Control	12.76	4.3	17.05	23.53	6.93	30.5	28.37	11.47	40.17
Vetch	9.14	7.09	16.23	34.13	6.7	40.87	25.4	13.87	39.27
Oat + Radish	14.26	7.63	21.89	12.97	4.6	17.57	34.1	8.43	42.57
Oat + Clover	-	-	-	30.73	8.67	39.43	31.53	7.6	39.17
Oat + Phacelia	-	-	-	30.87	10.73	41.7	25.33	4.17	29.5
ANOVA									
p-value	0.28	0.28	0.37	0.44	0.66	0.47	0.56	0.19	0.58
Root MSE	3.64	2.46	4.85	16.25	6.05	20.88	6.7	4.33	8.91
CoEff.Var	30.22	38.75	26.4	56.44	72.65	56.2	23.32	47.54	23.54
Vining pea 30-60cm									
Custom	-	-	-	20.23	1.03^{ab}	21.27	13.23	0.33^{b}	13.57
Control	13.13	2.08	15.21	24.97	3.83^{a}	28.8	15.3	0.07^{b}	15.37
Vetch	5.63	3.91	9.44	18.07	1.33^{ab}	19.4	20.5	3.77^{a}	24.3
Oat + Radish	6.59	5.75	12.34	12.63	0.73^{ab}	13.37	22.97	1.80^{ab}	24.77
Oat + Clover	-	-	-	15.87	0.20^{b}	16	20.77	0.17^{b}	20.97
Oat + Phacelia	-	-	-	17.17	1.30^{ab}	18.5	21.17	0.10^{b}	21.27
ANOVA									
p-value	0.35	0.73	0.66	0.44	0.03	0.24	0.13	0.01	0.11
Root MSE	6.34	5.5	7.56	7.1	1.17	7.35	4.54	1.21	5.24
CoEff.Var	75.05	141.9	61.33	39.11	82.94	37.6	23.89	116.2	26.17

	Molescroft 96			Eastfield Kilnwick			Vicarage Hills		
	NO_3	NH_4	SMN	NO_3	NH_4	SMN	NO_3	NH_4	SMN
Catch crop 0-30cm									
Control	57.5	4.3	61.8	90.5^{ab}	3.4^{c}	93.9^{ab}	65.6^{ab}	4.4	70.0^{ab}
Vetch	68.8	3.6	72.4	96.9^{ab}	6.8^{bc}	103.8^{ab}	65.9^{ab}	3.7	69.6^{ab}
Oat + Radish	67.9	4.5	72.4	126.4^{a}	6.0^{bc}	132.4^{ab}	90.8^{a}	3	93.8^{a}
Oat + Clover	-	-	-	99.2^{ab}	7.4^{bc}	106.5^{ab}	81.1^{ab}	3.8	84.9^{ab}
Oat + Phacelia	-	-	-	77.0^{ab}	10.4^{bc}	87.5^{ab}	71.0^{ab}	4.8	75.7^{ab}
Post Control	57.6	4.1	61.7	130.6^{a}	8.2^{bc}	138.8^{a}	72.9^{ab}	6.1	79.0^{ab}
Post Radish	48.2	5.9	54.1	67.9^{ab}	20.1^{a}	88.0^{ab}	33.9^{b}	5.7	39.6^{b}
Post Buckwheat	43.7	4.9	48.6	86.5^{ab}	6.4^{bc}	92.9^{ab}	54.6^{ab}	5	59.5^{ab}
Post Clover	52.8	5	57.8	82.8^{ab}	7.1^{bc}	89.9^{ab}	66.1^{ab}	4.6	70.7^{ab}
Control:Control	47.6	5	52.6	68.7^{ab}	6.3^{bc}	75.1^{ab}	80.2^{ab}	4.3	84.5^{ab}
Radish:Radish	39.4	5.2	44.6	35.3^{b}	13.2^{ab}	48.5^{b}	39.1^{b}	4.8	43.9^{b}
Phacelia:Buckwheat	-	-	-	52.8^{ab}	7.3^{bc}	60.1^{ab}	49.6^{ab}	6.2	55.9^{ab}
Clover:Clover	-	-	-	68.7^{ab}	4.8^{bc}	73.5^{ab}	36.0^{b}	5.3	41.2^{b}
Post Phacelia	40.3	5.2	45.5	-	-	-	-	-	-
Vetch:Clover	53.2	7.5	60.7	-	-	-	-	-	-
ANOVA									
p-value	0.35	0.07	0.46	0.01	<0.001	0.04	0.002	0.47	0.004
Root MSE	15.8	1.23	16.4	27	3.11	28.8	15.8	1.62	16.3
CoEff.Var	30.12	24.49	28.5	32.42	37.64	31.49	25.43	34.09	24.42
1st wheats 0-30cm									
Control	-	-	-	10.5	17.7	28.2	11.0	7.6	18.6
Vetch	-	-	-	14.0	3.6	17.6	7.8	6.6	14.3
Oat + Radish	-	-	-	16.3	4.5	20.8	12.3	5.2	17.5
Oat + Clover	-	-	-	11.8	3.2	15.0	25.3	9.2	34.5
Oat + Phacelia	-	-	-	18.8	3.3	22.1	11.1	10.1	21.2
Post Control	-	-	-	12.3	2.2	14.5	9.0	9.7	18.8
Post Radish	-	-	-	9.1	2.4	11.5	15.0	9.6	24.6
Post Buckwheat	-	-	-	13.9	3.1	17.0	8.7	11.9	20.6
Post Clover	-	-	-	14.2	10.7	24.9	41.9	15.2	57.1
Control:Control	-	-	-	14.3	3.4	17.6	26.5	24.6	51.1
Radish:Radish	-	-	-	9.1	4.1	13.2	9.3	12.1	21.4
Phacelia:Buckwheat	-	-	-	13.4	2.3	15.7	20.5	26.4	46.8
Clover:Clover	-	-	-	15.9	3.2	19.1	15.0	10.1	25.1
ANOVA									
p-value	-	-	-	-	-	-	-	-	-
Root MSE	-	-	-	4.49	9.01	11.7	15.2	10.7	24.6
CoEff.Var	-	-	-	33.65	185.6	64.3	92.6	88.2	86
Kruskal -Wallis									
χ^2	-	-	-	14.6	5.72	10.1	14.4	21.1	13.7
p-value	-	-	-	0.26	0.93	0.61	0.27	0.05	0.32

