Investigating the integration of cover cropping into vining pea rotations

Technical report for 3rd round of trials, 2018-2020.

Processors & Growers Research Organisation
Green Pea Company

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Contents

This report details all findings from three cover crop trials beginning August 2018 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 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 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 was 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 third 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.
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 but was necessary considering the practical implications of the trials (i.e. space). 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 29	Beverley	Late drilled	Moderate foot rot risk conferred by *Aphanomyces* and *Didymella*	Variable sandy loam atop variable sub-soil
Eastfield FNW (far north west)	Bainton	Mid season	Very light foot rot risk from *Fusarium*	Medium sandy clay loam with cover cropping and min-till history
Vicarage FS (far sands)	Asselby	Early drilled	Low risk from *Fusarium* and *Didymella*	Free draining sandy loam with poor inherent structure

The trial at Vicarage FS was performed in duplicate, with one trial shallow disc cultivation in front of vining pea drilling whilst the other was ploughed. This was done to investigate the interactions between cover cropping and cultivations on vining peas, plus any effect of contaminants at vining as ploughing reliably buries surface trash which could become a contaminant. Through-out the text these trials are distinguished after the cover crop stage assessments.

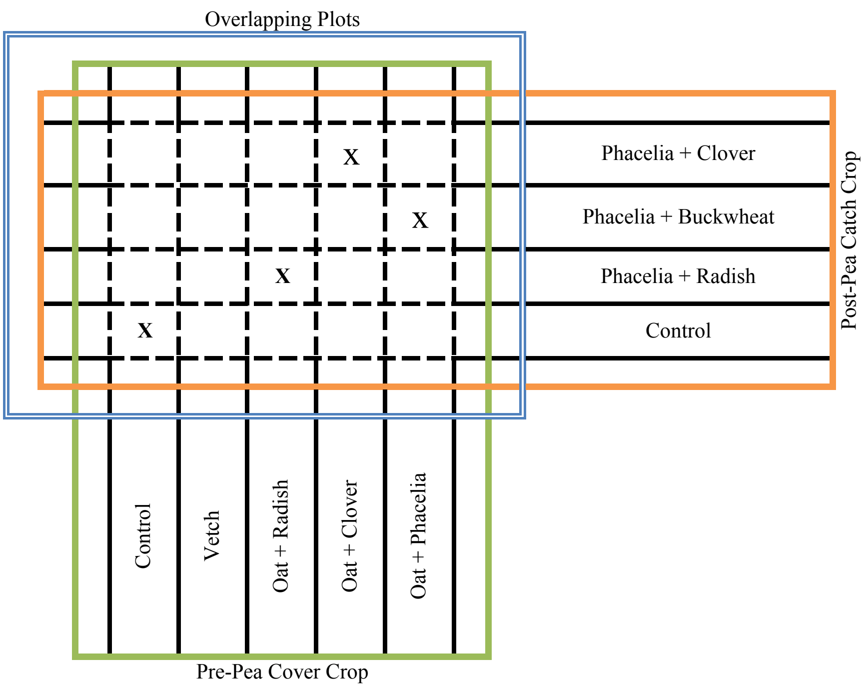

Figure 1. Experimental layout of field trials.

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

Table 2: Treatments / Species mixes

Name in text	Species mix	Rate
Control	Stubble	n/a
Vetch	100% Winter vetch (*Latigo*)	40kg/ha
Oat + Radish	45% Oil radish (*Defender*), 55% Black Oat	25kg/ha
Oat + Clover	75% Black oat (*Codex*), 25% Berseem clover (*Otto*)	40kg/ha
Oat + Phacelia	60% Black oat, 40% Phacelia (*Angelica*)	25kg/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	"Oat + Radish" "Post Radish" overlap	-
Phacelia:Buckwheat	"Oat + Phacelia" "Post Buckwheat" overlap	-
Clover:Clover	"Oat + Clover" "Post Clover" overlap	-

Numerous soil and plant parameters were assessed at various times through-out 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 (results pending). Through-out 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
- Macro-nutrients including phosphorus, potassium and magnesium
- Soil organic matter (LOI) and pH
- Soil moisture
- Compaction (penetrometer resistance)
- Assessment of soil structure (VESS)
- Innoculum 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

Cover crops were drilled at the end of a very dry summer (2018). Despite this they developed well. The winter of 2018/2019 was dry and temperatures were typical. Spring 2019 saw a dry warm period in late February, followed by a generally cool middle with prolonged dry periods. Fairly normal conditions returned by late spring 2019 and remained, broken only by a week of heavy rainfall in mid-June. Harvest and the autumn of 2019 was wet.

3 Results

3.1 Soil mineralisable nitrogen (SMN)

3.1.1 Cover crop

At Molescroft 29, SMN varied considerably in the 0-30cm soil profile but no distinct treatment effects were seen. SMN was approximately 4-fold lower in the deeper soil profile and no significant differences between treatments were observed, due o the restricted development of cover crops at this site. The Control here was the only treatment to have any appreciable ammonium. SMN in the 0-30cm range at Eastfield FNW was greatest in the Oat + Clover treatment. The 30-60cm soil depth demonstrated the mopping up ability of cover crops because nitrogen had leached into deeper soil in the Control. Practically no SMN was recorded in the deeper soil when cover cropped. Patterns of SMN abundance at Vicarage FS were similar to those seen at Eastfield FNW. At both Eastfield FNW and Vicarage FS the Oat + Clover mix maintained the highest SMN in the 0-30cm depth of soil. This could have been a consequence of nitrogen contributions from the clover, a leguminous species. However, the Vetch treatments established well but had modest levels of SMN.

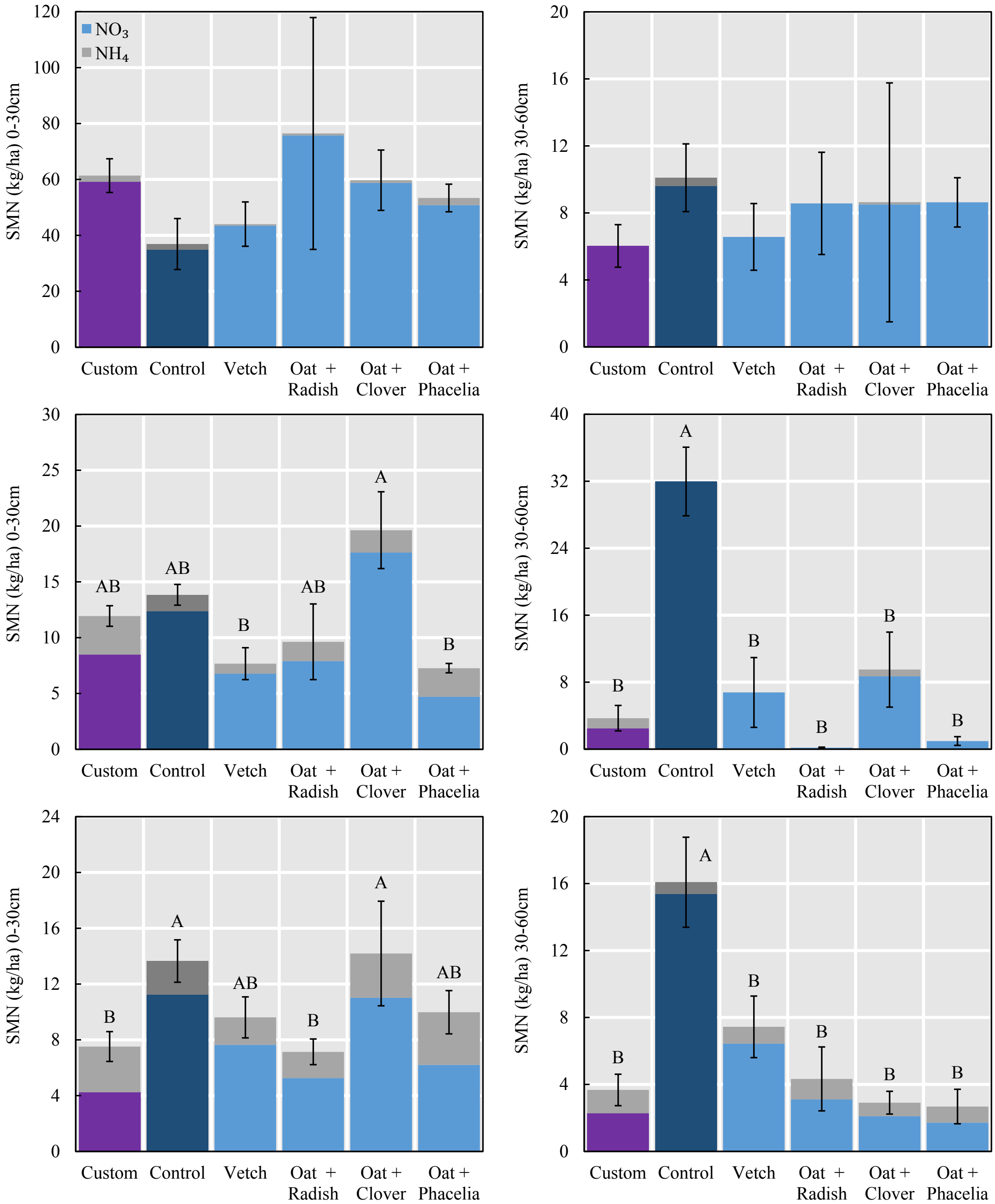

Figure 2: Soil mineral nitrogen at cover crop stage (January 2019). 0-30cm and 30-60cm soil depth (left to right). Molescroft 29, Eastfield FNW, Vicarage FS (top to bottom).

3.1.2 Vining pea

At vining pea stage, SMN was consistent throughout the soil depths at Molescroft 29, around 15-20 kg/ha with no differences between treatments. At Eastfield FNW, SMN in the top 30cm did not change much since the winter, although a considerable rise in SMN in the Oat + Radish treatment was observed. Downward movement of SMN had occurred since the previous sampling period where also, an exceptionally high increase in SMN at 30-60cm depth in the Oat + Clover treatment was seen. There were no significant treatment effects observed at neither the ploughed nor shallow disc trial at Vicarage FS. However, there was a spike in SMN in the 30-60cm depth in the ploughed trial from Vetch, most likely a consequence of burying the vetch plants at ploughing depth.

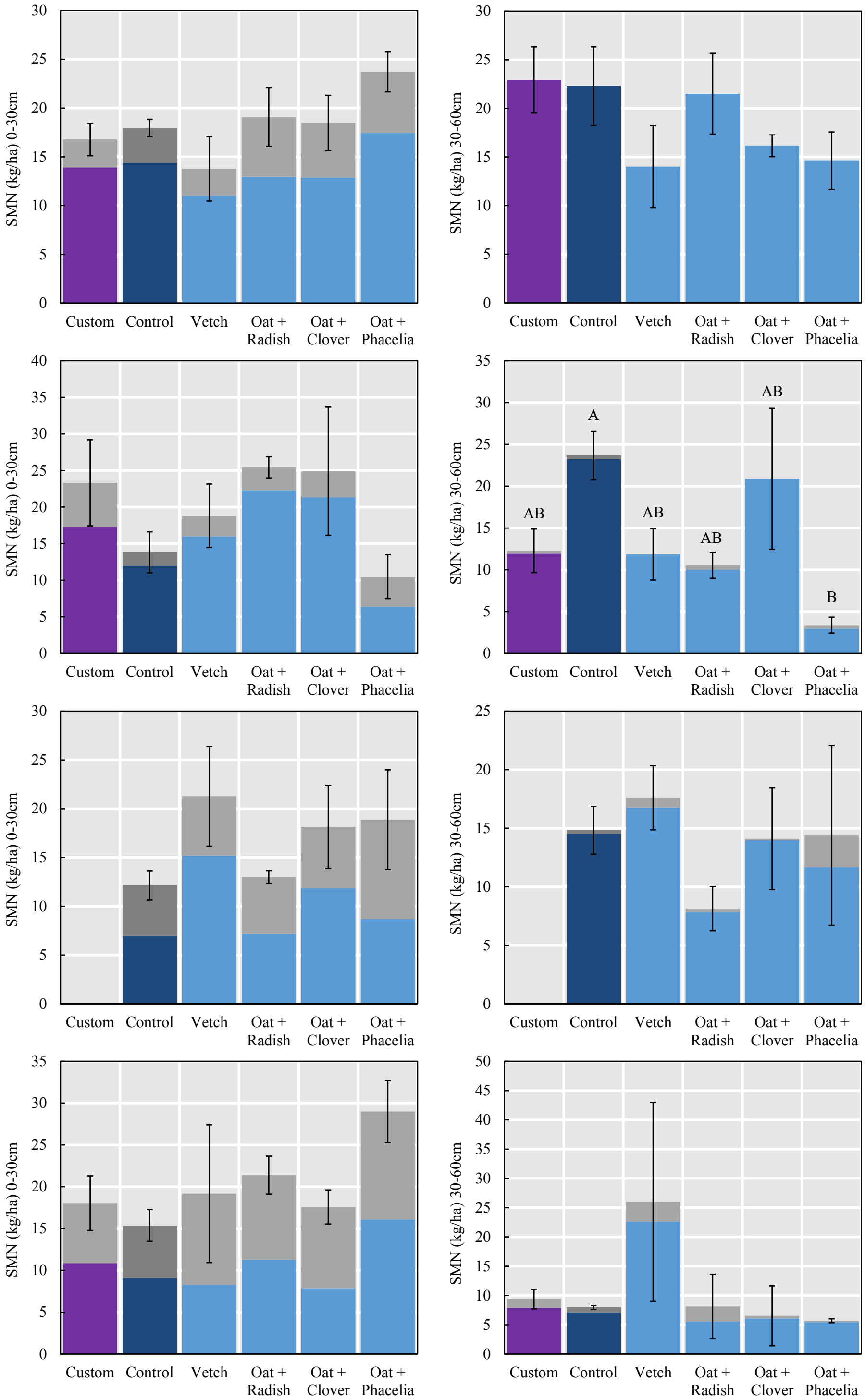

Figure 3: Soil mineral nitrogen at vining pea stage (July 2019). 0-30cm and 30-60cm soil depth (left, right). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top to bottom).

3.1.3 Catch crop

SMN was greatest in un-vegetated plots at this stage. Catch crops showed variable capacities to intercept residual nitrogen with oil radish taking up most. There was no significant difference in SMN between catch cropped treatments at any site. Nor were there differences between cover crop only treatments. However, there was a notable treatment effect on ammonium at Eastfield FNW and Vicarage FS (shallow disc). Oat + Phacelia treatments had significant and considerably greater quantities of ammonium compared to all other treatments. This has been observed slightly more subtly earlier in the trial and in previous trials.

