INNOVATIVE FARMERS
PART OF THE DUCHY FUTURE FARMING PROGRAMME

THE PRINCE OF WALES'S CHARITABLE FUND

ADAS

Field lab: Management Practices to Increase Deep Burrowing Earthworm Numbers, Crop Rooting Depth and Yields

Final report

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1 Field lab aims

The aim of the Deeper Rooting Field Lab was to test the effect of soil management practices on boosting deep burrowing earthworm populations and whether this could improve soil health and crop rooting depth, therefore promoting higher crop yields.

2 Background

Deep burrowing earthworms have beneficial effects on soil structure and nutrient cycling however the number of earthworms in arable soils is thought to be below historic and potential levels. Restricted rooting depth is suspected to be a major limitation to current crop yields, particularly linked to a crop's ability to access water. Cereal and oilseed rape roots are not able to penetrate through strong soils and instead exploit pre-existing cracks, fissures and channels. These could have been created by previous crop roots, mechanical loosening or earthworms.

The Deeper Rooting Field Lab involves three farmers who have each set up a tramline trial on farm to test the effects of different soil cultivation methods and in some cases farmyard manure (FYM) additions, on soil properties and earthworm numbers. The trials were established in autumn 2018 and have run for two years. Research over the 2018/2019 season was funded by EIP-AGRI as part of a Yield Enhancement Network Yield Testing Farm Innovation Group. In 2019/2020 the group became an Innovative Farmers Field Lab and work over the 2020 growing season has been funded by Innovative Farmers.

This report summaries results from the 2020 growing season.

The following farms took part in the field lab:

Trial	Farm	Location	Trial Summary	2020 Crop	Soil Type
1	A	Shropshire	Cultivation + FYM	OSR	Sandy Clay Loam
2	B	Leamington Spa	Cultivation	Spring Beans	Heavy Clay
3 & 4	C	Nottinghamshire	Cultivation	OSR & Spring Barley	Silty Clay Loam

Trial 2 was on the AHDB Strategic Cereal Farm and most of the assessments were undertaken as part of the on-going work with AHDB at this site.

3 Methodology and data collection

3.1 Data collection

Over the course of the year the following measurements have been recorded to monitor effects of treatments on earthworm populations, soil structural properties, soil chemistry, crop rooting and yield:

Earthworm counts: Earthworm counts were made in the spring by excavating replicate 20 cm long x 20 cm wide x 25 cm deep blocks of soil (0.01 m3 volume) and extracting all earthworms. Adult earthworms (individuals with a developed saddle) were classified into the following ecotypes: anecic, endogeic and epigeic.

- Epigeic earthworms live on the surface of the soil in leaf litter. These species tend not to make burrows but live in and feed on the leaf litter.
- Endogeic earthworms live in and feed on the soil. They make horizontal burrows through the soil to move around and to feed and they will reuse these burrows to a certain extent.
- Anecic (deep burrowing) earthworms make permanent vertical burrows in soil to depths of up to 2 m. They feed on decomposing plant material at the soil surface and are the largest species of earthworms in the UK.

Juvenile earthworm numbers were recorded but not classified into ecotypes due to the difficulty of identifying the ecotype of juvenile earthworms based on physiology. Further details of the earthworm count methodology is available at https://ahdb.org.uk/knowledge-library/how-to-count-earthworms.

Midden counts: Middens are small piles of earthworm casts and decomposing plant material, deposited at the entrance of anecic earthworm burrows and thus provide a useful indication of the number of anecic earthworms. At the same time as earthworm sampling, earthworm midden numbers were counted within a 1 m2 quadrat placed on the soil surface at replicate positions per treatment area.

VESS topsoil sampling: Topsoil structure was assessed using the visual evaluation of topsoil structure (VESS) scoring system which provides an estimate of soil structural condition and visual porosity. The lowest score (1) is given to the least compact and most porous soil condition. In contrast, the highest score (5) is given to very compacted soil with large aggregates and low visible porosity. VESS assessments were used to score the structure of the replicate 20 cm long x 20 cm wide x 25 cm deep blocks of soil per treatment used for assessing earthworm numbers (VESS block score). In some trials, distinct layers in soil structural condition were identified, and both the average score for the whole block of soil was recorded, as well as the score for the 'limiting layer' score i.e. the maximum score recorded.

See http://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure for further details of the VESS assessment method.

Soil chemistry analysis: Representative soil samples were collected at 0-15 cm depth and analysed for pH, extractable P, K & Mg, Organic matter (by loss on ignition -LOI) and CO_2 soil respiration.

Soil strength assessment: Soil strength (penetration resistance) was measured through the soil profile (to 60 + cm depth) using a penetrologger to provide a measure of soil compaction. Penetration resistance values of 0.5-1.25 MPa are considered optimal for root growth. Values of 1.25-2.0 MPa indicate a firm/partly compacted soil and values of greater than 2.0 MPa indicate compacted soil in which root development is likely to be impaired. Values of less than 0.5 MPa show the soil is loose.

Soil profile and rooting crop rooting depth observations: The soil profile was examined by digging soil pits to a depth of 1 m. Observations of crop rooting depth were made including maximum rooting depth and root spread and evidence of roots proliferating in earthworm burrows at depth was recorded when observed.

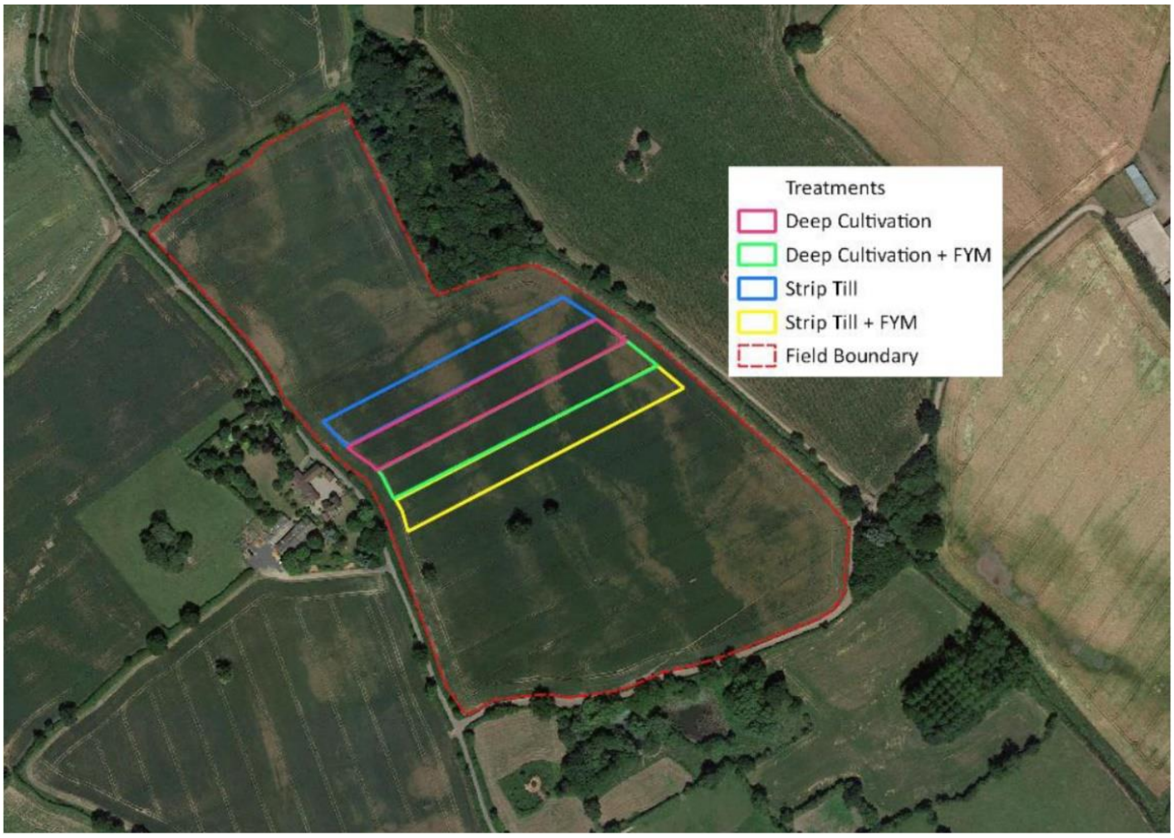
NDVI observations: The impact of the treatments on normalized difference vegetation index (NDVI) of the crop, was monitored through the season using satellite images. NDVI is a spectral reflectance index which shows a combination of canopy size and greenness, on a scale from 0 to 1. NDVI images are useful for monitoring crop performance over the growing season as they show spatial differences in the crop performance which may be due to treatments or underlying variation within the field. NDVI images are freely sourced from Data Farming (http://www.datafarming.com.au).

Yield analysis: The ADAS agronomics yield analysis methodology was used to compare the effect of treatments of on crop yield and test for the statistical significance of effects. First the combine yield data was cleaned to remove headlands, anomalous combine runs (header not full or spanning two treatment areas) and locally extreme data points, and to correct any offset created by changes in combine direction. Then a model of underlying variation was applied to the data to account for spatial variation across rows and along rows, and for the effect of the treatment. The statistical analysis returned treatment effects with standard errors, allowing calculation of 95% confidence limits and the probabilities that these treatment effects would occur in the absence of other spatial variation.

