December 2023

Annual Project Report
(harvest 2023)

On-farm trials at
Strategic Cereal Farm North

AHDB Cereals & Oilseeds is a part of the Agriculture and Horticulture Development Board (AHDB).

CONTENTS

1. Introduction

Host Farmer: David Blacker
Location: Church Farm, North Yorkshire
Duration: 2022–2028

AHDB Strategic Cereal Farms put cutting-edge research and innovation into practice on commercial farms around the UK. Each farm hosts field-scale and farm-scale demonstrations, with experiences shared via on-farm and online events to the wider farming community.

Improving soil condition and economic yield are key areas of focus for the duration of the six-year Strategic Cereal Farm North project.

2. Soil baselining (work package 1)

Trial leader: Anne Bhogal
Start date: September 2021
End date: August 2023

2.1. Headlines

The overall objective of this work package was to carry out in-depth assessments on soil biology and soil health (in the topsoil and subsoil) linked to crop health.

In this first baselining year, the results show that topsoil chemical properties were generally good across all fields. However, both topsoil and subsoil structure tended to score poorly, with depleted earthworm numbers.

2.2. What was the challenge/demand for the work?

The first year aimed to identify barriers to yield. The topsoil across the farm has been analysed regularly over several years (largely in relation to nutrient status), but little assessment has been done in the lower topsoil and subsoil.

The fields assessed can experience drought and flooding in the same year, with varied soil types within the field. Pans of compaction, which encourage shallower rooting, can exacerbate the effect of dry weather. On the other hand, prolonged waterlogging can cause root death. When the soil is wetter than field capacity and drainage is occurring, soluble nutrients, such as nitrate, are leached to lower levels in the soil profile. Shallow rooting systems (because of compacted soils) can reduce nutrient and water uptake, to the detriment of yield.

Therefore, the aim of this work package is to carry out in-depth soil assessments in the topsoil and subsoil.

2.3. How did the project address this?

Soil baseline sampling was carried out across five fields. Each field was divided into two or three sampling zones according to soil texture, identified using shallow electrical conductivity (EC) maps (Table 1).

Table 1. Field site details including number of soil sampling zones

Field name	Previous crop (harvest 2022)	Current crop (harvest 2023)	Number of soil zones per field
New Farm 4	Spring beans	Winter wheat	2
New Farm 5	Spring beans	Winter wheat	2
Newton 1	Fallow in AB scheme	Winter wheat	3
Overton 4	Winter wheat	Winter beans	2
Overton 5	Half winter wheat, half drains installed	Winter beans	2

Topsoil assessments: chemical analysis, penetrometer resistance, VESS, bulk density, gravimetric moisture, bacterial:fungal ratio, earthworm count and division into ecotypes.

Upper subsoil to subsoil assessments: chemical analyses, penetrometer resistance, bulk density and gravimetric moisture, subVESS, plant total available water holding capacity and porosity.

2.4. Results (to date)

Soil health scorecard (Table 2)

Topsoil chemical properties (pH, Ext. P, K and Mg) were at or close to target levels for optimal crop production in most fields, except for the lighter-textured soil zones in Overton 4 and 5, where an application of lime would be beneficial. Some soil zones would also benefit from additional P (over and above maintenance requirements). Soil organic matter (SOM) was above average in most soil zones. The lowest SOM contents were measured on the lighter textured soils in Newton 1.

VESS scores indicated that overall topsoil structure was ‘firm’ and occasionally ‘compact to very compact’ with limiting layers found at about 10–15 cm depth. Supplementary measurements of bulk density (Table 3) were high in relation to the organic matter content, indicating that soils were compacted.

Earthworm numbers were low or depleted in all fields and comprised mainly juveniles, with only four adult endogeic (topsoil) worms recorded during the sampling of all fields, and no adult species recorded in Overton 4 or 5.

Table 2. Soil health scorecard results

Field Name	Zone	Crop	Texture	% clay	pH	SOM (%)	Ext P (mg/l)	Ext K (mg/l)	Ext Mg (mg/l)	VESS limiting layer score	Earthworms (no./pit)
New Farm 4	1	Wheat	Clay	38	6.9	7.0	13.0 (1)	193 (2+)	328 (5)	3.0	6
	2		Clay loam	30	6.6	5.4	17.6 (2)	160 (2-)	232 (4)	3.0	7
New Farm 5	1	Wheat	Clay	37	7.2	6.6	16.4 (2)	216 (2+)	259 (5)	4.5	2
	2		Sandy clay loam	21	6.8	4.0	20.0 (2)	184 (2+)	116 (3)	2.5	6
Newton 1	1	Wheat	Sandy clay loam	22	7	3.4	19.6 (2)	123 (2-)	235 (4)	2.5	4
	2			19	7.1	3.0	19.6 (2)	145 (2-)	172 (3)	3.0	3
	3		Sandy loam	15	6.9	3.3	31.4 (3)	174 (2-)	113 (3)	2.5	3
Overton 4	1	Beans	Clay	39	7	5.4	12.0 (1)	150 (2-)	361 (6)	3.0	4
	2		Sandy clay loam	29	6	3.7	16.0 (2)	127 (2-)	123 (3)	3.0	6
Overton 5	1c	Beans	Clay loam	34	6.1	4.7	10.8 (1)	143 (2-)	196 (4)	2.5	3
	2c		Clay	57	6.8	7.0	17.2 (2)	148 (2-)	365 (6)	3.5	2

Red = investigate, amber = review and green = continue rotational monitoring. VESS limiting layer score is the maximum score recorded to 25cm depth. VESS scores of 1 or 2 indicate good soil structure (friable/intact) indicating no changes needed; a score of 3 indicates moderate structure (firm) with long-term improvements required and scores of 4 or 5 poor soil structure (compact or very compact) with short term improvements required. For earthworms, Red indicates earthworm numbers are depleted. Green is an active population. Orange is intermediate.

Table 3. Topsoil bulk density measured for each soil zone

Field Name	Zone	Current crop	Bulk density (g/cm^3)
New Farm 4	1	Wheat	1.33
	2		1.50
New Farm 5	1	Wheat	1.39
	2		1.42
Newton 1	1	Wheat	1.51
	2		1.59
	3		1.56
Overton 4	1	Beans	1.36
	2		1.42
Overton 5	1c	Beans	1.39
	2c		1.28

Topsoil bulk density 'trigger' values are based upon land use and SOM content. Note trigger values have only been developed for topsoil horizons.

Lower topsoil (15–30 cm), SubVESS (25–65 cm) and penetrometer resistance

New Farm 4 and Overton 4:

- SubVESS scores indicated that soil structure was firm in both fields (Table 4)
- Penetrometer resistances were typically optimal for root growth (i.e. between 0.5 and 1.5 MPa), becoming more firm/partly compact with depth (Figure 1 and Figure 4)

New Farm 5:

- Consistent with topsoil VESS results, SubVESS showed that the clay zone soil was compact/very compact, while the sandy clay loam zone soil was firm
- Penetrometer measurements indicated that the clay zone soil had optimal resistances for root growth from about 5 cm to 40 cm depth. However, the sandy clay loam soil showed evidence of a notably firmer layer between about 25 cm and 35 cm where resistances were borderline in terms of potentially impeding root growth (> 1.5 MPa); (Figure 2)

Newton 1:

- SubVESS showed that the subsoil was firm across all soil zones
- Penetrometer resistance indicated that within zone 1 (sandy clay loam) there was a compact/very compact layer at about 35 cm to 50 cm depth (resistances > 1.5 MPa); and within zone 3 (sandy loam) a compact/very compact layer at 32 cm to 38 cm depth (Figure 3)

Overton 5:

- SubVESS showed that the subsoil was firm across all soil zones
- Penetrometer resistance indicated that there was a firm layer between about 30 cm and 60 cm in the lighter textured zone (clay loam), while the clay zone soil was firm from about 50 cm onwards (Figure 5)

Table 4. Lower topsoil (15–30 cm) and SubVESS (25–65 cm)

Field Name	Zone	Crop	Texture	Clay (%)	pH	SOM (%)	Sub VESS (25 – 60 cm) score
New Farm 4	1	Wheat	Clay	41	7.5	6.4	3.4
	2		Heavy Clay Loam	34	7.2	4.7	3.0
New Farm 5	1	Wheat	Clay	44	7.8	5.4	4
	2		Sandy Clay Loam	19	7	3.4	3.8
Newton 1	1	Wheat	Sandy Clay Loam	22	7.5	3.3	3.0
	2			22	7.3	3	3.0
	3		Sandy Loam	16	6.9	4	2.8
Overton 4	1	Beans	Clay	47	7.7	5.5	3.3
	2		Sandy Clay Loam	21	6.3	3.6	3.0
Overton 5	1c	Beans	Clay loam	30	6.4	3.8	4.2
	2c		Clay	42	7.1	5.4	4.4

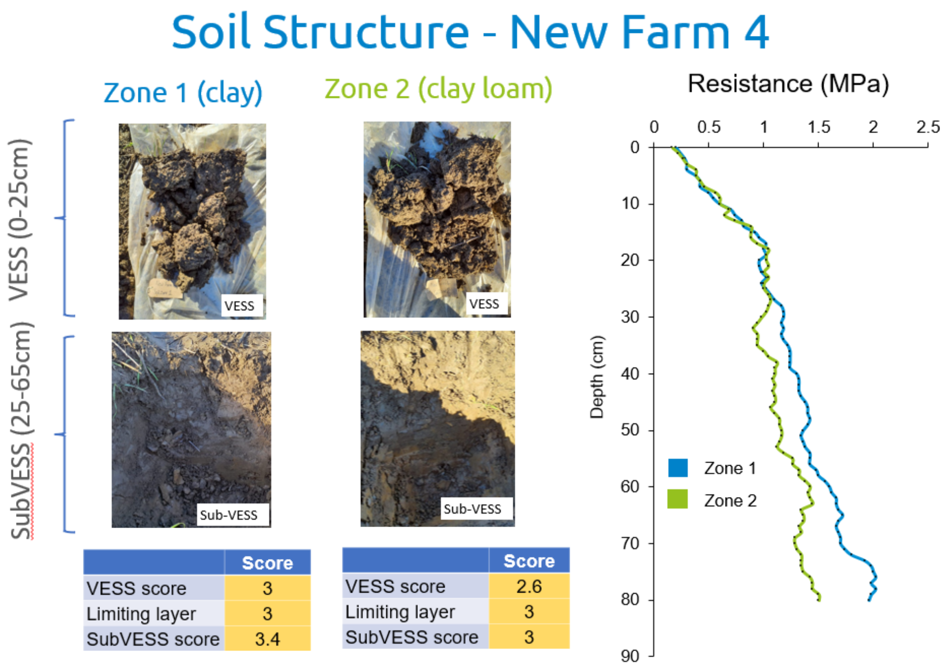

Figure 1. New Farm 4 VESS and SubVESS scores and photos from Zone 1 and 2, with corresponding penetrologer resistance (0–80 cm depth)

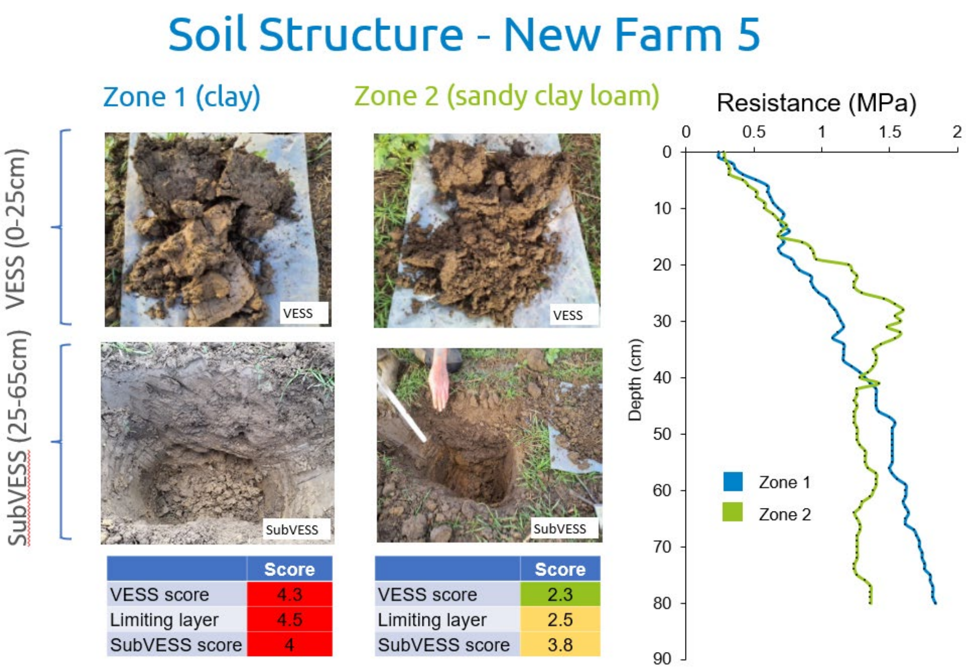

Figure 2. New Farm 5 VESS and SubVESS scores and photos from Zone 1 and 2, with corresponding penetrologer resistance (0–80 cm depth)