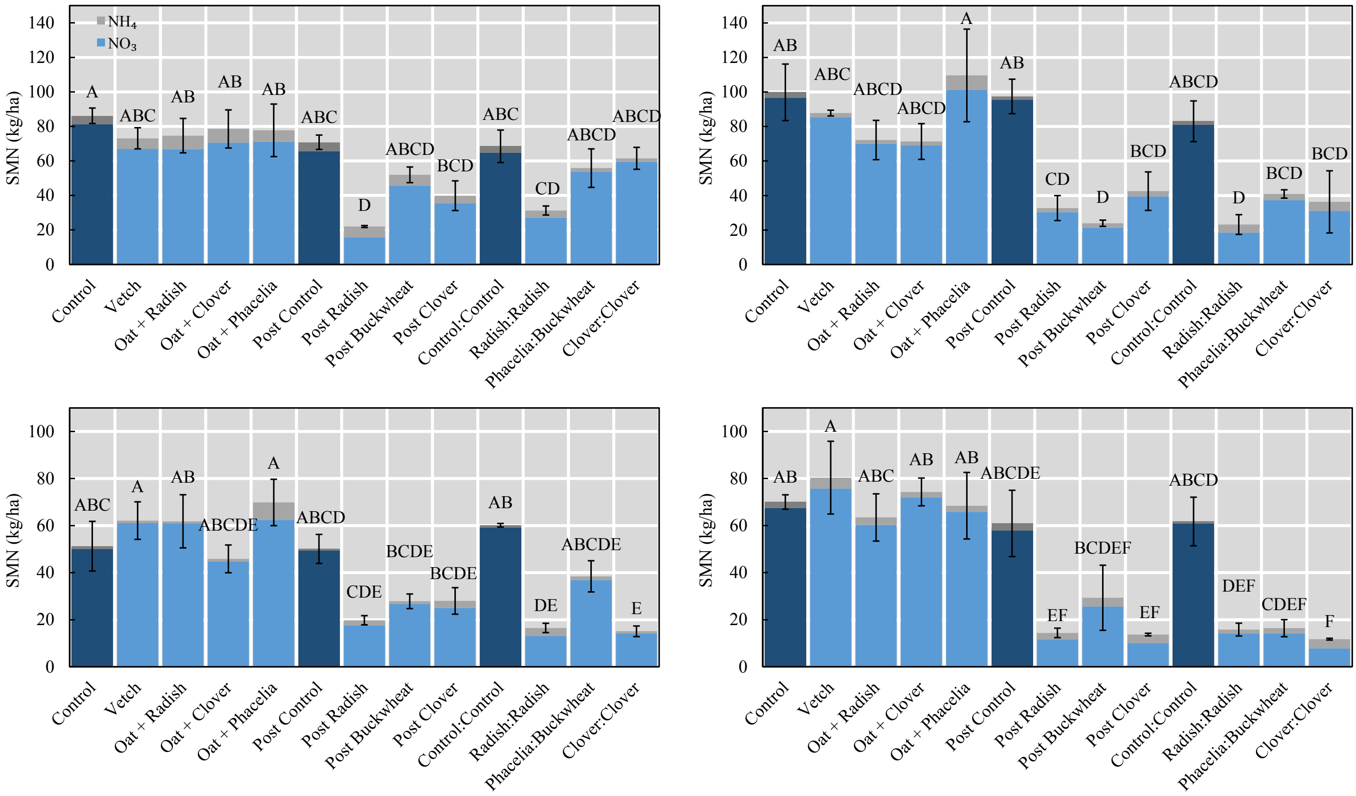

Figure 4: Soil mineral nitrogen at catch crop stage (September 2019). 0-30cm soil depth. Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

3.2 Soil nitrogen supply (SNS)

3.2.1 Cover crop

At Molescroft 29, there were no significant differences between treatments in SNS at cover crop stage. However, the Control treatment had less SNS than most other treatments here whilst the Oat + Radish treatment had more than double that of the Control and as was observed at Molescroft 29, the SNS values at Eastfield FNW were lowest in the Control and Vetch treatments respectively. The Oat + Clover treatment accrued the greatest quantity of nitrogen at this stage, a consequence of high nitrogen interception and perhaps the clover component. SNS at Vicarage FS was lowest in the Control and highest in the Oat + Clover treatment. Here, the Vetch treatment had far higher SNS compared to the other sites which was due the relatively greater biomass attained by the Vetch at this site. Overall, the Control had the lowest level of SNS at all sites whilst Oat + Clover fared well.

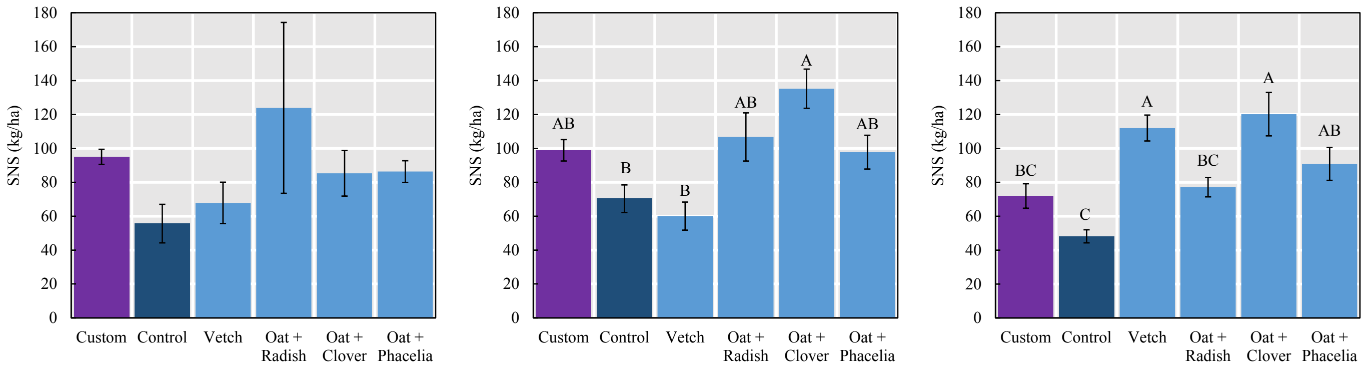

Figure 5: Soil nitrogen supply at cover crop stage (January 2019). Molescroft 29, Eastfield FNW, Vicarage FS (left to right).

3.2.2 Vining pea

At vining pea stage, the only significant treatment effect on SNS was seen in the shallow disc trial at Vicarage FS where the Control plots yielded approximately 80kg of nitrogen less per hectare than cover cropped treatments. Generally speaking, the Oat + Clover treatment had high/highest SNS in all trials.

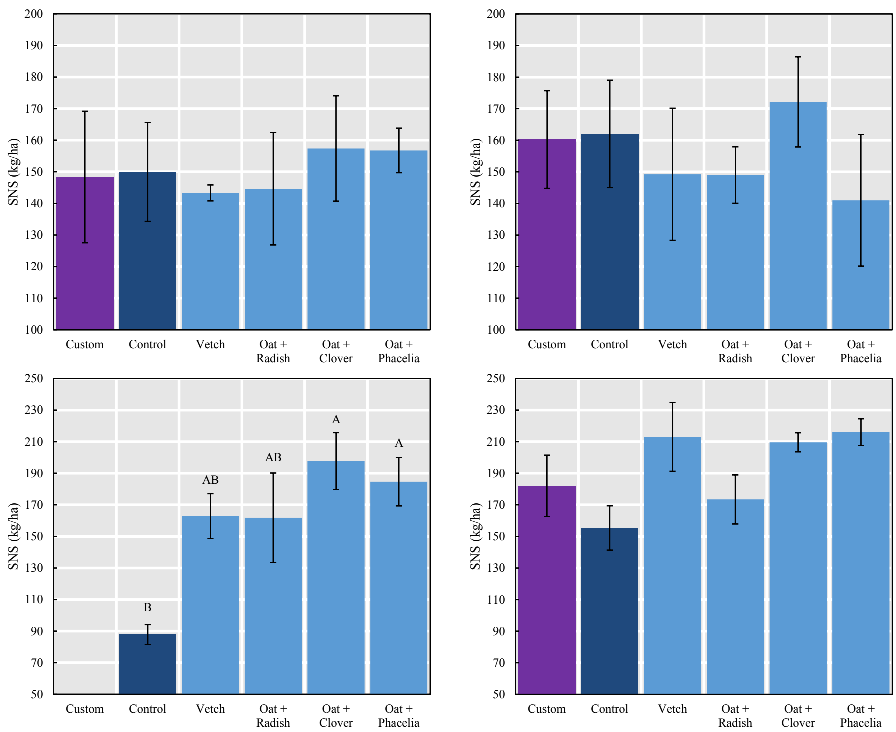

Figure 6: Soil nitrogen supply at cover crop stage (July 2019). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

3.2.3 Catch crop

At Molescroft 29, there were no treatment differences in SNS. This was probably due to the poor development of the catch crops, thus failing to accrue much nitrogen. Treatment effects were significant at Eastfield FNW, with some treatments accruing over 50% more nitrogen than others. However, no cover or catch crop treatment differed significantly from the control measures. Similar statements can be made for the SNS levels observed at the shallow disc trial at Vicarage FS. At the ploughed trial however, SNS was greater across all treatments compared to the shallow disc counterpart. This was due to the more successful biomass production of catch crops (and "Control" vining peas) on previously ploughed land, which in turn accumulated a greater quantity of nitrogen. Here, the Post Radish treatment accrued more than double the SNS than all the controls.

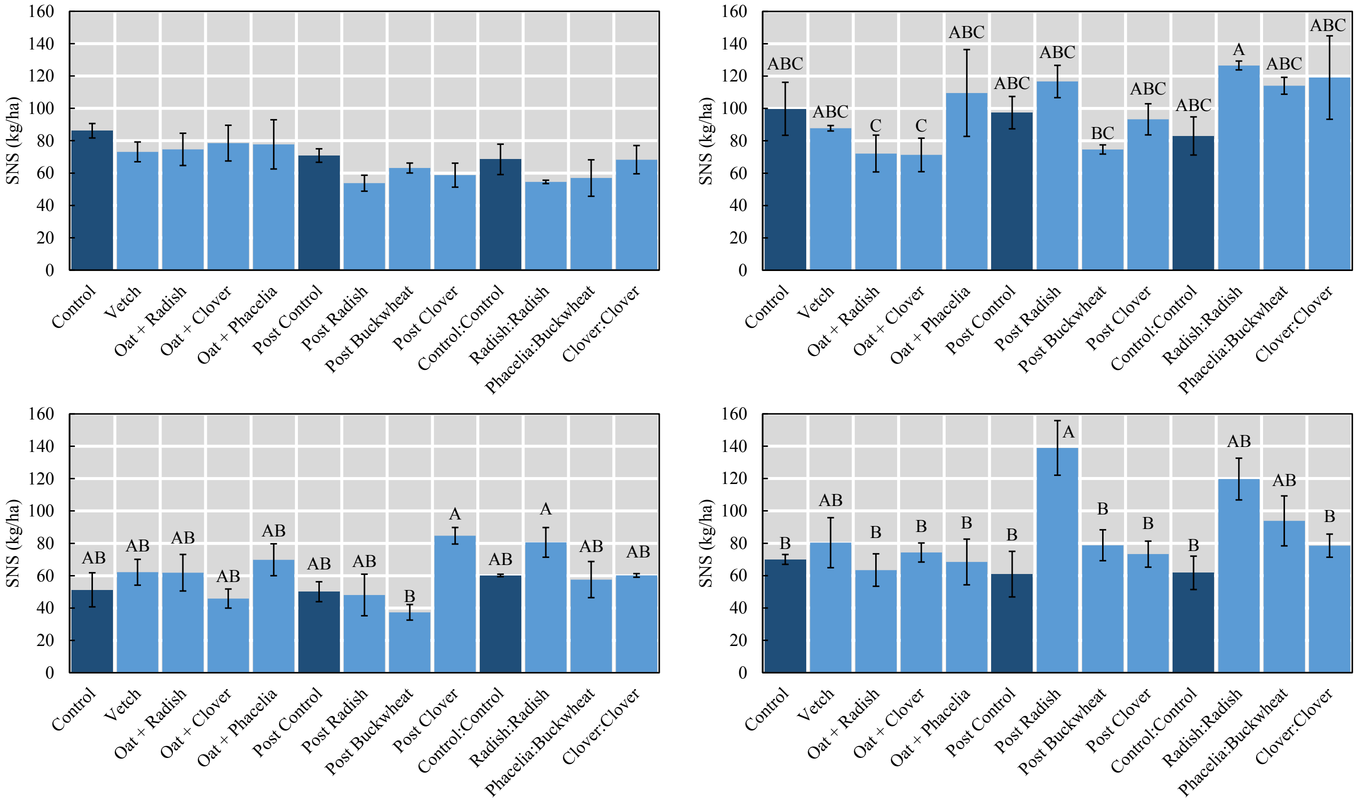

Figure 7: Soil nitrogen supply at catch crop stage (September 2019). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

3.3 Nutrient data

3.3.1 Cover crop

Phosphorus, Potassium, Magnesium

At cover crop stage, there were few treatment effects on soil macronutrient availability. One common trend at all sites was the relatively lower availability of potassium in the Oat + Phacelia treatment compared to the Control. At Eastfield FNW, magnesium was exceptionally low in the Control and the Oat + Clover treatments.

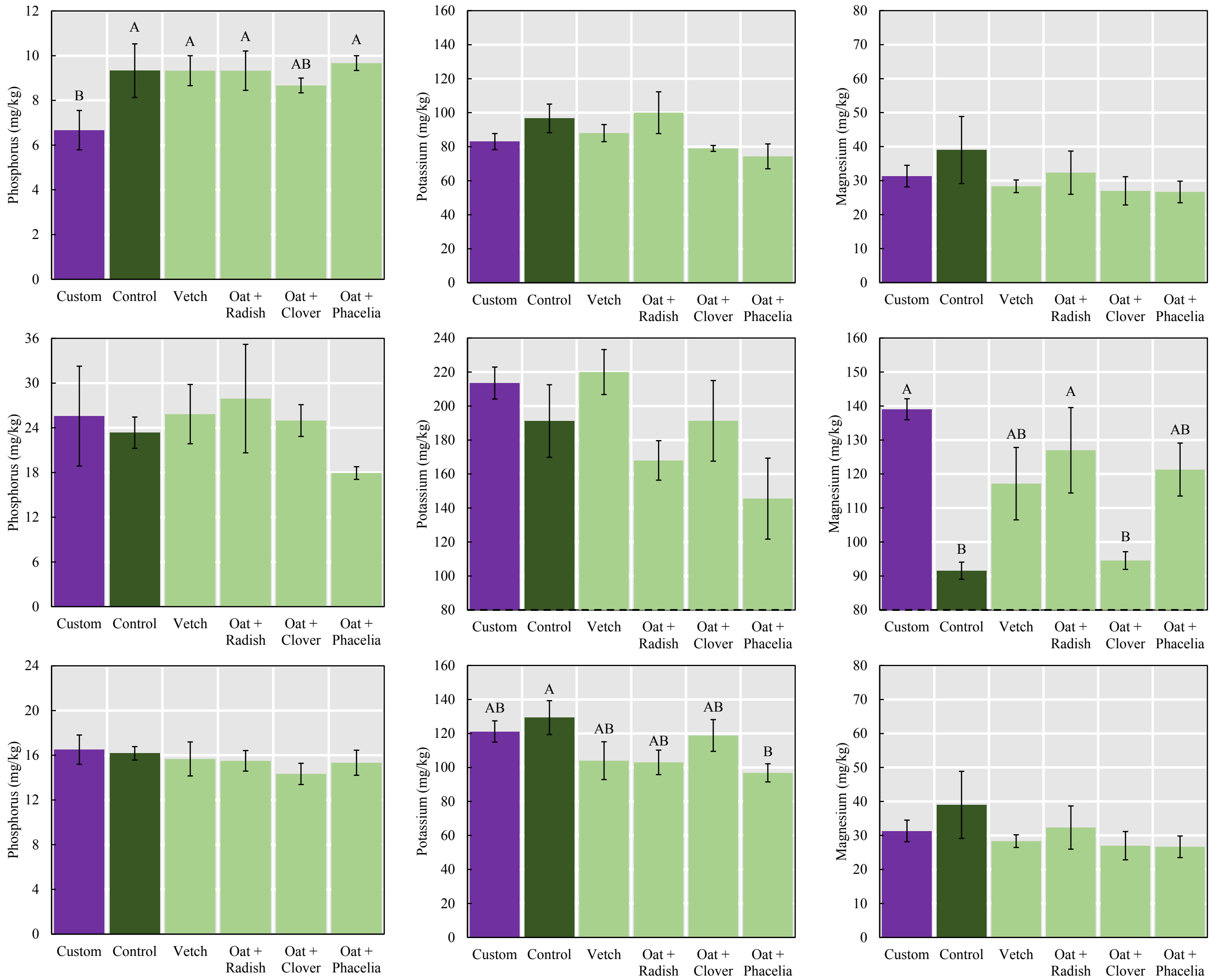

Figure 8: Macronutrient availability at cover crop stage (January 2019). Phosphorus, potassium, magnesium (left to right). Molescroft 29, Eastfield FNW, Vicarage FS (top to bottom).