3 Individual trials

3.1. Farm A cultivation and farmyard manure

Trial layout

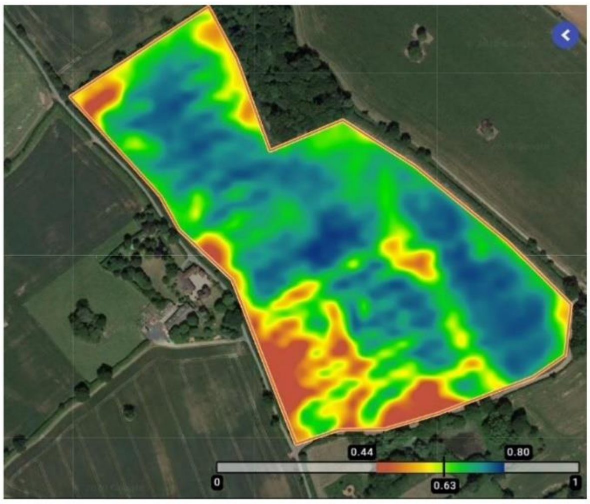


The farm standard for the field is strip tillage plus farmyard manure. The four treatment comparisons were:

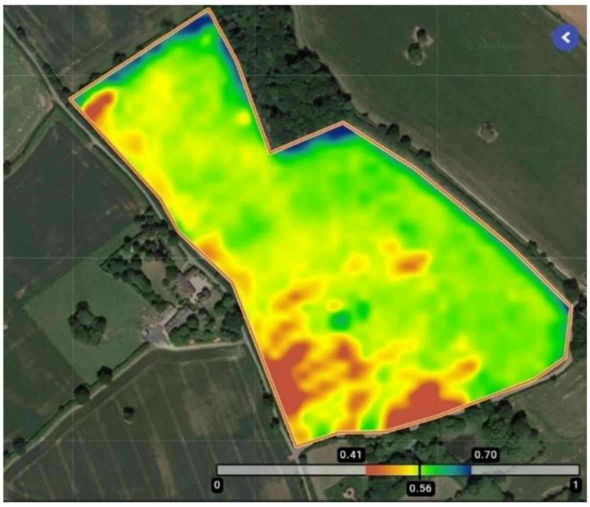
Treatment No.	Cultivation	Farmyard manure (FYM) addition
1	Strip till	+ FYM

2	Strip till	No FYM
3	Deep cultivation	No FYM
4	Deep cultivation	+ FYM

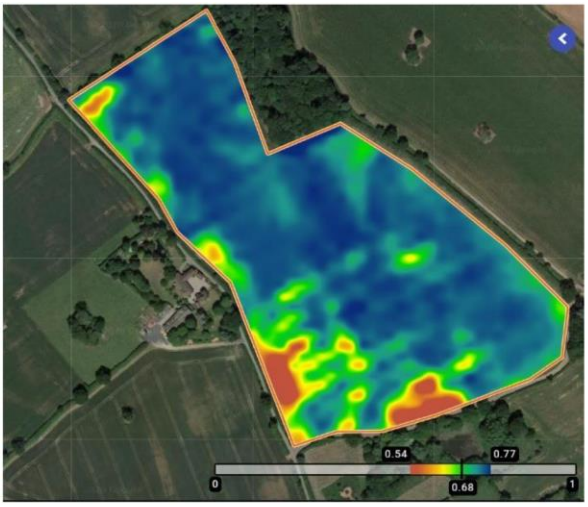
Farm A Satellite NDVI



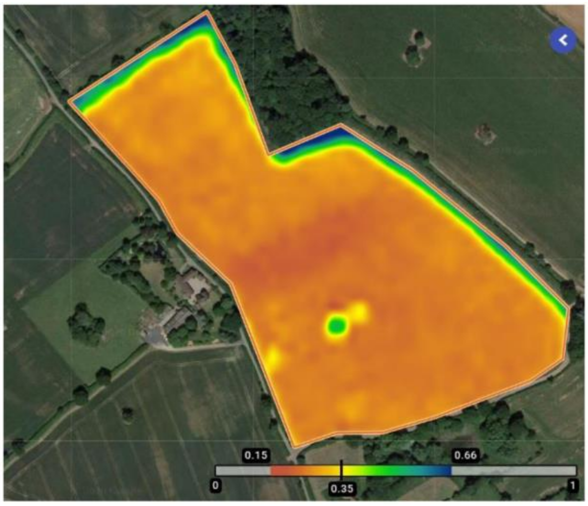
NDVI: 25th March 2020



NDVI: 24th April 2020



NDVI: 29th May 2020



NDVI: 21st September 2020

NDVI images over the 2020 growing season. NDVI is a spectral reflectance index which shows a combination of canopy size and greenness, on a scale from 0 to 1. The scale varies between images but always runs from red (low) through orange, yellow and green to blue (high). Source: Data Farming (http://www.datafarming.com.au).

The NDVI images of the trial field from 2020 showed a relatively consistent NDVI across the field with some small areas of lower NDVI at the south west edge of the field. This suggest there is relatively little underlying variation in the field. There was no visible effect of the cultivation or FYM treatments on NDVI in 2020.

Spring assessments of soil properties

Visual Evaluation of Soil Structure (VESS) is a method of scoring soil structure; VESS Scores of 1 and 2 indicate good friable soil whilst a score of 3 indicates some compaction and scores of 4 or 5 indicate structural damage and that a change in management is needed. The average VESS scores were 2.5 (strip till + FYM), 2.5 (deep cultivation + FYM), 3.0 (strip till, no FYM) and 2.5 (deep cultivation, no FYM); Figure 1. This suggests that the topsoil was reasonably well structured in all plots with slightly more compaction in the strip till only plot.

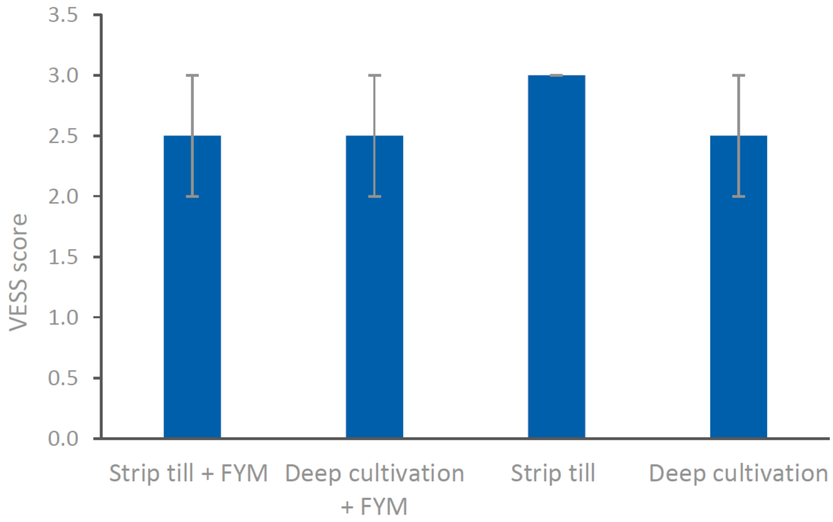


Figure 1. Topsoil VESS (Visual Assessment of Soil Structure) scores. Error bars are ±1 standard deviation of the treatment mean. Replication; n=2.

Soil chemistry measurements (Table 1) were similar between the trial plots with a trend for increased organic matter in the treatments which had received farmyard manure. These measurements were not replicated so the statistical significance of differences between treatments were not analysed.

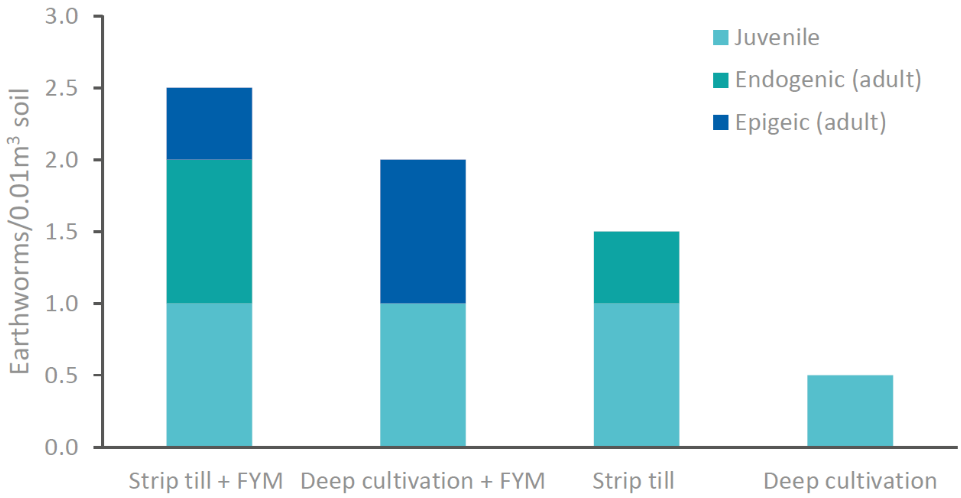
Table 1. Soil chemistry measurements at 0-15 cm soil depth. Nutrient index values are shown in brackets.

Measure	**Strip till + FYM**	**Deep cultivation + FYM**	**Strip till no FYM**	**Deep cultivation no FYM**
pH	6.7	6.7	6.8	6.8
P mg/l	34.2 (3)	24.0 (2)	31.6 (3)	33.6 (3)
K mg/l	149 (2-)	142 (2-)	170 (2-)	141 (2-)
Mg mg/l	111 (3)	110 (3)	88 (2)	94.7 (2)
SOM % LOI	8.9	8.5	8.1	8.3
CO_2-C mg/kg	102	99	105	111

Spring earthworm and midden counts

Figure 2. Mean earthworm numbers per treatment area. Earthworms were classed as anecic, epigeic or endogeic adults or juveniles. No anecic earthworms were found in any of the sampling pits. Replication; n=2.

Very few earthworms were recorded at the time of sampling, probably due to the exceptionally dry spring conditions in 2020. Earthworm activity is typically lower in dry soils, which also can cause some ecotypes to move deeper into the soil (below the 25 cm sampling depth). There were no significant differences in total earthworm numbers between treatments (Figure 2, Table 2). Due to low numbers of earthworms recorded per ecotype, only differences in total earthworm numbers were statistically analysed.