Mean soil pH, organic matter and soil nutrient supply (SNS). *SNS to 60 cm soil depth (cover crop and vining pea), to 30cm soil depth (1st wheats). N=3.

	Molescroft 96			**Eastfield Kilnwick**			**Vicarage Hills**		
	pH	OM%	SNS	pH	OM%	SNS	pH	OM%	SNS
Pre-CC									
	6.7	3.75	53.5	6.3	4	84	7	3	55.4
Cover crop									
Custom	-	-	-	6.7	4.2	112.6^{ab}	7.1^{abc}	2.6^{b}	77.8^{a}
Control	6.9	3.9	154.6	6.4	3.8	52.9^{b}	7.1^{abc}	3.1^{ab}	33.8^{b}
Vetch	6.6	3.8	104.8	6.7	3.8	135.3^{a}	6.9^{c}	2.9^{ab}	89.9^{a}
Oat + Radish	6.6	4	146.3	6.6	3.6	82.6^{ab}	7.3^{a}	2.9^{ab}	62.8^{ab}
Oat + Clover	-	-	-	6.9	3.7	61.2^{ab}	6.9^{bc}	3.2^{ab}	59.3^{ab}
Oat + Phacelia	-	-	-	6.8	3.7	67.3^{ab}	7.3^{ab}	3.4^{a}	62.6^{ab}
ANOVA									
p-value	0.07	0.61	0.25	0.89	0.42	0.06*	0.006	0.01	0.02
Root MSE	0.14	0.24	35	0.49	0.38	31.7	0.14	0.21	15.1
CoEff.Var	2.05	6.21	25.9	7.32	10.1	37.2	1.96	7.06	23.4
Vining pea						**Tukey's, α = 0.1*			
Custom	-	-	-	5.7	3.6	155.6	7.3^{ab}	2.4^{b}	176.8
Control	6.4	3.5	94.1	5.9	3.9	145.8	7.1^{b}	2.7^{ab}	181.4
Vetch	6.5	3.7	86.8	5.6	3.9	130.5	7.0^{b}	2.4^{b}	220.4
Oat + Radish	6.5	3.7	97.5	5.7	4.1	111.2	7.5^{a}	2.7^{ab}	201.8
Oat + Clover	-	-	-	6	3.9	156	7.2^{ab}	3.1^{a}	218.5
Oat + Phacelia	-	-	-	5.9	3.6	132.2	7.0^{b}	3.1^{a}	214.3
ANOVA									
p-value	0.9	0.36	0.86	0.42	0.4	0.37	0.007	0.002	0.34
Root MSE	0.15	0.22	23.9	0.27	0.3	19.2	0.14	0.2	31.7
CoEff.Var	2.32	6.01	25.8	4.7	7.8	13.9	1.96	7.2	15.7
Catch crop									
Control	-	-	-	-	-	93.9	-	-	70.0^{ab}
Vetch	-	-	-	-	-	103.8	-	-	69.6^{ab}
Oat + Radish	-	-	-	-	-	132.4	-	-	93.8^{ab}
Oat + Clover	-	-	-	-	-	106.6	-	-	84.9^{ab}
Oat + Phacelia	-	-	-	-	-	87.5	-	-	75.7^{ab}
Post Control	-	-	-	-	-	138.8	-	-	79.0^{ab}
Post Radish	-	-	-	-	-	123.6	-	-	59.1^{b}
Post Buckwheat	-	-	-	-	-	107.7	-	-	67.8^{ab}
Post Clover	-	-	-	-	-	110.2	-	-	81.9^{ab}
Control:Control	-	-	-	-	-	75.1	-	-	84.5^{ab}
Radish:Radish	-	-	-	-	-	76.7	-	-	99.0^{a}
Phacelia:Buckwheat	-	-	-	-	-	71.0	-	-	66.2^{ab}
Clover:Clover	-	-	-	-	-	82.9	-	-	76.0^{ab}
ANOVA									
p-value	-	-	-	-	-	0.06	-	-	0.04*
Root MSE	-	-	-	-	-	26.6	-	-	18.1
CoEff.Var	-	-	-	-	-	26.4	-	-	23.4
									*Welche's ANOVA

