Strategic Cereal Farm West
Harvest 2019

Strategic Cereal Farms are a key part of AHDB's Farm Excellence network. They provide a platform to showcase research in practice via a structured combination of short and long term field and farm scale trials.

Each Strategic Cereal Farm runs for six years to allow independent demonstration of research to be conducted across a full rotation.

The farms test and demonstrate new ways of working in a commercial setting. Approaches are subject to full cost-benefit analyses using Farmbench which helps other farmers to assess the possibility of changing approaches on their own farms.

Visit our website for more information on AHDB Farm Excellence network: ahdb.org.uk/farm-excellence

Contents

Strategic Cereal Farm West

Host farmer:	Rob Fox
	@SquabRob
Location:	Squab Hall Farm, Harbury Lane, Leamington Spa, Warwickshire CV33 9QB
Duration:	November 2018 – September 2024

1. Introduction

Rob Fox manages Squab Hall farm, based just outside Leamington Spa. The business is highly diversified, with a large enterprise around general storage and document storage, as well as machinery and labour sharing with three arable farms. Robert farms 400ha of owned and rented land, with a rotation of winter wheat, winter barley, winter oilseed rape, spring beans and spring barley.

The Strategic Cereal Farm West, hosted by Rob Fox at Squab Hall Farm, is a platform for the integration of research and practical farming that has the potential to change the way we farm for the better. The Strategic Cereal Farm West demonstrates research outputs and communicates the full net-margin cost benefit analysis of demonstrations to help farmers make real differences to their businesses and continue to be proud of our industry and the jobs we do.

The vision of the Strategic Cereal Farm West is to test research outputs in an independent, open, honest and transparent way. The project will help the UK agricultural industry, primarily farmers, to try out new strategies and develop practical solutions to address regional priorities and challenges.

Rob Fox joins a growing network of Strategic Farms, including Brian Barker who hosts the Strategic Cereal Farm East near Stowmarket, Suffolk.

A steering group of local farmers and advisers help to guide the programme and support Rob over the six years. If you have any questions or suggestions, please feel free to get in touch with the steering group members – Jock Willmott, Colin Woodward, Ian Matts, Mark Wood, Richard Meredith and Emily Pope.

2. Weather summary

Between 1 August 2018 and 31 August 2019, the Strategic Cereal Farm weather station recorded a total of 533 mm of rainfall. The maximum temperature recorded was 35.9°C in July 2019. The minimum temperature recorded was -7.7°C in January 2019.

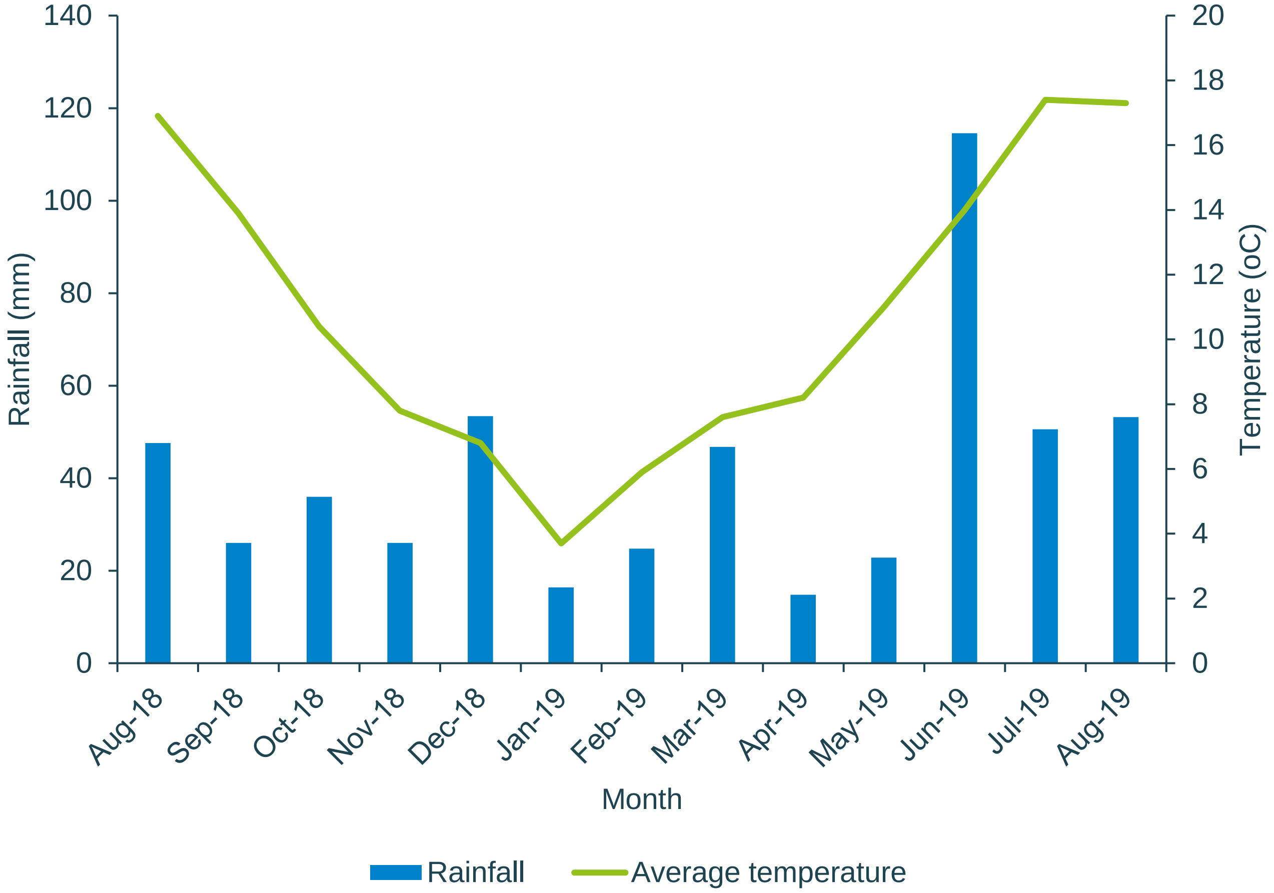


Figure 1. Weather data from weather station at Strategic Cereal Farm West (August 18–August 19)

3. Timeline of trials

2018-2019

Baselining

The aim of the first year of the Strategic Cereal Farm project, known as the baselining year, was to determine the starting point of a number of indicators within the farmed environment before any changes are investigated and evaluated. The following indicators have been assessed during the first year of the programme, 2018-2019, and will be monitored over the next six years:

- Weather station
- Soil nutrient analysis
- Earthworms
- Electrical conductivity scanning
- Soil physical structure
- Crop biomass
- Weeds
- LEAF Sustainability Review

Trials

- The impact of cultivation depth on soil properties and rooting on winter wheat yields
- The impact of reduced fungicide applications on yield of varieties with different disease resistance ratings
- The impact of cultivation depth on headland areas on soil health and crop productivity
- The impact of nutrient inputs on crop productivity

2019-2020 (proposed trials, subject to change)

- The impact of cultivation depth on soil properties and rooting on oilseed rape yields
- The impact of environmentally friendly methods of managing pests on oilseed rape yields
- The impact of reduced fungicide applications on yield of varieties with different disease resistance ratings
- The impact of cultivation depth on headland areas on soil health and crop productivity
- The impact of contrasting stubble management techniques on autumn weed control
- The impact of perennial flower strips on beneficial insect populations, pests and weeds

Full details about all of the baselining and trials at the Strategic Cereal Farm West are available online: ahdb.org.uk/farm-excellence

4. Assessing soil health

Trial leader: Anne Bhogal, ADAS

Start date: 1 March 2019

End date: 30 March 2019

Baseline soil properties were assessed on nine fields across the farm and evaluated using the soil health scorecard. Both Visual Evaluation of Soil Structure (VESS) and bulk density showed evidence of some compaction across the farm, with poorer structure observed on the heavier textured soils. Earthworm numbers were depleted in a number of fields.

What was the challenge/demand for the work?

Sustainable soil management is central to the delivery of economically and environmentally sound, resilient and productive cropping, with the assessment of soil health essential for informing decisions on soil and nutrient management in order to maximise crop yield and quality, whilst minimising production costs and environmental impacts. At the start of the Strategic Cereal Farm West programme it is therefore important to characterise the baseline soil condition, prior to the start of an extensive project of demonstrations and trials over the next six years. The results will help guide soil management decisions during the course of the programme and enable an evaluation of how different interventions over the next 6 years potentially affect soil health. Soil assessments have been evaluated using the soil health scorecard which is being developed by the AHDB/BBRO Soil Biology and Health Partnership programme over a similar time-frame to the strategic farm programme. The farm therefore provides a useful test-bed for the on-going evaluation of this approach.