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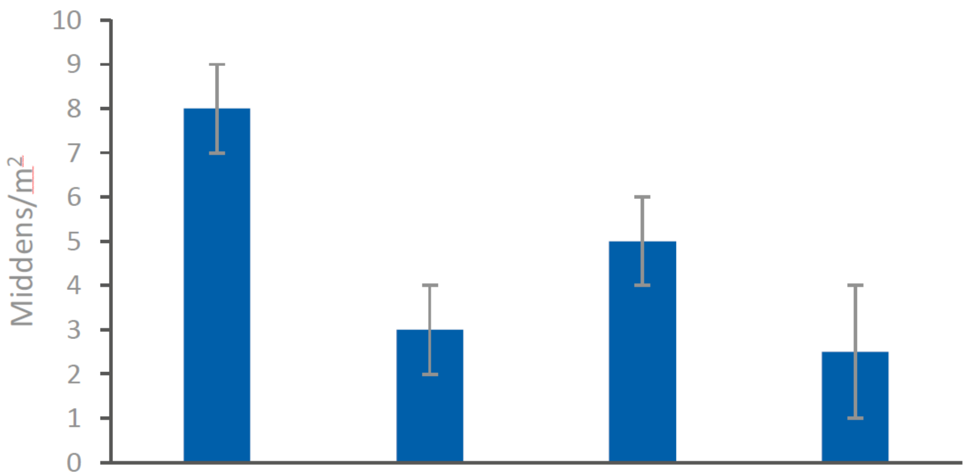


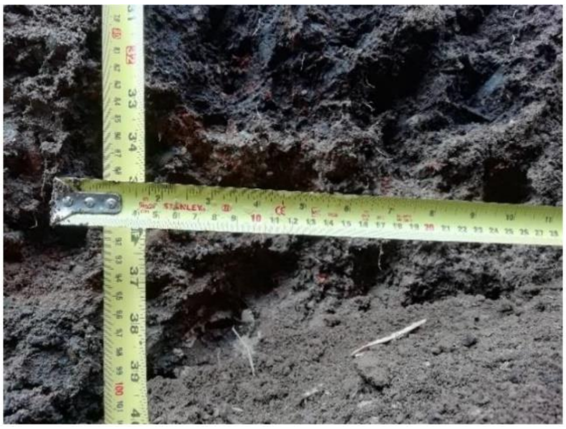
Figure 3. Midden counts. Error bars are ±1 standard deviation of the treatment mean. Replication; n=2.

significant differences in total earthworm numbers between treatments (Figure 2, Table 2). Due to low numbers of earthworms recorded per ecotype, only differences in total earthworm numbers were statistically analysed.

Treatments with strip tillage had significantly more middens than those with deep cultivation (overall treatment mean of 6.5 and 2.8 middens/m2 for strip tilled and deep cultivated plots respectively) (Figure 3, Table 2). This result suggests that there were more anecic (deep burrowing) earthworms in the strip tilled plots compared to the farm standard which may be due to the lower soil disturbance in these areas allowing anecic earthworm populations to recover. There was no significant effect of farmyard manure addition or interaction between farmyard manure addition and cultivation, although numbers were numerically higher where a combination of strip tillage plus FYM was used (Table 2).

Deep rooting, soil pits and photos

Soil pits were dug in June in two treatments; 1) deep cultivation + FYM, and 2) strip till, no FYM, to examine the soil profile and assess rooting at depth. There was evidence of OSR roots growing through earthworm burrows at depth in both the treatments. As shown in the photos, the crop was well rooted at depths of over 80 cm.



Deep cultivation + FYM; evidence of rooting at >80cm.

Strip till, no FYM; evidence of rooting at >80cm.

Deep cultivation + FYM; evidence of OSR roots growing down earthworm burrows.

Strip till, no FYM; evidence of OSR roots growing down earthworm burrows.

Deep cultivation + FYM; evidence of OSR roots growing down earthworm burrows at >80cm.

Figure 1Strip till, no FYM; evidence of OSR roots growing down earthworm burrows at depth >80cm.

Statistical summary

Table 2. Statistical analysis of results by two-way ANOVA test.

Cultivation				FYM addition				Cultivation * FYM addition			
P	***lsd***	***df***	***Significance***	***P***	***lsd***	***df***	***Significance***	***P***	***lsd***	***df***	***Significance***
0.031	3.181	7	*	0.201	3.181	7	NS	0.337	4.498	7	NS
0.482	2.688	7	NS	0.266	2.688	7	NS	0.809	3.802	7	NS

Significance values (*P ≤ 0.05, ** P ≤ 0.01, *** P ≤0.001); statistics performed on the replicate measurements undertaken within each treatment plot, as there was no replication of the treatments across the field

Table 3. Means and standard deviation values for midden and total earthworm counts; topsoil VESS.

Measurement	Strip till + FYM		Deep cultivation + FYM		Strip till		Deep cultivation	
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
VESS scores	2.5	0.7	2.5	0.707	3	0.707	2.5	0.707
Middens counts/m2 soil	8	1.4	3	1.41	5	1.41	2.5	2.12
Total earthworms/0.01 m3 soil	2.5	2.1	2	1.41	1.5	0.707	0.5	0.707

Agronomic analysis of crop yield

The ADAS Agronomics statistical model indicated that the modelled effect of the strip till without FYM treatment was to reduce yield by 0.209 t/ha relative to the farm standard treatment with a 95% confidence interval (estimate of error) of 0.56 t/ha. Whereas the modelled effect of the deep cultivation with or without FYM was to increase yield by 0.75 t/ha and 0.04 t/ha, respectively, with 95% confidence intervals of 0.56 t/ha and 0.57 t/ha, respectively. Based on the variation in the data, to be considered significant by conventional statistical thresholds the treatments needed to show a difference in yield of 1.1 t/ha or more, compared to the farm standard, therefore none of the treatments significantly affected yields (Figures 4 & 5).

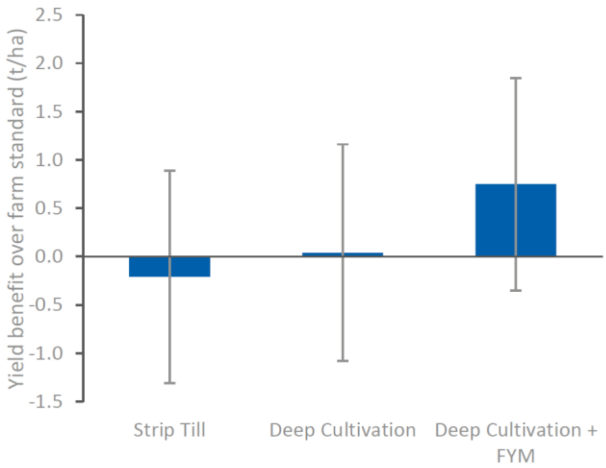


Figure 4. Yield benefit of treatments relative to the farm standard; strip till plus farmyard manure (FYM). Error bars show 95% confidence intervals.

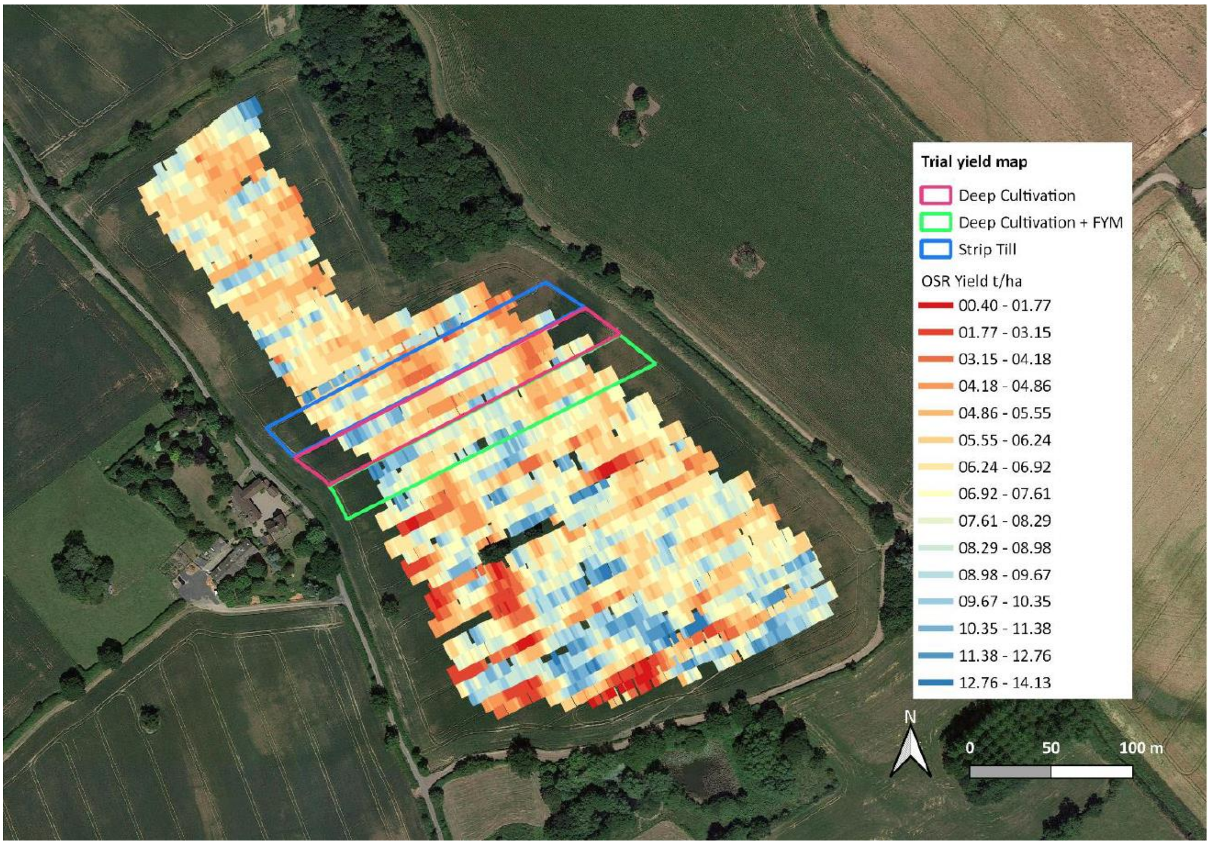


Figure 5. Yield map of OSR crop showing only yield data retained in the statistical analysis. The farm standard treatment was strip till with added farmyard manure (FYM).

Farm A cultivation and FYM trial summary

In summary the results from this trial show that:

- The soil was relatively well-structured in all trial plots.
- As would be expected, there was a trend for increased soil organic matter content in plots which had received farmyard manure additions.