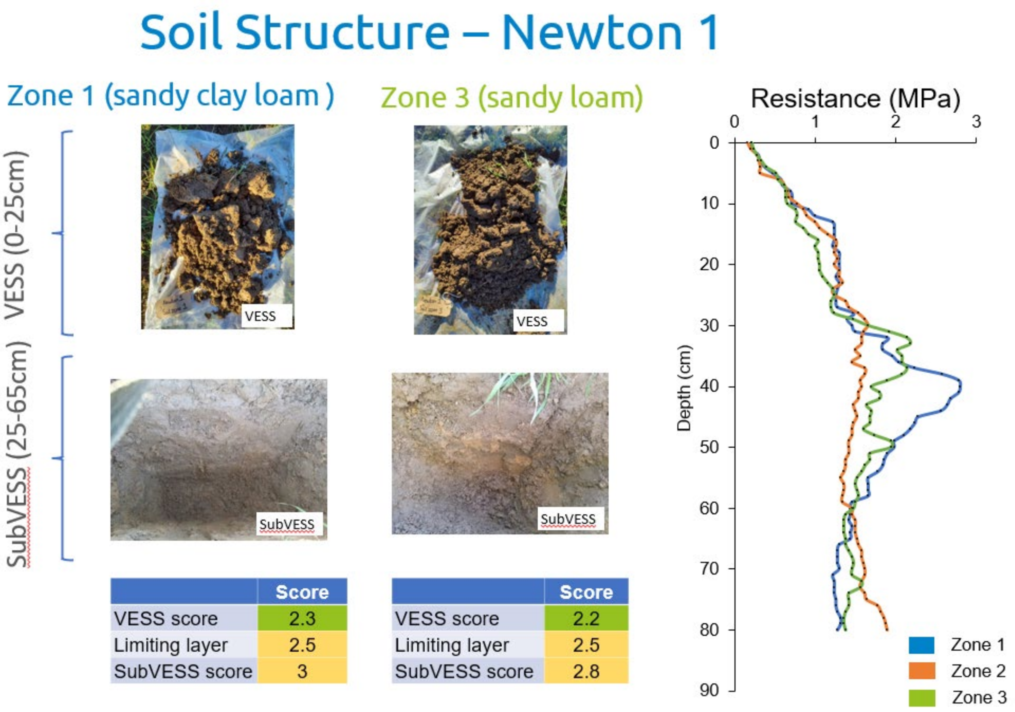

Figure 3. Newton 1 VESS and SubVESS scores and photos from Zone 1 and 3, with corresponding penetrologer resistance (0–80 cm depth)

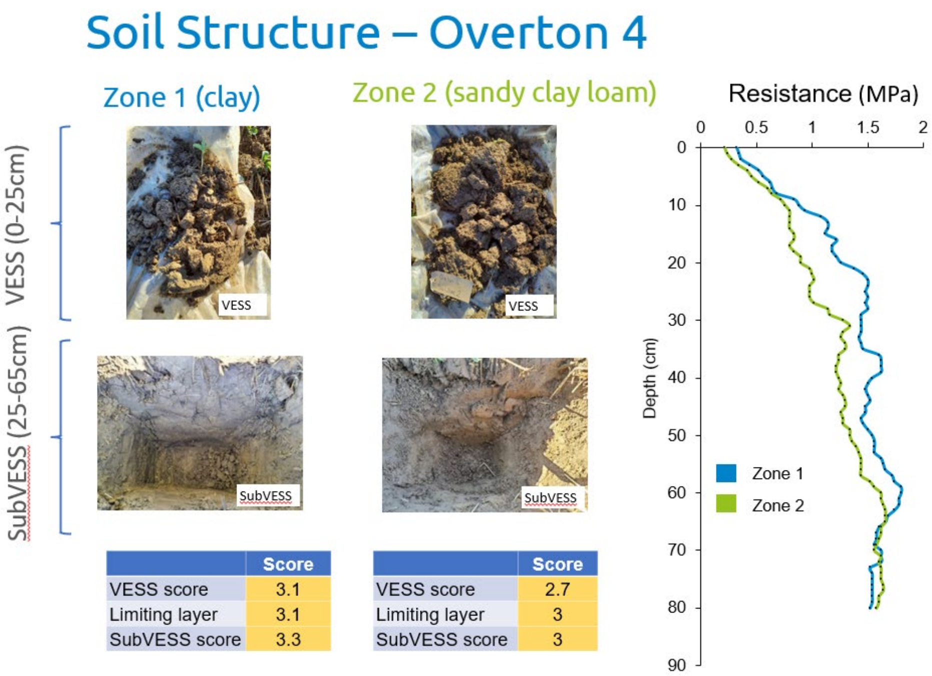

Figure 4. Overton 4 VESS and SubVESS scores and photos from Zone 1 and 2, with corresponding penetrologer resistance (0–80 cm depth)

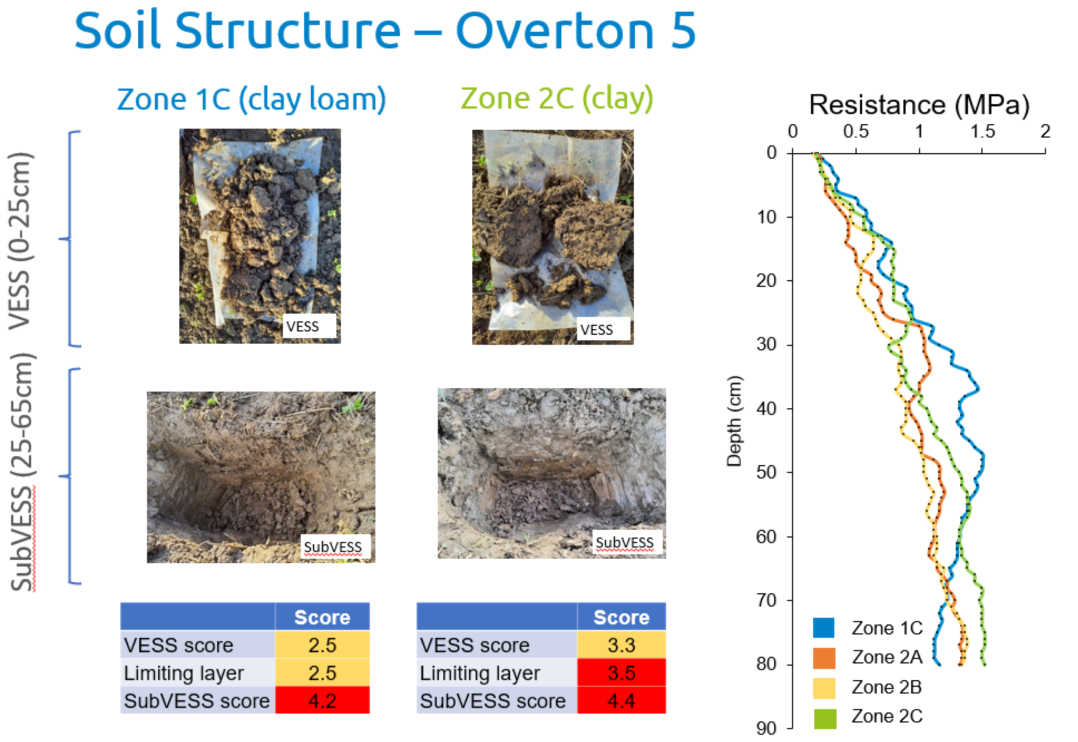

Figure 5. Overton 5 VESS and SubVESS scores and photos from Zone 1 and 2, with corresponding penetrologer resistance (0–80 cm depth)

Soil water availability and total porosity

Soils with a greater clay content typically have a high total water holding capacity, due to having more smaller sized pores (which hold on to water more tightly) compared to lighter textured soils. Soil structural condition also influences pore size distribution and the ability of a soil to store and release water. Compacted soils (i.e. indicated by a higher bulk density or VESS/subVESS scores) will have a lower total porosity consisting of smaller sized pores (on heavier clay soils this can result in waterlogging).

During this baselining year, the soil assessments indicate that:

- There was a positive correlation between clay content (%) and soil moisture at both field capacity (R^2 = 87%) and at permanent wilting point (R^2 = 93%), demonstrating that soils with a higher clay content can hold more water, but that water may not be all readily available for plant uptake
- Available water capacity for the lower topsoil ranged from 11% to 21%, being lowest on the clay soil zones in each field, and highest on the lighter textured soils in Newton 1. This was largely due to differences in the moisture content at permanent wilting point, which was higher on the heavier textured soils

Table 5. Lower topsoil (15-30 cm) soil moisture availability results

Field Name	Zone	Crop	Texture	Clay	Organic matter	Bulk density	Moisture at field capacity	Moisture at permanent wilting point	Available water capacity
				%	LOI %	g/cm^3	% v/v	% v/v	%
New Farm 4	1	Wheat	Clay	41	6.4	1.60	43.7	32.4	11.3
	2		Heavy Clay Loam	34	4.7	1.65	38.0	22.9	15.2
New Farm 5	1	Wheat	Clay	44	5.4	1.65	43.5	32.3	11.2
	2		Sandy Clay Loam	19	3.4	1.73	31.5	15.5	16.0
Newton 1	1	Wheat	Sandy Clay Loam	22	3.3	1.70	35.3	18.1	17.2
	2			22	3	1.77	35.1	15.4	19.7
	3		Sandy Loam	16	4	1.60	33.1	12.3	20.8
Overton 4	1	Beans	Clay	47	5.5	1.60	41.6	30.5	11.1
	2		Sandy Clay Loam	21	3.6	1.63	34.1	18.8	15.3
Overton 5	1c	Beans	Clay loam	30	3.8	1.46	41.1	22.2	18.8
	2c		Clay	42	5.4	1.38	46.4	29.2	17.2

Topsoil soil carbon stocks

Soil carbon stock (t/ha) is calculated from measurements of soil organic carbon (SOC %), bulk density and depth, correcting for any stones present.

Baseline total soil carbon stocks were measured for each soil zone, at both 0–15 cm and 15–30 cm soil depth, with total SOC content summed to give the carbon stock for 0–30 cm depth (Table 6).

- SOC stocks to 30 cm depth ranged from 62 to 124 t/ha. This compares to a typical carbon stock of arable land (to 30 cm depth) in England of 70 t/ha (National Soils Inventory data, from Bradley *et al.*, 2005)
- Differences between fields and zones in total SOC stock are not only due to differences in the carbon concentration (i.e. % SOC) but also the amount of soil in the sampling depth (which is linked to the level of compaction). For example, the high carbon stock (at 103t SOC/ha) measured in Newton 1, zone 3 is due to a combination of both a relatively high soil bulk density (*c*.1.6%) and SOC% (2.2%) in both the topsoil and lower topsoil

Table 6. Soil Carbon stocks (t/ha), calculation based on SOC%, bulk density and stone content at both 0-15 cm and 15-30cm depth. Results are summed to give a total carbon stock 0-30cm depth (t/ha)

Field Name	Zone	Current crop	Textural class	Carbon stock (t/ha)	Textural class	Carbon stock (t/ha)	Carbon stock (t/ha)
			(0–15 cm)		(15–30 cm)		(0–30cm)
New Farm 4	1	Wheat	Heavy	68	Heavy	56	124
	2		Medium	58	Medium	40	98
New Farm 5	1	Wheat	Heavy	58	Heavy	50	108
	2		Medium	42	Medium	40	82
Newton 1	1	Wheat	Medium	29	Medium	33	62
	2		Medium	38	Medium	31	69
	3		Light	51	Light	52	103
Overton 4	1	Beans	Heavy	47	Heavy	37	84
	2		Medium	28	Medium	34	62
Overton 5	1c	Beans	Medium	38	Medium	33	71
	2c		Heavy	54	Heavy	49	103

Next steps

Links between soil baseline condition and crop performance and rooting will be explored in the work package 2. It is envisaged that further assessments of soil health will be undertaken in years 3, 5 and 6 of the Strategic Cereal Farm North programme to see how soils change over time in relation to crop and soil management, as well as weather patterns.

2.5. Action points for farmers and agronomists

The assessments aim to capture interactions between soil physics, chemistry and biology, with topsoil assessments following the AHDB and BBRO soil health scorecard methodology.

The baselining results highlight that to improve soil health, management practices should be implemented which improve soil structure and earthworm populations.

When baselining soils, it is important to first divide fields into soil texture zones. The scorecard sampling protocol explains how and when to carry out the assessments and gives practical guidance for management interventions.

Soil health scorecard guidance: ahdb.org.uk/scorecard

3. Crop health (work package 2)

Trial leader: Charlotte White
Start date: September 2022
End date: December 2023

3.1. Headline

The objective was to assess the impact of soil health on plant development and performance and evaluate if there is a correlation with soil nutrient availability. In this first baselining year, nitrogen levels in both wheat and bean tissue samples were low. Rooting was variable between and within fields. Wheat grain nutrient analysis indicated that nitrogen was probably limiting. Phosphorous, sulphur and manganese grain concentrations were also low. However, yields ranged from 7.9 t/ha to 12.1 t/ha, depending on the field and soil zone. In beans, both calcium and molybdenum bean concentrations were low, indicating a potential deficiency in these nutrients. The bean crop grab sample results were generally lower than the bean YEN averages, however the average yield was high at about 4.6 t/ha.

3.2. What was the challenge/demand for the work?

The aim of the first year of the programme is to identify barriers to yield.