	Molescroft 96			Eastfield Kilnwick			Vicarage Hills		
	pH	OM%	SNS	pH	OM%	SNS	pH	OM%	SNS
1st wheats									
Control	-	-	-	5.9^{a}	3.5^{ab}	156.1^{abc}	7.1^{bcde}	2.9^{a}	228.6^{ab}
Vetch	-	-	-	5.8^{abcd}	3.5^{ab}	204.4^{abc}	6.9^{cde}	2.8^{ab}	203.2^{ab}
Oat + Radish	-	-	-	6.0^{a}	3.9^{ab}	210.7^{abc}	7.4^{ab}	2.8^{ab}	197.6^{ab}
Oat + Clover	-	-	-	5.6^{bcde}	3.7^{ab}	199.9^{abc}	6.8^{cde}	3.0^{a}	279.1^{ab}
Oat + Phacelia	-	-	-	5.4^{e}	3.4^{b}	264.9^{a}	6.7^{e}	2.7^{ab}	251.4^{ab}
Post Control	-	-	-	5.9^{abc}	3.6^{ab}	160^{abc}	7.6^{a}	2.4^{b}	204.4^{ab}
Post Radish	-	-	-	5.5^{de}	3.4^{b}	146.1^{bc}	7.1^{bcd}	2.4^{b}	209.2^{ab}
Post Buckwheat	-	-	-	5.7^{abcde}	3.7^{ab}	233.5^{abc}	7.2^{abc}	2.4^{b}	151.8^{b}
Post Clover	-	-	-	5.9^{abc}	3.8^{ab}	158.8^{abc}	7.2^{abc}	2.6^{ab}	214.9^{ab}
Control:Control	-	-	-	5.9^{ab}	3.8^{ab}	166^{abc}	6.9^{cde}	2.6^{ab}	239.8^{ab}
Radish:Radish	-	-	-	5.7^{abcde}	3.5^{ab}	152.7^{abc}	7.3^{abc}	2.8^{ab}	192.9^{ab}
Phacelia:Buckwheat	-	-	-	5.6^{abcde}	3.4^{b}	143.8^{c}	7.0^{bcde}	3.0^{a}	294.6^{a}
Clover:Clover	-	-	-	5.5^{cde}	4.1^{a}	260.2^{ab}	6.8^{de}	2.4^{b}	262.9^{ab}
ANOVA									
p-value	-	-	-	<0.001	<0.001*	<0.001*	<0.001	<0.001	0.047
Root MSE	-	-	-	0.13	0.23	38.5	0.15	0.16	46.1
CoEff.Var	-	-	-	2.26	6.27	20.4	2.05	6.04	20.4
									*Welche's ANOVA

Mean soil phosphorus, potassium and magnesium (mg/kg). N=3.