- There was evidence of crops achieving a good depth of rooting (> 80 cm deep) in both the strip till and deep cultivation treatments. There was also evidence of oilseed rape roots proliferating in anecic earthworm burrows.
- There were significantly more earthworm middens in trial plots which had been strip tilled compared with those which had been deep cultivated. This is a reliable indicator that deep burrowing earthworm numbers have increased in areas which have been strip tilled. Anecic earthworm recovery in strip tilled areas is probably due to soils with low disturbance being more favorable habitats, as deep cultivation destroys burrows and may directly kill earthworms or increase predation.
- There was no evidence that cultivation or farmyard manure treatments significantly affected yield of the OSR crop. This could be because a good depth of rooting was achieved in all trial plots or because rooting depth (and access to water and nutrients) was not a limiting factor in determining yield of this OSR crop.
- Due to the relatively slow reproductive cycle of deep burrowing earthworms (which can take several years to reach maturity) it is expected that anecic earthworm populations may take several years to increase in favorable conditions. Continuing the trial for further years will help to quantify these changes.

3.2. Farm B Cultivations trial

Trial setup

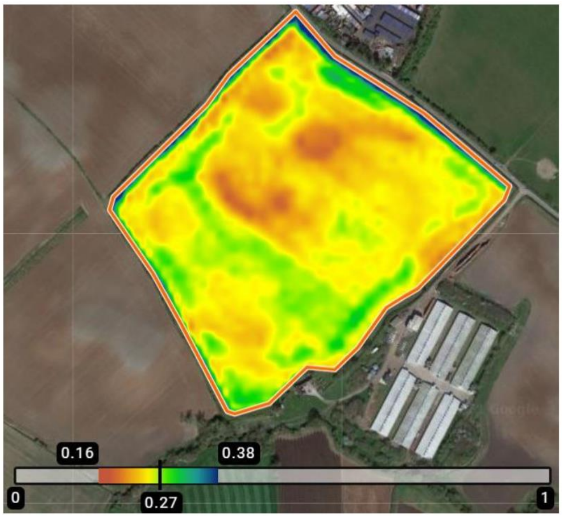
This trial on the AHDB Strategic Cereals Farm compared four cultivation depths, each with two replicate areas:

Treatment No.	Cultivation
1	Direct drill
2	5 cm cultivation
3	15 cm cultivation
4	30 cm cultivation

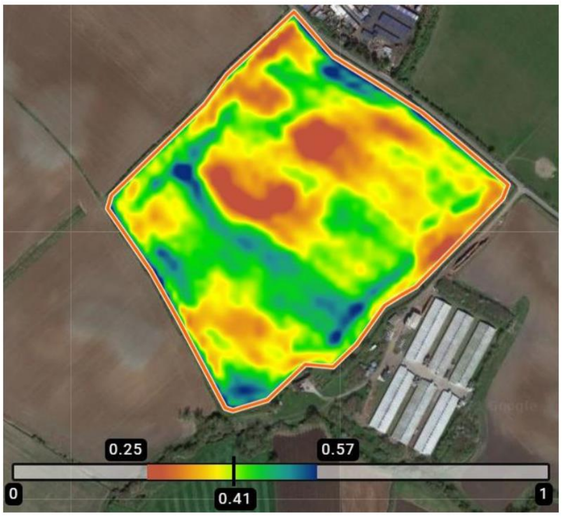
Further details of the trial history and results (including assessment of early rooting) can be found at: https://ahdb.org.uk/farm-excellence/strategic-cereal-farm-west

Satellite NDVI

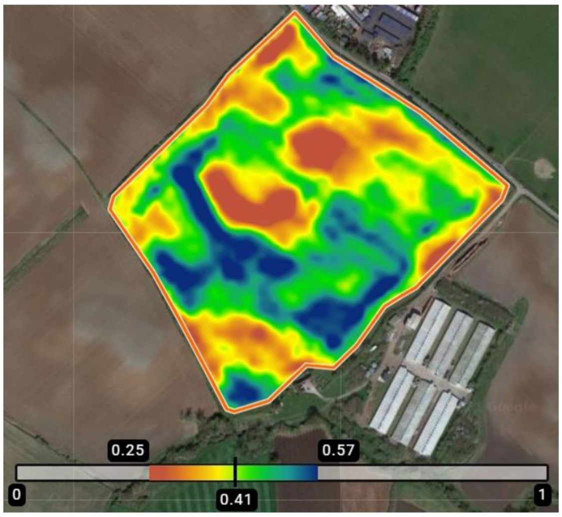
NDVI 24th April 2020



NDVI: 6th May 2020



NDVI: 29th May 2020



NDVI: 23rd June 2020

NDVI images over the 2020 growing season. NDVI is a spectral reflectance index which shows a combination of canopy size and greenness, on a scale from 0 to 1. The scale varies between images but always runs from red (low) through orange, yellow and green to blue (high). Source: Data Farming (www.datafarming.com.au).

The NDVI images of the trial field from 2020 showed a large amount of variation within the field with some large patches of low NDVI crop in the centre and north east of the field. This suggests underlying variation within the field such as differences in soil type which may bias the yield data and make it difficult to fairly test the effect of the cultivation treatments on crop yield.

Spring assessments of soil properties

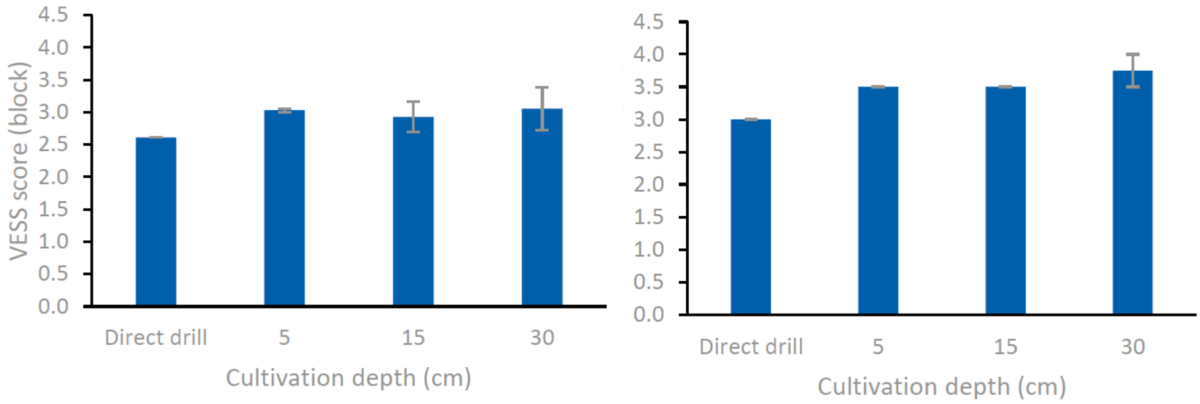


Figure 6. Topsoil VESS (Visual Assessment of Soil Structure) scores; (a) average block scores and (b) average limiting layer score. Error bars are ±1 standard deviation of the treatment mean. Replication; n=2.

Soil VESS scores were similar between treatments and did not differ significantly between treatments. VESS block scores averaged at between 2.5 and 3.0 in all treatments suggesting moderate compaction. VESS limiting layer scores averaged between 3.0 and 3.8 and showed a trend of more compaction (i.e. higher limiting layer scores) with deeper cultivation. N

Table 4. Soil chemistry measurements at 0-15 cm soil depth.

Measure	Direct drill	5 cm cultivation	15 cm cultivation	30 cm cultivation
pH	8.0	7.4	7.4	7.7
P mg/l	20.2	17.8	19.4	13.9
K mg/l	205	209	164	163
Mg mg/l	810	623	688.5	785
SOM % LOI	4.8	4.6	4.2	4.5
CO2-C mg/kg	79	107	90.5	83.5

There was no significant difference in soil chemistry between the cultivation treatments, except for soil P where significantly higher concentrations were measured in the direct drill and 15 cm depth cultivation treatment compared to the 30 cm depth cultivation treatment. This is probably due to greater mixing of P in the 30 cm cultivation treatment resulting in a dilution effect in the top 0-15 cm.

Soil strength

Penetration resistance measurements were recorded from the 5, 15 and 30 cm treatments in early May 2020. All treatments showed relatively high penetration resistance (> 1.5 MPa) which suggests that soil compaction may be restricting root growth however these high values may also be partly due to the dry soil conditions at the time of sampling. There was no significant difference in penetration resistance between the three soil cultivation treatments at any of the soil depths despite a trend for increased penetration resistance in soils with shallow cultivation at depths of 10-20 cm.

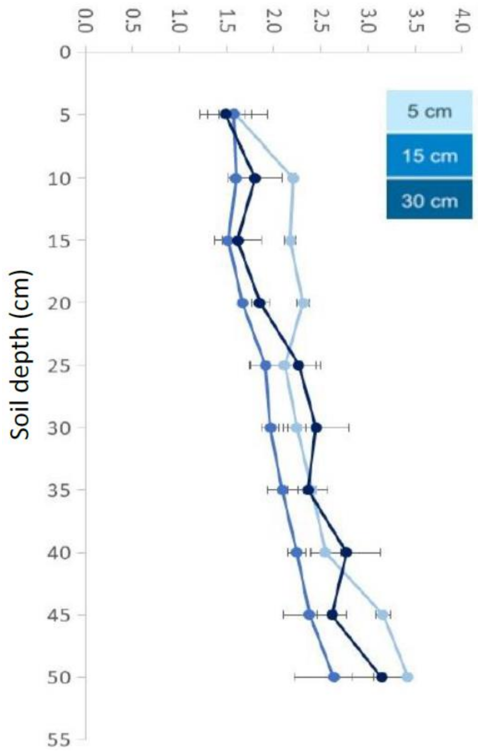


Figure 7. Soil strength measured at 0 to 55 cm depth in the 5, 15 and 30 cm depth cultivation treatments. Replication; n=2.