How did the project address this?

Nine fields at Squab Hall Farm were sampled in late March 2019. The fields were divided into soil management zones according to the underlying soil variability (as identified using the farm soil texture maps). Within each zone, three sampling points were selected according to the maximum, minimum and median soil penetration resistance (measured to 30cm depth using a cone penetrometer), in order to give an accurate representation of the range of soil structural conditions across the zone. The location of each sampling site was GPS-located for future reference, and a topsoil sample (0-15 cm; made up of *c*. 20 sub-samples) was taken from a 10m radius around the GPS location. The bulked samples were analysed for pH, extractable P, K & Mg, organic matter, respiration and potentially mineralisable N (PMN) to quantify the chemical status and microbial activity of the soils. At each sampling location, a soil pit (*c*. 20 x 20 x 25cm deep) was dug for Visual Assessment of Soil Structure (VESS assessment) and earthworm counts and bulk density at 5-10cm was determined by taking an intact soil core.

What results has the project delivered?

The draft soil health scorecard brings together information about the chemical, physical and biological properties of soil to help guide soil and crop management decisions. It is recommended that soil testing is conducted on a rotational basis, at the same point in the rotation and when the soils are moist (ideally close to field capacity) in order to minimise the impact of temporary factors that could mask long-term changes. ‘Traffic light’ coding is used to identify properties where further follow-up investigation is needed and guide management options that could minimise any potential risks to crop productivity and the environment: ‘Green’ – no action required; ‘Amber’ – monitor (perhaps a bit more frequently than planned); ‘Red’ – investigate. A red traffic light doesn’t necessarily mean soil health is poor, rather it indicates that further investigation is required to understand why a particular property has been highlighted (which may mean repeat testing).

The results for Field 25 demonstrate how the scorecard can be used to highlight potential soil related constraints to crop production and how this might vary with soil type across a field. There were no treatment comparisons in this field. Three major soil types were identified according to the farm soil maps: ‘heavy red’ (zone 1), ‘medium/heavy loam’ (zone 2) and ‘heavy clay’ (zone 3).

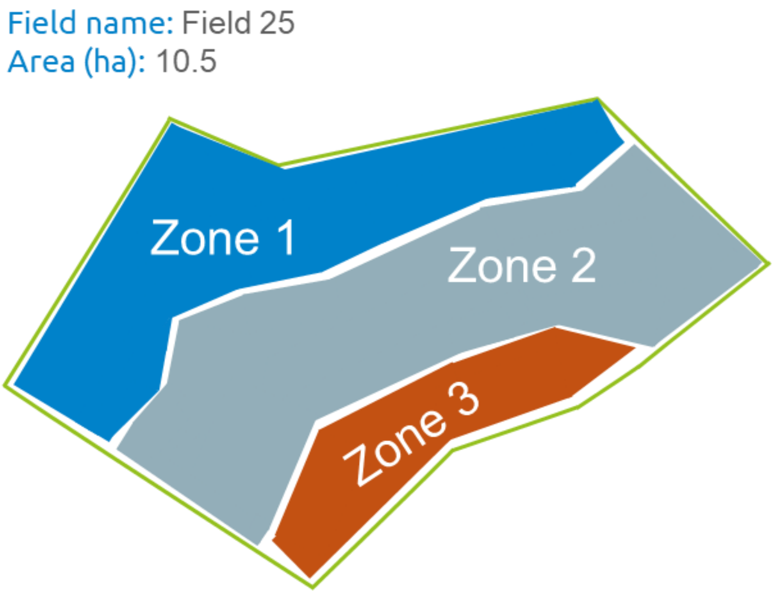


Figure 2 (left). Soil management zones in Field 25

Soil health scorecard

Table 1. Soil health scorecard for Field 25

Zone	**1**	**2**	**3**
Texture	clay	clay	clay
% clay	37	43	51
SOM (%LOI)	5.0	4.7	4.4
pH	7.5	8.1	8.1
Ext. P (mg/l)	18	13	21
Ext. K (mg/l)	344	375	433
Ext. Mg (mg/l)	849	708	675
VESS score (limiting layer)	3	4	4
Bulk density (g/cm^3)	1.17	1.26	1.28
Earthworms (number/pit)	6	1	2
PMN (mg/kg)	98	112	88
Respiration (mg CO_2-C/kg)	215	169	166

Note: benchmarks are subject to review

No action needed   Monitor   Investigate

- **Soil type:** whole field > 35% clay (heavy textured), although zone 1 was lighter than zones 2 and 3
- **SOM:** ≥ 5% is 'typical' for heavy textured soils, respectively; SOM levels are close to typical values in zones 1 and 2, borderline for zone 3.
- **pH:** target pH > 6.5 for arable soils & at pH > 7.5 there is the potential for nutrient interactions; see ahdb.org.uk/rb209 for specific crop advice.
- **Ext. P, K & Mg:** extractable P levels were low for zone 2 (Index 1) and extractable Mg levels were elevated across the whole field;
- **VESS:** a score of 3 indicates moderate soil structure ('firm') https://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure
- **Bulk density:** at 5-10cm, thresholds decrease with increasing SOM (benchmark = 1.17 g/cm^3 at 4-5% SOM).
- **Earthworms:** Total number of adults and juveniles; >8/pit = 'active' population for arable soils; < 4/pit = 'depleted'; very low numbers recorded in zones 2 & 3;
- **PMN:** Potentially Mineralisable Nitrogen (a measure of microbial activity) – benchmark data is currently under review, but suggest no action required
- **Respiration:** A measure of soil microbial respiration – benchmark data is currently under review, but suggest no action is required.

Key issues found in Field 25 are soil structure & earthworm numbers (particularly zones 2 & 3 associated with the heavier textures and below average organic matter contents)

Averaging across the individual zones within a field masks the sometimes large differences in soil texture, but can help to identify the major soil-related problems across the farm as a whole. These appear to be soil structure and earthworm numbers.

Overall evaluation

Table 2. Soil health scorecard results across all fields on the farm (field averages)

Field number	2	6	16	13	15	25	42	7	49
Crop	WW	WW	WW	WW	WW	Sba	OSR	WW	WW
Texture	sandy loam	clay loam	clay				clay loam	sandy clay loam	
SOM (%LOI)	3.7	4.3	6.6	5.0	4.1	4.7	7.4	4.0	5.6
pH	6.1	6.6	7.4	7.1	7.3	7.9	7.5	6.6	6.6
Ext. P (mg/l)	42	53	23	20	21	17	32	47	19
Ext. K (mg/l)	233	288	233	331	202	384	455	244	160
Ext. Mg (mg/l)	169	490	707	1089	812	744	178	301	175
VESS score	2	3	3	3	3	3	3	3	2
Bulk density (g/cm^3)	1.31	1.30	1.20	1.27	1.36	1.24	1.20	1.35	1.20
Earthworms (number/pit)	9	11	6	10	3	3	6	7	8
PMN (mg/kg)	54	63	49	58	53	100	126	64	64
Respiration (mg CO_2-C/kg)	133	124	106	145	117	183	184	158	192

Note: benchmarks are subject to review

No action needed | Monitor | Investigate

Both the VESS and bulk density assessments show evidence of some compaction across the farm (in all but two fields). None of the fields had a VESS score (Sq) of 1 'friable', with the majority of fields (77%) classed as having a 'firm' (Sq3) layer present typically located between 5-25cm depth or 10-25 cm depth. Higher structural scores (i.e. poorer soil structure) tended to be linked to the heavier textured zones within the fields, which can be more vulnerable to structural degradation, particularly if cultivated/trafficked when wet.

The most compact soils (Sq4) were observed in Field 15 on the shallow cultivation treatment. Soils with a Sq score of 4 contain mainly large, angular aggregates with few distinct macropores (Figures 3 and 4). These large aggregates are likely to have a negative effect on rooting and drainage in the affected fields. By contrast soils with a Sq score of 1 or 2 have a mixture of porous rounded aggregates which crumble very easily with roots distributed throughout. Interestingly, good examples of this were also found in the cultivations trial in Field 15, but under the deep cultivation treatment (Figure 3) and in Field 42 in the lighter textured zone (Figure 4).