Crop development can help determine the effect of soil on the growing crop. Research Review 43[1] notes that poor rooting can limit growth due to low uptake of water or nutrients.

Root systems respond dynamically to soil conditions, with some of the clearest examples of yield loss due to poor rooting from studies on soil compaction. In some clay soils, rooting in the subsoil is only possible through structural cracks and wormholes, so not all available water is accessible by the crop.

Therefore, the aim of this work package was to measure plant rooting, development and performance and, linked to work package 1, evaluate if there is a correlation with soil health, structure and nutrient availability.

3.3. How did the project address this?

Field crop assessments were carried out in the same five fields at Strategic Cereal Farm North as the soil baselining (work package 1).

The fields were divided into two or three sampling zones according to the soil texture, with soil assessments undertaken in all zones but only a single zone selected for crop assessments in each field (see Table 7 and Figure 6).

Additional zones were selected for root assessment and YEN nutrition to gather more information on the crop after looking at soil assessment results.

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[1] Lucas, M.E., Hoad, S.P., Russell, G. & Bingham, I.J. (2000) Management of cereal root systems. HGCA Research Review 43. Management of cereal root systems.pdf (windows.net)

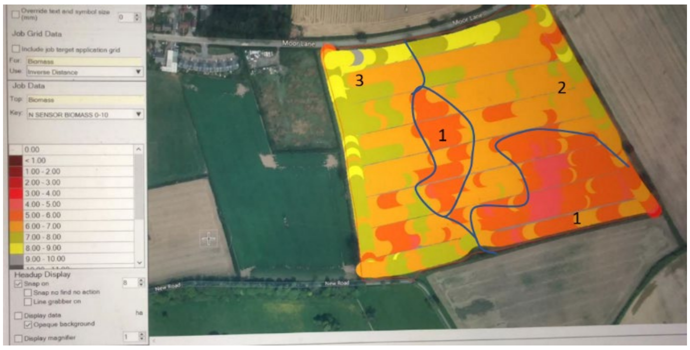


Figure 6a. Newton 1

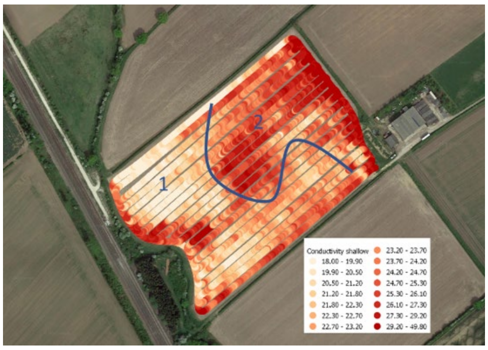


Figure 6b. New Farm 4

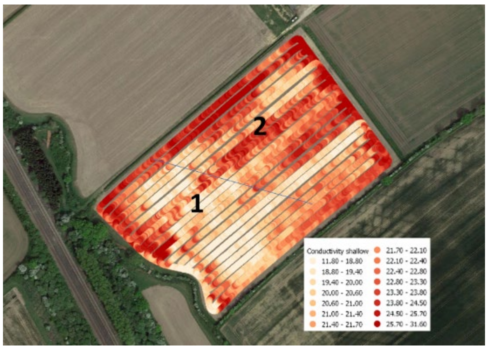


Figure 6c. New Farm 5

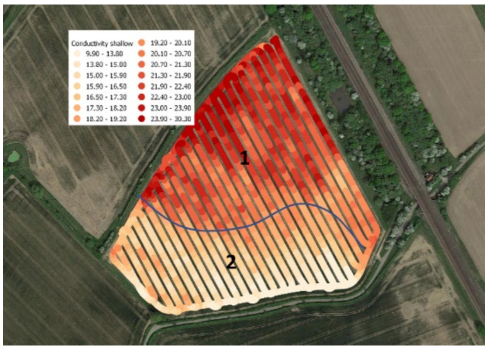


Figure 6d. Overton 4

Figure 6. Shallow electrical conductivity maps (fields b, c and d) and an N-sensor map (field a) and respective sampling zones

Table 7. Trial details for four fields in the crop health assessment trials

Field	Crop (variety)	Drilling date and seed rate	Total nitrogen applied	Crop sampling zone	Root sampling zone	YEN Nutrition zone
Newton 1	Winter wheat (Graham)	21/09/2022 440 seeds/m^2	164 kg N/ha	Zone 2	Zone 1 & Zone 2	Zone 2
New Farm 4	Winter wheat (Champion)	06/10/2022 480 seeds/m^2	150 kg N/ha	Zone 2	Zone 2	Zone 2
New Farm 5	Winter wheat (Graham)	17/09/2022 420 seeds/m^2	158 kg N/ha	Zone 1	Zone 1 & Zone 2	Zone 1 & Zone 2
Overton 4	Winter beans (Tundra)	04/10/2022 25 seeds/m^2	N/A	Zone 2	Zone 2	Zone 2

Crop assessments were taken at the following growth stages:

- Emergence: winter wheat GS13 and spring/winter beans GS10
  - Plant counts
  - Growth stage
  - NDVI and NDRE
- Ear emergence: GS51–59
  - Growth stage
  - NDVI and NDRE
- Flowering and milky ripe: winter wheat GS71 and winter beans GS63
  - Plant and tiller/stem counts
  - Growth stage
  - NDVI and NDRE (beans only)
  - Tissue analysis
- Pre-harvest*
  - Plant counts and tiller/stem counts
  - Growth stage
  - Biomass/tissue analysis
- Post-harvest
  - Soil cores for root analysis

*New Farm 4 and New Farm 5 were harvested before pre-harvest grab samples could be taken.

Normalised Difference Vegetation Index (NDVI) can be a useful indicator of canopy cover and greenness of the crop.

Normalised Difference Red Edge (NDRE) can be a useful indicator to chlorophyll content and crop nitrogen status, especially later in the season, when full canopy cover has been reached and NDVI becomes saturated.

3.4. Results (to date)

In this first (baselining) year, the crops were assessed at different points throughout the season to check against benchmarks and the soil baselining results (work package 1).

Emergence

At emergence, the three winter wheat fields were at similar growth stages and the plant population ranged between 135 and 200 plants/m^2, lower than the wheat growth guide[2] benchmark of 260 plants/m^2. Compared to the seed rate (420–480 seeds/m^2), the percentage establishment was low ranging from 28–45%.

Table 8. Mean emergence assessment results

Field	Growth stage	Plants/m^2	NDRE	NDVI
Newton 1	GS14	200	0.200	0.511
New Farm 4	GS14	135	0.156	0.402
New Farm 5	GS14	187	0.120	0.290
Overton 4	GS13	-	0.072	0.168

Ear emergence

When vegetation indices were assessed at the second assessment timing, there was more variation in the winter wheat fields than at establishment, with Newton 1 being the most ahead (GS57) and New Farm 4 being the most behind (GS51). This would be expected as New Farm 4 was drilled later, compared to the other two fields. The NDVI and NDRE values varied accordingly, with Newton 1 having the highest NDRE and NDVI values and New Farm 4 the lowest (Table 9).

Table 9. Mean ear emergence assessment results

Field	Growth stage	NDRE	NDVI
Newton 1	GS57	0.406	0.811
New Farm 4	GS51	0.290	0.660
New Farm 5	GS53	0.358	0.785

[2] Wheat Growth Guide https://ahdb.org.uk/knowledge-library/wheat-growth-guide

Milky ripe and flowering

The winter wheat assessments were taken later than planned, at milky ripe rather than flowering (Table 10). The plant population was similar between fields, ranging from 183 plants/m^2 in New Farm 4 to 191 plants/m^2 in Newton 1.

Variation between the plant population measured at the establishment timing and the milky-ripe timing is likely to be the result of infield variation between the sampling sites. However, there was a large variation in tiller number between the fields, with New Farm 4 having 375 tillers/m^2, the lowest of the three winter wheat fields, and Newton 1 had the greatest number of tillers at 529 tillers/m^2. For context the benchmark number of fertile shoots at flowering is 460/m^2.

The winter bean crop in Overton 4 was assessed at flowering (GS63) and had 60 shoots/m^2 on average.

Table 10. Mean flowering and milky ripe assessment results

Field	Growth stage	Plants/m^2	Tiller/m^2 Shoots/m^2	Ears/m^2	NDRE	NDVI
Newton 1	GS71	191	529	512	-	-
New Farm 4	GS71	183	375	327	-	-
New Farm 5	GS71	201	480	463	-	-
Overton 4	GS63	-	60	-	0.316	0.773

Tissue analysis No. 1 (winter wheat milky-ripe and winter beans flowering)

The winter wheat crop in Newton 1 had the highest nitrogen concentration at 1.33% and New Farm 4 the lowest at 1.04% (Table 11), although the differences in total N applied between the fields was small (< 15 kg/ha, Table 7), Newton 1 received the most nitrogen and New Farm 4 the least. New Farm 4 was also the field with the lowest percentage of nearly all the nutrients tested apart from potassium, copper and Iron. Newton 1 also had the highest concentration of calcium (24 %), manganese (39 mg/kg) and boron (4.2 mg/kg) compared to the other two fields. While New Farm 5 had the highest amount of potassium (1.63 %), sulphur (0.18 %) and copper (4.1 mg/kg). These nitrogen and potassium levels are generally low. New Farm 4 had the lowest nitrogen concentration and yielded much lower compared to the other two fields.

The winter bean crop in Overton 4 had 3.8 % w/v tissue concentration of nitrogen, which is lower than the long-term bean YEN dataset (leaf samples) average of 5.4% N. The phosphorus and sulphur concentrations were also low compared to the bean YEN long-term average of 0.4% and 0.3 %, respectively.

Table 11. Winter wheat milky ripe and winter bean flowering whole crop tissue analysis results

Field	Nitrogen % w/w	Phosphorus %	Potassium %	Calcium %	Magnesium %	Sulphur %	Manganese mg/kg	Copper mg/kg	Zinc mg/kg	Iron mg/kg	Boron mg/kg
Newton 1	1.33	0.23	1.26	0.24	0.11	0.13	39	3.6	18.2	206	4.2
New Farm 4	1.04	0.20	1.30	0.15	0.09	0.12	35.8	3.7	17.6	213	2.5
New Farm 5	1.20	0.23	1.36	0.20	0.11	0.18	36.1	4.1	18.2	152	2.7
Overton 4	3.83	0.33	2.16	0.66	0.19	0.13	36.4	10.4	27.4	116	23.8

Pre-harvest disease assessments

All fields received a full fungicide programme, which effectively managed disease (Table 12), with only low levels of septoria (< 3% severity) and trace amounts of brown rust recorded (< 1%) in the wheat. Some eyespot was recorded in Newton 1 and New Farm 5, which has been presented as a severity index out of 100. Very few stems showed eyespot symptoms and the score was very low (< 3%).

When comparing green leaf area (GLA) values, there did appear to be more green leaf area remaining in New Farm 4 than either of the other two fields. New Farm 4 was drilled with Champion, whereas the other two fields were drilled in Graham, Champion is slightly later to mature than Graham with a ripening score of 0 on the AHDB recommended list, compared to -1 for Graham, which explains this result. New Farm 5 had the lowest GLA remaining. Within fields, the differences between zones were generally smaller than between fields. In Newton 1, GLA in zone 2 was lower than 1 and 3. In both New Farm 4 and 5, GLA in zone 2 was lower than 1. Maintaining GLA later into the season usually results in higher yields by extending the grain filling period.

Table 12. Winter wheat fields disease severity (%) and green leaf area (GLA, %) and stem disease index score, assessed pre-harvest at the following growth stages: Newton 1, GS83, New Farm 4 GS77, New Farm 5 GS83

Field		Leaf 1			Leaf 2			Stems		
	Zone	Septoria	Brown rust	GLA	Septoria	Brown rust	GLA	Eyespot	Sharp eyespot	Fusarium
Newton 1	1	0.66	0.00	34	1.5	0.00	16	1.3	0.0	0.00
	2	0.20	0.00	25	0.5	0.00	4	0.0	2.0	0.00
	3	0.76	0.01	37	1.1	0.00	19	0.0	0.7	0.00
	Mean	0.53	0.00	32	1.0	0.00	13	0.4	0.9	0.00
New Farm 4	1	0.70	0.01	74	2.0	0.00	36	0.0	0.0	0.0
	2	0.86	0.00	65	3.0	0.00	15	0.0	0.0	0.0
	Mean	0.78	0.005	69	2.4	0.00	25	0.0	0.0	0.0
New Farm 5	1	2.86	0.03	26	1.0	0.01	5	2.0	0.0	0.0
	2	1.05	0.00	5	0	0	0	1.3	0.0	0.0
	Mean	2.20	0.02	15	0.5	0.005	2	1.7	0.0	0.0

Disease severity in the spring beans was also low, with less than 2% severity for downy mildew, leaf spot, chocolate spot or bean rust. As a result, GLA values all exceeded 90%. There were no clear differences between the different zone types.