3.3.2 Vining pea

Phosphorus, Potassium, Magnesium

At Molescroft 29, macronutrient availabilities were highest in the Control. The opposite was true for Eastfield FNW were the Control plots had the lowest macronutrient availabilities. No treatment effects were seen at the shallow disc trial at Vicarage FS but were present in the adjacent ploughed trial where very large differences in magnesium availability were observed. The shallow disc trial had slightly more phosphorus and potassium than the ploughed counterpart.

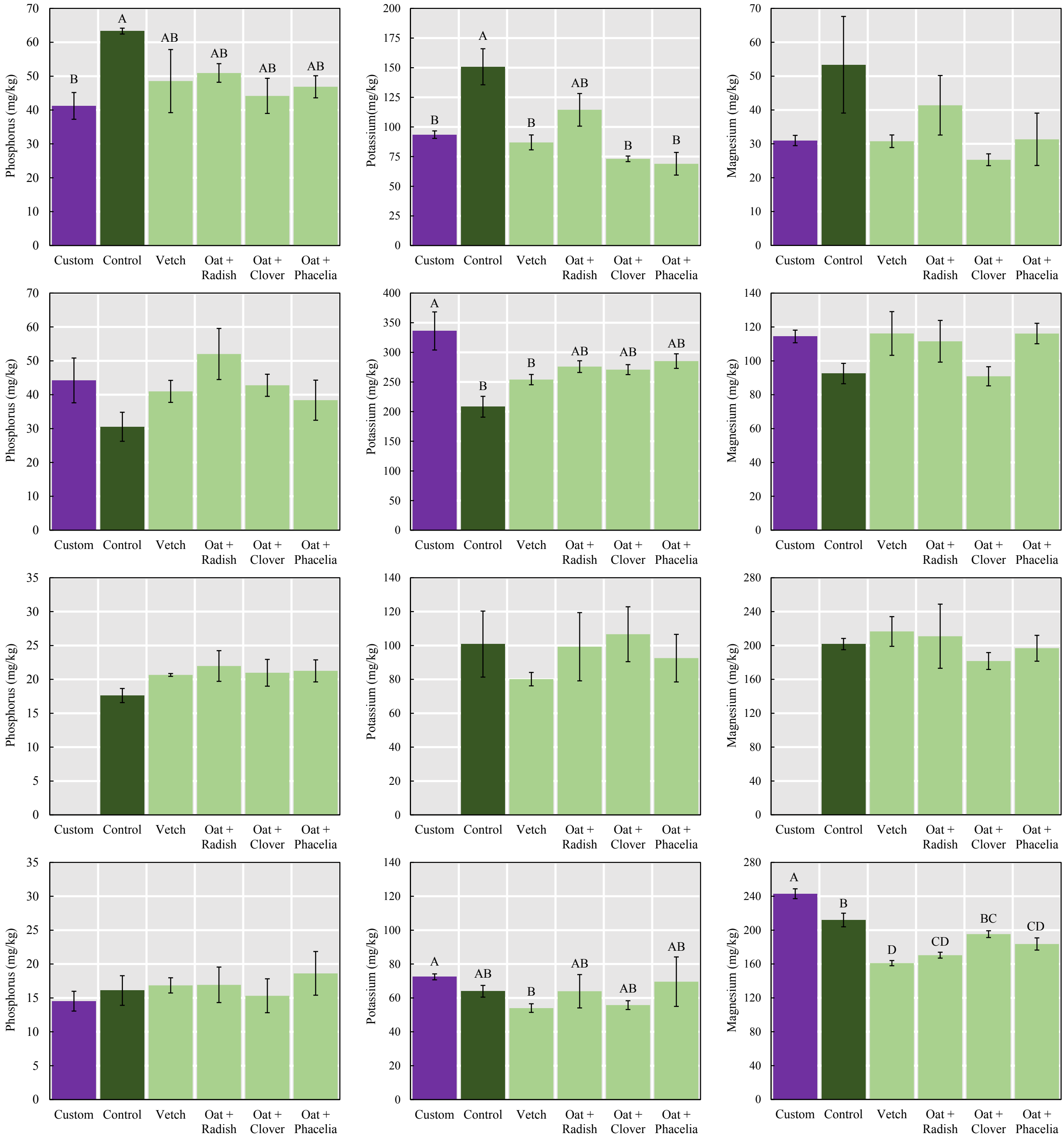

Figure 9: Macronutrient availability at vining pea stage (July 2019). Phosphorus, potassium, magnesium (left to right). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top to bottom).

Cover crop soil pH

Soil pH at cover crop stage was highest in the Control treatments at both Molescroft 29 and Vicarage FS. Conversely at Eastfield FNW, the Control had the lowest soil pH.

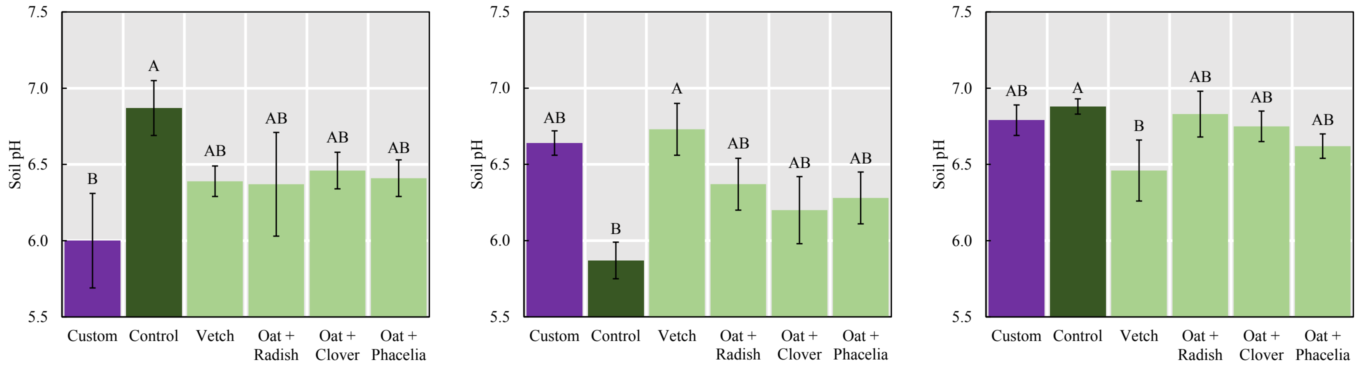

Figure 10: Soil pH at cover crop stage (January 2019). Molescroft 29, Eastfield FNW, Vicarage FS (left to right).

Vining pea soil pH

Soil pH at Molescroft 29 had dropped very slightly since the winter but did not change much in relative terms. No significant differences were observed between treatments. At Eastfield FNW, soil pH dropped to below pH 6 in most cases, with Control and Oat + Clover plots tying at the lowest pH. Soil pH was unaffected by cover crops at this stage in the shallow disc trial at Vicarage FS but there were some differences in the ploughed counterpart. The shallow disc trial was acidic in the top soil in contrast to the ploughed trial which was generally neutral/alkaline.

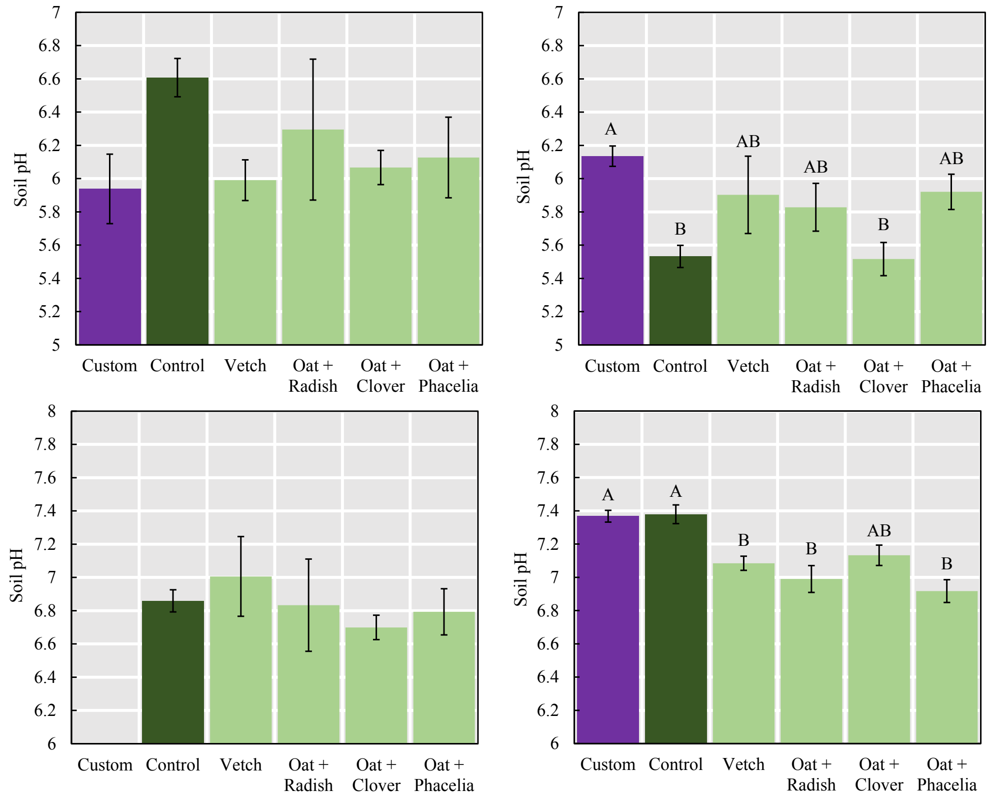

Figure 11: Soil pH at vining pea stage (July 2019). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

3.4 Soil organic matter

3.4.1 Cover crop

At the cover crop stage, cover cropped treatments did not differ in soil organic matter compared to the Control or one another with the exception that the Vetch treatment had less soil organic matter than the Control at all sites. Custom treatments were either the highest or lowest in soil organic matter.

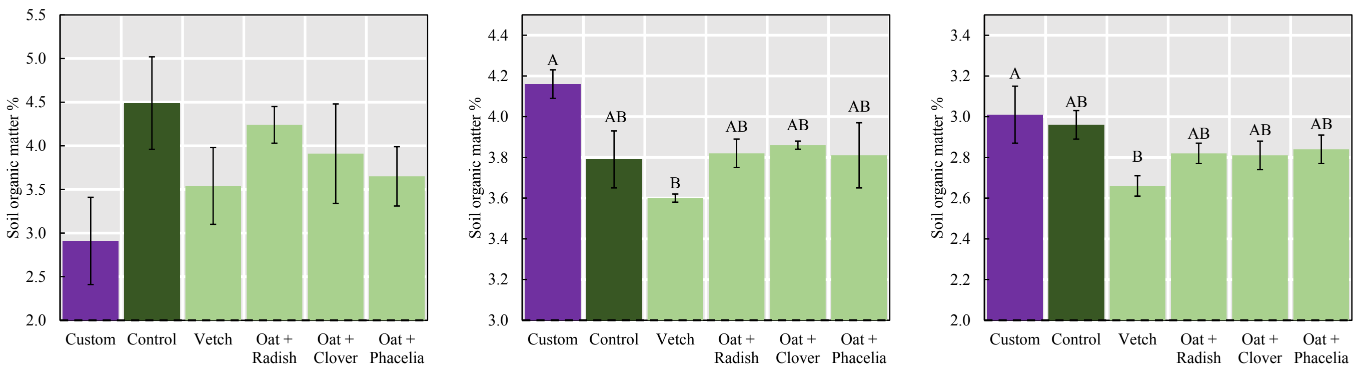

Figure 12: Soil organic matter at cover crop stage (January 2109). Molescroft 29, Eastfield FNW, Vicarage FS (left to right).

3.4.2 Vining pea

By this stage, soil organic matter at Molescroft 29 had hardly changed since the previous assessment. Soil organic matter had risen by roughly 0.2% across all treatments at Eastfield FNW, though there were no treatment effects. It should be noted here that there was a lot of straw residue from the previous crop at Eastfield FNW which may explain the soil organic matter rise in the Control. Soil organic matter had declined very slightly at the shallow disc trial at Vicarage FS, but nothing had changed in relative terms. A similar observation was made for the ploughed counterpart.

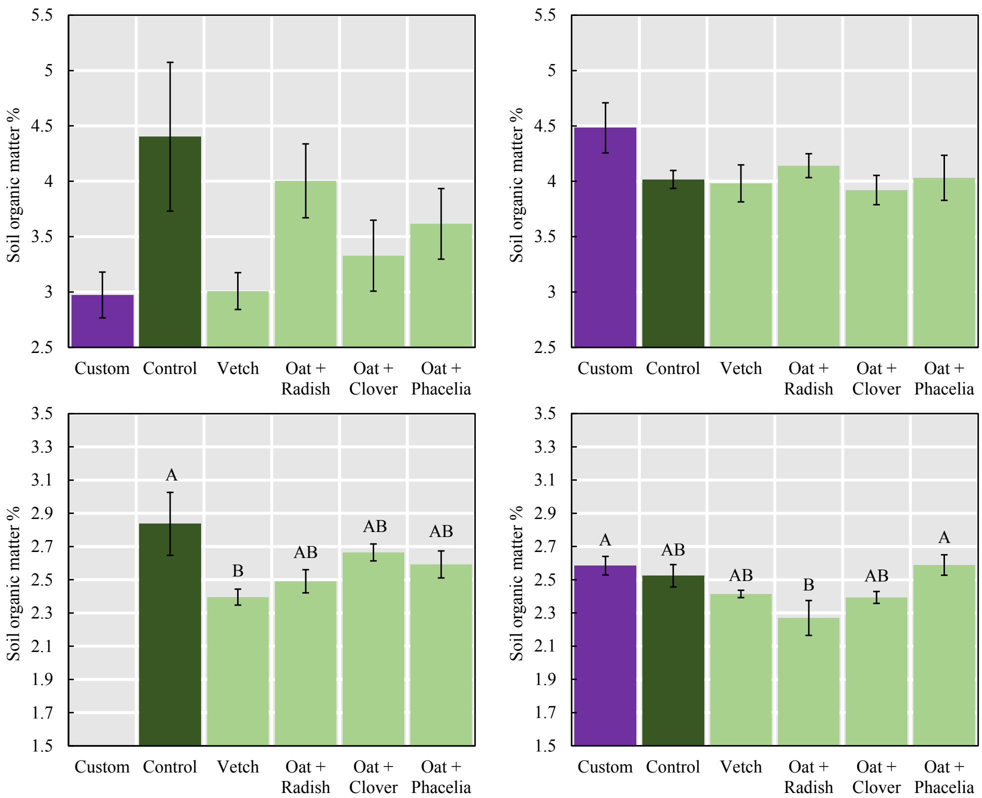

Figure 13: Soil organic matter at vining pea stage (July 2019). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

3.5 Foot rot risk

3.5.1 Cover crop

Pre drilling assessments of foot rot risk determined that risk was low/moderate at all sites. At Molescroft 29, *Fusarium* was barely detected. Cover crops did not have a significant effect on *Didymella* inoculum although there were considerable differences between some treatments. *Aphanomyces euteiches* was also present at Molescroft 29 (data not shown). The levels of both *Fusarium* and *Didymella* at Eastfield FNW were very low. However, there was an exceptional assessment of *Fusarium* risk from the Oat + Radish treatment. There was no treatment effect present at Vicarage FS for either pathogen.