Earthworm numbers were 'depleted' in two fields (< 4/pit, equivalent to < 100 individuals per m^2), 'intermediate' in 4 fields (4-8/pit or up to 200/m^2) and 'active' (>8/pit or 200/m^2) in 3 fields. Soil moisture can affect local patterns of earthworm distribution and activity, which may explain why numbers were low across the farm, as measurements were undertaken in March 2019, which was unusually dry. However, numbers varied within a field, with lower numbers often associated with either lighter textured zones and/or zones with a lower SOM content. Cultivation is also likely to be an important factor causing the relatively low number of earthworms in some areas

Field 15 zone 2 (deep cultivation): Sq 2 'intact'

Field 15 zone 3 (shallow cultivation): Sq 4 'compact'

Figure 3. VESS assessments in Field 15

Field 42 zone 1: Sq 2 ‘intact’

Field 42 zone 2 Sq 4: ‘Compact’

Figure 4. VESS assessments in Field 42

Action points for farmers and agronomists

Regularly assess soil health in order to guide management and track the effect of any interventions. It is recommended this is done on a rotational basis, at the same point in the rotation, at a similar time of the year (ideally autumn once the soils have wetted up and at least 1 month after cultivation; or in stubbles) and from the same location in the field (GPS positioning is useful here). Soils should not only be assessed for soil chemical properties, but also involve the physical evaluation of soil structure and an assessment of soil biological activity (e.g. earthworm counts). The draft soil health scorecard is a useful tool to help benchmark and interpret your findings.

Links to further information/ references

- AHDB/BBRO Soil Biology and Health Partnership – a range of resources and case studies of the work currently being conducted as part of this programme can be found at **ahdb.org.uk/greatsoils**
- SRUC. Visual Evaluation of Soil Structure Score Card: **www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure**

5. The impact of reduced fungicide applications on yield of varieties with different disease resistance ratings

Trial leader:	Anne Bhogal and Christina Clarke, ADAS
Start date:	12 October 2018
End date:	4 August 2019

There was no significant difference in yield between the farm standard and low input treatments. However, large differences were observed between soil types.

What was the challenge/demand for the work?

In order to maintain activity of fungicides and disease control there needs to be a step-change in the way cereal fungicides are used. AHDB already plays a key role in fungicide anti-resistance through monitoring and research of key diseases to develop the most effective anti-resistance strategies, including more resistant varieties. The AHDB Recommended Lists have raised minimum standards for variety disease resistance which potentially enables the reduced use of, and thus reduces pressure on, fungicides.

The aim of this demonstration is to determine the effect of reduced input regimes and cost of production to promote stewardship and raise awareness of practical anti-resistance measures.

How did the project address this?

A split field trial was established into winter wheat variety Graham using deep tine to 8 inches, discs, drill and roll.

The standard crop protection treatments used dressed seed while reduced input was untreated. For the reduced input treatment, the program of insecticides and fungicides was adapted in response to disease development. The standard treatments had the conventional treatment program regardless of disease or pest development.

Two major soil types were identified in the field and treatments were carried out on both soil types. Therefore the field has been split into four sampling zones to correspond with each treatment area (Figure 5). Within each zone, three sampling points were identified corresponding to the maximum, median and minimum penetrometer resistance measurements to a depth of 30cm. Each sampling point was marked and assessments taken from within a 10m radius.

Assessments included:

Soil

- Spring 2019
- Soil health, including topsoil bulk density (5-10cm depth), VESS, earthworm counts, microbial biomass C, nematodes
- Visual evaluation of soil structure (VESS)

Rooting

- Shovelomics: excavate the crop and the top 20-30cm of soil and assess root crown (number of tillers, nodal roots per tiller) and biomass
- Root cores: soil cores between flowering and grain fill in wheat to complete root scanning and root biomass assessments (results TBC)

Crop

- At GS30, GS31-33, GS39, GS61-65 and pre-harvest
- Biomass and tissue testing
- Disease assessments: foliar, stem, ear
- Yield

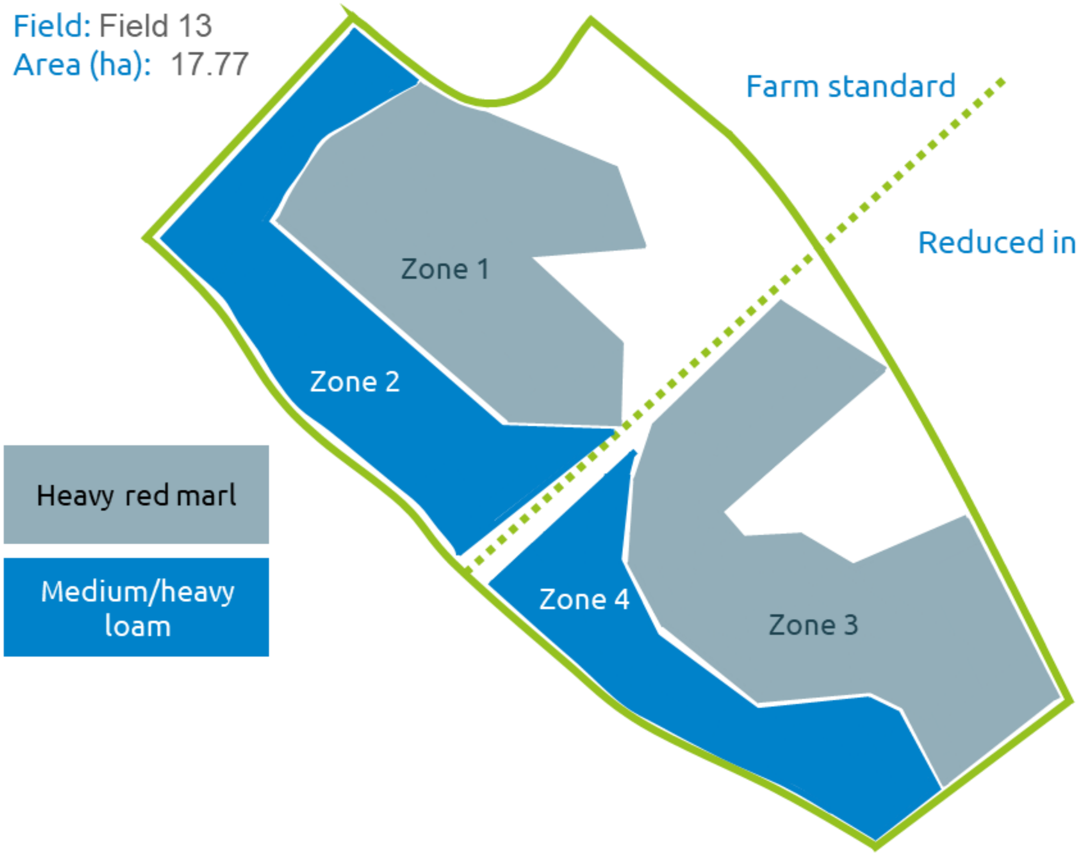


Figure 5. Sampling zones (two major soil types) within Field 13 for farm standard and reduced input treatment

Soil health scorecard

Table 3. Soil health scorecard results for Field 13

Zone	Heavy red marl	Medium/heavy loam
Texture	Clay	Clay
% clay	57	38
SOM (%LOI)	5.6	4.4
pH	7.3	6.8
Ext. P (mg/l)	18	23
Ext. K (mg/l)	408	254
Ext. Mg (mg/l)	1234	943
VESS score (limiting layer)	3	3
Bulk density (g/cm^3)	1.27	1.27
Earthworms (total number)	10	9
PMN (mg/kg)	78	39
Respiration (mg CO_2-C/kg)	149	141

Note: benchmarks are subject to review

No action needed   Monitor   Investigate

- **Soil type:** whole field > 35% clay (heavy textured), with zone 1 'heavier' than zone 2
- **SOM:** ≥ 5% is 'typical' for heavy textured soils, respectively; zone 2 is therefore borderline
- **pH:** target pH > 6.5 for arable soils; see https://ahdb.org.uk/nutrient-management-guide-rb209 for specific crop advice
- **Ext. P, K & Mg:** No nutrients were limiting to crop production; Ext. Mg levels elevated
- **VESS**: A score of 3 indicates moderate soil structure ('firm')
- **Bulk density**: at 5-10cm, thresholds decrease with increasing SOM (benchmark = 1.17 g/cm3)
- **Earthworms:** Total number of adults and juveniles; >8/pit = 'active' population for arable soils;
- **PMN:** Potentially Mineralisable Nitrogen (a measure of microbial activity) – benchmark data is currently under review, but suggest below average activity in zone 2
- **Respiration:** A measure of soil microbial respiration – benchmark data is currently under review, but suggest no action is required
- **Free living nematodes:** although presence of some plant feeders (stunt/spiral & root lesion) were detected, these were all well below threshold levels considered harmful to plants

Key issues found in Field 13 is soil structure.