	Molescroft 96			Eastfield Kilnwick			Vicarage Hills		
	P	K	Mg	P	K	Mg	P	K	Mg
Pre-CC									
	40.61	229.9	42.98	27.16	269.7	95.47	59.26	201.4	44.53
Cover crop									
Custom	-	-	-	23.7	304.8	111.75	49.62^{ab}	144.4^{ab}	30.75^{b}
Control	22.34	173	40.89	27.85	245.3	95.82	50.42^{ab}	135.5^{ab}	41.44^{ab}
Vetch	26.94	216.6	40.14	21.94	303.1	97.27	48.96^{ab}	136.4^{ab}	39.37^{ab}
Oat + Radish	26.5	178.4	39.31	20.44	220.1	103.05	40.78^{b}	98.2^{b}	55.74^{a}
Oat + Clover	-	-	-	20.76	240.4	90.27	50.29^{ab}	108.1^{b}	42.6^{ab}
Oat + Phacelia	-	-	-	17.29	212.1	93.17	57.22^{a}	211.7^{a}	52.27^{ab}
ANOVA									
p-value	0.27	0.28	0.91	0.45	0.07	0.43	0.048	0.006	0.027
Root MSE	3.48	32.7	4.5	6.1	13.8	13.1	5.12	28.8	8.07
CoEff.Var	13.77	17.27	11.22	27.75	16.63	13.3	10.34	20.71	18.46
Vining pea									
Custom	-	-	-	40.67	239.33	78.67	71.33	64	20.67
Control	24.67	116	28	44.67	256.67	84.33	71	68.67	23.67
Vetch	29	118.3	27.67	43	225	82.33	75.33	67	25
Oat + Radish	29.67	125	26.67	42	240.33	81	67.67	70.67	52.3*
Oat + Clover	-	-	-	44	243.67	85	72.33	72	23
Oat + Phacelia	-	-	-	41.33	236.67	84	74	85	34.67
ANOVA									
p-value	0.25	0.7	0.94	0.99	0.94	0.98	0.73	0.77	0.06
Root MSE	3.59	13	4.96	8.14	36.2	11.9	6.18	17.8	12.1
CoEff.Var	12.92	10.88	18.06	19.11	15.08	14.42	8.59	25.1	40.4
1st wheats									**exceptional value*
Control	-	-	-	37.8^{ab}	156.6^{abcd}	85.1^{abcde}	63.1^{bc}	67.5^{ab}	41.0^{cde}
Vetch	-	-	-	25.0^{bc}	127.9^{d}	71.4^{e}	69.1^{abc}	75.8^{ab}	36.6^{cde}
Oat + Radish	-	-	-	31.3^{abc}	167.0^{abcd}	77.3^{bcde}	45.0^{c}	59.3^{b}	73.1^{a}
Oat + Clover	-	-	-	27.7^{abc}	130.4^{cd}	73.8^{de}	62.5^{bc}	85.4^{ab}	50.5^{bc}
Oat + Phacelia	-	-	-	27.8^{abc}	144.2^{bcd}	74.4^{cde}	63.3^{bc}	90.9^{a}	64.7^{ab}
Post Control	-	-	-	21.0^{c}	205.3^{a}	93.0^{ab}	95.1^{a}	68.2^{ab}	15.8^{f}
Post Radish	-	-	-	31.3^{abc}	173.9^{abcd}	75.5^{bcde}	65.5^{bc}	72.0^{ab}	31.5^{def}
Post Buckwheat	-	-	-	39.2^{a}	194.6^{ab}	91.7^{abc}	78.3^{ab}	78.9^{ab}	26.3^{ef}
Post Clover	-	-	-	39.7^{a}	177.7^{abcd}	95.8^{a}	59.7^{bc}	59.1^{b}	31.2^{def}
Control:Control	-	-	-	32.0^{abc}	188.5^{ab}	91.2^{abcd}	65.8^{bc}	60.6^{b}	39.4^{cde}
Radish:Radish	-	-	-	30.6^{abc}	187.0^{ab}	78.9^{abcde}	62.1^{bc}	74.4^{ab}	36.9^{cde}
Phacelia:Buckwheat	-	-	-	28.8^{abc}	179.4^{abc}	77.3^{bcde}	65.4^{bc}	84.6^{ab}	50.0^{bc}
Clover:Clover	-	-	-	34.9^{ab}	194.0^{ab}	90.0^{abcd}	59.4^{bc}	75.0^{ab}	44.4^{cd}
ANOVA									
p-value	-	-	-	<0.001*	<0.001*	0.001*	0.016*	0.003	<0.001*
Root MSE	-	-	-	4.49	17.1	5.93	9.69	9.17	5.4
CoEff.Var	-	-	-	14.3	10	7.17	14.7	12.5	13
									*Welche's ANOVA