Spring earthworm and midden counts

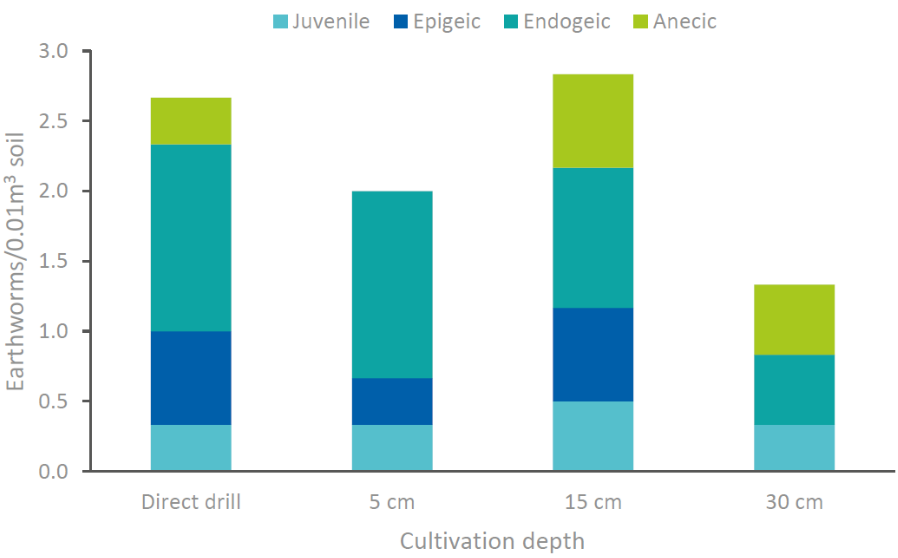


Figure 8. Mean earthworm numbers per treatment area. Earthworms were classed as anecic, epigeic or endogeic adults or juveniles. Replication; n=2.

Very few earthworms were recorded at the time of sampling probably due to the exceptionally dry spring conditions in 2020. Earthworm activity is typically lower in dry soils, which also can cause some ecotypes to move deeper into the soil (below the 25 cm sampling depth). Due to low numbers of earthworms recorded per ecotype, only differences in total earthworm numbers were statistically analysed. Total earthworm numbers averaged at: 2.7, 2.0, 2.8 and 1.3 individuals for direct drill and 5, 15 and 30 cm cultivation depths respectively, with no significant difference between treatments. Likewise, there were no middens found in any treatment. This suggests anecic earthworm numbers were very depleted in all treatments.

Statistical summary

Table 5. One-way ANOVA test for effect of cultivation depth on soil and earthworm measurements

Measurement	Cultivation			
	P	*F*	*df*	*Significance*
pH	0.318	1.815	3	NS
P mg/l	0.024	15.74	3	*
K mg/l	0.699	0.517	3	NS
Mg mg/l	0.974	0.066	3	NS
SOM % LOI	0.886	0.206	3	NS
CO2-C mg/kg	0.415	1.311	3	NS
Total earthworms/0.01 m^3 soil	0.694	0.527	3	NS

*Significance values (*P ≤ 0.05, ** P ≤ 0.01, *** P ≤0.001), Replication was at the plot level (n = 2).*

Agronomic analysis of crop yield

The average measured yield of the farm standard (30 cm depth cultivation) was 2.22 t/ha. Agronomics analysis showed there was no significant effect of the 15 cm depth cultivation or direct drill on yield compared to the farm standard however yield was significantly reduced in the 5 cm depth cultivation treatment (Figure 9 & 10).

The modelled effect of the 5 cm cultivation treatment was to reduce yield by 0.701 t/ha ± 0.256 t/ha compared to the 30 cm cultivation treatment. Based on the variation in the data, to be considered significant by conventional statistical thresholds this treatment needed to show a difference in yield of 0.502 t/ha or more, compared to the 30 cm cultivation treatment therefore the effect of this treatment was significant.

The modelled effect of the direct drill treatment was to reduce yield by 0.525 t/ha ± 0.298 t/ha compared to the 30 cm cultivation treatment. Based on the variation in the data, to be considered significant by conventional statistical thresholds this treatment needed to show a difference in yield of 0.584 t/ha or more, compared to the 30 cm cultivation treatment and therefore did not have a significant effect on yield.

The modelled effect of the 15 cm cultivation treatment was to reduce yield by 0.092 t/ha ± 0.262 t/ha compared to the 30 cm cultivation treatment. Based on the variation in the data, to be considered significant by conventional statistical thresholds this treatment needed to show a difference in yield of 0.513 t/ha or more, compared to the 30 cm cultivation treatment and therefore did not have a significant effect on yield.

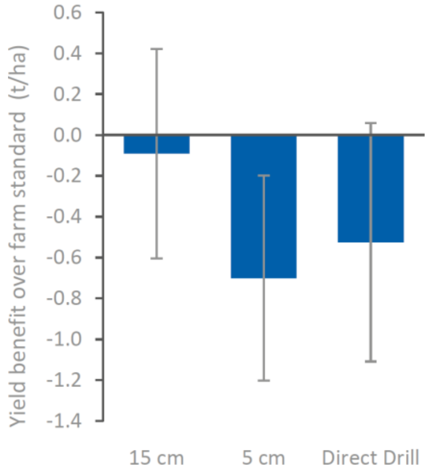


Figure 9. Yield benefit of cultivation treatments relative to the farm standard; cultivation to 30 cm depth. Error bars show 95% confidence intervals.

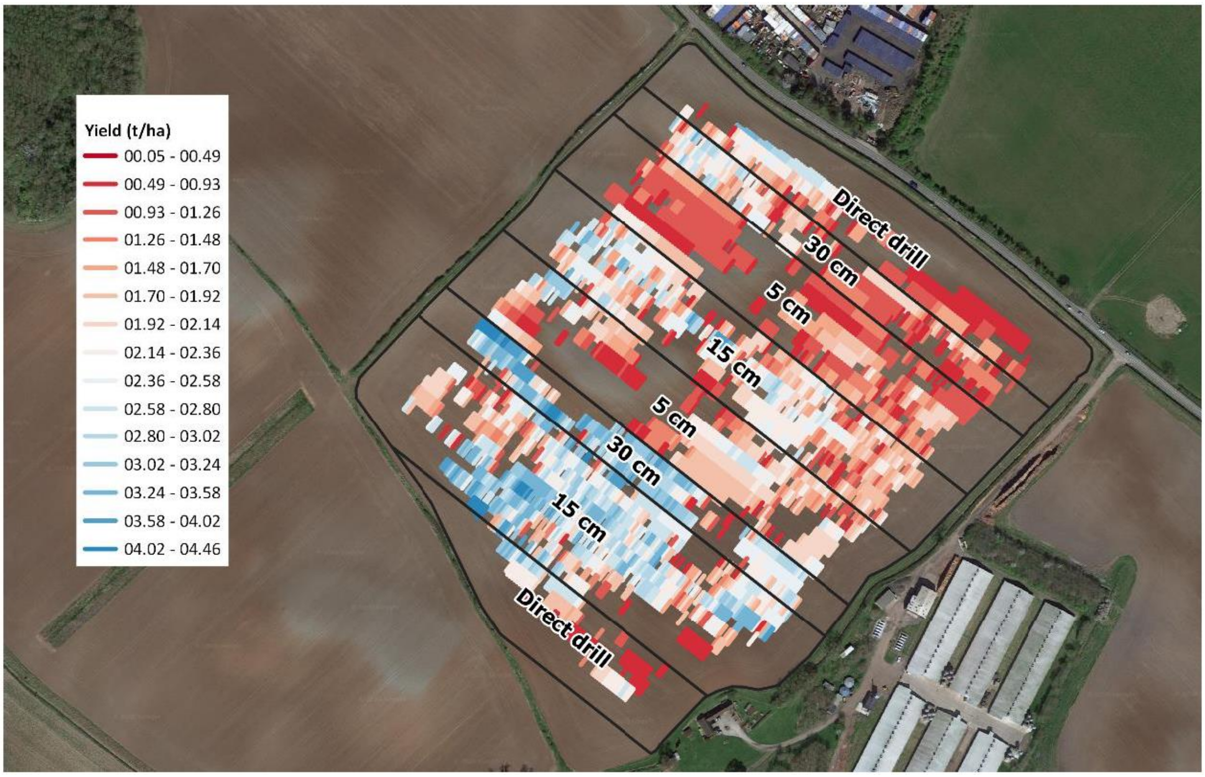


Figure 10. Yield map of spring bean crop showing only yield data retained in the statistical analysis. The farm standard treatment was 30 cm depth cultivation.

Trial summary – Farm B

In summary the results from this trial show:

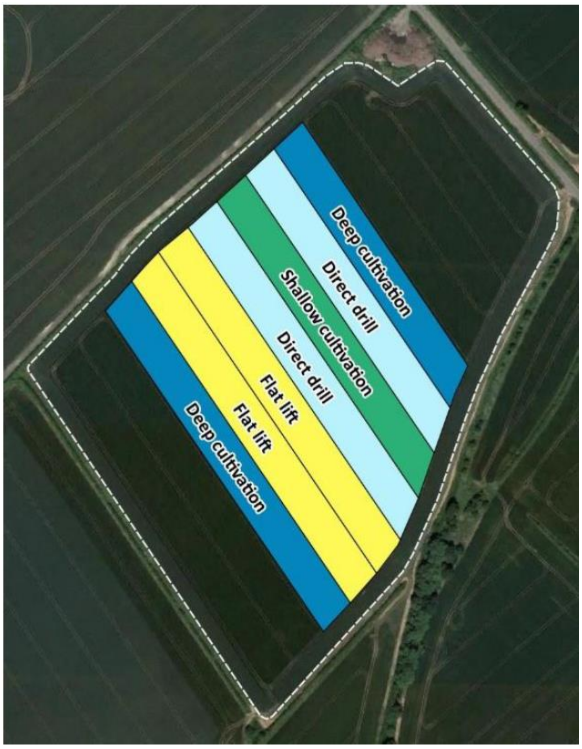
- Soil structure (topsoil VESS block and limiting layer scores) were similar between the cultivation treatments and showed some topsoil compaction, particularly on the deep cultivation treatment. Soil strength measurements of the 5, 15 and 30 cm cultivation treatment suggested that these soils were compacted to an extent which may limit root development, particularly at depths greater than 30 cm.