What results has the project delivered?

Yield

Yield data was obtained by Rob Fox by cutting a number of swaths within each of the treatment field areas with a yield mapping combine. The ADAS agronomics analysis system was used to partition combine runs within each of the soil zones to allow comparison of treatment and soil type effects on yield. There were no significant differences in yield between the farm standard and low input treatments. However, large differences were observed between soil types.

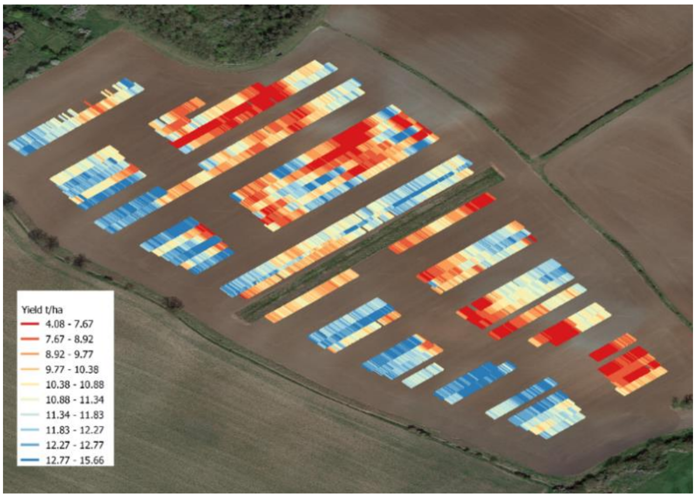


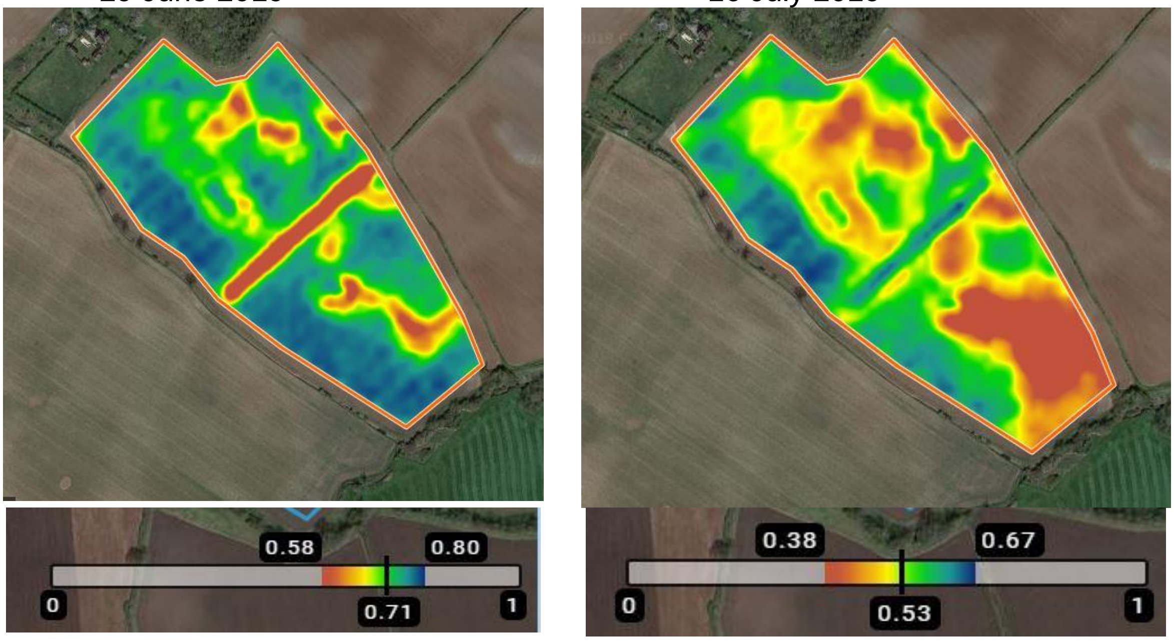
Figure 6. (left) Agronomics field map for Field 13

Overall yield for the farm standard treated area was calculated as 10.99 t/ha and the low input as 10.87 t/ha (this compares to Rob Fox's farm estimates of 11.0 and 10.91t/ha respectively).

Table 4. Statistical analysis of yield in each zone in Field 13

Treatment	Farm standard		Low input	
Zone	Zone 1	Zone 2	Zone 3	Zone 4
Soil type	Heavy red marl	Medium/heavy loam	Heavy red marl	Medium/heavy loam
Yield t/ha	10.09	11.88	9.85	11.80
Treatment		P=0.581	sed=0.278	
Soil zone		P=<0.01	sed=0.278	
Interaction		P=0.771	sed=0.393	

29 June 2019 16 July 2019



Source: Datafarming

Figure 7. NDVI images taken on 29 June 2019 (left) and 16 July 2019 (right)

Both images showed the effect of soil type on wheat growth. Zones 1 and 3 'heavy red soil' showed lower NDVI than zones 2 and 4 ''Medium/heavy loam'. This was more evident in the later season as the crop began to senesce. There were no differences in disease levels between zones.

Normalised Difference Vegetation Index (NDVI): the relationship between visible light reflectance and near infrared reflectance of a crop canopy that allows assessment of its size, nutrient status and health. Healthy vegetation absorbs most of the visible light that it receives and reflects a lot of the near-infrared light, while unhealthy or sparse vegetation reflects more visible light and less near-infrared light.

Disease

There were no differences between soil zones. No stem diseases were observed in either treatment and foliar disease levels were low in both treatments. There were no significant differences in disease levels or green leaf area between the farm standard and low input areas. At flowering, the green leaf area was slightly lower on leaf 1 in the low input treatment, but this could not be attributed to disease.

Table 5. Disease and green leaf (% area) at T0

	Leaf 1		Leaf 2		Leaf 3	
	Septoria	Green leaf	Septoria	Green leaf	Septoria	Green leaf
Farm standard	0.38	98.00	8.33	84.10	16.17	54.1
Low input	0.32	98.00	7.30	85.53	16.70	66.9
p	0.542	NS	0.343	0.335	0.702	0.03
SED	0.109	NS	1.08	1.538	1.386	4.09

Disease levels at T0 were low. There was no significant difference between the Farm Standard and Low Input areas.

Table 6. Disease and green leaf (% area) at T1

	Leaf 1	Leaf 2		Leaf 3
	Green leaf	Green leaf	Septoria	Green leaf
Farm standard	99.0	97.2	1.3	86.5
Low input	99.0	97.2	1.0	89.0
p	NS	NS	0.326	0.569
SED	NS	NS	0.131	4.21

At T1 the only disease present was septoria but this was at low levels in both treatments

Table 7. Disease and green leaf (% area) at T2

	Leaf 1	Leaf 2				Leaf 3		
	Green leaf	Septoria	Mildew	Yellow rust	Green leaf	Septoria	Mildew	Green leaf
Farm standard	97.93	0	0	0.1	95.17	0.77	0.07	90.47
Low input	98.40	0.07	0.33	0	95.97	0.67	0.57	90.17
p	0.123	0.148	<0.001	0.078	0.102	0.359	<0.01	0.691
SED	0.259	0.045	0.085	0.056	0.481	0.108	0.123	0.752

At T2 mildew appeared only in the Low input treatment, but again at very low levels.

Table 8. Disease and green leaf (% area) at flowering

	Leaf 1		Leaf 2	Leaf 3	
	Brown rust	Green leaf	Green leaf	Septoria	Green leaf
Farm standard	0.083	97.33	97.17	0.13	94.63
Low input	0	95.23	96.6	0.03	95.57
p	0.011	0.035	0.304	0.249	0.221
SED	0.031	0.971	0.560	0.086	0.755

Disease levels were very low in both treatments at flowering. Low levels of brown rust were detected in the farm standard treatment. The green area of leaf 1 in the low input treatment was slightly lower but this could not be attributed to disease.

Biomass

There were significant differences between zones from April onwards, fresh weight yield was greater with the low input treatment, although this is not born out by NDVI imagery on page 15, and may be more about precise sample location than an overall trend. Further analysis based on precise GPS location may be necessary to validate this result.