Table 13. Winter bean disease severity (%) and green leaf area (GLA, %) assessed pre-harvest (GS75)

Field	Zone	Downy mildew	Leaf spot	Chocolate spot	Bean rust	GLA
Overton 4	1	0.25	0	1.17	0.16	95
	2	0.12	0	0.23	0.06	98
	Mean	0.19	0	0.70	0.11	97

Pre-harvest samples, grain quality and nutrition

The winter wheat pre-harvest sample results for Newton 1 (winter wheat) can be seen in Table 14. The samples were taken at GS91 (grain hard, difficult to divide) and there were 675 ears/m^2, which is higher than the AHDB benchmark of 460 ears/m^2. There were 22,196 grains/m^2, which is around the benchmark number of 22,000 grains/m^2. The crop had a total biomass of 19.4 t/ha with a Harvest index of 48%. The thousand grain weight was 49.3 g. Using the grain N results (Table 17) the nitrogen harvest index (NHI) was calculated to be 78%. Overall, these results are in-line with benchmarks (wheat growth guide).

Table 14. Mean Newton 1 pre-harvest grab sample, tissue analysis and grain quality results

Field	Growth stage	Ears/m^2	Total biomass t/ha	DMHI %	TGW at 15% moisture (g)	Grains/ear	Grains/m^2	NHI %
Newton 1	GS 91	675	19.4	48.0	49.3	33.3	22,196	78.0

The winter bean pre-harvest sample results for Overton 4 can be seen in Table 15. The samples were taken at GS89, fully ripe, nearly all pods dark, seeds dry and hard. There were 35 plants/m2 with 1.7 shoots/plant, which is close to the 1.8 shoots/plant average from the bean YEN data set, but higher than the 1.4 shoots per plant from the crops which were in the top 25% of ranked yields. The crop had a HI of 47%, which is lower than the average of 0.53 in the bean YEN dataset and lower than the 55% average of the crops in the top 25% of ranked yields. TSW was 417 g which is low compared to the average of 693 g from the bean YEN data set.

Table 15. Mean Overton 4 pre-harvest grab sample, tissue analysis and grain quality results

Field	Growth stage	Plants/m^2	Shoot/plant	Total biomass t/ha	DMHI %	TSW at 15% moisture (g)	NHI %
Overton 4	GS 89	35	1.73	21.2	47.3	417	65

Table 16. Mean pre-harvest grab sample tissue (straw and chaff) analysis results

Field	Nitrogen % w/w	Phosphorus %	Potassium %	Calcium %	Magnesium %	Sulphur %	Manganese mg/kg	Copper mg/kg	Zinc mg/kg	Iron mg/kg	Boron mg/kg
Newton 1	0.43	0.04	0.56	0.26	0.06	0.07	26.9	1.80	5.60	51.4	2.40
Overton 4	2.29	0.17	1.71	0.58	0.17	0.11	27.6	8.5	20.2	47.2	28.2

Grain nutrition results

The grain nutrition results are summarised in Table 17. The grain samples were entered into YEN nutrition and more detailed analysis and interpretation for these samples can be obtained from the YEN nutrition reports.

For Overton 4 winter beans both calcium and molybdenum bean concentrations were at or below the YEN low values, which can indicate a potential deficiency in these nutrients. The bean nitrogen concentration was high compared to the previous 75% of bean YEN entries. Interestingly, in the bean YEN, grain potassium concentration has been associated with high yields, with the top 25% of entrants for yield having an average of 1.19% K in the bean. Overton 4 had a higher amount than this, at 1.21% K.

In each of the wheat fields, the grain nitrogen concentrations were low, which indicates that N was probably limiting, possibly due to limited N uptake. In New Farm 4 and 5 Zone 2, the phosphorous concentrations were also low. Additionally in New Farm 4 and 5, sulphur and manganese concentrations were low. Although the zinc values were flagged as low, they were still above the critical value of 15 mg/kg.

Table 17. Mean grain nutrition results, cells highlighted in yellow indicate those nutrients that are below YEN-low values (below 75% of all previous YEN results for this crop type); cells highlighted in blue indicate those nutrients that are above YEN-high values (above 75% of all previous YEN results for this crop type)

Field	N %	P %	K %	Mg %	S %	B mg/kg	Ca %
Newton 1	1.66	0.33	0.51	0.12	0.13	1.33	0.05
New Farm 4 zone 2	1.71	0.25	0.41	0.09	0.09	1.09	0.03
New Farm 5 Zone 1	1.74	0.27	0.43	0.09	0.10	0.94	0.04
New Farm 5 Zone 2	1.70	0.25	0.42	0.09	0.10	1.25	0.03
Overton 4	4.83	0.53	1.21	0.15	0.21	10.34	0.11

Field	Cu mg/kg	Fe mg/kg	Mn mg/kg	Mo mg/kg	Zn mg/kg	N:P ratio	N:S ratio
Newton 1	4.5	51.3	30.8	0.91	26.7	5.03	12.8
New Farm 4 zone 2	3.5	49.6	16.1	1.09	16.2	6.81	18.2
New Farm 5 Zone 1	3.1	45.3	16.4	0.74	17.1	6.37	17.6
New Farm 5 Zone 2	3.9	38.8	16.3	0.59	17.8	6.88	17.5
Overton 4	15.5	75.2	16.7	0.41	49	9.11	23.0

Rooting

Crop rooting to 1 m depth was assessed in each field.

Newton 1 (Zones 1 & 2):

The root length density (RLD, cm/cm^3) was not statistically different between the two zones (Figure 7). Although, zone 2 was less well rooted between 20 cm and 40 cm soil depth compared to zone 1. The critical RLD for extracting available soil water is 1 cm/cm^3, and in Newton 1 RLDs were less than this below 30 cm depth, which is typical for wheat crops in the UK (white *et al*., 2015). The average root diameter for both zones was 0.22 mm.

The average root dry weight for zone 1 was 0.113 mg/cm^{3,} which was greater than that of zone 2 (0.079 mg/cm^3), but this difference was not statistically significant.

Although, there was a marked increase in soil strength in zone 1 at around 35–50 cm depth in March (Figure 7) this didn't appear to have had a dramatic effect on crop rooting when assessed post-harvest. Counterintuitively, Zone 2 appeared to be less well rooted compared to zone 1 between 30 and 70 cm depth.

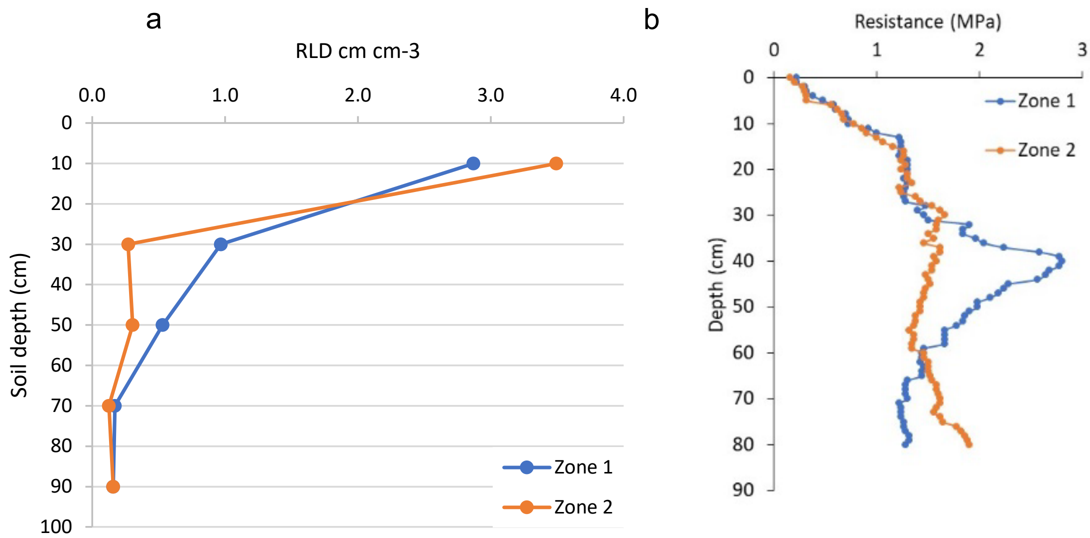


Figure 7a. Root length density (RLD, cm.cm^3) from Newton 1 taken just after harvest in zone 1 and Zone 2. Figure 7b Penetrologer resistance in March (work package 1 soil baselining report)

New Farm 4 (Zone 2):

The RLD in the top 20cm was very high (Figure 8) compared to expectations (typically between 0.5 to 3.75 cm/cm^3; White et al., 2015). The lower horizons were all well rooted and were either above or just below the critical RLD of 1 cm/cm^3. This is consistent with the penetrometer results. The average root diameter was 0.22 mm as would be expected and the average root dry weight was 0.17 mg/cm^3.

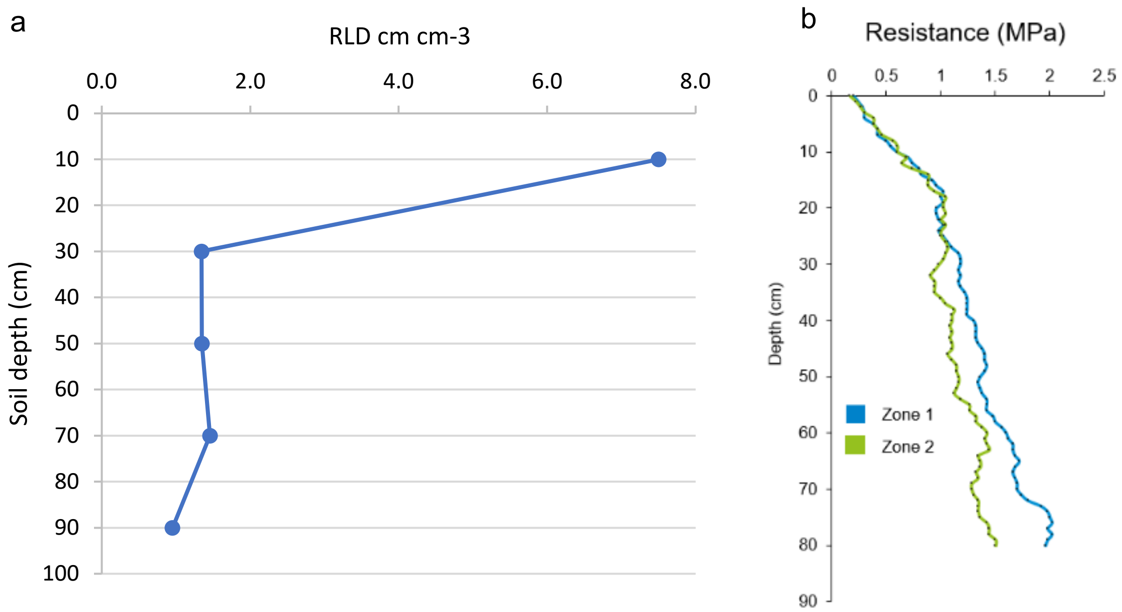


Figure 8a. Root length density (RLD, cm.cm^3) from New Farm 4 taken just after harvest in zone 1. Figure 8b. Penetrologer resistance in March (work package 1 soil baselining report)

New Farm 5 (Zones 1 & 2):

The RLDs in New Farm 5 were also higher than expectations for the top 20 cm (Figure 9 a). The lower horizons were well rooted, being either above or close to the critical RLD of 1 cm/cm^3 until 80 cm soil depth. There were no statistically significant differences between the two zones. The average root dry weight was 0.12 mg/cm^3 in zone 1, lower than the 0.14 mg/cm^3 reported for zone 2 (Figure 9b), however this different wasn't statistically significant.

There was an almost significant (P<0.1) interaction between the two zones and soil depth driven by a reduction in root dry weight in zone 2 at 20–40 cm soil depth. At all other soil depths, zone 2 had a greater root dry weight than zone 1. There was no clear correlation between rooting profiles post-harvest and penetration resistance profiles measured in the spring (Figure 9). Clearly the increased resistances measured were not limiting to root growth.

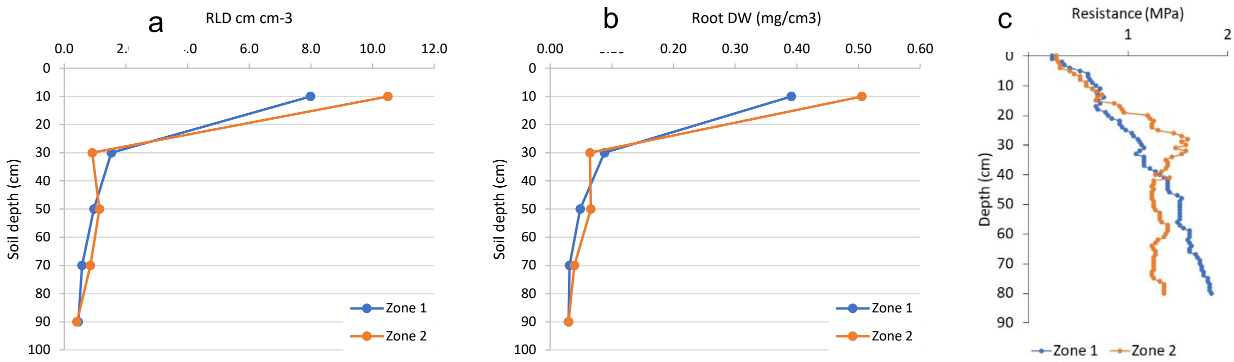


Figure 9a. Root length density (RLD, cm.cm^3). Figure 9b. Root dry weight (mg/cm^3) from New Farm 5 taken just after harvest in zone 1 & 2. Figure 9c. penetration resistance in March (work package 1 soil baselining report)

Overton 4 (Zone 2):

The RLDs in Overton 4 zone 2 were generally lower at 0.9 cm/cm^3 in the top 20cm of soil (Figure 10a) compared to those of the other bean crop in Overton 5 (1.17 cm/cm^3 and 1.28 cm/cm^3 in the undrained and old-drained treatments, reported in the work package 4 drainage trial report). The pattern of rooting down the soil profile was similar to that of the old-drained treatment in Overton 5, with a lower RLD at 20-40 cm soil depth, which may be noise in the data, as the penetration resistance data didn't show any significantly compacted layers (Figure 10b). The critical root length density of 1 cm/cm^3 of soil for available soil water extraction was developed in cereals, so it is uncertain whether the low RLDs measured here are problematic for water extraction by the bean crop. The average root diameter was 0.27 mm. Root dry weight data was not available for this field.