- Earthworm numbers were depleted in all areas of this trial. Deep burrowing (anecic) earthworms were only recorded in three of the four treatments (direct drill, 15 cm cultivation and 30 cm cultivation) and no middens were found in any of the treatment areas. Low earthworm count numbers may partly be explained by the exceptionally dry spring conditions at the time of sampling which can reduce earthworm activity and cause some ecotypes to move deeper into the soil (beneath the 25 cm depth of sampling), however lack of middens suggests that there were few anecic earthworms present.
- Agronomics analysis of crop yield suggests that yields were significantly reduced with the 5 cm cultivation treatment compared to the 30 cm depth cultivation treatment and that yields were on average also lower with direct drill and 15 cm cultivation treatments. NDVI was variable within the trial field indicating underlying variation due to for example differences in soil type, which may also partly explain spatial differences in yield within the trial area.
- Overall, the results suggest that, as yet, none of the cultivation treatments in this trial (which have been in place for two years) were effective at supporting earthworms, including deep burrowing earthworm species. Due to the relatively slow reproductive cycle of deep burrowing earthworms (which can take several years to reach maturity) it is expected that anecic earthworm populations may take several years to increase in favourable conditions. Continuing the trial for further years will help to quantify these changes.

3.3. Farm C – trials 3 and 4 – cultivation trials

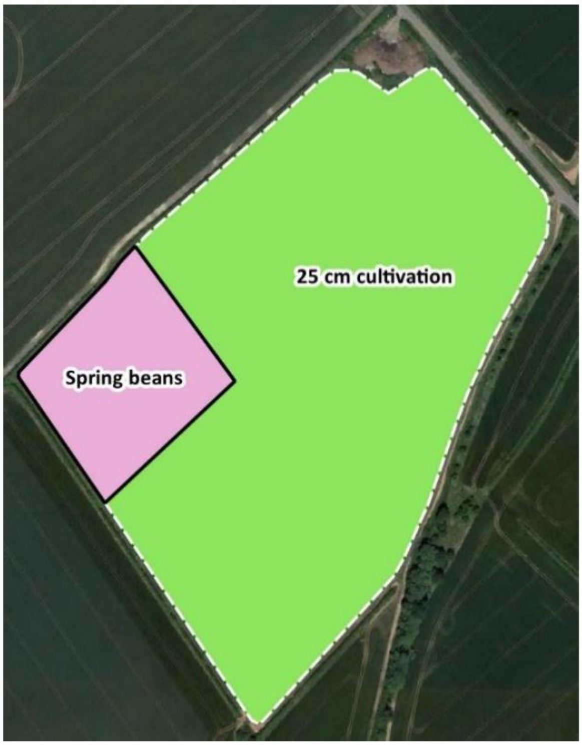
Trial setup

Trial 3: 2020, crop = spring barley. Two cultivation treatments compared: direct drill and cultivation to 25cm



Trial 4: 2019

Crop = winter wheat. All plots received farmyard manure (fresh cattle). In Autumn 2018 trial plots were established comparing four cultivation treatments: (1) direct drill, (2) shallow cultivation to 10 cm) (3) flat lift to 30 cm, (4) deep cultivation to 30 cm.



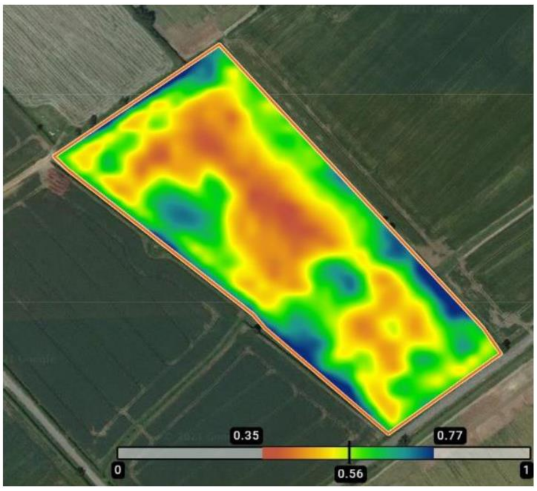
Trial 4: 2020

Crop = oilseed rape (OSR). In Autumn 2019 the entire field was cultivated to 25 cm depth. The 2020 assessments were made in each of the plot areas established in 2018/2019 to test the legacy effect of these treatments.
In part of the field the OSR crop failed due to cabbage stem flea beetle damage. This area was sown with spring beans and excluded from the 2020 trial area.

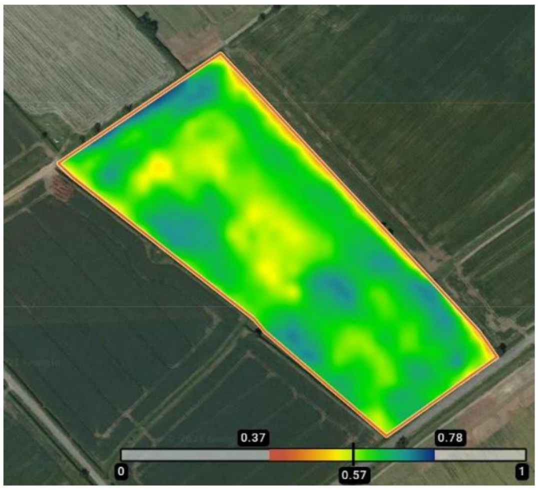
Satellite NDVI

NDVI images over the 2020 growing season. NDVI is a spectral reflectance index which shows a combination of canopy size and greenness, on a scale from 0 to 1. The scale varies between images but always runs from red (low) through orange, yellow and green to blue (high). Source: Data Farming (http://www.datafarming.com.au).

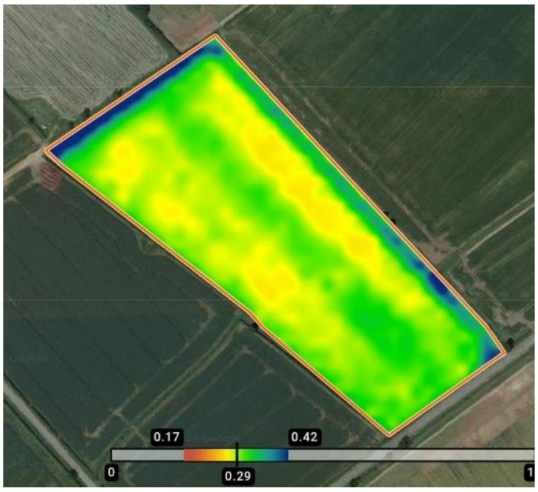
Trial 3: Spring barley



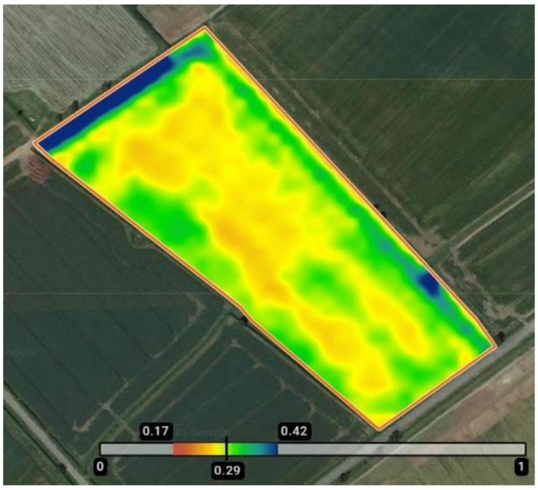
NDVI: 29th May 2020



NDVI: 23rd June 2020



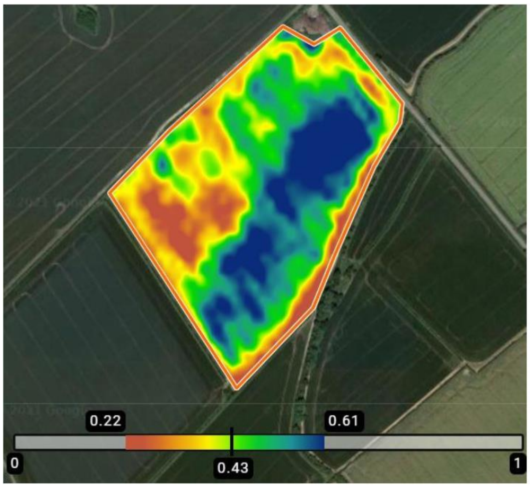
NDVI: 12th August 2020



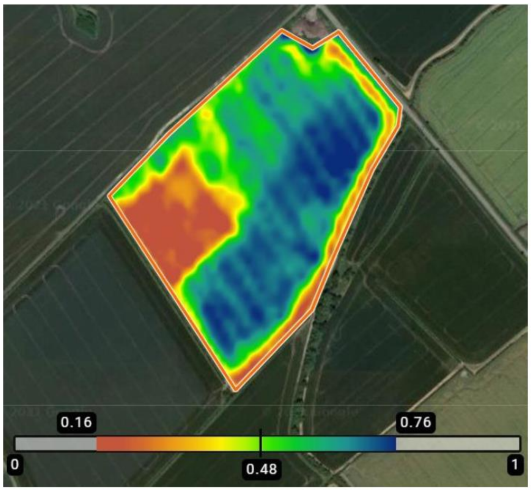
NDVI: 18th September 2020

Trial 3: NDVI was variable within the field during May and to a lesser extent June. In August there was an area of slightly higher NDVI running down the centre of the field that corresponded with the area which had been direct drilled in 2019 however by September these differences were less clear.