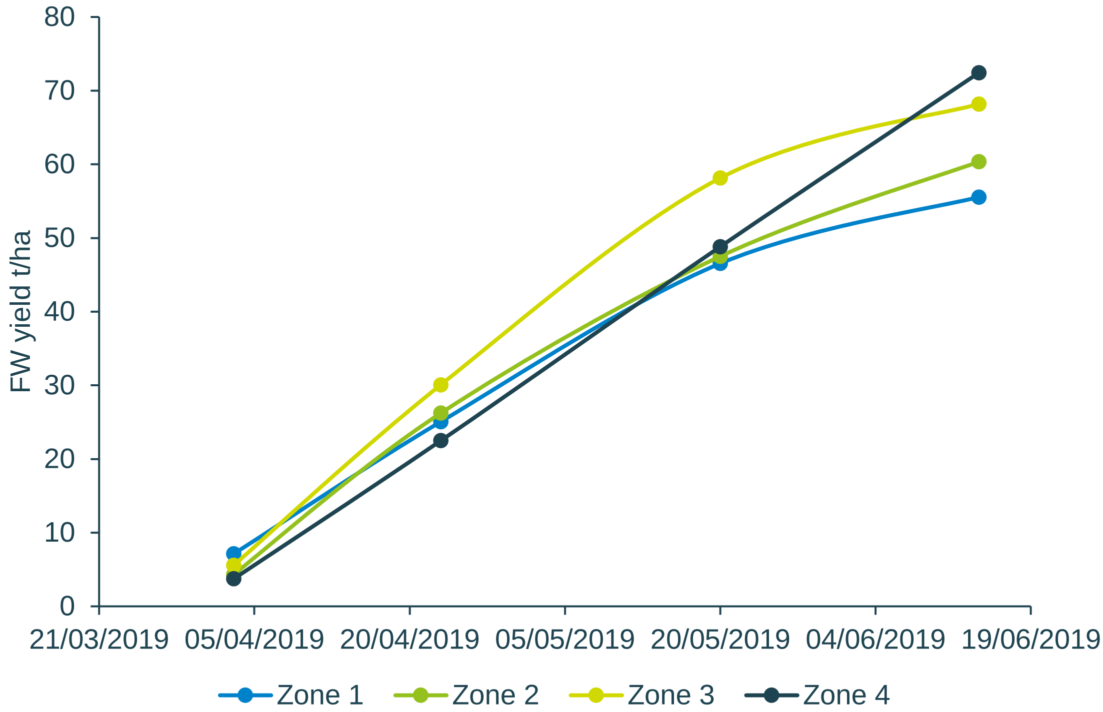


Figure 14. Fresh weight (t/ha) in each sampling zone taken in March, April and May

Like fresh weight yield, there were significant differences between treatment areas in June.

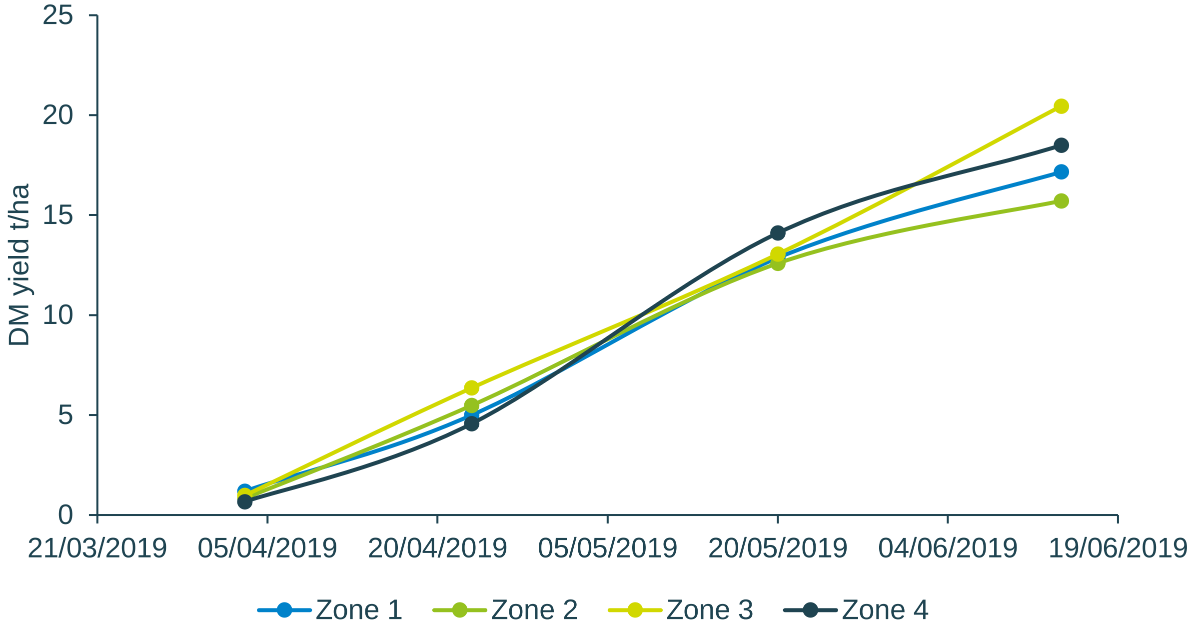


Figure 15. Dry matter yield (t/ha) in each sampling zone taken in March, April and May

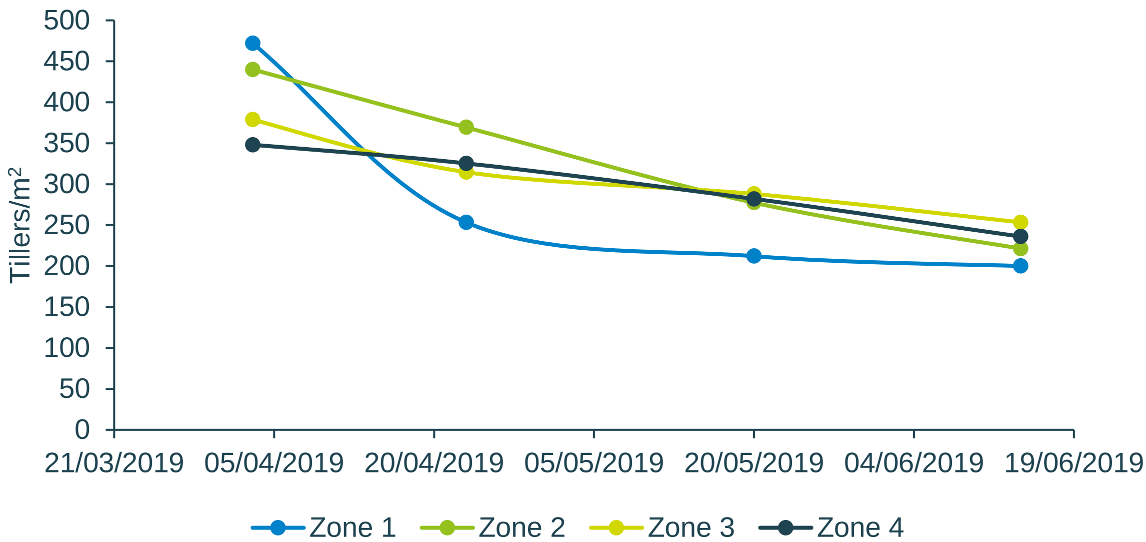


Figure 16. Tillers (m^2) in each sampling zone taken in March, April and May

Tiller numbers declined steadily throughout the season and were low in June, particularly in the heavier soil zones; there were no significant differences between treatment areas. The sharp decline in tiller numbers in zone 1 in April and May is unexpected and cannot be explained with the data available. Overall tiller retention was low compared to expected numbers for a crop of this type. Tiller numbers were significantly higher in April on the farm standard treatment, as might be expected from the use of untreated seed; however the greater loss of tillers from the farm standard treatment meant tiller populations were similar for both treatments before grain formation.

Costings

Table 10. Costing comparisons for farm standard and low input management

	Farm standard	Low input
Yield (t/ha)	**11.03**	**10.91**
Variable costs		
Total seed costs (£/ha)	23	6
Total fertilisers (£/ha)	151	151
Fungicides (£/ha)	80	62
Total crop protection (£/ha)	180	159
Total variable costs (£/ha) (direct)	354	316
Fixed costs		
Total labour, machinery and equipment (£/ha)	500	500
Total property and energy costs (£/ha)*	71	69
Total administration costs (£/ha)*	30	30
Cost of production and margins (per hectare)		
Full economic cost of production (£/ha)	954	914
Cost of production (per tonne)		
Full economic cost of production (£/t)	86	84

**These costs are the West regional averages from Farmbench for harvest 2018*

Action points for farmers and agronomists

There were no yield differences between farm standard and low input areas where fungicide applications were applied depending on disease risk. Monitor crops, use forecast tools and check thresholds to assess risk and apply fungicides accordingly.