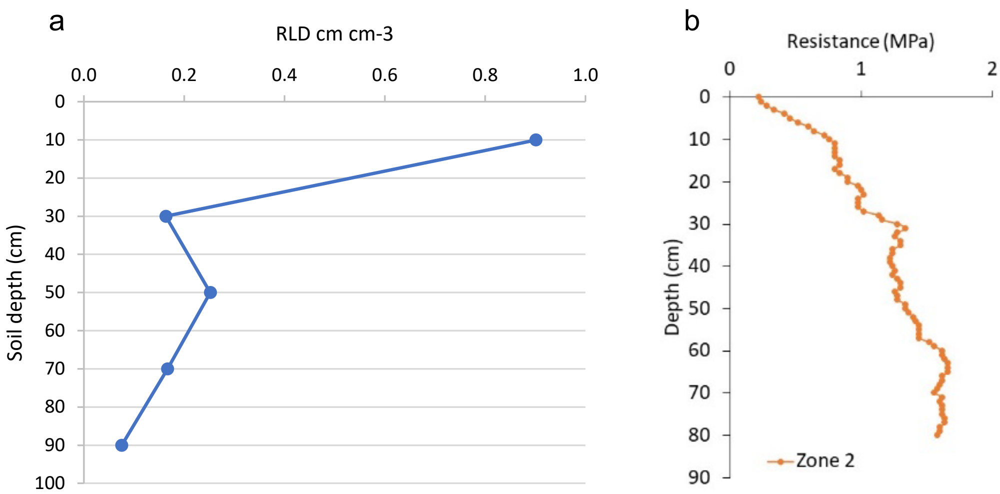


Figure 10a. Root length density (RLD, cm.cm^3) from Overton 4 taken just after harvest in zone 2. Figure 10b. Penetration resistance in March zone (work package 1 soil baselining report)

Yield

The fields were harvested with a yield mapping combine and processed to calculate an average yield for the different soil zones, excluding the headlands.

Table 18. Average yield (t/ha) within the different soil zones

Field	Zone 1	Zone 2	Zone 3
Newton 1	11.25	11.58	11.37
New Farm 4	8.32	7.91	-
New Farm 5	11.86	12.14	-
Overton 4	4.61	4.68	-

Newton 1: The yield was quite even across the three zones compared to most fields, with 80% of values in range 7.7–12.6 t/ha and 60% in range 9.8–12.2 t/ha. Zone 1 has the heaviest soil texture and the lowest AWC of the three zones (see WP 1 report) and had the lowest average yield, albeit only marginally.

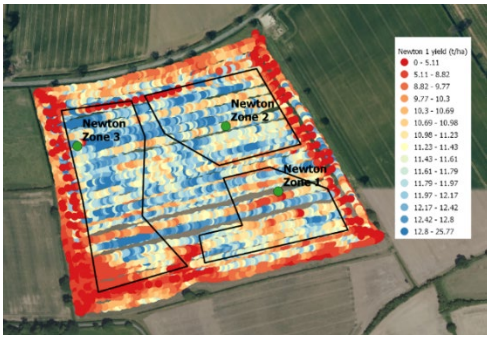


Figure 11. Newton 1 yield map (raw), with mapped soil zones used to determine average yield and marked sampling points

New Farm 4: The yield was quite even, with 80% in the range 5.6–8.9 t/ha and 60% in range 7.2–8.6 t/ha. There was no clear effect of soil zones on yield.

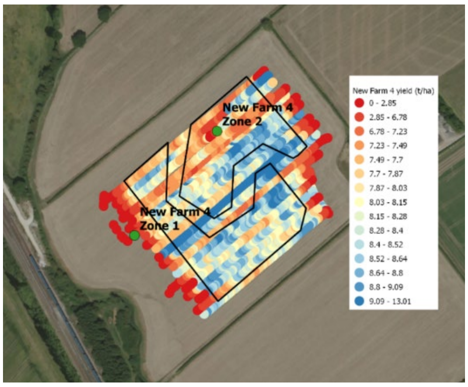


Figure 12. New Farm 4 yield map (raw), with mapped soil zones used to determine average yield and marked sampling points

New Farm 5: The yield in this field was more variable, with 80% of the data in range 6.6–13.1 t/ha and 60% in 10.0–12.6 t/ha. There was no obvious effect of the soil zone on yield.

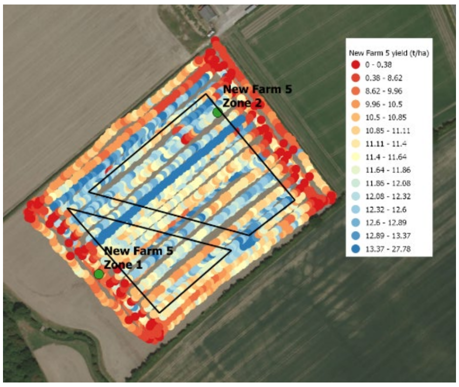


Figure 13. New Farm 5 yield map (raw), with marked soil zones used to determine average yield and marked sampling points

Overton 4: The yield in this map was also quite even, with 80% of the data in the range 3.4–5.3 t/ha and 60% in the range 4.0–5.1 t/ha. There was no obvious soil zone effect.

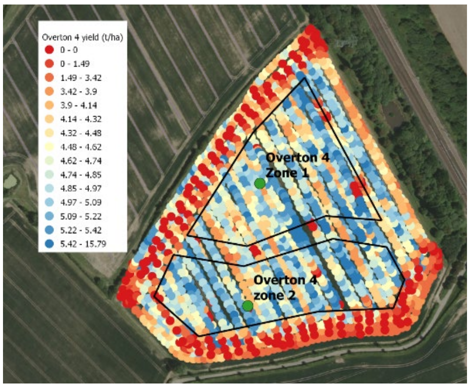


Figure 14. Overton 5 yield map (raw), with marked soil zones used to determine average yield and marked sampling points

Overall evaluation

Overall, there was limited correlation between soil and crop performance indicators.

Newton 1: a high seed rate, better early development and the lightest-textured soil with the highest topsoil AWC of the three wheat fields monitored, translated into a consistently high yield across the field with no clear variation associated with the underlying soil zones. Wheat was least well rooted below 20-30 cm soil depth. Grain N % was low – the lowest of all the wheat fields, indicating poor N uptake and/or utilisation.

New Farm 4: the highest seed rate, but lowest plant number, demonstrating the reasoning for the approach of sowing at a high seed rate to achieve a close to optimal final plant population. Early development (indicated by NDVI and NDRE) was better than New Farm 5, but less than Newton 1, with the lowest number of tillers and ears translating into the lowest-yielding winter wheat field monitored. This field was drilled with Champion, which is a later-maturing variety compared to Graham, which was drilled in the other two winter wheat fields. The crop was well-rooted, but grain P was low, despite zone 2 having soil index of 2. Several grain nutrients were also low, indicating poor nutrient uptake, including N, S, Ca, Mn and Zn.

New Farm 5: the lowest seed rate, but the highest plant population with good tillering and ear number. Highest yielding of the three fields. Soils were very similar to New Farm 4 and had the heaviest texture of the wheat fields monitored (i.e. the greatest clay content). Surface compaction was evident in zone 1, but this did not affect yields and the crop was well rooted. In zone 2 grain P was low, and as with New Farm 4, the grain nutrient analysis results showed low nutrient values including S, Ca, Cu, Mn and Zn. Crop rooting post-harvest was not correlated with soil strength assessed in March and all the wheat crops were well rooted in the top 20 cm, in some beyond what would normally be expected.

Overton 4 (winter beans): Drilled at the recommended seed rate, tissue N, P and S values at flowering and harvest index were lower than the bean YEN long-term average, however yields were consistent across the field. Bean seed calcium and molybdenum concentrations were low, which may be linked to the slightly lower pH in this zone, as deficiency of both is linked to acidic soils (although usually more acidic than found here). In most fields it is recommended to review nutrient applications as well as addressing barriers to nutrient uptake.

Next steps

Crop health and yield will be monitored on the different fields included in the Strategic Farm North programme for the next six years, which, together with periodic soil health assessments, will add to the database analysed as part of work package 3, with an overall aim on farm to improve soil structure, earthworm numbers and nutrient uptake.

3.5. Action points for farmers and agronomists

It is important to measure and check different crop metrics to understand how crop yield is being formed through the season and to identify areas for improving performance and enhancing yields. The first year of baselining provides examples of different on-farm-checks that could be used to assess how crops are building yield through the season.

Resources

The AHDB wheat growth guide

The AHDB pea and bean crop walkers guide

How to promote and measure root growth and distribution in cereals

YEN nutrition

White, C.A., Sylvester-Bradley, R. and Berry, P.M. (2015). Root length densities of UK wheat and oilseed rape crops with implications for water capture and yield. Journal of Experimental Botany. 66(8):2293-303

4. Analysis of past farm data (work package 3)

Trial leader: Susie Roques, ADAS

Start date: January 2023

End date: July 2023

4.1. Headlines

- Waterlogging was probably the biggest cause of yield variation
- Average field yields were lower in the seasons with wetter autumn/winter conditions
- In most seasons, yield was lowest at the downhill ends of fields
- Good wheat yields (for the Yorkshire/Humber region) were achieved across the fields and years studied, but oilseed rape yields were unreliable
- Yield was negatively correlated with the ratio of organic matter to clay content
- This finding is contrary to the prevailing idea that high soil organic matter (SOM) indicates a healthier, higher-yielding soil
- This is unlikely to be a causal relationship, with higher SOM levels also associated with waterlogged soils

4.2. What was the challenge/demand for the work?

Previous AHDB-funded work[3], which included a 'chessboard' trial on David Blacker's farm, has demonstrated the wide yield variation commonly seen within UK fields. The project showed that across six chessboard trials, each covering 3–5 ha, the range of yield at optimal nitrogen (N) rates was between 2.5 t/ha and 4.1 t/ha. The same project showed that, although there was also large variation within fields in fertiliser N requirement, N availability was not the main source of yield

[3] Kindred, D.R., Hatley, D., Ginsburg, D., Catalayud, A., Storer, K., Wilson, L., Hockridge, B., Milne, A., Marchant, B., Miller, P., Sylvester-Bradley, R. (2014). Automating nitrogen fertiliser management for cereals (Auto-N). AHDB Project Report No. 561.
Kindred, D.R., Milne, A.E., Webster, R., Marchant, B.P., 2015. Exploring the spatial variation in the fertiliser-nitrogen requirement of wheat within fields. J. Agric. Sci. 153 (1), 25–41.

variation. The project concluded that the main causes of yield variation are more likely to be soil factors, including water availability. Analysis of the ADAS YEN database has also highlighted the importance of soil factors in determining yield, with water retentive soils (e.g. clays and medium loams) tending to yield more than sandier soils.

Precision farming data, including yield and soil maps, provide an opportunity to investigate the causes of yield variation both within and between fields. Therefore, this work package aimed to analyse data held by David Blacker to identify trends in crop performance and investigate potential underlying causal factors and any gaps in knowledge that could inform future trials on the farm to improve yield.

4.3. How did the project address this?

For five fields (Table 19), David Blacker supplied yield maps from 2012 to 2022 and soil maps, including electrical conductivity (EC), extractable phosphorus (P) and potassium (K), pH, clay content and organic matter (OM). Weather data for the same seasons was sourced from Iteris ClearAg. ADAS analysed the data to investigate between and within-field variation.

Table 79. Cropping summary for the five fields included in the study (from 2012 to 2022)

Year	New Farm 4	New Farm 5	Newton 1	Overton 4	Overton 5
2012	WOSR	WOSR	Winter wheat	Winter barley	Winter barley
2013	Winter wheat	Winter wheat *	Winter barley *	WOSR / S Oats	Spring oats
2014	Winter wheat	Winter wheat	WOSR	Winter wheat	Winter wheat
2015	Winter barley	Winter barley	Winter wheat	Spring beans	Spring beans
2016	WOSR	WOSR	Spring Beans	Winter wheat *	Failed wheat
2017	Winter wheat	Winter wheat	Winter wheat	WOSR *	Winter wheat
2018	Spring beans	Spring beans	WOSR	Winter wheat	WOSR
2019	Winter wheat	Winter wheat	Winter wheat	Spring beans	Spring Beans
2020	Failed OSR	Failed OSR	Spring beans	Winter wheat	Winter wheat
2021	Winter wheat	Winter wheat	Winter wheat	WOSR	WOSR
2022	Spring beans	Spring beans	Fallow (stewardship)	Winter wheat	Winter wheat

*Crops in New Farm 5 2013, Newton 1 2013, Overton 4 2016 and Overton 4 2017 failed in large patches of the fields.