Mean foot rot risk. Colony counts of *Fusarium solani* and *Didymella pinodella* from laboratory plate tests. N=4.

	Molescroft 96			Eastfield Kilnwick			Vicarage Hills		
	Fusarium	Didymella	Total	Fusarium	Didymella	Total	Fusarium	Didymella	Total
Cover crops									
Custom	2.75	41	43.75	1.5	4	5.5	3.50[ab]	33.75	37.25
Control	2	20	22	4.75	9.5	14.25	2.25[b]	40.5	42.75
Vetch	6	44.25	50.25	3	14	17	4.75[ab]	42.5	47.25
Oat + Radish	-	-	-	3.75	8.5	22.25	2.00[b]	62.25	64.25
Oat + Clover	-	-	-	4.25	13.5	17.75	3.25[b]	37.75	41
Oat + Phacelia	-	-	-	3	14.25	17.75	9.00[a]	49	58
ANOVA									
p-value	0.57	0.2	0.21	0.59	0.67	0.66	0.01	0.34	0.41
Root MSE	1.62	18.79	11.51	2.64	10.1	11.5	2.57	18.49	20.3
CoEff.Var	77.97	53.55	82.2	78.2	95.2	82.2	62.4	41.75	41.93
Vining pea									
Custom	2.5	25	27.5	9	4.25	13.25	13	37.75	50.75
Control	3.5	12.8	16.3	8	5.5	13.5	6.5	57.5	64
Vetch	10.8	19	29.8	8.25	2.5	10.75	5.25	34	39.25
Oat + Radish	-	-	-	15	2.5	17.5	10	63.25	73.25
Oat + Clover	-	-	-	9.75	7	16.75	4.25	66.4	70.75
Oat + Phacelia	-	-	-	11.25	5.25	16.5	3.25	73.5	76.75
ANOVA									
p-value	0.45	0.32	0.33	0.45	0.32	0.33	0.07	0.28	0.43
Root MSE	9.48	10.35	12.45	9.48	10.35	12.45	4.67	27.1	28.5
CoEff.Var	170	54.7	50.8	169.8	54.7	50.8	66.3	48.8	45.7