Links to further information and references

- AHDB develops practical tools for disease forecasting and fungicide performance. More information is available online at cereals.ahdb.org.uk/research/disease-research
- The encyclopaedia of cereal diseases is the definitive guide to cereal diseases in the UK and contains full colour photographs for identification plus information on hosts, symptoms and life cycles (online)
- Fungicide futures is a joint initiative led by AHDB and FRAG-UK to help put good anti-resistance practice at the heart of fungicide programmes (online)
- See ahdb.org.uk/rb209 for specific crop advice

6. The impact of cultivation depth on soil properties and rooting on winter wheat yields

Trial leader: Anne Bhogal, ADAS

Start date: 19 October 2018

End date: 8 August 2019

Key soil constraints across the farm are structure and earthworm numbers. Shallow cultivation, to a depth of 5 cm, increased topsoil strength. This was associated with a steeper root angle that led to greater rooting in the subsoil. However, subsoil properties had a greater impact on measured crop traits than cultivation depth. At harvest there were no significant yield differences.

What was the challenge/demand for the work?

There is an increasing need to manage soils sustainably, with the recognition of the importance of soil for providing food and delivering ecosystem services. Soil erosion, loss of organic matter and compaction are some of the main issues affecting arable soils. One way to conserve soil quality could be to adopt minimum tillage practices. Additionally, it has been calculated that high yielding crops need to capture all the water in soil down to 1.5 m. Rooting measurements in recent years have shown that many crops have insufficient roots (less than $1cm^{-3}$) to fully access water below 40 cm deep. Limited rooting of crops could be a major limitation to crop yields (White et al. 2015).

To reach deeper soil depths roots are dependent on exploiting pre-existing cracks, fissures and channels. This is an important issue due to the predicted decreases in summer rainfall in the UK and the sensitivity of anthesis and grain fill growth stages to water limited conditions. Cereal and oilseed roots cannot penetrate through strong soils. There is a need for UK, farm-based replicated trials to test the impacts of different cultivation practices on soil quality, health and rooting in both the long and short term.

How did the project address this?

A tramline trial with three cultivation depths (5, 15 and 30 cm), two replications per treatment, was established in winter wheat var. Graham. The field was divided into six sampling zones to correspond with each treatment area. Within each sampling zone, three sampling points were identified corresponding to the maximum, median and minimum penetrometer resistance measurements to a depth of 30 cm. Each sampling point was marked and all assessments taken from within a 10 m radius.

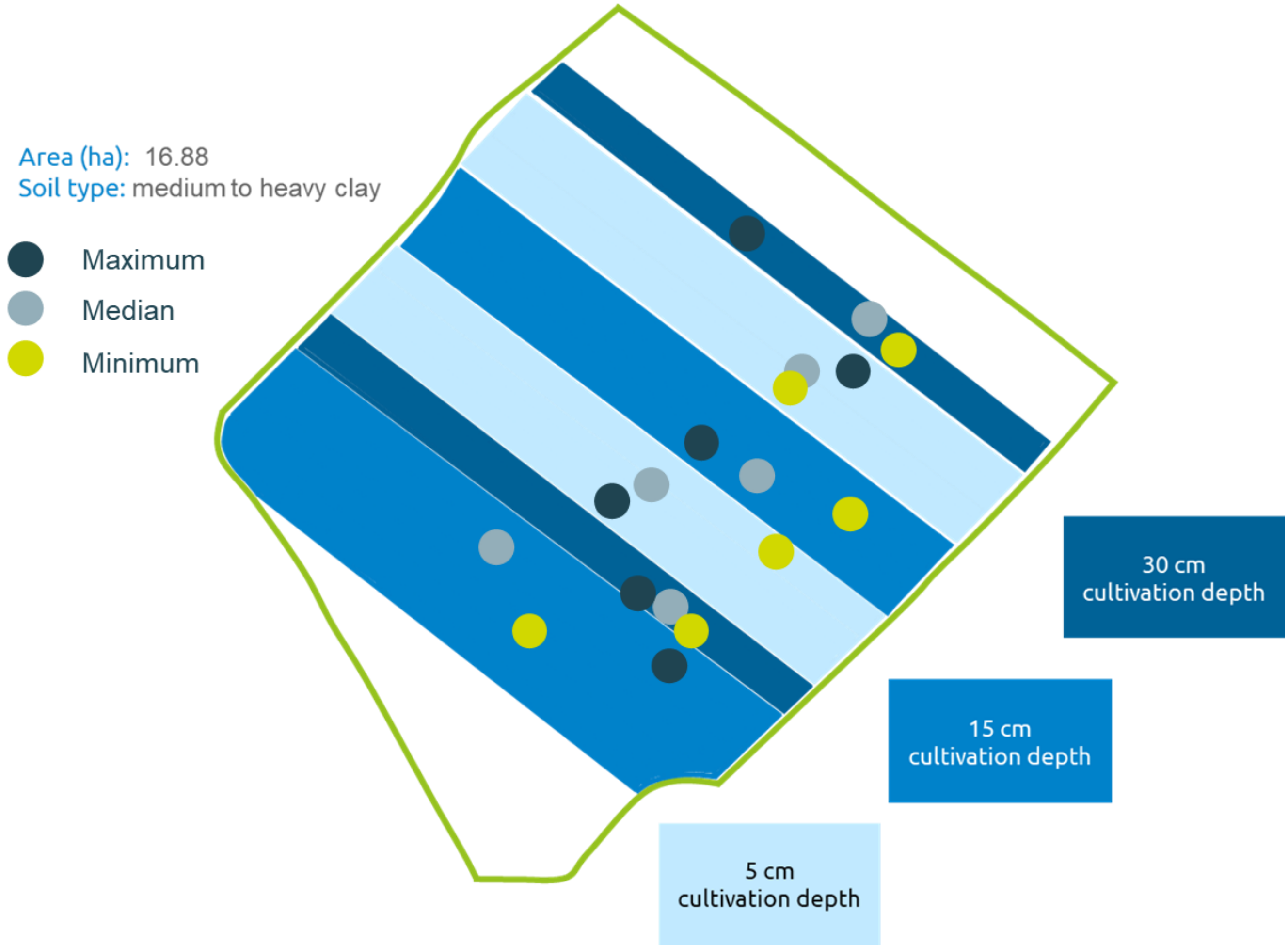


Figure 17. Cultivation map for Field 15. Positions of maximum, medium and minimum penetration resistance were chosen as sample points within each zone.

Soil

- Soil health, including topsoil bulk density (5-10cm depth), earthworm counts, microbial biomass C, and Visual Evaluation of Soil Structure (VESS) in spring 2019

Crop

- At GS30, GS31-33, GS39, GS61-65 and pre-harvest
- Biomass and tissue testing
- Yield

Rooting

- Shovelomics: an assessment of phenotypic traits in the root crown (Trachsel et al., 2011) completed by excavating the crop and the top 20-30cm of soil to assess root crown (number of tillers, nodal roots per tiller) and biomass in spring 2019 at GS30
- Root cores: soil cores to 1m depth between flowering and grain fill to determine root length density (RLD)

What results has the project delivered?

Topsoil properties

The draft Soil biology and Soil Health Partnership scorecard evaluated soil properties and identified key issues including below average soil organic matter levels, some evidence of soil compaction, indicated by VESS and bulk density, and a depleted earthworm population.

Soil health scorecard

Table 11. Soil health scorecard for Field 15

Treatment (cultivation depth)	5cm	15cm	30cm
Texture	Clay	Clay	Clay
% clay	38	39	39
SOM (%LOI)	4.1	4.1	4.1
pH	7.2	7.0	7.7
Ext. P (mg/l)	20	26	16
Ext. K (mg/l)	192	199	216
Ext. Mg (mg/l)	712	821	902
VESS score (limiting layer)	4	3	3
Bulk density (g/cm^3)	1.38	1.33	1.37
Earthworms (total number)	2	3	4
PMN (mg/kg)	50	45	65
Respiration (mg CO_2-C/kg)	121	121	110

No action needed Monitor Investigate

Note: benchmarks are subject to review. Results are an average of the two replicate tramlines per treatment

- **Soil type:** whole field > 35% clay (heavy textured)
- **SOM**: ≥ 4 and 5% is 'typical' for medium and heavy textured soils, respectively; texture is borderline heavy, so SOM levels are close to typical values
- **pH**: target pH > 6.5 for arable soils; see ahdb.org.uk/rb209 for specific crop advice
- **Ext. P, K & Mg**: No nutrients were limiting to crop production; Ext. Mg levels were elevated;
- **VESS:** A score of 4 indicates poor soil structure ('compact') and 3 indicates moderate soil structure ('firm') https://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure
- **Bulk density:** at 5-10cm, thresholds decrease with increasing SOM (benchmark = 1.26 g/cm^3 at 4% SOM)
- **Earthworms:** Total number of adults and juveniles; >8/pit = 'active' population for arable soils; < 4/pit = 'depleted'; very low numbers recorded across the field
- **PMN:** Potentially Mineralisable Nitrogen (a measure of microbial activity) – benchmark data is currently under review, but suggest no action required
- **Respiration**: A measure of soil microbial respiration – benchmark data is currently under review, but suggest no action is required

The effect of cultivation on penetrometer resistance and crop rooting

The shallow cultivation depth (5 cm) had significantly (*P*<0.05) greater penetration resistance in the top 10cm of soil, compared to 15 and 30 cm cultivation depths, as shown in the graph on the right (± SED). This increased topsoil resistance had no significant impact on aboveground biomass assessed at GS31, 39 and 61. Underlying subsoil compaction was present within the 30 cm cultivation depth tramlines.