Assessments

Yield maps were cleaned, by removal of headlands and locally extreme (anomalous) data points, using open access software (QGIS) and ADAS Agronomics software[4]. Yields were expressed as a percentage of the Yorkshire & Humber regional average for that crop and year (Defra data), to allow yields from different crops to be considered on the same scale. Yield maps and soil maps were interpolated to give data covering the whole field area excluding headlands, then averaged over a grid of 24m x 24m squares laid over each field in line with the tramlines. Maps were then created to show how yield varied between years in each grid square, indicating which fields and parts of fields were consistently high or low yielding, and which were inconsistent between years.

Weather data was summarised to give an overview of the challenges of each season, such as notably wet or dry periods, which are likely to affected yield.

Restricted Maximum Likelihood analysis (REML) was used to investigate the soil factors that explained the most yield variation. Principal components analysis (PCA) was also used to examine correlations between yields and soil variables, and the results of both analyses examined considering the weather data.

[4] Marchant, B., Rudolph, S., Roques, S., Kindred, D., Gillingham, V., Welham, S., Coleman, C., Sylvester-Bradley, R. (2019). Establishing the precision and robustness of farmers' crop experiments. Field Crops Research 230, 31-45.

4.4. Results (to date)

Variation between fields and seasons

Newton 1 was the highest yielding of the five fields in the study, consistently performing more than 25% above the regional average yield for that crop and year, except in 2013, when a winter barley crop failed in the southern half of the field (Table 20).

Overton 5 was the worst-performing and the most variable, with good yields in 2013, 2015 and 2017 – years notable for drier than average weather and an absence of other extremes – balanced by a crop failure in 2016 and very poor OSR yields in 2018 and 2021. Harvest years 2016 and 2021 were both marked by very wet winters. Overton 5 has known problems with waterlogging, hence its use for a drainage trial in the 2022/23 season.

Across the five fields, the worst years (low yields and crop failures) were 2016 and 2020, both of which were marked by very wet weather in autumn and winter (130% and 148% respectively of the long-term average rainfall from September to February), which is likely to have impacted the establishment of winter crops by delaying drilling and/or causing waterlogging after drilling. Spring beans performed well in these seasons, relative to winter crops, presumably because they were not affected by winter waterlogging.

Soil mapping in 2019, 2021 and 2022 showed little difference in the average soil type (% sand, silt and clay) or pH between the five fields (Table 21), although there was marked variation in soils across individual fields. Recent baseline sampling (from work package 1) indicates that Newton 1 has the lightest textures (sandy clay loams), and Overton 5 the heaviest (clay/clay loams).

Average soil organic matter varied from 2.1% in Newton 1 to 4.2% in Overton 5, in line with the variation in soil texture (i.e. higher organic matter levels in heavier textured soils). At the time of sampling, soil P levels in Overton 4 and 5 averaged around the borderline between indices 1 and 2, but the other three fields were at P index 3.

Table 80. Yields for each field/season, expressed as a percentage of the regional average yield (Defra data) for that crop and season. Data excludes headlands. Yields are coloured by crop: green for winter wheat, yellow for oilseed rape, red for spring beans, blue for winter barley, pink for spring oats

Year	Notable weather issues	New Farm 4	New Farm 5	Newton 1	Overton 4	Overton 5
2012	Dry autumn/winter; wet spring/summer	113	147	131	123	126
2013	Cold, damp winter/spring, dry summer	138	83 [c]	28 [c]	[b]	146
2014	Wet winter in southern England but closer to average in Yorkshire	105	125	135	107	106
2015	No extremes; high yields across UK	110	133	153	148	151
2016	Mild, very wet winter	[a]	85	125	31 [c]	[b]
2017	Mild, dry year, wetter in early summer	113	129	133	77 [c]	164
2018	Good autumn; dry late spring /summer	115	101	131	126	20
2019	Good autumn; dry winter; wet summer	168 [d]	114	[a d]	109	69
2020	Very wet autumn/winter; dry spring	[b]	[b]	195	146	116
2021	Wet winter	112	137	127	207	19
2022	Dry, hot summer; early harvest	82	85	[b]	141	112
Mean		**117**	**114**	**128**	**122**	**99**

[a] Only partial yield maps were available for New Farm 4 2016 and Newton 1 2019, so these crops were excluded from the analyses.

[b] Years in which a whole field was fallowed or had a crop failure were excluded from the analysis, as was Overton 4 2013 because the field was split between two crops. For crop failures, cells are coloured according to the failed crop.

[c] Average yields were low in New Farm 5 2013, Newton 1 2013, Overton 4 2016 and Overton 4 2017 because the crops failed in parts of the fields and these failed areas were included in analyses at 0 yield.

[d] New Farm 4 2019 included a cover crop trial; Newton 1 2019 included a nitrogen trial

Table 21. Selected soil variables, from Precision Decisions soil maps, averaged across each field

Field	New Farm 4	New Farm 5	Newton 1	Overton 4	Overton 5
Sample year	2022	2022	2019	2021	2021
% sand	22.8	25.9	25.8	25.0	23.2
% silt	53.3	53.9	52.0	51.3	53.2
% clay	23.9	20.2	22.5	23.7	23.5
% OM	3.66	3.76	2.09	3.12	4.15
pH	6.70	7.06	6.27	6.75	6.48
P (mg/kg)	33.2	33.6	28.8	16.1	14.9

Variation between crops

Winter wheat was the most successful crop in the fields and seasons in this study: on average, the farm achieved 125% of the regional average wheat yield. However, the headlands, which are typically the lowest-yielding parts of a field, were excluded from the analysis. Wheat was also the most reliable crop, except for one partial crop failure, with a smaller yield range than oilseed rape, barley or beans, despite grown the most often (Figure 15). Oilseed rape was the most unreliable crop, with yields ranging from 19–207% of the regional average, as well as crop failures in two fields in 2020.

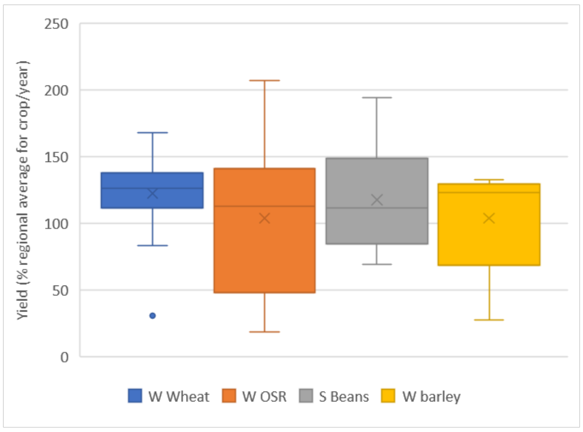


Figure 15. Variation in field mean yield (expressed as a percentage of the regional average for that crop and year) for the four most grown crops in the study. Box and whisker plots show mean (x) median (horizontal line), interquartile range (box), outliers (dot) and total range, excluding outliers (whiskers)

Patterns of in-field variation

Principal components analysis for individual fields showed that spatial patterns of yield were closely correlated between most seasons. In other words, the same parts of the field performed well or poorly in those seasons, but that there were some seasons that broke the pattern.

In New Farm 4 and New Farm 5, 2013 was the notable outlier. This was also the year in which the crop failed in half of Newton 1, and Overton 4 was split between two crops due to difficulties with establishment. Maps of New Farm 4 show how in 2013, the east side of the field was lowest yielding, but in most other seasons it was higher yielding (Figure 16). Similarly in New Farm 5, the north-east end of the field was higher yielding in many years, including 2012, 2016, 2017 and 2018, but lower yielding in 2013 (Figure 17). This may be because although the autumn was wet in 2012/2013, it was followed by more typical rainfall through the winter, then the weather turned very dry in summer, such that the better drained, drier parts of the field may have been disadvantaged by summer drought stress.

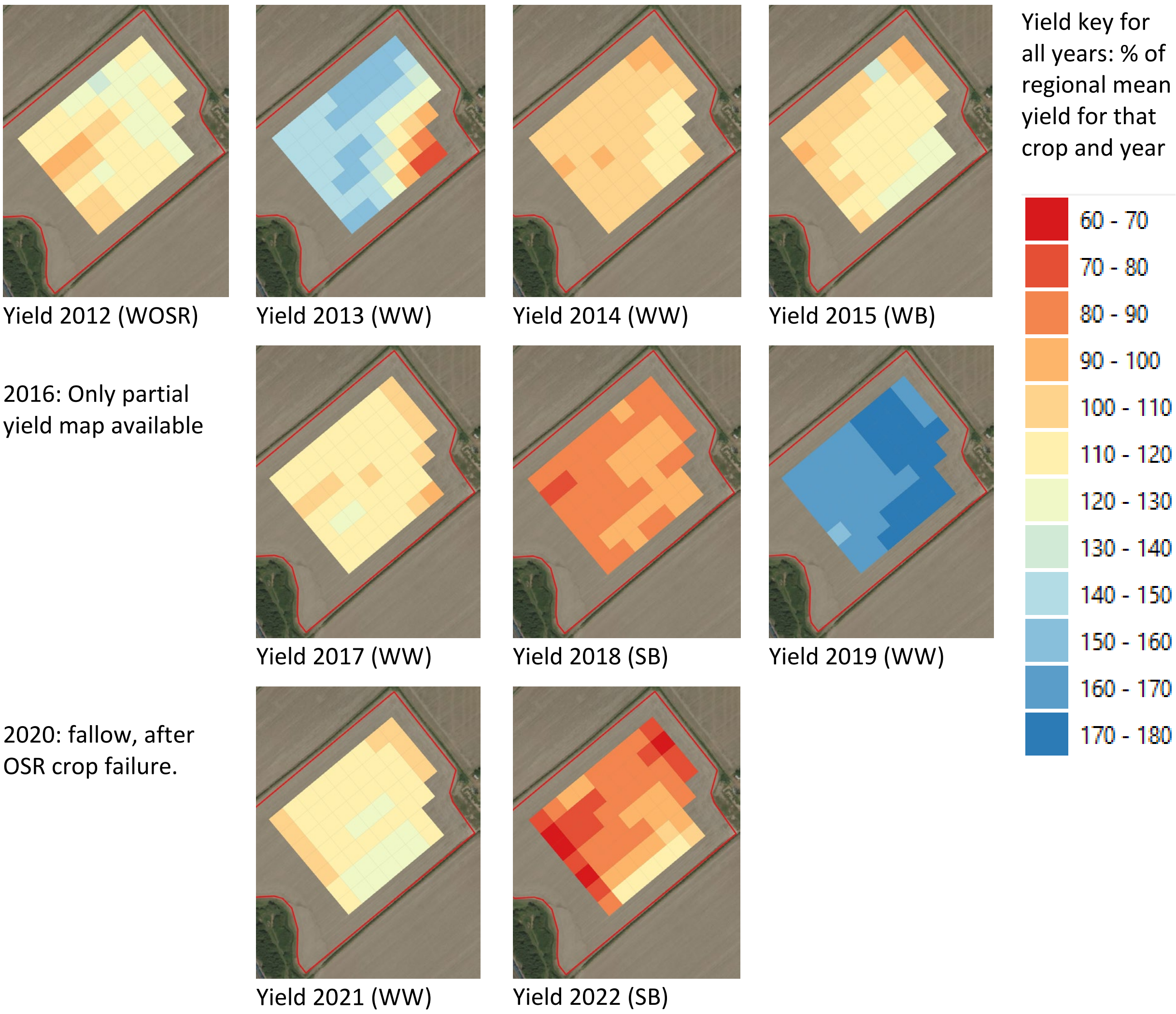
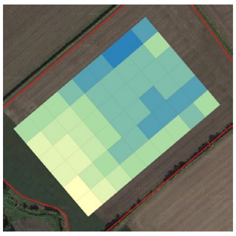
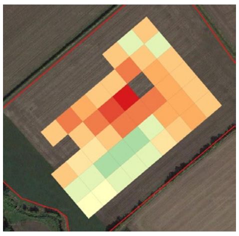
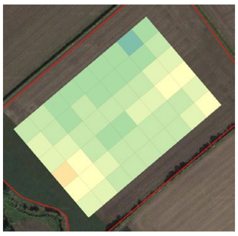


Figure 16. Yield maps for New Farm 4, averaged across 24m x 24m grid squares and expressed as a percentage of the regional average for that crop and year

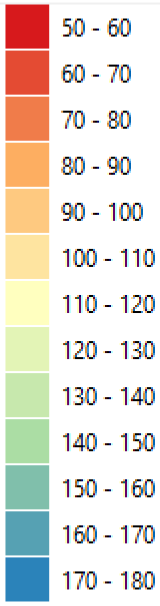

Yield 2012 (WOSR)

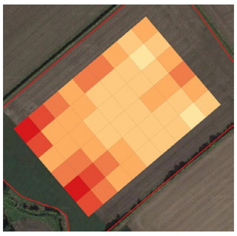

Yield 2013 (WW)


Yield 2014 (WW)

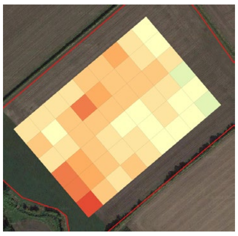

Yield 2015 (WB)

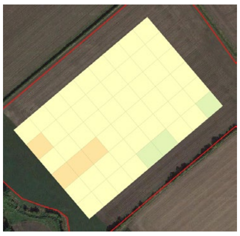
Yield key for all years: % of regional mean yield for that crop and year




Yield 2016 (WOSR)


Yield 2017 (WW)


Yield 2018 (SB)


Yield 2019 (WW)

2020 fallow, after OSR crop failure.