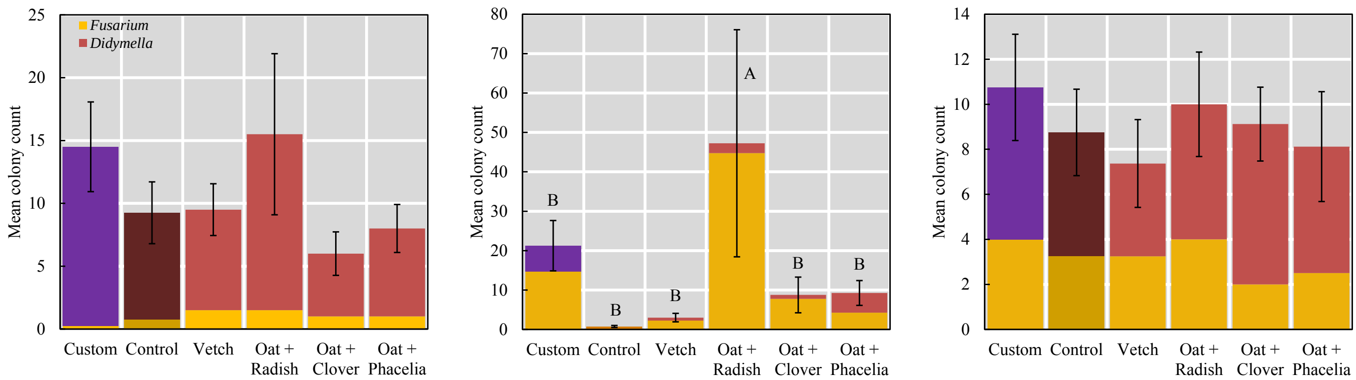

Figure 14: Foot rot pathogen pressure at cover crop stage (January 2019). Molescroft 29, Eastfield FNW, Vicarage FS (left to right).

3.5.2 Vining pea

By the vining pea stage, the level of *Fusarium* inoculum had remained unchanged since the previous assessment at Molescroft 29 however the inoculum pressure of *Didymella* had increased massively. No significant differences were present but there were considerable variation between treatments which, at this time, followed a field gradient.
The foot rot inoculum pressure at Eastfield FNW was practically absent at this stage. The moderate *Fusarium* pressure seen in the Oat + Radish treatment at the cover crop stage had diminished, presumably due to the germination of *Fusarium* resting spores since the previous sampling period.
At Vicarage FS (shallow disc trial), the levels of *Fusarium* inoculum had declined since the previous assessment whilst the *Didymella* inoculum had risen very slightly. Overall, levels were low and no treatment effects were observed. In the ploughed trial however, *Didymella* inoculum had increased dramatically. This increase was clearly a consequence of the cultivation although it was not clear whether ploughing created an environment where *Didymella* thrived or if the inoculum had been brought up from below the typical sampling depth by the plough. It should be noted here that the difference in foot rot development in crop between the ploughed and shallow disc trial was subtle. These tests assessed foot rot inoculum at vining, whereas foot rot risk in crop is determined by pre drilling (cover crop) assessments. Regardless, there were treatment effects. Oat + Radish and Vetch had lower levels of *Didymella* inoculum at this stage.

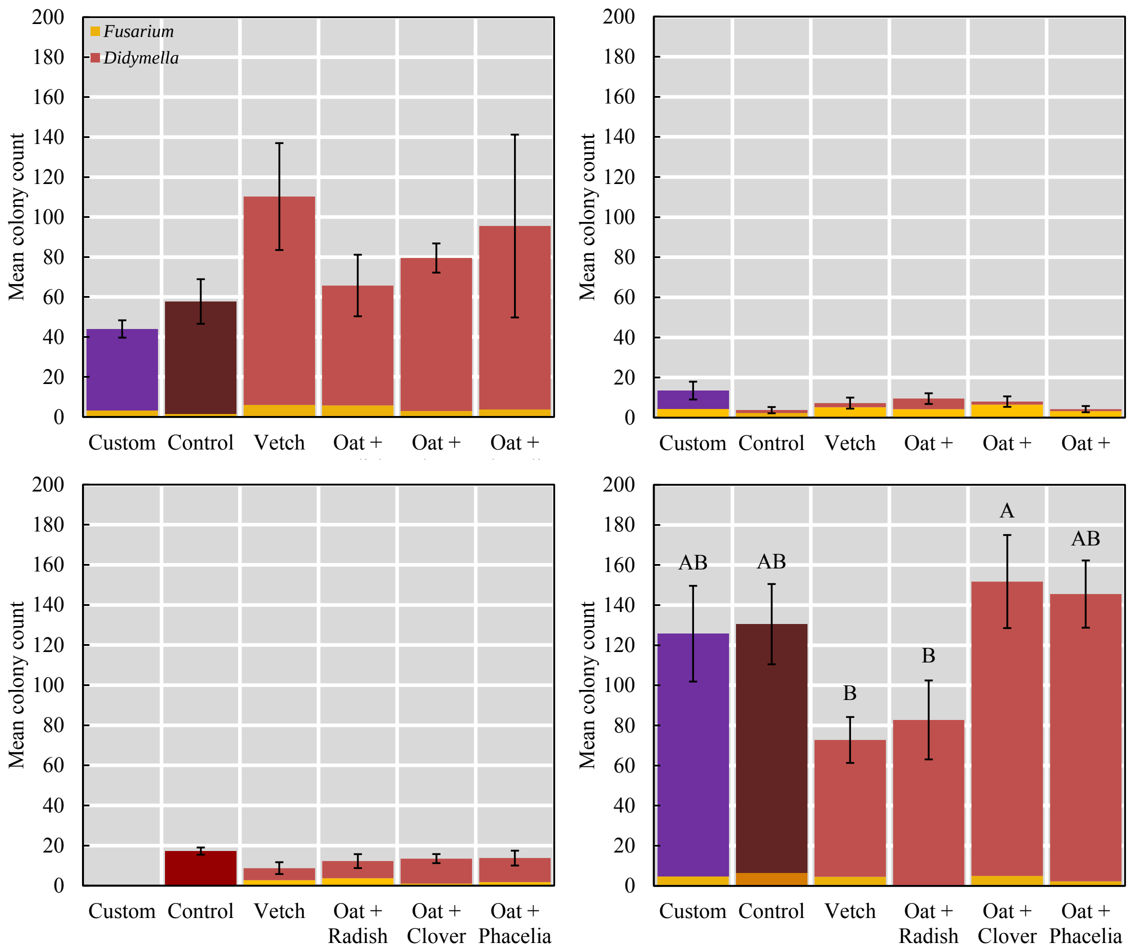

Figure 15: Foot rot pathogen pressure at vining pea stage (July 2019). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

3.5.3 Catch crop

Despite large variations in *Didymella* abundance at Molescroft 29, no significant treatment effects were found between treatments. At Eastfield FNW, *Fusarium* levels differed slightly. Here, the Radish.Radish treatment had the greatest *Fusarium* risk. Foot rot risk varied massively at the Vicarage FS shallow disc trial, however, no significant or otherwise clear patterns were apparent. In the ploughed trial, some treatments did differ significantly from one another. Generally speaking, catch cropped plots had much lower *Didymella* risk compared to other treatments but differences between catch cropped treatments were not present.

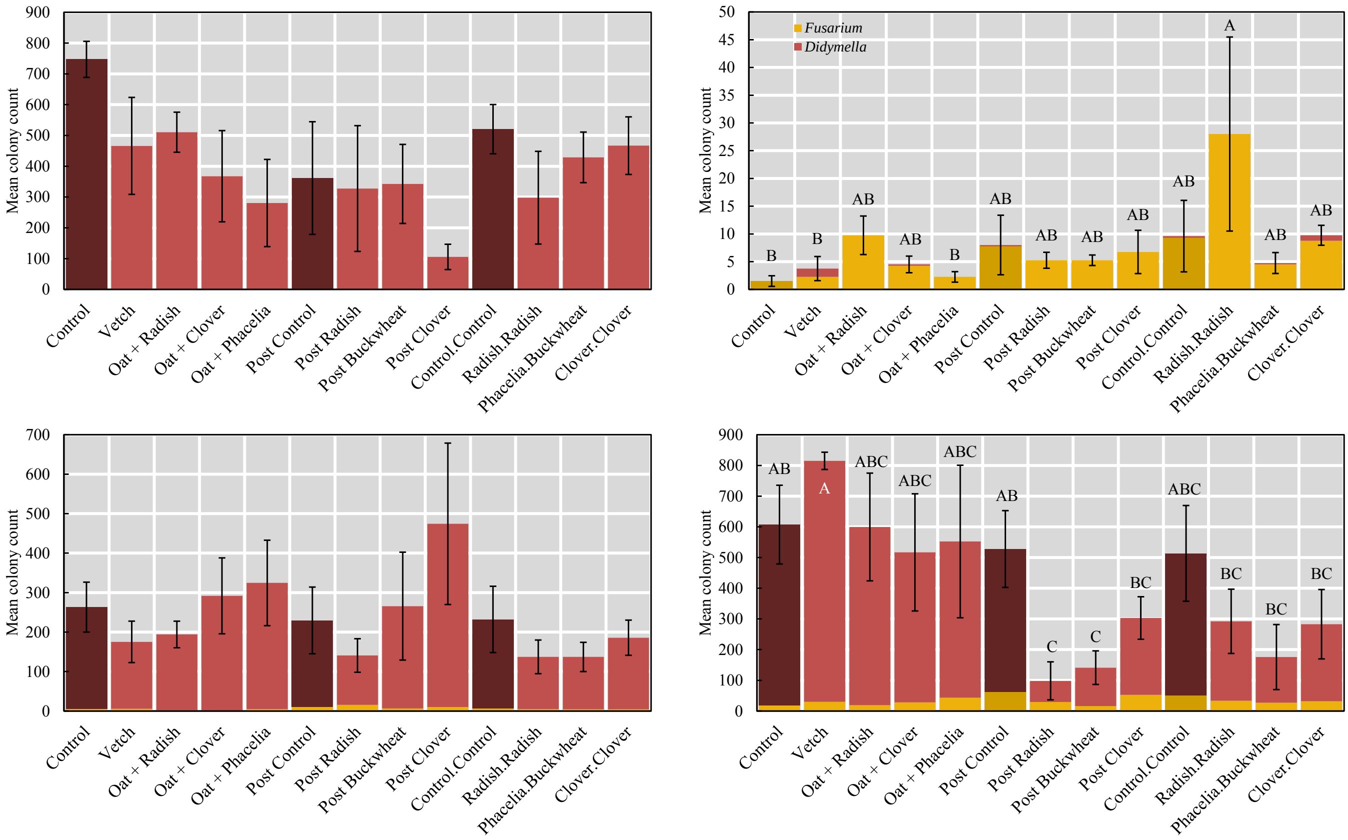

Figure 16: Foot rot pathogen pressure at catch crop stage (September 2019). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

3.6 Crop Health and development

3.6.1 Foot rot development

At Molescroft 29 *Aphanomyces* symptoms were present in addition to *Fusarium* and *Didymella* symptoms but foot rot severity remained low/moderate. Treatment effects were quite subtle. Oat + Clover and Oat + Phacelia treatments showed the lowest overall foot rot severity. Control, Vetch and Oat + Radish treatments had significantly more highly/severely infected plants compared to Custom, Oat + Clover and Oat + Phacelia. These "treatment effects" however might have been a consequence of soil texture rather than cover crops. The areas hosting Oat + Clover and Oat + Phacelia treatments were lighter in subsoil whereas the remaining areas had a higher clay constituent. These textural discrepancies, and the moisture retention properties that follow are thought to have been responsible for greater foot rot on the heavier areas.

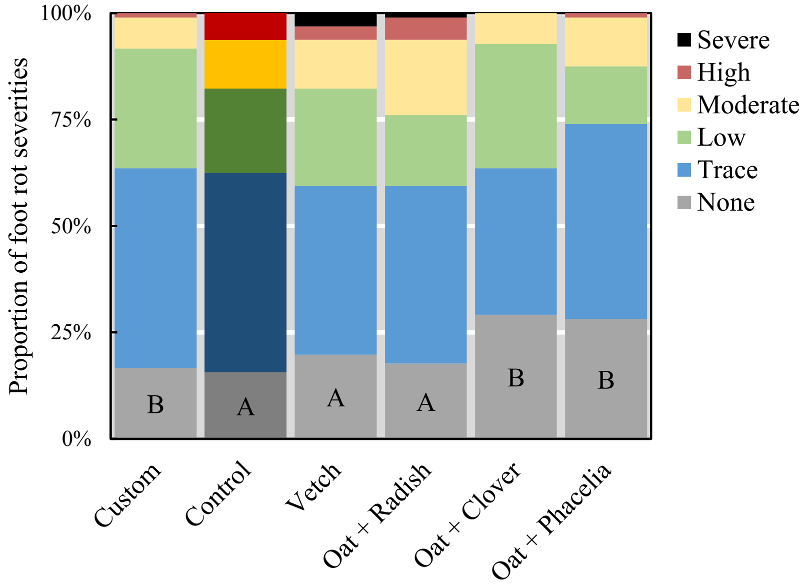

Figure 17: Molescroft 29, proportion of foot rot severity at Vining pea stage (June 2019).

The foot rot assessments at Eastfield FNW were conducted at a point where it was possible to assess both *Fuasrium* and *Didymella* separately as foot rot severity here was very low. Results are presented as percentage of plants affected. The Oat + Radish treatment showed greater *Fusarium* infection by far, five times greater than Oat + Clover and four times greater than the Control for example. This was predicted by laboratory tests at the cover crop stage. Oat + Clover had the lowest incidence of *Fusarium* infection followed closely by the Control treatment. Custom was also high in both pathogens, perhaps partially a consequence of the minor oil radish component of that mix. Oat + Radish and Vetch treatments showed moderate levels of *Didymella* infection compared to the Control and Oat + Clover treatments. This somewhat reflected the results seen at Molescroft 29 where Vetch and Oat + Radish showed more severe *Didymella* symptoms, although soil texture was important in that case. Again as seen with *Fusarium*, Oat + Clover was least affected by *Didymella* followed closely by the Control.

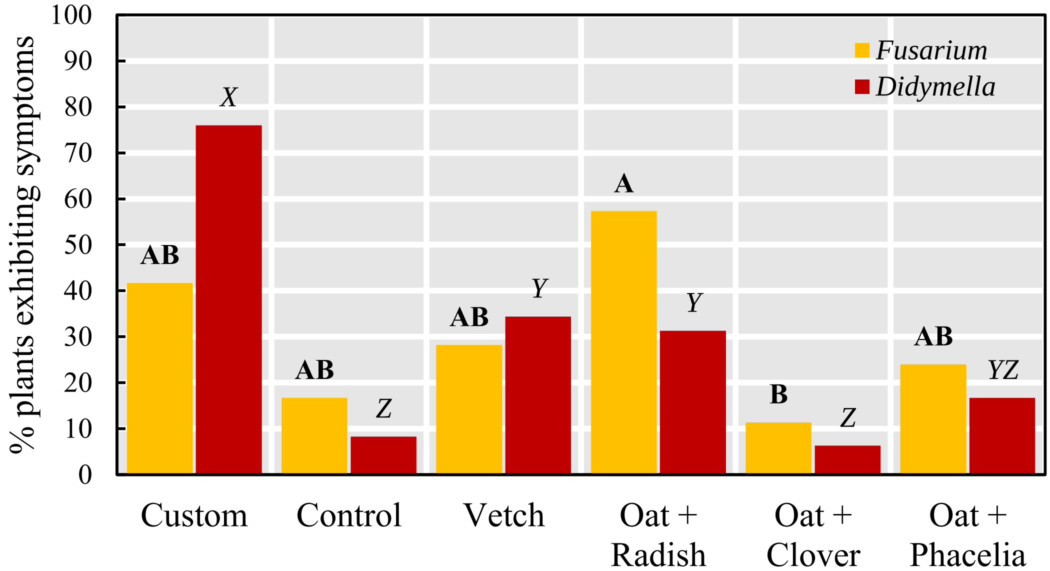

Figure 18: Eastfield FNW, proportion of plants showing symptoms of foot rot at vining pea stage (June 2019).

At Vicarage FS, foot rot development was light, and generally lower in ploughed trial. This may have been a little skewed by staggered maturity between the cultivation methods but foot rot was certainly more severe in the shallow disc trial. No data are available for Custom (shallow disc). In the ploughed trial, the only significant difference was the higher foot rot severity in the Custom treatment. In the shallow disc trial, the Control treatment showed marginally greater foot rot development, mostly significantly so. Vetch treatments exhibited the least severe foot rot symptoms overall. Oat + Radish showed no negative impacts on foot rot development on this occasion.