The graph below shows the average root angle for each cultivation treatment, assessed at GS30 (± SED). There was a significant (*P*<0.05) positive association between penetration resistance at 15 cm depth and root angle (r=0.49). Crop root angle was greater (steeper), in the shallow cultivation depth, indicating that increased consolidation in the topsoil promoted downward growth of roots. Root growth becomes restricted at >1.5 MPa (Whalley et al. 2008).

RLD and root dry weight in the subsoil (80cm) post anthesis were positively associated (*P*<0.05) with a steeper root angle (r=0.55).

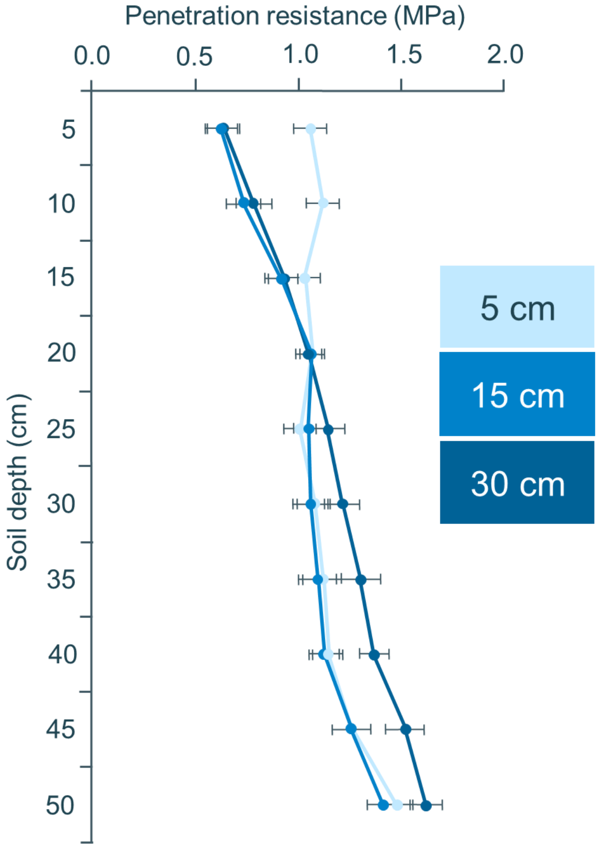


Figure 18. Penetration resistance (MPa) at 5 cm, 15 cm and 30 cm cultivation depths

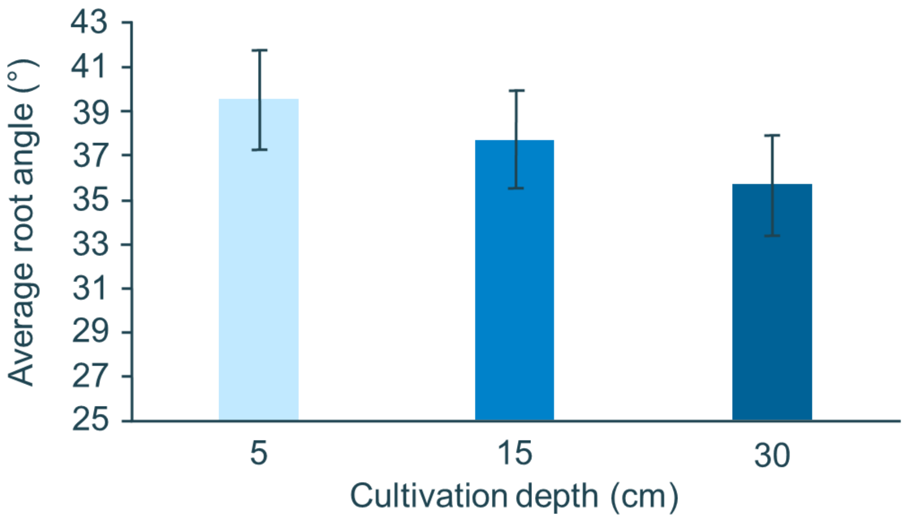
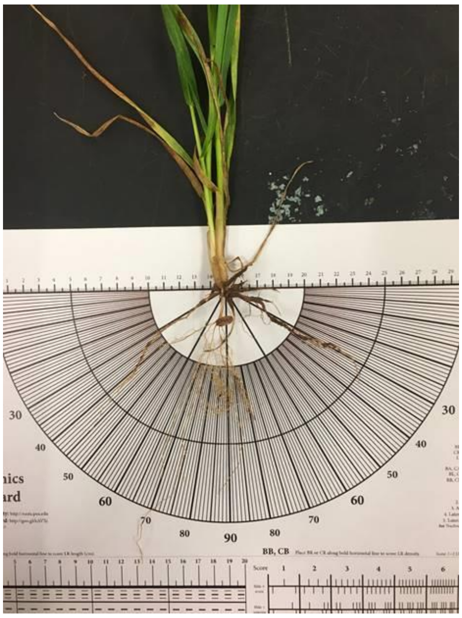


Figure 19. Average root angle at 5 cm, 15 cm and 30 cm cultivation depths

- Depth to maximum width: the vertical distance from the base of the shoot system to the point of maximum width
- Root system angle: the angle from the horizontal of the outermost roots on both sides of the crown at approximately 5 cm from the shoot base
- Whole crown branching density: the number of roots coming off the main axes, measured using a 1–5 scale, where 5 is the highest
- Nodal root length and number of nodal roots per tiller: nodal roots appear primarily on the crown, which is typically one to two centimetres below the soil surface
- Number of seminal roots: seminal roots emerge before the second leaf appears, sometimes referred to as primary roots, and generally grow deeper into the soil than nodal roots
- Root biomass: the total dry weight of live roots



Rooting and subsoil compaction

The association between RLD at 60 cm depth, measured post-anthesis, and penetrometer resistance at 25, 30, 35 and 40 cm depths, assessed at GS30 is shown in the graph below. Increased soil strength between 25 to 40 cm soil depth was associated with less rooting (RLD cm/cm^3) in the subsoil (60 cm soil depth). This negative association was statistically significant (*P*<0.05) (r =-0.67 to -0.75).

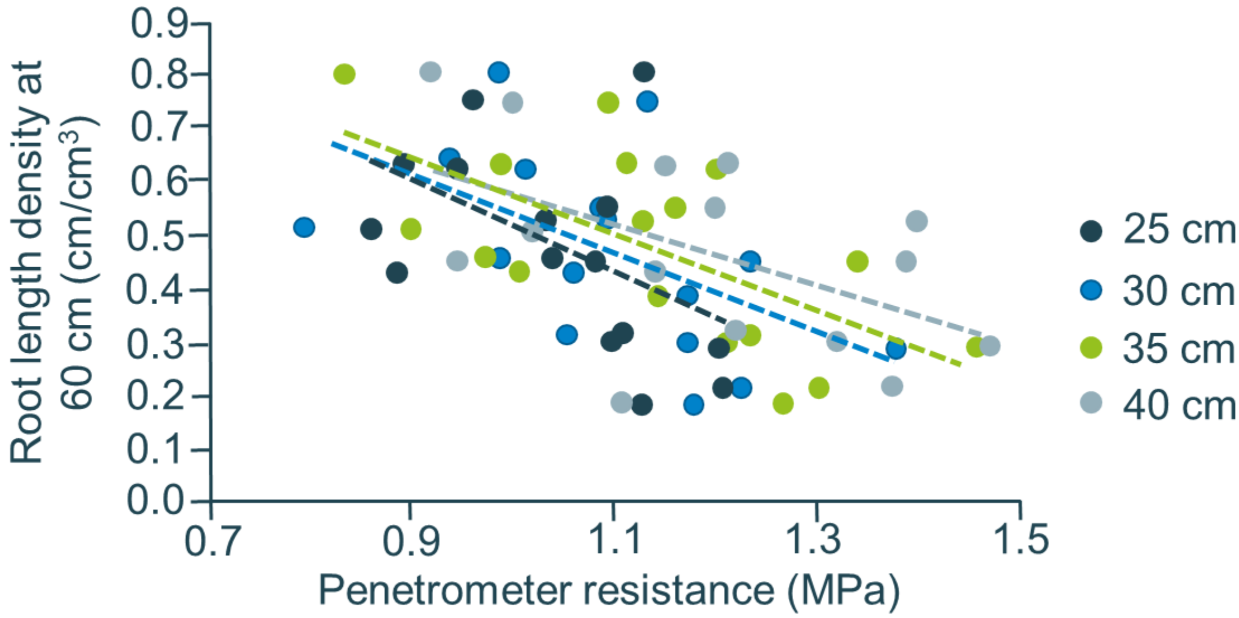


Figure 20. Association between root length density at 60 cm/cm3 and penetrometer resistance post-anthesis