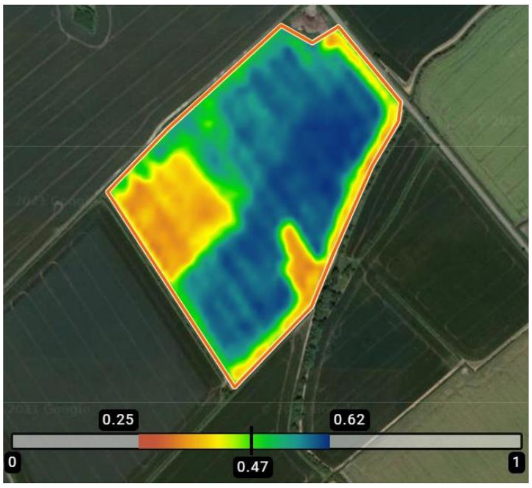
Trial 4: Oilseed rape



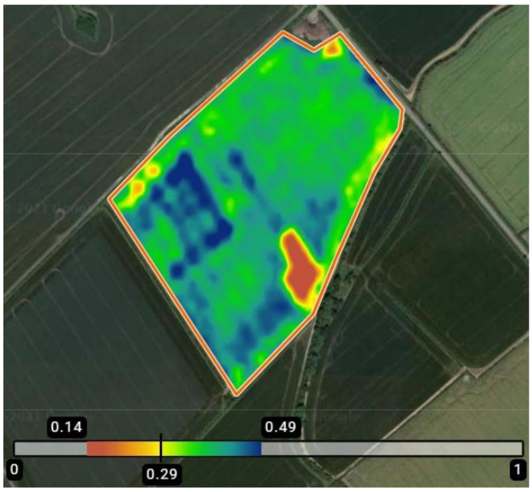
NDVI: 25th March 2020



NDVI: 14th April 2020



NDVI: 29th May 2020



NDVI: 25th June 2020

Trial 4: There was no clear legacy effect of the 2019 cultivation on the 2020 oilseed rape crop. The south side of the field shows a higher NDVI during March, April and May suggesting underlying variation within the field such as differences in soil type or drainage.

NDVI measurements were used as a proxy for crop performance in both trials as no yield mapped data was available for either of the trial fields.

Spring assessments of soil properties

Table 6. Trial 3 soil chemistry results (0-15 cm depth).

Measure	Direct drill	25 cm cultivation
pH	6.7	6.9
P mg/l	20 (2)	22.0 (2)
K mg/l	308 (3)	273 (3)
Mg mg/l	218 (4)	242 (4)
SOM % LOI	9.7	9.6
CO_2-C mg/kg	102	109

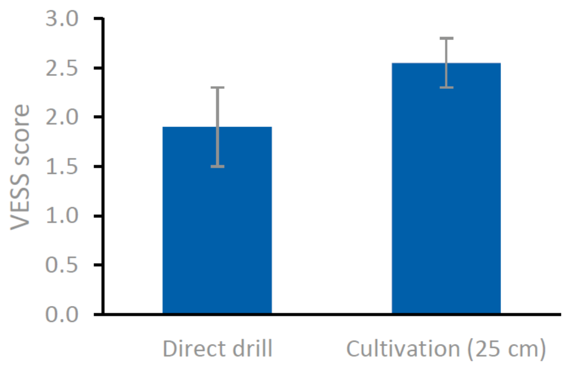


Figure 10. Trial 3 overall block VESS scores. Error bars are ±1 standard deviation of the treatment mean. Replication; n=2.

VESS assessments showed both treatments areas had good soil structure. The direct drill area (mean VESS score of 1.9) had a particularly good friable soil structure compared to the 25 cm cultivation area (mean VESS score of 2.5) which was slightly more compacted but still generally well structured. Soil chemistry analysis showed similar values between the two cultivation treatments with high soil organic matter content (≥ 9.6%) in both.

Table 7. Trial 4 soil chemistry results (0-15 cm depth). Treatment labels refer to autumn 2018 cultivations as all plots received 25 cm depth cultivation in autumn 2019.

Measure	Direct drill	Flat lift	Shallow lift	Deep cultivation
pH	6.7	6.8	6.7	6.8
P mg/l	21.1	16.6	15.4	17.4
K mg/l	466	389	405	430
Mg mg/l	269	259	300	300
SOM % LOI	9.2	9.5	8.9	9.4
CO_2-C mg/kg	123.0	125.5	123.0	127.0

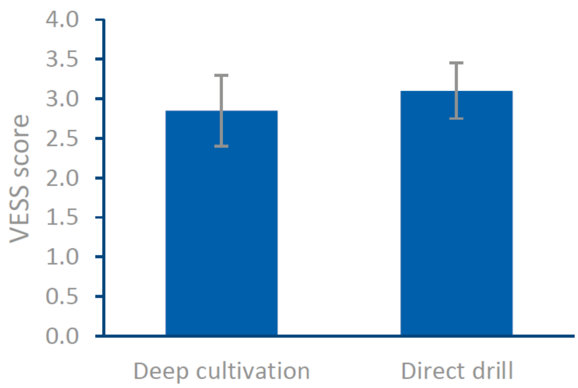


Figure 11. Trial 4 overall block VESS scores comparing the legacy direct drill and deep cultivation treatments only. Replication; n=2, Error bars are ±1 standard deviation of the treatment mean. Treatment labels refer to autumn 2018 cultivations as all plots received 25 cm depth cultivation in autumn 2019.

VESS assessments showed both treatments areas had a moderate soil structure. VESS scores were similar between the two treatments: direct drill area (mean VESS score of 2.9) and deep cultivation area (mean VESS score of 3.1). Soil chemistry analysis showed similar values between cultivation treatments with high soil organic matter content (≥ 8.9%) in all areas. These results indicate no legacy effect of the cultivation treatments.

Spring earthworm and midden counts

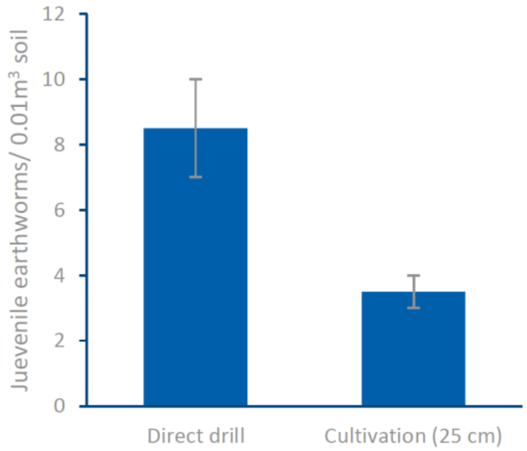


Figure 12. Trial 3 total earthworm counts. Error bars are ±1 standard deviation of the treatment mean. Only juvenile earthworms were found in this trial therefore ecotypes were not identified. Replication; n=2.

No adult earthworms or earthworm middens were found during spring earthworm sampling in trial 3. This suggest earthworm populations were depleted within the sampling area. A greater number or juvenile earthworms were found in the direct drill treatment compared to the 25 cm cultivation treatment.

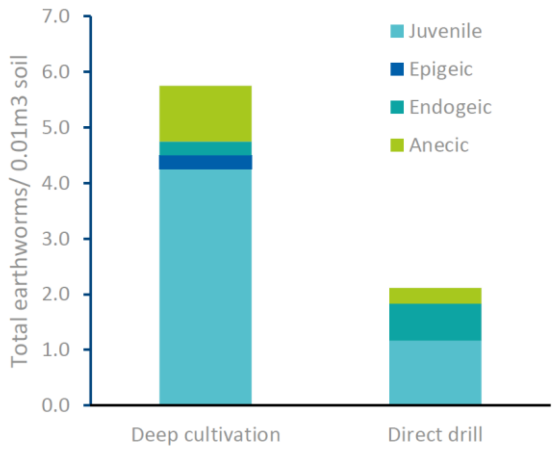


Figure 13. Total earthworm counts for Trial 4 legacy cultivation treatments. No earthworms were found in the flat lift or shallow cultivation treatment areas. Treatment labels refer to autumn 2018 cultivations as all plots received 25 cm depth cultivation

Spring earthworm counts in the Trial 4 field showed low earthworm populations. This may be partly explained by the exceptionally dry spring conditions at the time of sampling. No earthworms were found in the flat lift or shallow cultivation treatments and mostly juvenile earthworms were found in the deep cultivation and direct drill treatments. There were significantly fewer earthworm middens in the direct drill treatment (direct drill 2018, followed by 25 cm cultivation 2019) compared to the other cultivation types (P = 0.046, Table 8).

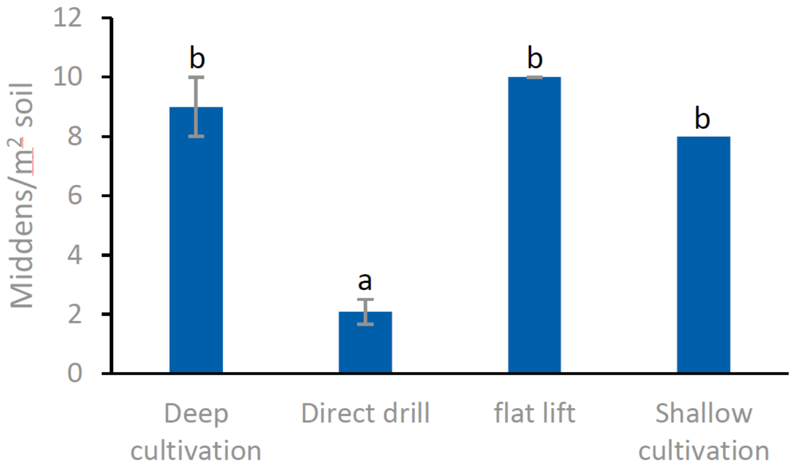


Figure 14. Midden counts for trial 4 legacy cultivation treatments. Error bars are ±1 standard deviation of the treatment mean. Different letters denote significant differences between treatments; Tukey HSD P < 0.05. Treatment labels refer to autumn 2018