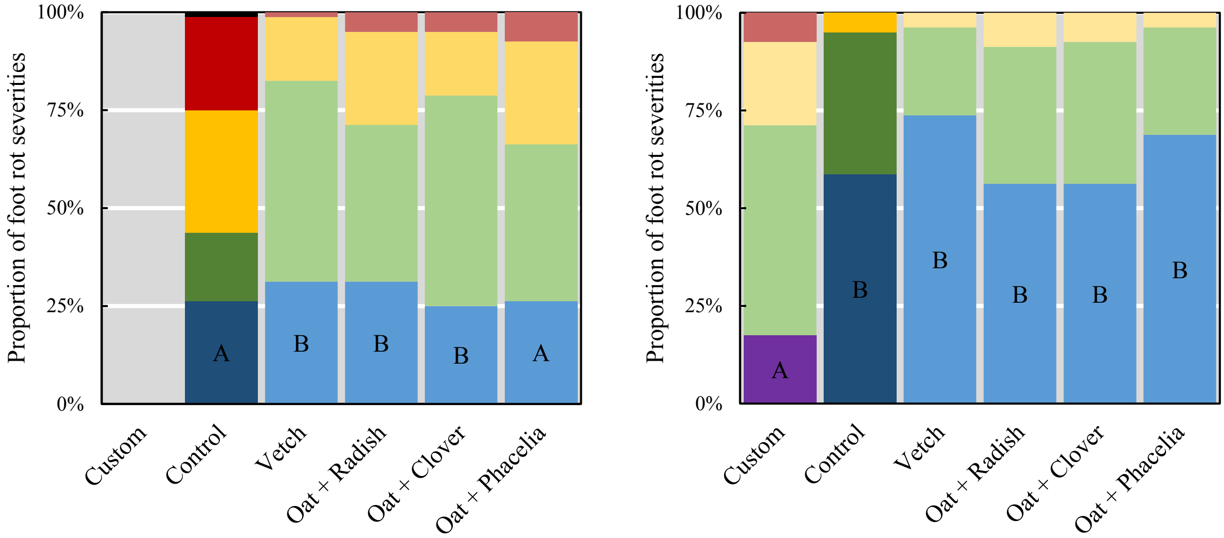

Figure 19: Vicarage FS, proportion of foot rot severity at Vining pea stage (June 2019). *Shallow disc* left, *plough* right.

Treatment	Molescroft 29	Vicarage FS *shallow disc*	Vicarage FS *plough*
Custom	1.55_b	n/a	2.19_a
Control	1.75_a	2.56_a	1.46_b
Vetch	1.59_a	1.88_b	1.36_b
Oat + Radish	1.79_a	2.03_b	1.53_b
Oat + Clover	1.38_b	2.01_b	1.51_b
Oat + Phacelia	1.34_b	2.15_a	1.35_b

Table 3: Mean foot rot score at vining pea stage (June 2019). Score 0-5 (0=none, 5=severe).

3.6.2 Emergence and haulm biomass

No significant differences in seedling emergence were seen at any trial. Emergence at Vicarage FS may have been subject to a field gradient.

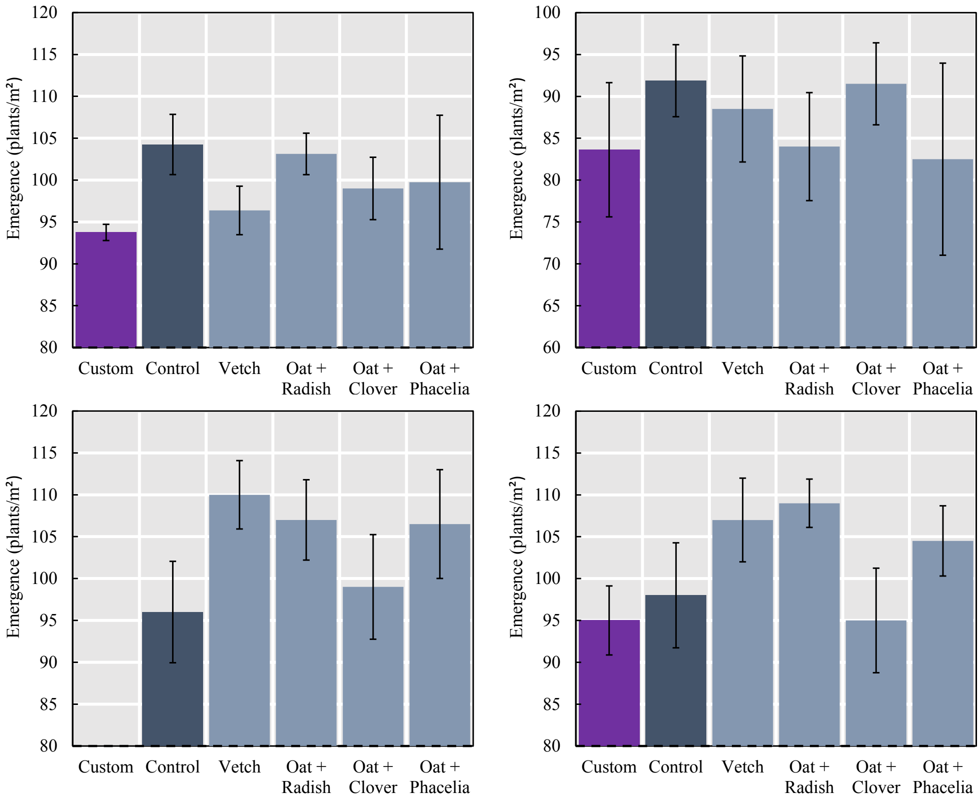

Figure 20: Seedling emergence. Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

Figure 21: Vining peas at harvest. Plot area taken for assessment of yield.

No significant treatment effects on haulm biomass were present at Molescroft 29, though Oat + Radish had accumulated 20% more haulm than the Custom treatment. Haulm biomass did not respond to cover crop treatments at Eastfield FNW either. Here however, Oat + Radish had the lowest biomass in contrast to Molescroft 29. At Vicarage FS, haulm biomass was not significantly affected by cover crop treatments in the ploughed trial although the Control had the lowest haulm biomass. In the shallow disc trial however, cover cropping significantly increased biomass by roughly 75% (across all treatments), doubling in the Oat + Clover treatment in comparison to the control. Coincidently, the results from Eastfield FNW mirrored those of the ploughed trial at Vicarage FS very closely.

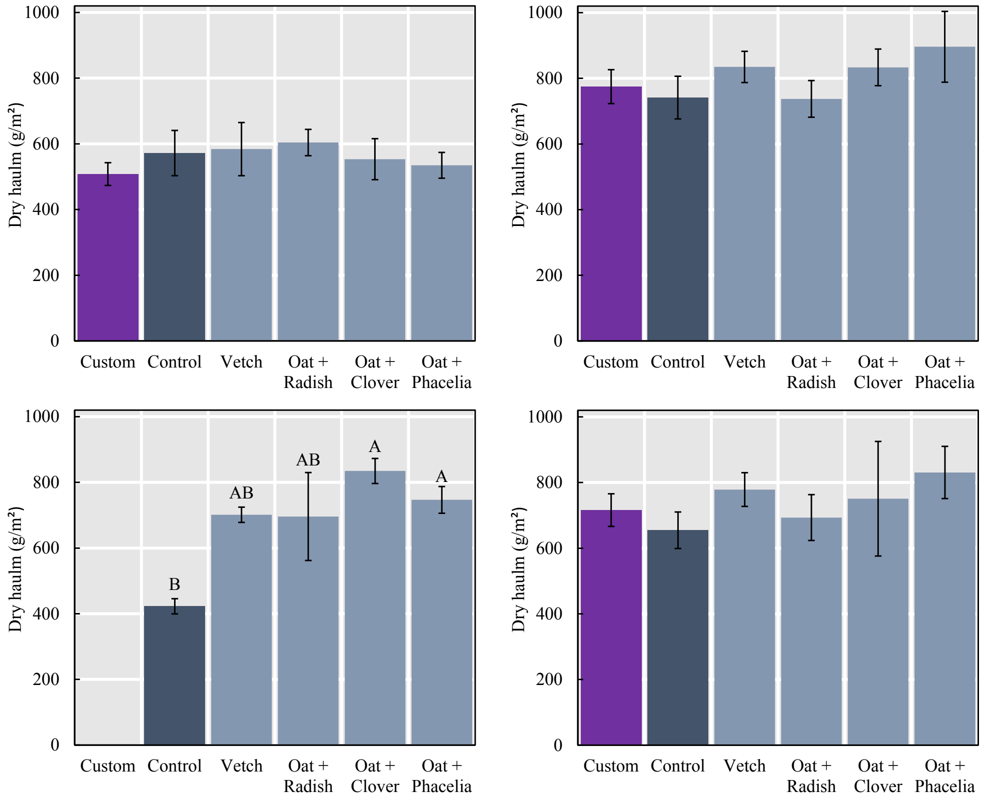

Figure 22: Biomass at vining pea stage (July 2019). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

3.6.3 Yield

No significant impact on yield was observed at Molescroft 29. The treatments that scored higher for foot rot infection yielded higher than the treatments less affected by foot rot. This was most likely due to the soil textural variability discussed in section 3.6.1. Slightly greater moisture retention on heavier soil has probably lifted yield. Oat + Clover and Oat + Phacelia plots had landed by pure coincidence on exclusively sandy loam subsoil whereas other plots had generally more adhesive subsoil.

At Eastfield FNW, yield was significantly lower in the Control treatment compared to Custom, Oat + Radish and Oat + Clover. Cover cropping has improved yield across the board in a field that already yielded well, with yields increasing by as much as 1.5 t/ha. Again, as with Molescroft 29, foot rot did not appear to be implicated in yield reduction although on this occasion the severity of foot rot was very minor.

Treatment effects on yield were not significant in the ploughed trial at Vicarage. That said, the Oat + Phacelia treatment yielded 1.5 t/ha more than the Control on average. Similarly in the shallow disc trial, treatment effects were not statistically significant however the Oat + Clover treatment differed from the Control and Vetch treatments by over a 1 t/ha (+20%). Independent t-tests showed that the Oat + Clover treatment yielded significantly higher than both Control and Vetch treatments in the shallow disc trial.

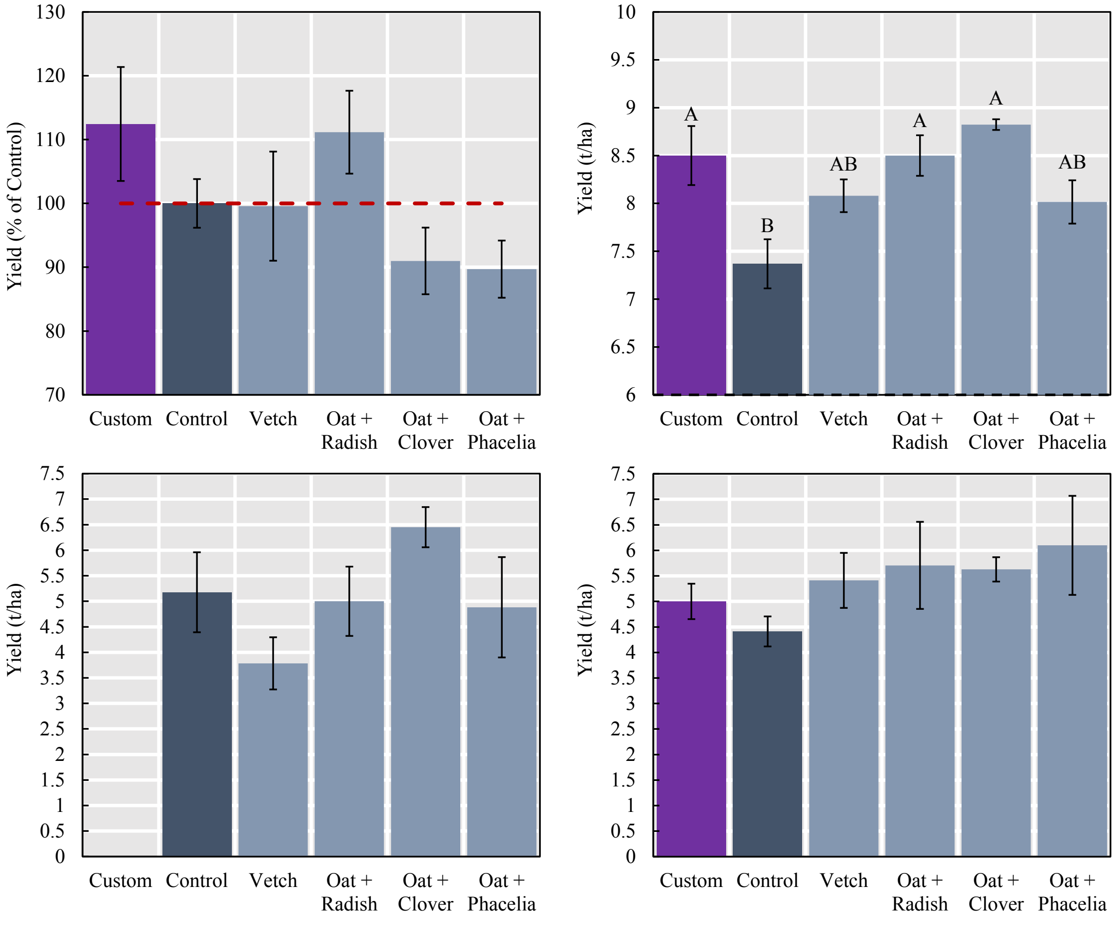

Figure 23: Vining pea yields (July 2019). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

Data on winter wheat development and yield are pending. This document will be updated when the information becomes available.

3.7 Soil health

At the cover crop stage soil structure was not significantly affected by treatment at either Molescroft 29 or Eastfield FNW. At Vicarage FS structure was best in the Control and Oat + Clover treatments. By the vining pea stage, no significant treatment effects were seen. That said, the Control and Oat + Radish treatments consistently showed the higher VESS scores and thus poorer soil structure. The superior structure in the Oat + Clover treatment compared to the Control at Vicarage FS is believed to have been predominantly responsible for greater moisture retention through the season (section 3.8). Eastfield FNW was not assessed at vining pea stage due to ground conditions. Earthworm numbers were assessed at the cover crop stage. No significant treatment effects were noted.

Treatment	Molescroft 29	Eastfield FNW	Vicarage FS
Custom	2.00	1.75	1.69_{b}
Control	1.25	2.5	1.19_{ab}
Vetch	1.50	1.75	1.44_{b}
Oat + Radish	1.13	2.75	1.56_{ab}
Oat + Clover	1.25	2.13	1.06_{a}
Oat + Phacelia	1.25	1.63	1.69_{b}

Table 4: Mean VESS scores at cover crop stage (January 2019). Lower scores denote better structure.

Treatment	Molescroft 29	Vicarage FS	
		shallow disc	*plough*
Custom	2.25	2.50	2.63
Control	2.63	3.25	3.00
Vetch	1.50	3.00	2.38
Oat + Radish	2.75	3.13	2.63
Oat + Clover	2.13	2.50	2.38
Oat + Phacelia	2.38	2.88	2.38

Table 5: Mean VESS scores at vining pea stage (June 2019). Lower scores denote better structure.

Figure 24: Consolidated mass of soil below working depth. Pea forced to grow laterally leaving it vulnerable to drought and foot rot. Molescroft 29 (July 2019).

3.8 Soil moisture

The soil moisture readings from Eastfield FNW covered the period from cover crop destruction until pea harvest in the Control and Oat + Clover treatments. The cover cropped treatments retained slightly more moisture over the whole growing period. The greater retention of moisture in the late spring is believed to have supported greater yield in the Oat + Clover plots compared to the control. Soil moisture in the immediate period after drilling and at the early stages of pod development were positively related to final yield (r^2=0.75 and 0.8 respectively.)