Yield 2021 (WW)

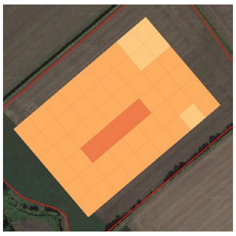

Yield 2022 (SB)

Figure 17. Yield maps for New Farm 5, averaged across 24m x 24m grid squares and expressed as a percentage of the regional average for that crop and year

The effects of waterlogging

Overton 4 and 5 and New Farm 4 and 5 all tend to become lower yielding as they slope slightly downhill towards the railway that runs between them (Figure 18). This makes sense, given the known problems these fields experience with drainage and waterlogging; all the fields have heavier soils going down the slopes and waterlogging is likely to be more serious at the downhill ends of fields. Newton has a similarly gentle slope and is also heavier textured and lower yielding at the downhill (southern) side.

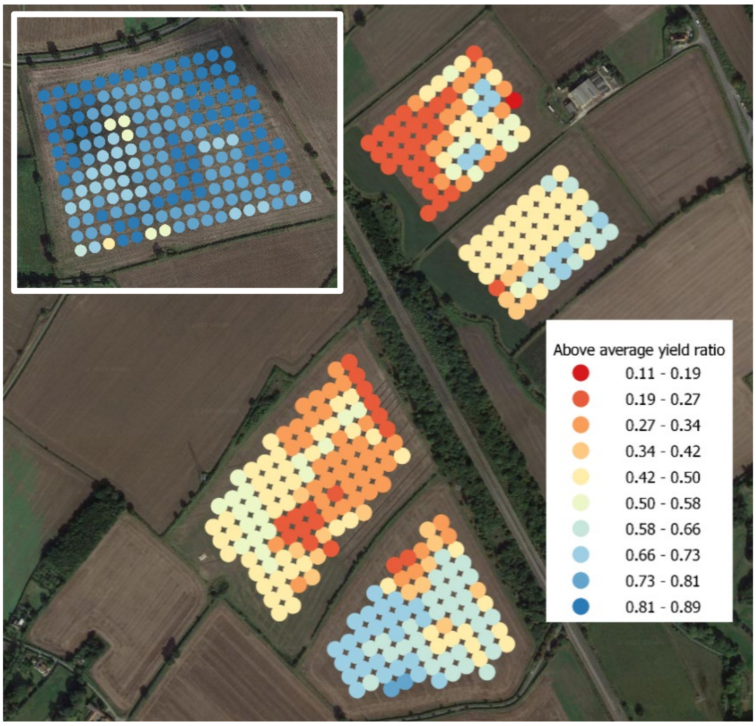


Figure 18. The proportion of years in which yield for a given 24 x 24m grid cell is above average for the farm (this set of five fields), after yield is expressed as a percentage of the regional average for that crop and year

The 24m x 24m grid squares used in the analysis can also be categorised into those which are usually higher or lower yielding, and those which are 'unstable' – sometimes high and sometimes low yielding (Figure 19). This is similar to an approach suggested by Donat *et al*. (2022)[5] to divide fields in zones for patch cropping.

Yields were reliably higher yielding only at the north side of Newton 1 and the south end of Overton 4. Consistently poorer yields occurred at the downhill ends of New Farm 4, Overton 4 and Overton 5, while the rest of the fields were categorised as 'unstable' – having a mix of higher and lower yielding years. This is consistent with waterlogging being the biggest factor affecting yield, given that its effect on yield will vary according to seasonal weather.

[5] Donat, M., Geistert, J, Grahmann, K., Bloch, R., Bellingrath-Kimura, S.D. (2022). Patch cropping- a new methodological approach to determine new field arrangements that increase the multifunctionality of agricultural landscapes. Computers and Electronics in Agriculture 197. https://doi.org/10.1016/j.compag.2022.106894

Figure 19. 24m x 24m grid squares categorise as ‘usually higher yielding’ (at least six years in which yield, expressed as a % of the regional average for that crop and season, was above the 60th percentile of the full dataset), ‘usually lower yielding’ (at least six years in which yield was below the 40th percentile of the full dataset), ‘usually average yielding’ (yield was between the 40th and 60th percentiles of the dataset in at least half the years) or ‘unstable’

The effects of organic matter content

The ratio of organic matter (OM) or soil organic carbon (SOC; organic matter contains about 58% carbon) to clay content has been suggested as a useful measure of soil health or quality. It was one of the factors included in the analyses of Strategic Farm North data. This ratio is used rather than simple organic matter content because soils with higher clay content can maintain higher organic matter contents.

Based on data from long-term experiments at Rothamsted Research and soil survey data from across the UK, SOC:clay content thresholds have been suggested to categorise soils as very good, good, moderate and degraded (Prout *et al*., 2020)[6], and these categories have been shown to correlate with soil structural quality (as characterised by the ALC for England and Wales). The soils in this study span the full range of SOC:clay categories from ‘degraded’ (SOC/clay ≤ 0.08) to ‘very good’ (SOC/clay ≥ 0.125).

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[6] Prout, J.M., Shepherd, K.D., McGrath, S.P., Kirk, G.J.D., Haefele, S.M. (2020). What is a good level of soil organic matter? An index based on organic carbon to clay ratio. European Journal of Soil Science 72, 2493–2503. https://doi.org/10.1111/ejss.13012

The REML analysis identified SOC:clay content as a significant factor, explaining far more of the yield variation than other soil variables (including pH, P, K, Mg and electrical conductivity).

Somewhat surprisingly, the correlation between SOC:clay content and yield was negative. Yield was generally lower where OM was higher, both within and between fields. This pattern was stronger in some fields and seasons than others. The strongest negative correlations were seen in Overton 4 in 2017 and 2021 (Figure 20) and in New Farm 4 in 2022 (Figure 21), with more modest negative correlations in New Farm 5. SOC:clay content could not be analysed for Overton 5 because the available soil map was too sparse. Newton 1 was the only field showing positive correlations between SOC:clay ratio and yield, and then only in 2013, 2016, 2018 and 2020. In other years there was no relationship (Figure 22). Newton 1 was also the field with the lowest average OM:clay content (Table 21), despite being the field with the highest average yield.

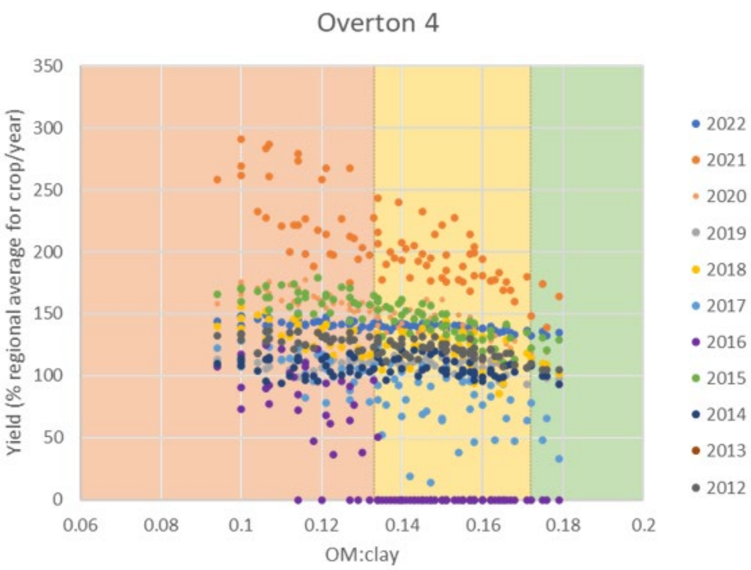


Figure 20. Relationship between the ratio of organic matter (OM) to clay content and yield (expressed as a percentage of the regional average for that crop and year), for Overton 4 in each year. Each data points represents a 24m x 24m grid square. Coloured background areas show the thresholds considered degraded (red), moderate (amber), good (green) and very good (blue) by Prout et al. (2020)

Figure 21. Relationship between the ratio of organic matter (OM) to clay content and yield (expressed as a percentage of the regional average for that crop and year), for New Farm 4 in each year. Each data points represents a 24m x 24m grid square. Coloured background areas show the thresholds considered degraded (red), moderate (amber), good (green) and very good (blue) by Prout et al. (2020)

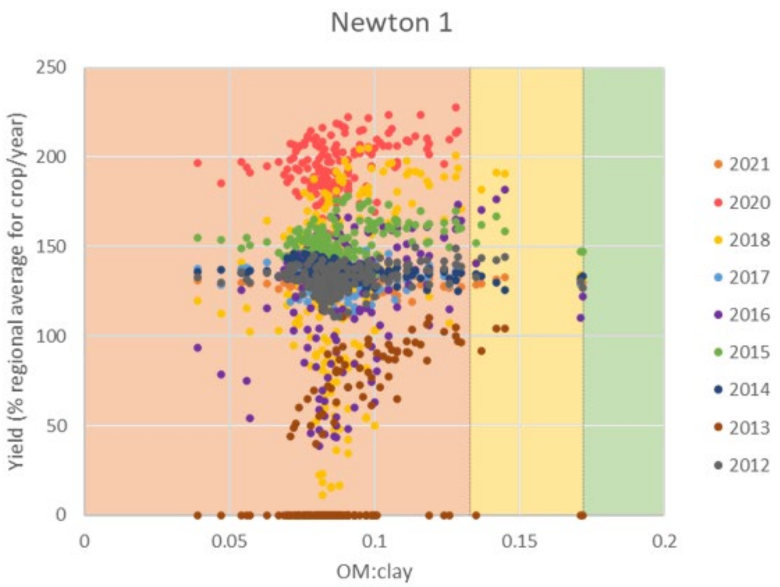


Figure 22. Relationship between the ratio of organic matter (OM) to clay content and yield (expressed as a percentage of the regional average for that crop and year), for Newton 1 in each year. Each data points represents a 24m x 24m grid square. Coloured background areas show the thresholds considered degraded (red), moderate (amber), good (green) and very good (blue) by Prout et al. (2020).

A possible explanation for these unexpected negative relationships between OM and yield is that the fields in the study are often affected by waterlogging, and organic matter is broken down more slowly in waterlogged soils. Hence, waterlogging may be the cause of both higher OM and lower yield, rather than OM content having any direct causative effect on yield. This is supported by observation of the soil variation within the Overton and New Farm fields (Figure 23). There is little pattern in how clay content varies across the fields, but OM clearly increases down the slopes towards the railway. Newton 1 is known to be the field with the least trouble with waterlogging, which may explain why its relationship between OM:clay and yield is more in line with the expectations of the literature.

It should be noted that a REML analysis of the cereal YEN database (2012 to 2020) found no association between OM and yield, and the Rothamsted Research study, which proposed thresholds for OM:ratio to define good and degraded soils, did not include any analysis of yield (Prout *et al*., 2020).

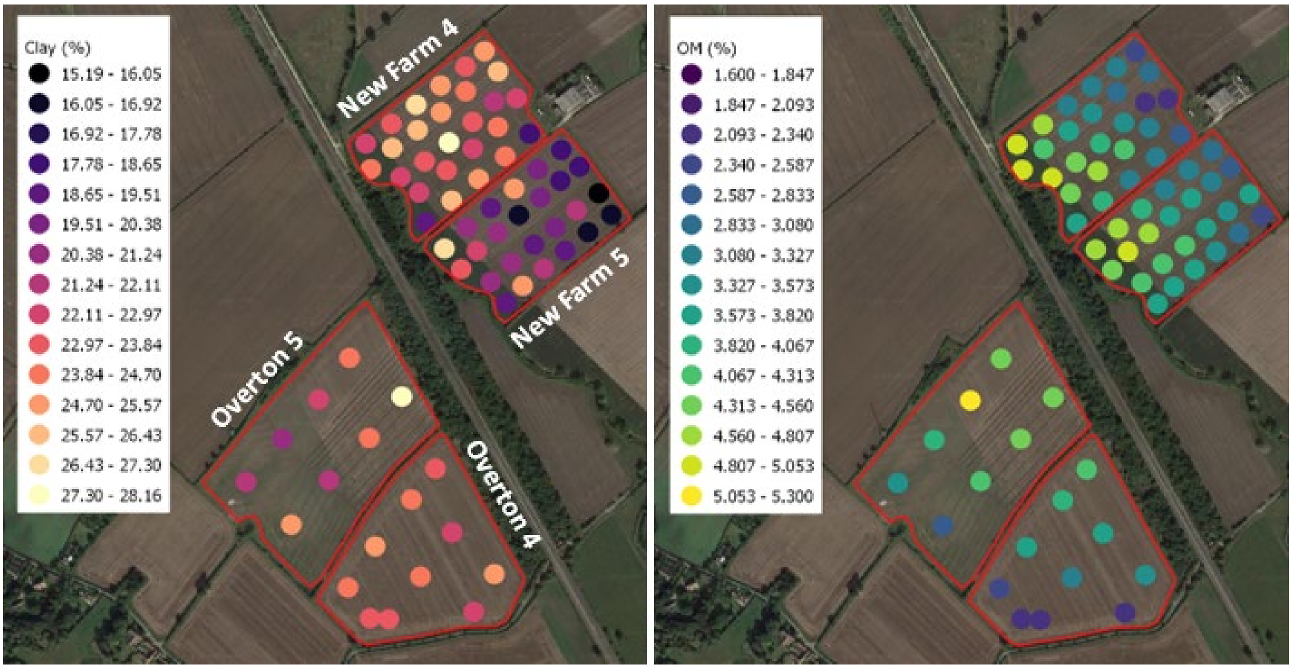


Figure 23. Variation in clay content and soil organic matter across four fields

4.5. Action points for farmers and agronomists

- Examine yield maps, in conjunction with soil maps and known field issues, to understand the causes of yield variation on your farm
- Where waterlogging is having a major impact on yield, consider improving drainage