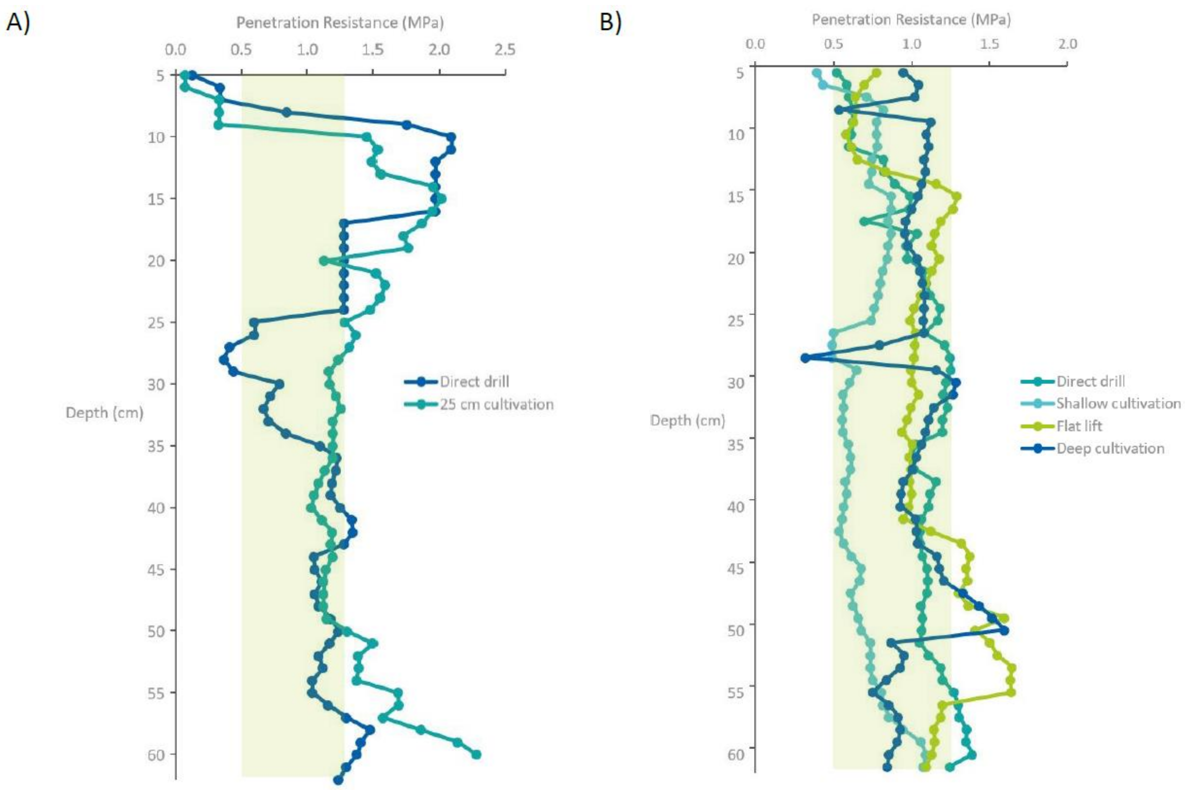


Figure 15. Soil strength at depth measurements. Soil strength at depth measurements. A) Trial 3: Comparison of soil strength between direct drill and 25 cm cultivation treatment, B) Trial 4: Comparison of soil strength at depth between direct drill, shallow cultivation, flat lift and deep cultivation treatment (legacy treatments). Treatment labels refer to autumn 2018 cultivations as all plots were cultivated to 25 cm depth in autumn 2019. Shaded green areas indicate the range of penetration resistance values considered to be optimal for root development (0.5 to 1.25 MPa).

Trial 3: Soil in both the direct drill and 25 cm cultivation treatments showed some compaction at the 10-16 cm depth range particularly in the direct drill treatment. From 25 to 55 cm depths penetration resistance values were generally within the optimal range for both treatments.

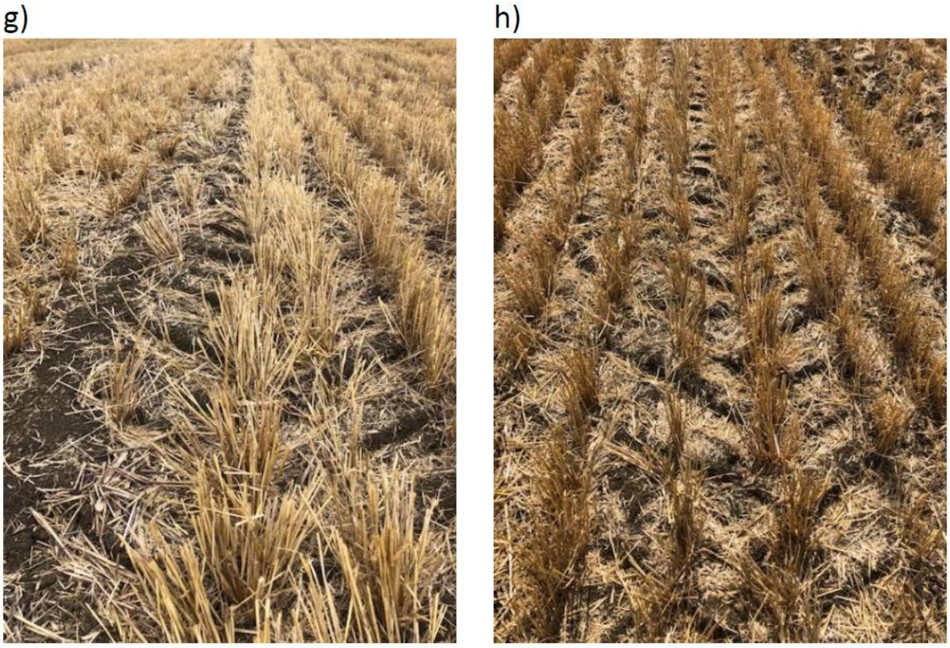
Trial 4: Penetration resistance values for all legacy treatments generally fell in the optimal range for root development at all soil depths.

Soil and rooting observations (early September 2020)

a) b) c)

Photos a-c, structure of direct drilled soil in trial 3. Relatively good structure with signs of earthworms and middens.

Photos d-f show some compaction in worked ground in trial 3. Horizontal planes at 8, 13 and 20 cm depth indicate the soil may have been worked whilst too wet in September 2019.



Trial 3 farmer observation that direct drilled ground (g) was less rutted to travel on than deep cultivated area (h).

Table 8. Trial 4 statistical analysis of results by one-way ANOVA test

Measurement	Cultivation			
	P	*LSD*	*df*	Significance
Total earthworms/0.01 m^3 soil	0.046	4.095	6	*
Middens/m2	0.009	3.135	6	**

Significance values (*P ≤ 0.05, ** P ≤ 0.01, *** P ≤0.001)

Table 9. Trial 4 mean and standard deviation values for midden and total earthworm counts and topsoil VESS.

Measurement	Direct drill		Shallow cultivation		Flat lift		Deep cultivation	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
VESS block score	3.1	0.50	nd	-	nd	-	2.9	0.64
Middens counts /m^2 soil	2.8	0.59	8	0	10.0	0	9.0	1.41
Total earthworms/0.01 m^3 soil	2.6	0.94	0	-	0	-	5.7	1.77

Nd = no data

Due to limited sampling replication of trial 3, the effect of the cultivation treatments on VESS scores, earthworm counts were not statistically tested.

Trial 3: This trial tested differences in soil structure, earthworm populations and crop rooting between cultivation treatments: direct drill in autumn 2019 (following 30 cm cultivation in 2018) and 25 cm cultivation in autumn 2019 (following direct drill in 2018). In summary the results from this trial show:

- VESS assessments showed generally good structure in both treatment areas with high organic matter content. Soil strength measurements in both the direct drill and 25 cm cultivation treatments showed the soils were more compact at the 10-16 cm depth particularly in the direct drill treatment, however at depths of 25 to 55 cm, penetration resistance values were generally within the optimal range for root development.

- Both treatment areas were depleted in earthworms with no adult earthworms and no middens found in either trial area. This may be partly explained by the relatively high level of soil disturbance in both plots as both had received deep cultivation within 1 or 2 years. The dry spring conditions at sampling may also partly explain the low earthworm numbers.
- There was no clear effect of the cultivation treatments on NDVI over the growing season (which was measured as a proxy for crop performance).

Trial 4: This trial tested differences in soil structure, earthworm populations and crop rooting between four legacy cultivation treatments: (1) direct drill, (2) shallow cultivation (3) flat lift and (4) deep cultivation (autumn 2018) followed by 25 cm depth cultivation (autumn 2019). In summary the results from this trial show:

- VESS assessments of the deep cultivation and direct drill showed both had a moderate soil structure. Soil organic matter content in all plots was high (≥ 8.9%). Penetration resistance values to 60 cm depth measured in all plots suggested that soil strength was in the optimal range for root development.
- Earthworms were depleted across all areas. Mainly juvenile earthworms were found in the legacy deep cultivation and direct drill plot whilst none were found in the flat lift or shallow cultivation treatment. Some middens were found indicating presence of anecic earthworms which may have moved deeper into the soil during the dry conditions.
- There was no effect of the cultivation treatments on NDVI over the growing season (which was measured as a proxy for crop performance).

4 Conclusions/Recommendations

Although earthworms were depleted due to dry spring conditions, evidence of increased midden numbers with strip tillage was shown in Trial 1. This suggests recovery of deep burrowing earthworm numbers with less disruptive soil management (strip tillage) compared to deep cultivation.

Springtime pit sampling showed that earthworm populations (numbers of all ecotypes and juveniles) were depleted in most of the trial plots, with earthworms absent from some sampling pits. This may be at least partly explained by the exceptionally dry spring conditions in April 2020 and demonstrates the importance of soil moisture for earthworm activity. Dry condition can cause earthworms to become less active and some ecotypes move deeper into the soil which could have resulted in fewer earthworms in the 0-25 cm depths sampled.

There was good evidence of crop roots utilising earthworm burrows at depths of > 80 cm in Trial 1 although this did not result in improved crop performance. It would be expected that benefits to crop yield from deep rooting would occur if access to water and nutrients was a factor limiting yield which may not have been the case during the 2020 growing season at this site. No benefit of the trial treatments on crop performance were shown in any of the trial sites.

As deep burrowing earthworms have a relatively slow reproductive cycle, the effectiveness of strategies to boost populations need to be monitored over multiple growing seasons. Earthworm populations are spatially variable therefore having a good level of replication of sample pits per treatment as well as sampling early in the season to ensure adequate soil moisture would be advised to enable accurate measurement of earthworm populations in future trials.

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