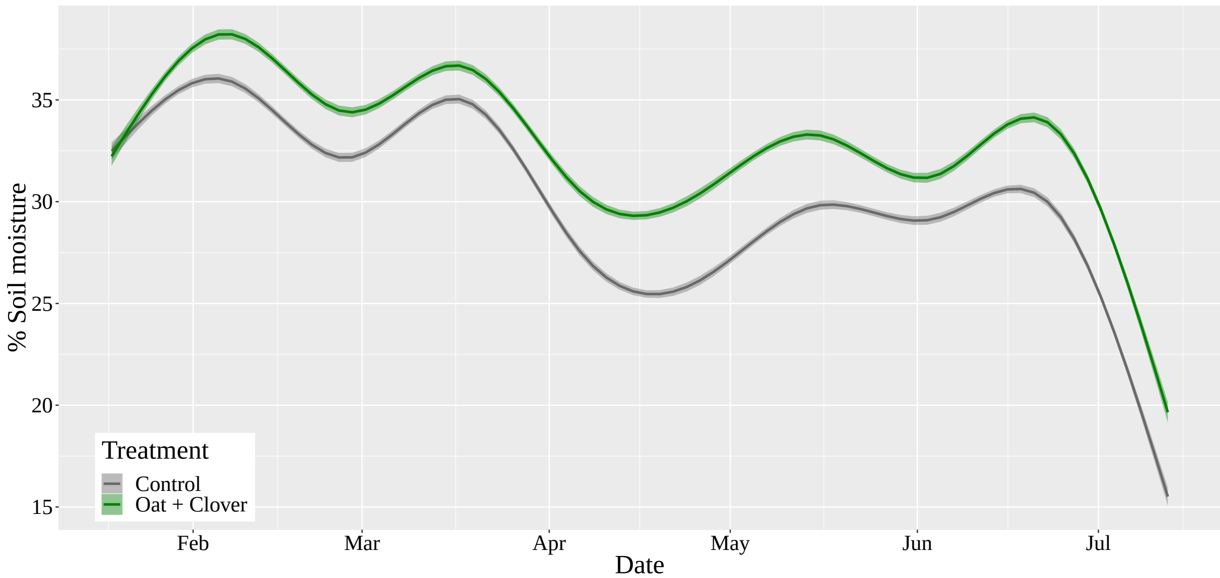

Figure 25: Soil moisture Eastfield FNW.

Soil moisture at Vicarage FS was recorded from shortly after drilling until vining. Comparing Oat + Clover to Control, it was seen that the cover cropped plots held more moisture than the Control plots in the spring. This difference had diminished by the early summer. After prolonged heavy rainfall in mid June, the Control plots had higher soil moisture. This was probably a consequence of either improved drainage in the Oat + Clover treatments or greater transpiration from larger, healthier plants in the cover cropped plots. Shallow disc Control plots held slightly more moisture than ploughed plots in the spring and retained more moisture in the prelude to June. There was no difference in soil moisture between cultivations in the later part of the season. When both cover crop treatment and cultivation are considered interactions can be deciphered. The Oat + Clover treatment had generally retained more moisture in the spring regardless of cultivation, plus the summer drainage/transpiration was improved by the Oat + Clover mix. Soil moisture has responded far more strongly under the Control conditions. The shallow disc Control plots retained greater soil moisture than ploughed Control plots for the entire period. Perhaps the additional soil structuring offered by the cover crop helped to retain moisture even after ploughing. In the dry period after drilling, soil moisture was positively correlated to final yield (r^2=0.45).

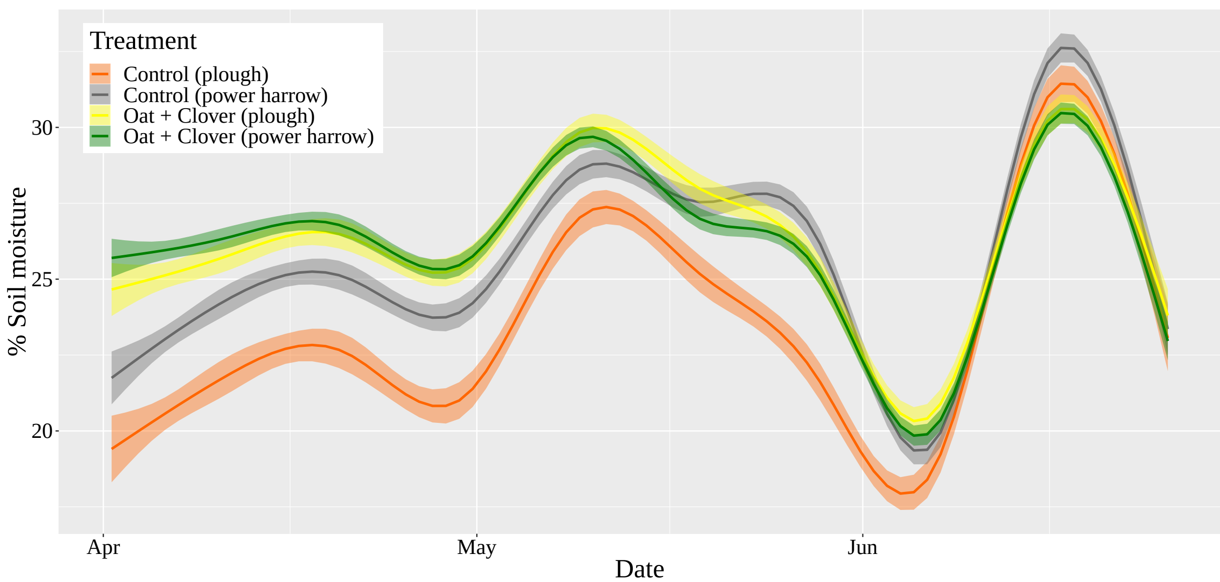

Figure 26: Soil moisture Vicarage FS.

3.9 Compaction

3.9.1 Cover crop

Soil compaction at the cover crop stage was assessed at Eastfield FNW and Vicarage FS. Penetrometer data from Eastfield FNW suggested that Oat + Radish and Custom plots exhibited the greatest soil compaction although this may have partially been the consequence of a field gradient. At Vicarage FS penetrometer readings were lowest in the Control, overall and through-out the soil profile assessed. This was likely due to the drying effect of the cover crops on light land, in an unusual winter dry spell, which increased penetration resistance.

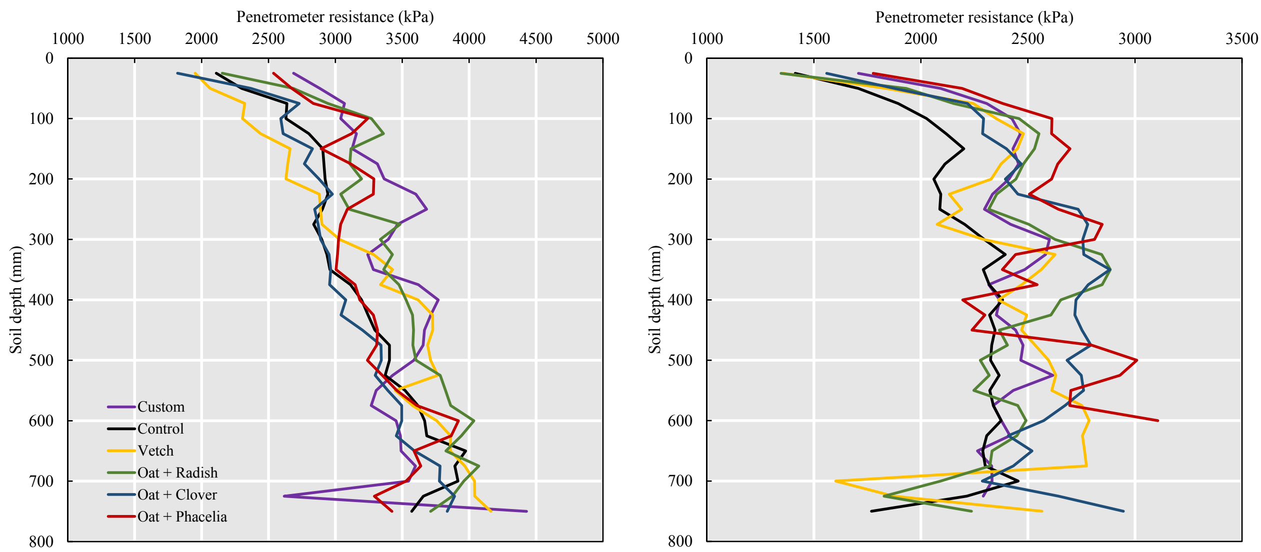

Figure 27: Penetrometer resistance profiles at cover crop stage (January 2019). Eastfield FNW left, Vicarage FS right.

Treatment	Eastfield FNW	Vicarage FS
Custom	3483_{a}	2699_{bc}
Control	3206_{c}	2391_{d}
Vetch	3284_{c}	2739_{c}
Oat + Radish	3492_{a}	2737_{b}
Oat + Clover	3134_{c}	2726_{bc}
Oat + Phacelia	3297_{b}	2977_{a}

Table 6: Least square mean penetrometer resistance (kPa) through 600mm soil profile at Cover crop stage (January 2019).

3.9.2 Vining pea

At Molescroft 29, penetrometer resistance was greatest in the Oat + Clover treatment and lowest in the Control. Oat + Clover and Oat + Phacelia plots had lighter subsoil than other plots which would have retained less moisture, thus becoming dryer and ”stronger” than other plots in the summer which explains the penetrometer resistance differences here. No treatment effects were observed at Eastfield FNW. At Vicarage FS, topsoil penetrometer resistance varied massivly between the shallow disc and ploughed trials. Resistance was much lower in the ploughed trial topsoil. Below plough depth however, the trials resemble one another more closely with the Control treatment having lower penetration resistance than cover cropped treatments. The assessments here were made after very heavy rain making the insertions of the instrument very easy. The lesser structure and transpiration in Control plots combined with the sodden earth offered little resistance to the probe whereas cover cropped treatments did. The penetrometer resistance did therefore not equate to compaction in this instance.

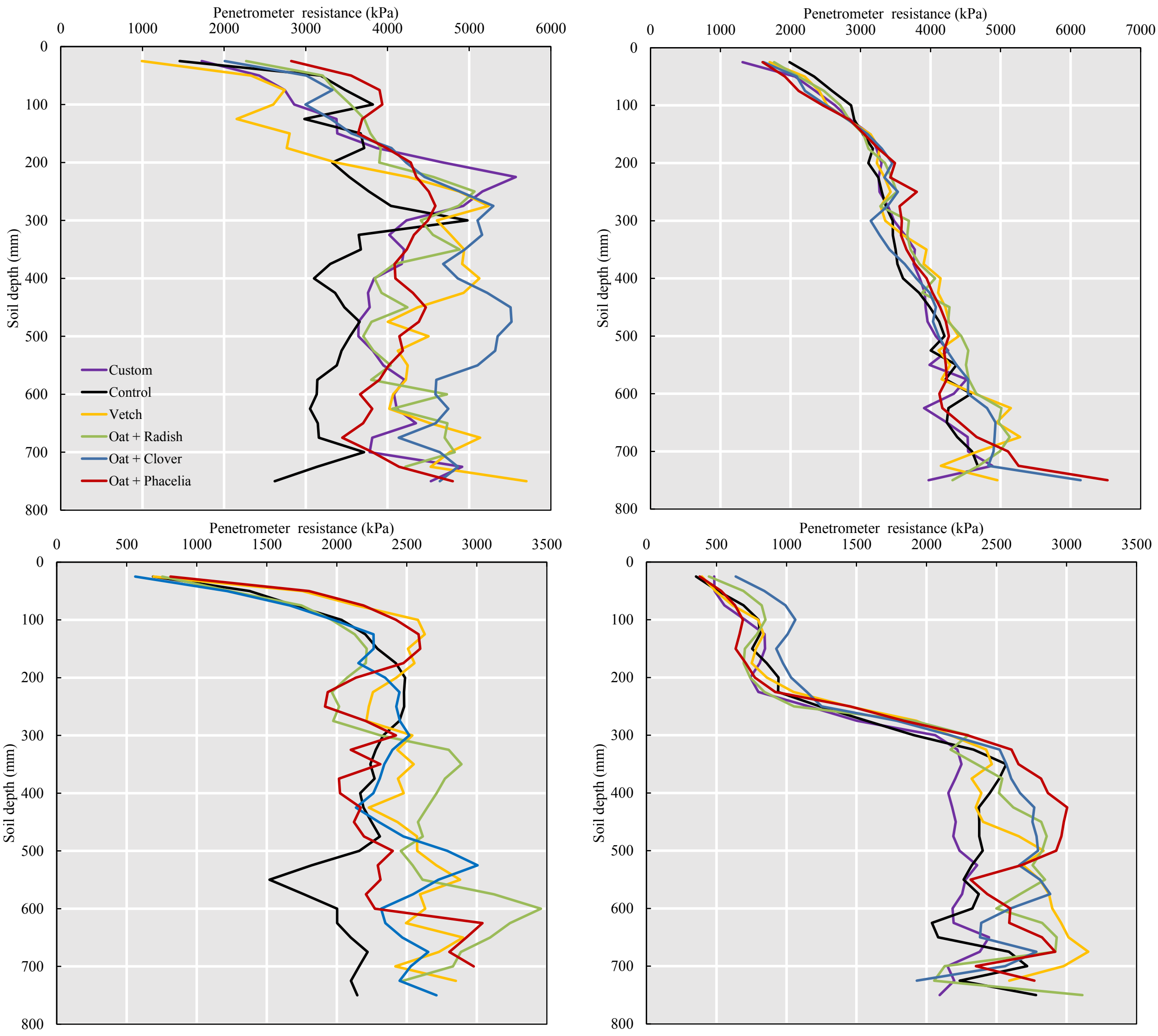

Figure 28: Penetrometer resistance profiles at vining pea stage (June 2019). Molescroft 29, Eastfield FNW, Vicarage FS *shallow disc*, Vicarage FS *plough* (top left to bottom right).

Treatment	Molescroft 29	Eastfield FNW	Vicarage FS *shallow disc*	Vicarage FS *plough*
Custom	3833_{bc}	3542	n/a	1721_{c}
Control	3442_{c}	3565	2080_{b}	1796_{bc}
Vetch	3871_{b}	3700	2377_{a}	1952_{ab}
Oat + Radish	4024_{ab}	3745	2333_{a}	1942_{ab}
Oat + Clover	4333_{a}	3617	2270_{a}	2021_{a}
Oat + Phacelia	4005_{ab}	3634	2249_{a}	1951_{ab}

Table 7: Least square mean penetrometer resistance (kPa) through 600mm soil profile at vining pea stage (June 2019).

4 Conclusions

Nitrogen

Where cover crops were well developed significant quantities of nitrogen were taken up, thus not lost to winter leaching. Cover cropping always resulted in greater system nitrogen retention compared to no cover. SNS was improved by greater production of plant biomass whether it be vining pea or cover/catch crop. Interception of nitrogen was more effective at building SNS than short term fixation by vetch. Phacelia plots contained higher levels of ammonium, as has been observed in previous trials.

Macronutrients

Treatment effects were sparse and patterns of nutrient availability inconsistent. Soil pH often responded to cover cropping but was dependent on site and cultivation. Initial statistical exercises have shown both nutrients and pH to have important implications in yield and haulm production. Progress on those analyses will be presented in final report documents.

Soil organic matter

Cover cropping did not increase soil organic matter at any site from the start to the end of the vining pea season. Treatment effects generally concerned Vetch which often appeared to reduce soil organic matter.

Foot rot

Foot rot development was low at all sites. Oil radish increased the severity and frequency of *Fusarium* infection at one site, as predicted by pre-drilling laboratory tests. The Oat + Clover treatment fared best overall in terms of foot rot development. Statistical analysis has shown that on these occasions foot rot development did impact yield but must be considered alongside other important soil criteria.

Crop health and yield

Cover cropping had no significant effect on emergence. Haulm growth responded massively to cover cropping in one trial, doubling haulm biomass in one instance. Otherwise treatment effects were absent/subtle although haulm biomass was increased by cover cropping in 3 out of 4 trials. Yield responses were mixed. On two occasions, cover cropping did not differ significantly in yield compared to the control. On two other occasions, cover cropping increased yield across all treatments and sometimes quite considerably (+1.5 t/ha). The Oat + Clover treatment stood out as a good candidate for increasing yield. This was demonstrated at three of the four trials and was strongly linked to improved soil water relations.