	Molescroft 96			Eastfield Kilnwick			Vicarage Hills		
	Fusarium	Didymella	Total	Fusarium	Didymella	Total	Fusarium	Didymella	Total
Catch crop									
Control	79.8^{a}	0.0^{b}	79.8^{a}	14	0	14	5.75	11.25	17^{b}
Vetch	77.0^{ab}	0.5^{b}	77.5^{a}	7	0.25	7.25	11.25	27.5	38.75^{ab}
Oat + Radish	62.3^{abc}	0.8^{b}	63.0^{ab}	17.25	0.25	17.5	23.25	293.75	317^{a}
Oat + Clover	-	-	-	9.75	0.5	10.25	9.75	4.75	14.5^{b}
Oat + Phacelia	-	-	-	31.25	0.25	31.5	9.25	6.5	15.75^{b}
Post Control	18.5^{cd}	2.3^{b}	20.8^{bc}	7	1.75	8.75	11.25	207.25	218.5^{ab}
Post Radish	43.0^{abcd}	0.0^{b}	43.0^{abc}	8	0	8	8.75	23.75	32.5^{ab}
Post Buckwheat	14.5^{d}	0.3^{b}	14.8^{c}	3.25	0.25	3.5	9.5	59.5	69^{ab}
Post Clover	34.8^{bcd}	0.0^{b}	34.8^{abc}	5.75	0	5.75	12.75	14.75	27.5^{ab}
Control:Control	35.3^{bcd}	12.3^{a}	47.5^{abc}	11.25	0	11.25	7.25	178.25	185.5^{ab}
Radish:Radish	16.0^{d}	3.5^{b}	19.5^{bc}	12.25	0	12.25	2.75	38.75	41.5^{ab}
Phacelia:Buckwheat	-	-	-	13.25	0	13.25	32.25	3.5	35.75^{ab}
Clover:Clover	-	-	-	5.25	0	5.25	8	56.75	64.75^{ab}
Post Phacelia	18.8^{cd}	3.3^{b}	22.0^{bc}	-	-	-	-	-	-
Clover:Vetch	15.0^{d}	4.0^{b}	19.0^{bc}	-	-	-	-	-	-
ANOVA									
p-value	-	-	-	-	-	-	0.102	0.134*	0.138*
Root MSE	-	-	-	-	-	-	11.9	118.1	120.2
CoEff.Var	-	-	-	-	-	-	102.1	165.8	145
Kruskal Wallis									*Welches ANOVA
χ^2	17.1	23.7	16.2	14.74	13.61	14.18	-	-	-
p-value	0.07*	0.01*	0.09*	0.256	0.326	0.29	-	-	-
	**Duncan's multiple range test, α=0.1*								
1st wheats									
Control	-	-	-	29.3	0.0	29.3	22.8	15.3	38.0
Vetch	-	-	-	24.0	1.8	25.8	26.0	65.3	91.3
Oat + Radish	-	-	-	36.0	0.3	36.3	20.3	75.8	96.0
Oat + Clover	-	-	-	41.3	0.3	41.5	15.0	30.3	45.3
Oat + Phacelia	-	-	-	15.8	1.3	17.0	9.0	24.0	33.0
Post Control	-	-	-	19.0	0.0	19.0	33.3	44.5	77.8
Post Radish	-	-	-	8.5	0.0	8.5	34.8	2.0	36.8
Post Buckwheat	-	-	-	22.8	0.5	23.3	27.0	33.0	60.0
Post Clover	-	-	-	22.5	1.0	23.5	36.8	0.0	36.8
Control:Control	-	-	-	41.5	0.8	42.3	31.5	60.8	92.3
Radish:Radish	-	-	-	35.5	0.0	35.5	21.3	31.8	53.0
Phacelia:Buckwheat	-	-	-	24.8	0.0	24.8	31.5	1.3	32.8
Clover:Clover	-	-	-	40.5	0.0	40.5	34.0	1.0	35.0
ANOVA									
p-value	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a
Root MSE	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a
CoEff.Var	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a

Mean scores of foot rot severity (0-5, none to critical). N= 100.

	Molescroft 96	Eastfield Kilnwick	Vicarage Hills
Custom	-	1.73	2.15^{ab}
Control	1.67^{b}	1.8	2.28^{a}
Vetch	1.76^{b}	1.53	1.96^{bc}
Oat + Radish	2.03^{a}	1.93	2.06^{abc}
Oat + Clover	-	1.71	1.75^{c}
Oat + Phacelia	-	1.71	2.17^{ab}
χ^2 Independence of fit			
χ^2	17.71	13.91	39.4
p-value	0.024	0.83	<0.001

Vining pea development. Yield (t/ha), Haulm length (cm), Biomass (g/m²) and Emergence (plants/m²). N = 3, 75, 3, 4 respectively.

	Molescroft 96	Eastfield Kilnwick	Vicarage Hills
Yield			
Custom	-	1.33	2.4^{ab}
Control	-	1.68	1.32^{c}
Vetch	-	1.37	2.12^{b}
Oat + Radish	-	2.19	2.25^{ab}
Oat + Clover	-	2.07	2.69^{a}
Oat + Phacelia	-	2.07	2.47^{ab}
ANOVA			
p-value	-	0.38	<0.001
Root MSE	-	-	0.16
CoEff.Var	-	33.89	7.32
Haulm length			
Custom	-	27.9^{c}	44.4^{c}
Control	19.6	29.9^{b}	46.3^{bc}
Vetch	19.7	30.1^{b}	47.3^{ab}
Oat + Radish	20.2	29.6^{bc}	45.0^{c}
Oat + Clover	-	31.8^{a}	45.7^{bc}
Oat + Phacelia	-	32.4^{a}	49.7^{a}
ANOVA			
p-value	0.49	<0.001	<0.001
Root MSE	3.4	3.61	4.89
CoEff.Var	0.09	0.16	0.1