Root and shoot associations

The association between RLD at 80 cm depth, measured post-anthesis, and crop tissue nitrogen (N) concentration at GS31 is shown in the graph below. Improved rooting in the subsoil was positively associated (P<0.05) with aboveground crop biomass at anthesis and increased tissue N concentration at GS31 (Fig. 5, r=0.64).

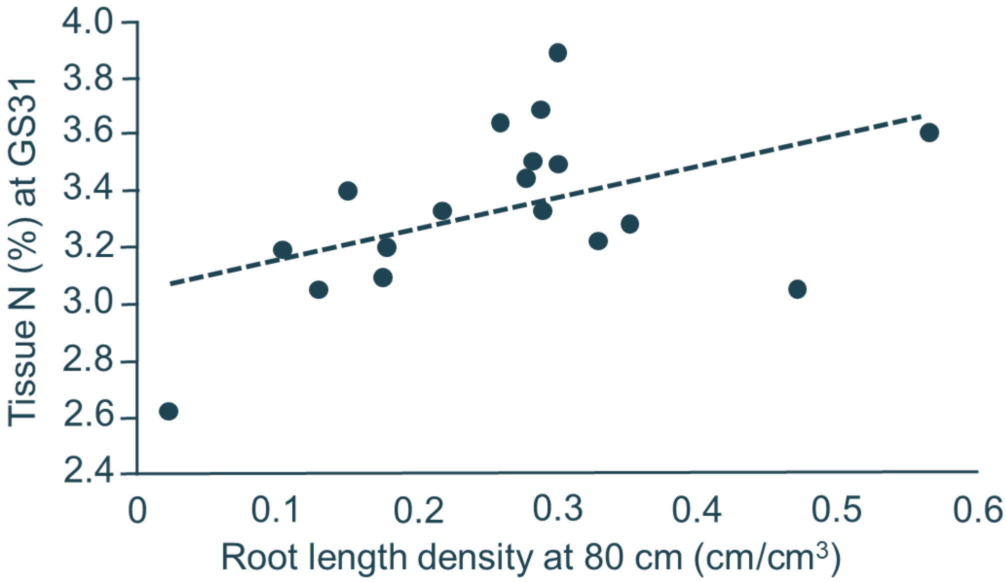
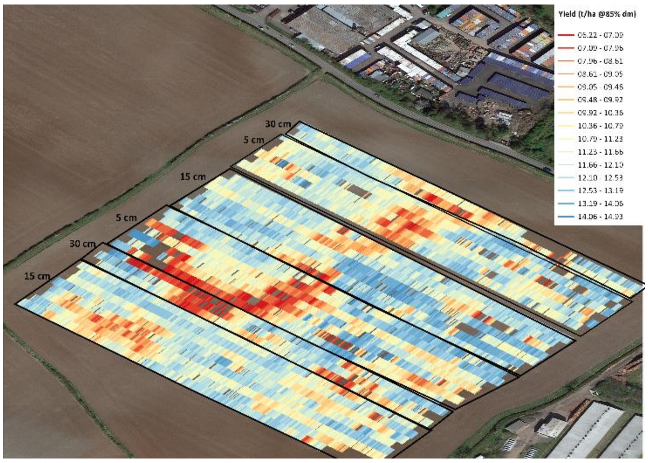


Figure 21. Association between root length density at 80cm/cm^3 and crop tissue nitrogen at GS31

Crop yield

Yield map data were analysed using ADAS Agronomics. Data were first cleaned to remove headlands, anomalous combine runs (header not full or spanning two treatment areas) and locally extreme data points. They were corrected for any offset created by changes in combine direction. A statistical model was fitted to the data to account for spatial effects along and across rows, and effects associated with the treatment(s). The statistical analysis estimated treatment effects and probabilities that these were due to the treatment, rather than being caused by background spatial variation.



The average measured yield for the 15 cm treatment was 11.57 t/ha. We estimated apparent treatment differences from this yield, after correcting for spatial variation within the field. For the 5 cm cultivation treatment a yield decrease of 0.44 ± 0.71 t/ha was estimated compared to the farm standard cultivation (15 cm), and for the 30 cm cultivation treatment a decrease of 0.77±0.84 t/ha was estimated. The statistical model indicated that the size of these yield differences could have been due to chance or other sources of variation, such as soil differences.

Figure 22 (left). Agronomics field map for Field 15

Table 12. Yield comparisons for 5 cm, 15 cm and 30 cm cultivation depths (Agronomics data: data cleansed to remove background variation)

Treatment	15 cm	5 cm	30 cm
Mean yield, t/ha	11.57		-
Estimated treatment effect, t/ha	-	-0.44 ± 0.71	-0.77± 0.84
Confidence in effect being due to the treatment	-	47%	64%

Costings

Table 13. Costings for 5 cm, 15 cm and 30 cm cultivation depths (Combine data: yields not analysed using Agronomics)

	5 cm	15 cm	30 cm
Yield (t/ha)	10.90	11.61	11.10
Variable Costs			
Total seed costs (£/ha)	77	77	77
Total fertilisers (£/ha)	183	183	183
Total crop protection (£/ha)	205	205	205
Total variable costs (£/ha)	464	464	464
Fixed costs			
Total labour, machinery and equipment (£/ha)	486	499	532
Total property and energy costs (£/ha)*	73	77	71
Total administration costs (£/ha)*	30	32	29
Cost of production (per hectare)			
Full economic cost of production (£/ha)	1,053	1,072	1,096
Cost of production (per tonne)			
Full economic cost of production (£/t)	97	92	99

**These costs are the West regional averages from Farmbench for harvest 2018*

Action points for farmers and agronomists

Regular monitoring of soil structural condition is vital at the field level to inform soil management decisions. The most effective and practical method for determining soil structure is the direct visual and physical examination of the soil profile (e.g. VESS). Earthworm counts are also a useful indicator of overall soil health, important in the development of good soil structure.

This cultivation trial is in the first year of reporting, the impact of cultivation treatments on soil quality and crop performance are best assessed over the long term, which we have the opportunity to do over the five years of the Strategic Farm programme.

Links to further information and references

- **Research Review No. 43**: Management of cereal root systems (online)
- **Student Report No. SR41**: Quantifying rooting at depth in a wheat doubled haploid population with introgression from wild emmer (online)
- Practical information on soil management and soil assessment methodologies can be found online: **ahdb.org.uk/greatsoils**
- Soil Biology and Health Partnership project: **ahdb.org.uk/greatsoils**
- Traschel, S., Kaeppler, S. M., Brown, K. M., Lynch, J. P. (2011) Shovelomics: High throughput phenotyping of maize (Zea mays L.) root architecture in the field *Plant and Soil*: 341; 75-87.
- Whalley, W. R. et al. (2008) The effect of soil strength on the yield of wheat *Plant and Soil*: 306; 237-247.
- White, Sylvester-Bradley & Berry (2015) Root length densities of UK wheat and oilseed rape crops with implications for water capture and yield. Journal of Experimental Botany 66 p2293-2303
- Jackie Stroud produced a simple methodology for assessing earthworm numbers under #60minuteworms initiative at **www.wormscience.org,** produced in an AHDB Factsheet: **ahdb.org.uk/knowledge-library/how-to-count-earthworms**

Notes

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- **Read blogs with Strategic Farm updates: cereals-blog.ahdb.org.uk/**
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