Soil conditioning

Topsoil structure was improved by cover cropping at all sites, but this could only be observed once the vining pea crop was established. Assessments of soil compaction showed few differences between cover crop mixes but indirectly demonstrated the importance of soil moisture. Soil compaction was also important in the development of foot rot (not discussed in this document). Soil moisture retention was strongly affected by cover cropping. Only one cover crop mix was compared against the control. It was demonstrated that cover cropping retained soil moisture at times of modest water stress which protected yield later on. Also, cover cropping was shown to buffer the negative effect of heavier cultivations on moisture retention.

Agronomy

Establishment of clover in both cover and catch crops was quite successful in these trials compared to previous years. This was achieved by drilling the clover separately at a shallower depth than the other species. Comments were made by growers that the clover was very vulnerable to predation by weevils and phytotoxicity from residual Clomazone. Part of the reason for having a ploughed and shallow disc trial at Vicarage FS was to determine the consequences of lesser trash burial. Comments from the processors were *"no discernible effect on quality or contamination of vining peas"* suggesting that shallow cultivations provided ample trash burial on this occasion. Where cover crops did not accrue much biomass, treatment effects were either absent or the result of variable soil textures at one trial site.

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 mineralisable 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 treatment. 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 100 individual plants per treatment. Each plant was assessed on an ordinal scale ranging from 0 to 5 (no infection to severe root infection). In an exceptional case, the proportion of 100 plants displaying symptoms of *Fusarium* and/or *Didymella* were recorded. Vining pea yield was determined by threshing $8m^2$ plots replicated 3 times per treatment. The estimated yields were extrapolated by equating the mean value of "Custom" plots to the field yield. 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 a digital 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. Soil moisture was recorded using SM150T probes (Delta-t technologies). Due to a limited number of probes the data were only recorded in two treatments but replicated three times. At the cover crop stage at Vicarage FS, replication were performed in duplicate (i.e. three soil cores taken per treatment, but twice over both trial areas thus six in total). Field cultivations, drilling and crop maintenance were conducted by GPC project partners. Details can be found in the diary. Drill specifications are not yet provided.

	Molescroft 29	Eastfield FNW	Vicarage FS
Initial sampling	14/08/18	14/08/18	14/08/18
Cover crop drilled	10/09/18	10/08/18	20/08/18
Destruction	Plough (winter)	Sprayed February	Sprayed January
Cultivation	Power harrow	Light power harrowing	Plough + Shallow disc
Cover crop sampling	17/10/18	16/01/19	15/01/19
Peas drilled	16/05/19	25/04/19	22/03/19
Variety	Plover	Boston	Aloha
Vining pea sampling	25/07/19	12/07/19	25/06/19
Harvest	26/07/19	20/07/19	29/06/19
Catch crop drilled	10/08/19	23/07/19	05/07/19
Catch crop sampling	18/09/19	17/09/19	16/09/19
1st wheats sampling			

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 analysed once 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 interpreted 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). NO_3 - nitrate, NH_4 - ammonium. N=3.

	Molescroft 29			Eastfield FNW			Vicarage FS		
	NO_3	NH_4	SMN	NO_3	NH_4	SMN	NO_3	NH_4	SMN
Pre-CC (0-30cm)									
	46.0	5.1	51.2	51.9	8.2	60.1	35.4	5.9	41.3
Pre-CC (30-60cm)									
	4.4	1.1	5.5	3.8	3.6	7.4	4.8	1.4	6.1
Cover crop (0-30cm)									
Custom	59.2	2.2	61.4	8.5^{b}	3.5	11.9^{ab}	4.2^{b}	3.3	7.5^{b}
Control	34.9	2	36.9	12.4^{ab}	1.5	13.9^{ab}	11.2^{a}	2.4	13.7^{a}
Vetch	43.5	0.5	44	6.8^{b}	0.9	7.7^{b}	7.6^{ab}	2	9.6^{ab}
Oat + Radish	75.8	0.7	76.4	7.9^{b}	1.7	9.6^{ab}	5.3^{ab}	1.9	7.1^{b}
Oat + Clover	58.7	1	59.7	17.6^{a}	2	19.6^{a}	11.0^{a}	3.2	14.2^{a}
Oat + Phacelia	50.8	2.6	53.4	4.7^{b}	2.6	7.3^{b}	6.2^{ab}	3.8	10.0^{ab}
ANOVA									
p-value	0.71	0.28	0.74	0.005	0.66	0.03	0.01	0.18	0.02*
Root MSE	32	1.23	32.7	3.08	1.91	15.4	3.66	1.47	4.06
CoEff.Var	59.4	82.6	59.1	32	94.5	33.7	48.2	53.6	39.3
									*DMRT, α=0.05
Cover crop (30-60cm)									
Custom	6	0	6	2.5^{b}	1.2	3.7^{b}	2.3^{b}	1.4	3.7^{b}
Control	9.6	0.5	10.1	32.0^{a}	0	32.0^{a}	15.4^{a}	0.7	16.1^{a}
Vetch	6.6	0	6.6	6.8^{b}	0	6.8^{b}	6.4^{b}	1	7.4^{b}
Oat + Radish	8.6	0	8.6	0.2^{b}	0	0.2^{b}	3.1^{b}	1.2	4.3^{b}
Oat + Clover	8.5	0.1	8.6	8.7^{b}	0.8	9.5^{b}	2.1^{b}	0.8	2.9^{b}
Oat + Phacelia	8.6	0	8.6	1.0^{b}	0	1.0^{b}	1.7^{b}	1	2.7^{b}
ANOVA									
p-value	0.96	0.54	0.94	<0.001	0.19	<0.001	<0.001	0.85	<0.001
Root MSE	5.42	-	5.36	5.06	-	5.25	3.9	1	4.27
CoEff.Var	68	-	66.3	59.5	-	59.3	75.5	98.8	69.1
Cover crop (60-90cm)									
Control	-	-	-	26.7	0	26.7^{a}	28.7^{a}	1.01	29.7^{a}
Clover	-	-	-	8.17	0.2	8.37^{b}	2.08^{b}	0.62	2.70^{b}
T-test									
p-value	-	-	-	-	-	0.02	<0.001	0.38	<0.001
Student's T	-	-	-	-	-	3.92	7.71	0.92	7.88

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

	Molescroft 29			Eastfield FNW			Vicarage FS					
							Shallow disc			Plough		
	NO_3	NH_4	SMN	NO_3	NH_4	SMN	NO_3	NH_4	SMN	NO_3	NH_4	SMN
Vining pea (0-30cm)												
Custom	13.9	2.9	16.8	17.3	6.0	23.3	-	-	-	10.8	7.2	18.0
Control	14.4	3.6	18.0	11.9	1.9	13.8	7.0	5.2	12.1	9.1	6.3	15.4
Vetch	11.0	2.8	13.8	16.0	2.8	18.8	15.2	6.1	21.3	8.3	10.9	19.2
Oat + Radish	13.0	6.1	19.1	22.3	3.1	25.4	7.2	5.8	13.0	11.3	10.1	21.4
Oat + Clover	12.8	5.6	18.5	21.3	3.6	24.9	11.9	6.3	18.1	7.8	9.7	17.6
Oat + Phacelia	17.5	6.2	23.7	6.3	4.2	10.5	8.7	10.2	18.9	16.1	12.9	29.0
ANOVA												
p-value	0.57	0.09	0.10	0.09	0.60	0.06	0.16	0.25	0.14	0.14	0.42	0.20
Root MSE	4.0	1.9	3.7	7.5	2.4	6.0	4.5	4.0	6.5	4.0	4.0	6.6
CoEff.Var	29.2	42.6	20.4	47.3	68.0	30.9	41.7	52.2	35.3	37.9	42.4	32.9
Vining pea (30-60cm)												
Custom	22.9	0.0	22.9	11.9	0.4	12.3^{ab}	-	-	-	7.9	1.5	9.4
Control	22.3	0.0	22.3	23.2	0.4	23.6^{a}	14.5	0.3	14.8	7.1	0.8	7.9
Vetch	14.0	0.0	14.0	11.8	0.0	11.8^{ab}	16.8	0.8	17.6	22.6	3.4	26.0
Oat + Radish	21.5	0.0	21.5	10.0	0.5	10.5^{ab}	7.8	0.3	8.1	5.5	2.6	8.1
Oat + Clover	16.1	0.0	16.1	20.9	0.0	20.9^{ab}	14.0	0.1	14.1	6.1	0.5	6.5
Oat + Phacelia	14.6	0.0	14.6	3.0	0.4	3.4^{b}	11.7	2.7	14.4	5.4	0.2	5.7
ANOVA												
p-value	0.37	-	0.37	0.06	0.56	0.05	0.23	0.50	0.45	0.55	0.65	0.51
Root MSE	6.45	-	6.45	7.11	0.48	7.16	5.77	1.99	6.79	11.4	2.66	13.8
CoEff.Var	34.7	-	34.7	52.8	153	52	49.3	181	53	124	176	130.1
Catch crop (0-30cm)												
Control	81.3^{a}	4.8	86.2^{a}	96.57^{ab}	3.3	99.8^{ab}	50.1^{ab}	1.2^{b}	51.3^{abc}	67.4^{ab}	2.6^{ab}	70.0^{ab}
Vetch	66.9^{ab}	6.2	73.1^{abc}	85.4^{abc}	2.4	87.8^{abc}	61.1^{a}	1.1^{b}	62.1^{a}	75.8^{a}	4.6^{a}	80.4^{a}
Oat + Radish	66.9^{ab}	7.8	74.6^{ab}	69.9^{abcde}	2.2	72.2^{abcd}	61.0^{a}	0.9^{b}	61.8^{ab}	60.3^{abc}	3.1^{ab}	63.4^{abc}
Oat + Clover	70.6^{ab}	7.9	78.5^{ab}	69.0^{abcde}	2.2	71.3^{abcd}	44.8^{bcd}	1.1^{b}	45.9^{abcde}	71.9^{ab}	2.3^{ab}	74.3^{ab}
Oat + Phacelia	71.1^{ab}	6.6	77.7^{ab}	101.2^{a}	8.4	109.6^{a}	62.4^{a}	7.4^{a}	69.8^{a}	65.8^{ab}	2.6^{ab}	68.4^{ab}
Post Control	65.7^{ab}	5.1	70.8^{abc}	95.4^{ab}	2.0	97.4^{ab}	49.4^{bcd}	0.7^{b}	50.1^{abcd}	57.9^{abcd}	3.0^{ab}	60.9^{abcde}
Post Radish	15.8^{d}	6.1	22.0^{d}	30.3^{cde}	2.4	32.7^{cd}	17.5^{cd}	2.3^{b}	19.8^{cde}	11.5^{de}	2.8^{ab}	14.4^{ef}
Post Buckwheat	45.8^{abcd}	6.2	51.9^{abcd}	21.4^{de}	2.6	23.9^{d}	26.6^{bcd}	1.2^{b}	27.8^{bcde}	25.6^{bcde}	3.8^{ab}	29.3^{bcdef}
Post Clover	35.5^{bcd}	4.3	39.8^{bcd}	39.4^{bcde}	3.1	42.5^{bcd}	25.0^{bcd}	3.0^{b}	28.0^{bcde}	10.1^{de}	3.6^{ab}	13.7^{ef}
Control:Control	64.6^{ab}	3.8	68.5^{abc}	81.0^{cde}	2.1	83.0^{abcd}	59.2^{a}	0.9^{b}	60.1^{ab}	60.8^{abc}	0.9^{b}	61.7^{abcd}
Radish:Radish	27.1^{cd}	4.2	31.3^{cd}	18.6^{e}	4.6	23.2^{d}	13.1^{d}	3.4^{b}	16.5^{de}	14.2^{cde}	1.6^{ab}	15.8^{def}
Phacelia:Buckwht	53.7^{abc}	2.2	55.8^{abcd}	37.4^{bcde}	3.5	40.9^{bcd}	36.9^{abcd}	1.5^{b}	38.4^{abcde}	14.1^{cde}	2.3^{ab}	16.4^{cdef}
Clover:Clover	59.5^{abc}	2.0	61.5^{abcd}	31.1^{cde}	5.2	36.3^{bcd}	14.2^{d}	0.9^{b}	15.1^{e}	7.8^{e}	3.9^{ab}	11.7^{f}
ANOVA												
p-value	<0.001	0.38	<0.001	<0.001*	0.15*	<0.001*	<0.001	0.03*	<0.001	<0.001*	0.03*	<0.001*
Root MSE	12.5	3.07	14.3	20.2	2.39	21.5	10.8	2.56	11.5	16.3	1.09	15.9
CoEff.Var	22.4	59.3	23.4	33.7	70.7	34.1	27	130	27.3	38.9	38.2	35.7

**Welche's ANOVA*

Mean soil nitrogen supply (SNS) (kg/ha), soil organic matter and pH. N=3.

	Molescroft 29			Eastfield FNW			Vicarage FS		
	SNS	OM %	pH	SNS	OM %	pH	SNS	OM %	pH
Pre-CC									
		-	-		4.2	5.5		2.8	6.5
Cover crop									
Custom	95	2.9	6.0^{b}	98.9^{ab}	4.2^{a}	6.6^{ab}	71.9^{bc}	3.0^{a}	6.8^{ab}
Control	55.6	4.5	6.9^{a}	70.3^{b}	3.8^{ab}	5.9^{b}	48.1^{c}	3.0^{ab}	6.9^{a}
Vetch	67.8	3.5	6.4^{ab}	60.0^{b}	3.6^{b}	6.7^{a}	112.0^{a}	2.7^{b}	6.5^{b}
Oat + Radish	123.9	4.2	6.4^{ab}	106.7^{ab}	3.8^{ab}	6.4^{ab}	77.1^{bc}	2.8^{ab}	6.8^{ab}
Oat + Clover	85.3	3.9	6.5^{ab}	135.2^{a}	3.9^{ab}	6.2^{ab}	120.2^{a}	2.8^{ab}	6.8^{ab}
Oat + Phacelia	86.3	3.7	6.4^{ab}	97.8^{ab}	3.8^{ab}	6.3^{ab}	90.8^{ab}	2.8^{ab}	6.6^{ab}
ANOVA									
p-value	-	0.13	0.04	0.007	0.02	0.03	<0.001	0.07	0.07
Root MSE	40.2	0.64	0.26	18.6	0.15	0.27	19.3	0.2	0.25
CoEff.Var	46.9	17	3.99	19.6	3.84	4.28	22.2	6.99	3.68
Kruskal-Wallis									
χ^2	6.57	-	-	-	-	-	-	-	-
p-value	0.25	-	-	-	-	-	-	-	-

Mean soil nitrogen supply (SNS) (kg/ha), soil organic matter and pH. N=3.