	Molescroft 96		Eastfield Kilnwick		Vicarage Hills	
Emergence						
Custom		98		85		107
Control		74		70		101
Vetch		99		87		104
Oat + Radish		90		82		101
Oat + Clover		-		82		102
Oat + Phacelia		83		91		116
ANOVA						
p-value		0.27		0.45		0.56
Root MSE		3.14		2.39		2.13
CoEff.Var		20.9		17.34		12.21
	Fresh	Dry	Fresh	Dry	Fresh	Dry
Biomass						
Custom	-	-	2015	395	2768	683
Control	1001	304	2033	385	2687	637
Vetch	1033	317	1753	328	2809	716
Oat + Radish	1020	332	2036	416	3093	728
Oat + Clover	-	-	2140	416	3089	723
Oat + Phacelia	-	-	2040	400	3481	787
ANOVA						
p-value	0.96	0.76	0.62	0.33	0.58	0.81
Root MSE	135.9	44.5	264.9	49.45	574.7	129.8
CoEff.Var	13.35	14.01	13.23	12.68	19.23	18.23

1st wheat yields and straw weights. % of Control:Control. N=3.

	Eastfield Kilnwick		Vicarage Hills	
	Straw	Estimated yield	Straw	Estimated yield
Control	83.2	97.2	130.9^{a}	106.7^{ab}
Vetch	107.4	96.3	123.1^{ab}	93.8^{ab}
Oat + Radish	105.0	85.5	86.3^{b}	71.8^{b}
Oat + Clover	93.8	99.2	104.0^{ab}	94.7^{ab}
Oat + Phacelia	117.7	114.2	93.3^{ab}	113.1^{a}
Post Control	94.7	91.4	111.9^{ab}	92.0^{ab}
Post Radish	91.5	99.9	106.5^{ab}	76.9^{b}
Post Buckwheat	109.0	104.7	102.9^{ab}	80.8^{ab}
Post Clover	102.7	96.3	111.9^{ab}	103.4^{ab}
Control:Control	100	100	100^{ab}	100^{ab}
Radish:Radish	118.9	93.1	106.7^{ab}	100.5^{ab}
Phacelia:Buckwheat	100.3	94.7	113.9^{ab}	102.9^{ab}
Clover:Clover	115.3	112.7	127.8^{ab}	97.6^{ab}
ANOVA				
p-value	0.35	0.06	0.05*	0.007
Root MSE	-	-	**Tukey's, α= 0.1*	
CoEff.Var	16.6	9.8	14.6	12.6

Least squared means from accumulated compaction ANCOVA procedure. N=8.

	Molescroft 96	Eastfield Kilnwick	Vicarage Hills
Cover crop (kPa)			
Custom	-	1014.3[c]	1505.8[c]
Control	-	1320.8[a]	1078.3[d]
Vetch	-	1230.9[b]	1619.4[b]
Oat + Radish	-	1252.3[ab]	1777.5[a]
Oat + Clover	-	991.2[c]	1576.9[bc]
Oat + Phacelia	-	977.1[c]	1107.7[d]
ANCOVA			
p-value	-	<0.001	<0.001
Root MSE	-	228.3	280.1
CoEff.Var	-	20.19	19.39
1st wheats (kPa)			
Control	-	12810[ef]	7848[a]
Vetch	-	13300[cde]	5921[ef]
Oat + Radish	-	13029[def]	5542[f]
Oat + Clover	-	13749[abc]	6974[abcd]
Oat + Phacelia	-	13136[de]	6182[def]
Post Control	-	13868[ab]	7039[abcd]
Post Radish	-	13718[abc]	7676[ab]
Post Buckwheat	-	12574[f]	6961[bcd]
Post Clover	-	14216[a]	6638[cde]
Control:Control	-	14218[a]	7134[abc]
Radish:Radish	-	13561[bcd]	6377[cdef]
Phacelia:Buckwheat	-	13306[cde]	6794[cde]
Clover:Clover	-	13842[abc]	6575[cde]
ANOVA			
p-value	-	<0.001	<0.001
Root MSE	-	1318	1585
CoEff.Var	-	9.77	23.5