	Molescroft 29			Eastfield FNW			Vicarage FS					
							Shallow disc			Plough		
	SNS	OM %	pH	SNS	OM %	pH	SNS	OM %	pH	SNS	OM %	pH
Vining pea												
Custom	148.3	3.0	5.9	160.2	4.5	6.1^{a}	-	-	-	182.0	2.6^{a}	7.4^{a}
Control	150.0	4.4	6.6	162.0	4.0	5.5^{b}	87.9^{b}	2.8^{a}	6.9	155.4	2.5^{ab}	7.4^{a}
Vetch	143.3	3.0	6.0	149.2	4.0	5.9^{ab}	162.9^{ab}	2.4^{b}	7.0	213.0	2.4^{ab}	7.1^{b}
Oat + Radish	144.6	4.0	6.3	149.0	4.1	5.8^{ab}	161.8^{ab}	2.5^{ab}	6.8	173.4	2.3^{b}	7.0^{b}
Oat + Clover	157.4	3.3	6.1	172.2	3.9	5.5^{b}	197.7^{a}	2.7^{ab}	6.7	209.6	2.4^{ab}	7.1^{ab}
Oat + Phacelia	156.8	3.6	6.1	141.0	4.0	5.9^{ab}	184.7^{a}	2.6^{ab}	6.8	216.0	2.6^{a}	6.9^{b}
ANOVA												
p-value	0.97	0.11	0.39	0.81	0.24	0.04	0.01	0.02	0.19	0.08	0.03	<0.001
Root MSE	25.8	0.65	0.4	29	0.28	0.23	29.2	0.14	0.29	26.4	0.11	0.1
CoEff.Var	17.2	18.2	6.49	18.6	6.82	3.93	18	5.4	4.16	13.8	4.47	1.44
Catch crop												
Control	86.2	-	-	99.8^{abc}	-	-	51.3^{ab}	-	-	70.0^{b}	-	-
Vetch	73.1	-	-	87.8^{abc}	-	-	62.1^{ab}	-	-	80.4^{ab}	-	-
Oat + Radish	74.6	-	-	72.2^{c}	-	-	61.8^{ab}	-	-	63.4^{b}	-	-
Oat + Clover	78.5	-	-	71.3^{c}	-	-	45.9^{ab}	-	-	74.3^{b}	-	-
Oat + Phacelia	77.7	-	-	109.6^{abc}	-	-	69.8^{ab}	-	-	68.4^{b}	-	-
Post Control	70.8	-	-	97.4^{abc}	-	-	50.1^{ab}	-	-	60.9^{b}	-	-
Post Radish	53.7	-	-	116.7^{abc}	-	-	48.1^{ab}	-	-	138.9^{a}	-	-
Post Buckwheat	63.1	-	-	74.7^{bc}	-	-	37.4^{b}	-	-	78.8^{b}	-	-
Post Clover	58.7	-	-	93.3^{abc}	-	-	84.7^{a}	-	-	73.3^{b}	-	-
Control:Control	68.5	-	-	83.0^{abc}	-	-	60.1^{ab}	-	-	61.7^{b}	-	-
Radish:Radish	54.5	-	-	126.6^{a}	-	-	80.6^{a}	-	-	119.7^{ab}	-	-
Phacelia:Buckwht	56.9	-	-	114.0^{abc}	-	-	57.6^{ab}	-	-	93.8^{ab}	-	-
Clover:Clover	68.3	-	-	119.1^{abc}	-	-	60.1^{ab}	-	-	78.5^{b}	-	-
ANOVA												
p-value	0.2	-	-	<0.001*	-	-	0.02	-	-	0.002	-	-
Root MSE	14.5	-	-	23.4	-	-	14.4	-	-	20.3	-	-
CoEff.Var	21.2	-	-	24	-	-	24.3	-	-	24.8	-	-

**Welche's ANOVA*

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

	Molescroft 29			Eastfield FNW			Vicarage FS		
	P	K	Mg	P	K	Mg	P	K	Mg
Pre-CC									
	-	-	-	28.4	211	105.5	19.3	128.2	156.2
Cover crop									
Custom	6.7^{b}	83.0	31.3	25.6	213.5	139.0^{a}	16.5	121.2^{ab}	196.8
Control	9.3^{a}	96.7	39.0	23.4	191.2	91.6^{b}	16.2	129.3^{a}	201.3
Vetch	9.3^{a}	88.0	28.3	25.8	220.0	117.2^{ab}	15.7	104.0^{ab}	163.5
Oat + Radish	9.3^{a}	100.0	32.3	27.9	168.0	127.0^{a}	15.5	103.0^{ab}	170.8
Oat + Clover	8.7^{ab}	79.0	27.0	25.0	191.3	94.5^{b}	14.3	118.8^{ab}	175.0
Oat + Phacelia	9.7^{a}	74.3	26.7	17.9	145.5	121.3^{ab}	15.3	96.8^{b}	167.0
ANOVA									
p-value	0.057	0.24	0.57	0.62	0.12	0.002	0.74	0.07*	0.1
Root MSE	1.08	13.6	8.91	6.95	32	10.7	2.48	20.4	27.4
CoEff.Var	12.2	15.7	29	28.6	17	9.31	15.9	18.2	15.3
								α =0.1	

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

	Molescroft 29			Eastfield FNW			Vicarage FS					
							Shallow disc			Plough		
	P	K	Mg	P	K	Mg	P	K	Mg	P	K	Mg
Vining pea												
Custom	41.2^{b}	93.5^{b}	31.0	44.2	336.1^{a}	114.4	-	-	-	14.5	72.4^{a}	243^{a}
Control	63.3^{a}	150.8^{a}	53.4	30.5	208.3^{b}	92.5	17.6	100.8	201.7	16.1	63.9^{ab}	212^{b}
Vetch	48.5^{ab}	87.0^{b}	30.8	41.0	254.0^{b}	116.2	20.7	80.1	216.6	16.9	54.0^{b}	161^{d}
Oat + Radish	50.9^{ab}	114.5^{ab}	41.4	52.0	275.9^{ab}	111.6	22.0	99.3	211.0	16.9	63.9^{ab}	170^{cd}
Oat + Clover	44.2^{ab}	73.1^{b}	25.3	42.8	270.9^{ab}	90.9	21.0	106.7	181.7	15.3	55.8^{ab}	195^{bc}
Oat + Phacelia	46.9^{ab}	69.0^{b}	31.3	38.4	285.3^{ab}	116.2	21.3	92.5	196.7	18.6	69.6^{ab}	184^{cd}
ANOVA												
p-value	0.01*	<0.001	0.19	0.21	0.005	0.16	0.08	0.18	0.72	0.85	0.03*	<0.001
Root MSE	8.61	16.8	13.2	9.36	29.5	14.8	2.57	25.4	33.1	3.98	13	9.7
CoEff.Var	17.5	17.2	37.2	22.6	10.8	13.8	13.5	28.7	16.2	24.3	20.6	4.99
											**Welche's ANOVA*	

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

	Molescroft 29			Eastfield FNW			Vicarage FS		
	Fus.	*Didy.*	Total	*Fus.*	*Didy.*	Total	*Fus.*	*Didy.*	Total
Pre-CC									
	1.8	8.0	9.8	2.0	8.6	10.6	1.6	7.9	9.5
Cover crop									
Custom	0.3	14.3	14.5	14.8	6.5	21.3	4	6.8	10.8
Control	0.8	8.5	9.3	0.8	0	0.8	3.3	5.5	8.8
Vetch	1.5	8	9.5	2.3	0.8	3	3.3	4.1	7.4
Oat + Radish	1.5	14	15.5	44.8*	2.5	47.3*	4	6	10
Oat + Clover	1	5	6	7.8	1	8.8	2	7.1	9.1
Oat + Phacelia	1	7	8	4.3	5	9.3	2.5	5.6	8.1
ANOVA									
p-value	-	0.2	0.2	-	-	-	0.47	0.82	0.88
Root MSE	1.13	5.87	5.78	23.9	4.15	24.1	2.34	4.56	5.95
CoEff.Var	113	62.1	55.3	192	158	160	73.8	78	66
Kruskal-Wallis									
χ^2	5.08	-	-	16.8	10.5	16.7	-	-	-
p-value	0.41	-	-	*0.005	0.06	*0.005	-	-	-

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

	Molescroft 29			Eastfield FNW			Vicarage FS					
							Shallow disc			Plough		
	Fus.	*Didy.*	Total	*Fus.*	*Didy.*	Total	*Fus.*	*Didy.*	Total	*Fus.*	*Didy.*	Total
Vining pea												
Custom	3.3	40.8	44.0	4.5	9.0	13.5	-	-	-	4.75	121	126^{ab}
Control	1.5	56.3	57.8	2.5	1.3	3.8	0.0	17.3	17.3	6.5	124	131^{ab}
Vetch	6.0	104.3	110.3	5.3	2.0	7.3	2.7	6.0	8.8	4.5	68.25	73^{b}
Oat + Radish	5.8	60.0	65.8	4.3	5.3	9.5	3.7	8.5	12.3	0.25	82.5	83^{b}
Oat + Clover	3.0	76.5	79.5	6.5	1.5	8.0	1.0	12.5	13.5	5	146.75	152^{a}
Oat + Phacelia	3.8	91.8	95.5	3.3	1.0	4.3	1.7	12.0	13.8	2.25	143.25	146^{ab}
ANOVA												
p-value	0.59	0.44	0.98	0.81	0.11	0.19	0.34	0.14	0.40	0.52	0.06	0.04
Root MSE	4.0	47.5	46.4	4.3	4.4	5.5	2.4	8.6	6.12	4.8	39.2	39.2
CoEff.Var	102.0	66.4	61.2	97.8	132.0	71.9	129.0	58.9	45.1	123.0	34.3	33.2
Catch crop												
Control	3.5	747.0	750.5	1.5^{b}	0.0	1.5^{b}	5.0	258.3	263.3	17.8	589^{ab}	607^{ab}
Vetch	1.0	466.0	467.0	2.3^{b}	1.5	3.8^{b}	5.8	169.5	175.3	29.8	785^{a}	815^{a}
Oat + Radish	0.5	510.5	511.0	9.8^{ab}	0.0	9.8^{ab}	2.3	191.8	194.0	19.3	580^{abc}	599^{abc}
Oat + Clover	1.5	367.5	369.0	4.3^{ab}	0.3	4.5^{ab}	1.5	290.3	291.8	28.5	488^{abc}	517^{abc}
Oat + Phacelia	2.0	280.5	282.5	2.3^{b}	0.0	2.3^{b}	4.8	319.8	324.5	43.3	509^{abc}	552^{abc}
Post Control	4.8	361.5	366.3	7.8^{ab}	0.3	8^{ab}	11.3	218.3	229.5	62.3	466^{ab}	527^{ab}
Post Radish	5.5	327.5	333.0	5.3^{ab}	0.0	5.3^{ab}	15.8	125.0	140.8	29.5	69^{c}	98^{c}
Post Buckwheat	1.0	342.5	343.5	5.3^{ab}	0.0	5.3^{ab}	6.5	259.3	265.8	16.3	125^{c}	141^{c}
Post Clover	2.8	105.5	108.3	6.8^{ab}	0.0	6.8^{ab}	10.3	464.0	474.3	52.5	251^{bc}	303^{bc}
Control:Control	3.0	520.3	637.9	9.3^{ab}	0.3	9.6^{ab}	7.1	225.0	232.1	51.6	462^{abc}	514^{abc}
Radish:Radish	6.3	297.8	304.0	28^{a}	0.0	28^{a}	5.0	132.3	137.3	33.5	259^{bc}	292^{bc}
Phacelia:Buckwht	3.3	428.8	432.0	4.5^{ab}	0.3	4.8^{ab}	4.5	132.5	137.0	27.3	149^{bc}	176^{bc}
Clover:Clover	1.5	466.8	468.3	8.8^{ab}	1.0	9.8^{ab}	4.3	181.5	185.8	31.5	251^{bc}	283^{bc}
ANOVA												
p-value	-	-	-	-	-	-	-	-	-	-	-	-
Root MSE	3.6	274.0	273.8	11.9	1.0	11.9	8.5	188.3	188.2	37.5	316.1	316.3
CoEff.Var	128.2	69.9	69.4	166.2	363.0	160.2	133.6	82.4	80.1	115.2	83.9	77.3
Kruskal wallis												
χ^2	12.0	14.3	14.2	22.2	11.3	20.0	8.6	10.4	10.4	5.0	23.3	23.6
p-value	0.4	0.2	0.2	0.0	0.4	0.0	0.7	0.5	0.5	0.9	0.0	0.0

Foot rot development in field. Mean foot rot severity score (0-5, where 0=none, 5=severe) applicable to Molescroft 29 and Vicarage FS. % of plants showing foot rot symptoms at Eastfield FNW. N=100.

	Molescroft 29	Eastfield FNW		Vicarage FS		
		Fusarium	*Didymella*	S. disc	Plough	Total
Custom	1.55	41.7[ab]	76[a]		2.19[a]	1.94[b]
Control	1.75*	16.7[b]	8.3[c]	2.56[a]	1.46[b]	2.01[b]
Vetch	1.59*	28.2[ab]	34.4[b]	1.88[b]	1.30[b]	1.59[a]
Oat + Radish	1.79*	57.3[a]	31.3[b]	2.03[b]	1.53[b]	1.83[ab]
Oat + Clover	1.38	11.4[b]	6.3[c]	2.01[b]	1.51[b]	1.76[ab]
Oat + Phacelia	1.34	24[ab]	16.7[bc]	2.15[a]	1.35[b]	1.81[ab]
Kruskal wallis						
χ^2	10.8	-	-	80.3	92.5	20.7
p-value	0.056	-	-	<0.001	<0.001	<0.001
χ^2 independance of fit						
χ^2	47.7	-	-	33	75.6	66.3
p-value	0.004	-	-	<0.001	<0.001	<0.001
GLM	*Significanty higher incidences of severe infection					
Wald χ^2	-	16.8	116	-	-	-
p-value	-	0.005	<0.001	-	-	-

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

	Molescroft 29	Eastfield FNW	Vicarage FS		
			S.disc	Plough	Total
Emergence					
Custom	94	84	101	95	-
Control	104	92	96	98	-
Vetch	96	89	110	107	-
Oat + Radish	103	84	107	109	-
Oat + Clover	99	92	99	95	-
Oat + Phacelia	100	83	107	105	-
ANOVA					
p-value	0.088*	0.568	0.430	0.220	-
Root MSE	8.42	13.80	10.60	9.87	-
CoEff.Var	8.47	15.90	10.30	9.74	-
			Welche's ANOVA		
Haulm biomass					
Custom	508	775	677[ab]	716	697[ab]
Control	572	741	423[b]	655	539[b]
Vetch	584	835	701[ab]	779	740[ab]
Oat + Radish	604	737	696[ab]	693	695[ab]
Oat + Clover	553	833	835[a]	751	793[a]
Oat + Phacelia	535	896	747[a]	831	789[a]
ANOVA					
p-value	0.859	0.531	0.018	0.711	0.038
Root MSE	98.8	116.0	115	157	137
CoEff.Var	17.7	14.5	16.9	21.3	19.3
Yield					
Custom	112.4	8.5[a]	5.69	4.31	5.00
Control	100.0	7.37[b]	5.18	4.41	4.79[b]
Vetch	99.6	8.08[ab]	3.78	5.41	4.60[b]
Oat + Radish	111.2	8.5[a]	5.00	5.71	5.35
Oat + Clover	91.0	8.82[a]	6.45	5.63	6.04[a]
Oat + Phacelia	89.7	8.02[ab]	4.88	6.10	5.49
ANOVA					
p-value	0.126	0.008	0.183	0.278	0.322*
Root MSE	11.3	0.38	1.14	1.05	1.16
CoEff.Var	11.3	4.63	22.1	20.0	22.3
			* independant t-tests		

Mean structural quality scores (SQ) and worm counts. N=4 or 8 (Vicarage FS).

	Molescroft 29		Eastfield FNW		Vicarage FS	
	SQ	Worms	SQ	Worms	SQ	Worms
Cover crop						
Custom	2	0.8	1.8	4.8	1.7[b]	2.6[a]
Control	1.3	0.8	2.5	1.5	1.2[ab]	0.4[b]
Vetch	1.5	0	1.8	2.3	1.4[b]	1.1[b]
Oat + Radish	1.1	0.8	2.8	3.5	1.6[ab]	1.1[b]
Oat + Clover	1.3	1	2.1	1.8	1.1[a]	0.9[b]
Oat + Phacelia	1.3	1	1.6	0.5	1.7[b]	0.8[b]
ANOVA						
p-value	-	0.7	-	0.13*	-	<0.001
Root MSE	-	0.97	-	1.39	-	0.97
CoEff.Var	-	134	-	81.4	-	82.3
χ^2 Independence of fit					**Welches ANOVA*	
χ^2	22.1	-	20.9	-	35.5	-
p-value	0.11	-	0.14	-	0.002	-

Mean structural quality scores (SQ). N=4.

	Molescroft 29	Vicarage FS	
		Shallow disc	Plough
Vining pea			
Custom	2.25	2.5	2.63
Control	2.63	3.25	3
Vetch	1.5	3	2.38
Oat + Radish	2.75	3.13	2.63
Oat + Clover	2.13	2.5	2.38
Oat + Phacelia	2.38	2.88	2.38
χ^2 Independence of fit			
χ^2	28.3	21.3	8.5
p-value	0.103	0.13	0.9