Appendix 1: summary of weather for years included in the study

Harvest year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total rainfall (% of 10-year average for this site)										
Autumn		76	79	100	76	109	102	170	86	74
Winter	55	112	48	160	83	86	88	126	130	99
Spring	81	113	83	152	80	171	109	32	78	101
Summer	77	89	87	114	155	70	148	142	78	39
Average temperature (ºC deviation from 10-year average for this site)										
Autumn		-0.6	0.5	-0.4	-0.3	0.1	0.0	-1.0	-0.1	1.0
Winter	-1.4	0.7	-0.6	1.1	0.2	-0.9	0.5	1.1	-0.9	0.5
Spring	-2.0	0.8	-0.4	-0.8	1.1	0.4	0.3	0.9	-1.0	0.7
Summer	0.1	-0.4	-1.2	-0.3	-0.5	1.1	0.3	-0.4	0.2	1.1

5. Drainage trial (work package 4)

Trial leader: Kate Smith, ADAS

Start date: September 2022

End date: August 2023

5.1. Headlines

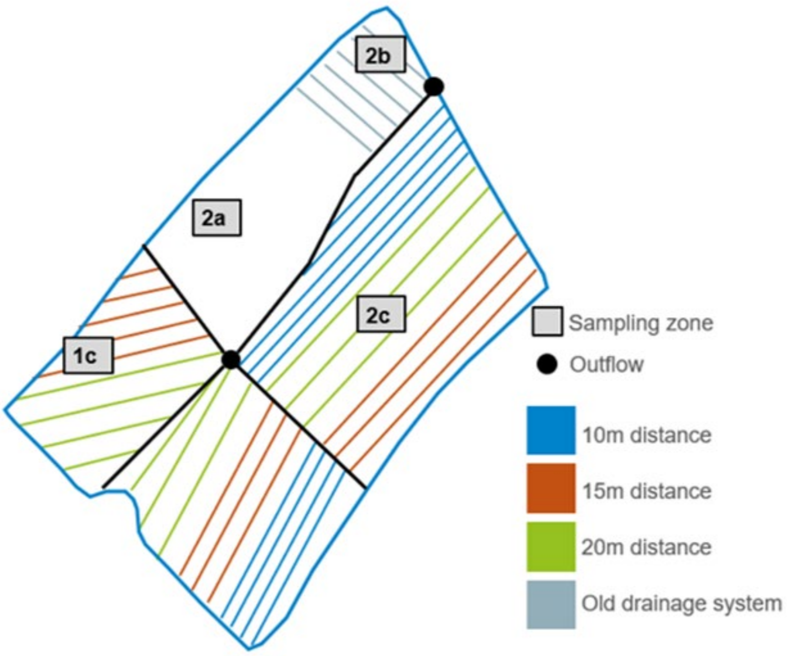
- The overall objective of the trial was to investigate the impact of drainage approaches on crop performance
- In this first baselining year, the results show that on heavy clay soil drainage improved winter wheat yield compared to both old drains and no drainage zones
- Soil structural condition was poor in the subsoil and moderate-to-poor in the topsoil
- Soil structural condition and soil health will be assessed in later years to fully evaluate the impact of the new drainage installation

5.2. What was the challenge/demand for the work?

Strategic Cereal Farm North is on a heavy clay soil, which is slowly permeable and can be waterlogged for long periods without adequate drainage. There has been a general reduction in organic matter levels in arable soils over the past 70 years which makes them more susceptible to waterlogging and more in need of drainage. There is interest in the time it takes for the soil to restructure, increase in porosity and improve microbial activity following drainage.

5.3. How did the project address this?

Yields in Overton 5 tend to be lower towards the base of the slope, that runs towards a railway. The field experiences significant issues with drainage and waterlogging.



Site details

Field name: Overton 5

Size: 11.6 ha

Soil texture: clay loam to clay

Crop: winter beans

Drilling date: 11/10/23

Figure 24. Location of the sampling zones (labelled 1c, 2a, 2b and 2c) in relation to the drainage treatments and soil type within Overton 5

Between May and September 2022, Overton 5 was redrained with lateral drains at 10, 15 and 20 m intervals, covering both lighter (clay loam: 1c) and heavier soil textures (clay: 2c).

Within the same field, there is an undrained area (2a) and a section with the old drainage system in place (2b). As part of the trial, soil and crop sampling was carried out in each of the four zones labelled 1c, 2a, 2b and 2c (Figure 24).

Assessments	Details
Drainage water	Nutrient (NO_3-N, NH_4-N and total P) content of drainage water samples taken on three occasions over the winter period from drainage inspection hatches in the centre of the field and in the north-eastern field boundary
Crop biomass	Growth stage, plant count, NDVI, tiller count, plant tissue analysis
Topsoil	Chemical analysis, penetrometer resistance, VESS, plant total available water holding capacity and porosity, bulk density, gravimetric moisture, bacterial: fungal ratio, earthworm count and division into ecotypes
Upper subsoil to subsoil	Chemical analyses, penetrometer resistance, bulk density and gravimetric moisture, subVESS, plant total available water holding capacity & porosity
Disease	Foliar
Yield	Pre-harvest biomass sampling, yield map analysis, grain nutrition rooting measured post-harvest

5.4. Results (to date)

Drainage water

Nitrate concentrations in drainage water varied during the overwinter period. There was no obvious trend in concentrations between the different outflow pipes, with the samples taken from the centre of the field assumed to have largely come from the lighter textured soil. Concentrations were either above or below the EC-drinking water nitrate-N limit of 11.3 mg NO_3-N/l (Figure 25). Total P and ammonium concentrations were below the limit of detection (<0.1 mg/l) for most samples.

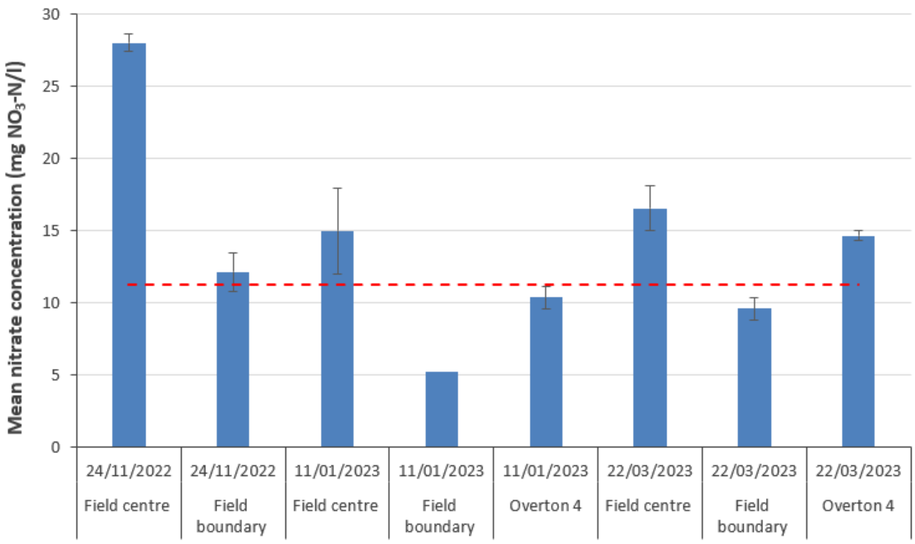


Figure 65. Nitrate concentrations in over-winter (2022–23) drainage water samples collected from inspection hatches in Overton 5 and Overton 4 (two occasions)

Soil health scorecard

- SOM was above average for the soil type and region, but markedly higher on the heavier-textured soil (in line with expectations). This was associated with a higher soil nutrient status and pH (Table 22)
- 'Poor' topsoil structure was observed, where new drains had been installed on the heavier-textured soil, with a VESS limiting layer score of 3.5 recorded at about 10 cm depth. In all other zones, soil structure was 'firm' with a limiting layer score ranging from 2.5 to 3.0 (26)
- Overall, earthworm numbers were very low, except in the old drainage zone which scored amber (mean of 6 worms/pit). All worms were juveniles.

Soil health scorecard guidance

Table 22. Soil health scorecard for topsoil Overton 5, in winter beans. Measurements taken November 2022. Cells are colour coded according to the scorecard traffic light system. Red = Investigate, Amber = review and Green = monitor

Zone	Texture	% clay	pH	SOM	Ext P	Ext K	Ext Mg	VESS limiting layer score[a]	Earthworms [b]
				% LOI	mg/l (Index)				No/pit
1c New drains	Clay Loam	34	6.1	4.7	10.8 (1)	143 (2-)	196 (4)	2.5	3.3
2a No drains	Clay	58	6.4	7.2	14.6 (1)	156 (2-)	342 (5)	3	3.0
2b Old drains	Clay	55	7	6	15.2 (1)	151 (2-)	519 (6)	3	6.3
2c New drains	Clay	57	6.8	7	17.2 (2)	148 (2-)	365 (6)	3.5	1.7

[a]VESS limiting layer score is the maximum score recorded to 25cm depth. VESS scores have been colour coded according to the soil health scorecard. Scores of 1 or 2 indicate good soil structure (friable/intact) indicating no changes needed; a score of 3 indicates moderate structure (firm) with long-term improvements required and scores of 4 or 5 poor soil structure (compact or very compact) with short-term improvements required. For earthworms, red indicates earthworm numbers are depleted. Green is an active population. Orange is intermediate.

Lower topsoil (15–30 cm) and subVESS (25–60 cm)

- SOM was slightly lower in the 15–30 cm horizon compared to 0–15 cm, with pH marginally higher (Table 22)
- SubVESS assessments indicated that the limiting layer (below about 35 cm) consisted of compact or large-scale structures (Table 23), mostly grey in colour, indicating anaerobic conditions. SubVESS scores were lower (i.e. less compact) in upper layers (about 25–45 cm depth) and where soil texture was lighter (e.g. in zone 1c)

Table 93. Lower topsoil (15–30 cm) characteristics and SubVESS (25–60 cm) from Overton 5.

Drainage treatment (Overton 5 only)	Texture	Clay <0.002 mm	pH	SOM	SubVESS limiting layer score
		% w/w		% LOI	25–60 cm
1c New drains	Clay loam*	30	6.4	3.8	5
2a No drains	Clay	45	6.9	6.3	4.5
2b Old drains	Clay	51	7.3	6.3	5
2c New drains	Clay	42	7.1	5.4	4.5

*On the boundary of CL/SCL/SC

Zone 1C (new drains)

Intact/Firm; **Sq2.5**

Zone 2A (no drains)

Firm; **Sq 3**

Zone 2B (old drains)

Firm; 0-10cm: Sq2.5; 10-25cm **Sq3**

Zone 2C (new drains)

Firm – compact: **Sq 3.5**

Figure 26. VESS assessments and associated scores within Overton 5. Note: the higher the VESS score the ‘poorer’ the soil structure

Zone 1C

Sq 3.5 (25-35cm) / Sq 5 (35-48cm) / Sq4 (48-65cm)

Zone 2A

Sq 3.5 (25-45cm) / Sq 4.5 (45-65cm)

Zone 2B

Sq 5 (25-45cm) / Sq 4 (45-65cm)

Zone 2C

Sq 4 (25-37cm) / Sq 4.5 (37 -65cm)

Figure 27. SubVESS assessments and associated scores within Overton 5

Soil bulk density, available water and total porosity

Soils with a greater clay content typically have a high total water holding capacity, due to having more smaller sized pores (which hold on to water more tightly) compared to lighter textured soils. Soil structural condition also influences pore size distribution and the ability of a soil to store and release water. Compacted soils (i.e. indicated by a higher bulk density or VESS/ subVESS scores) will have a lower total porosity consisting of smaller sized pores; on heavier clay soils this can result in waterlogging, particularly where old drains need to be replaced.

During this baselining year the soil assessments indicate that:

- Topsoil bulk density for zones 1c, 2b and 2c were high (compacted soils), while zone 2a (no drains) scored a moderate bulk density (Table 24)
- There was a weak positive correlation between clay % and soil moisture at both field capacity (R^2 = 65%) and at permanent wilting point (R^2 = 47%), demonstrating that soils with a higher clay content can hold more water, but that water may not be all readily available for plant uptake
- In the topsoil, across all soil zones, the available water capacity (AWC) was greater than the estimated values for soil texture in ALC (1988):
  - In zone 1c (clay loam soil), AWC was 21% compared to a typical value (18%)
  - In zones zones 2a–2c (clay soil), AWC ranged from 19–22% compared to a typical value (17%)
- In the lower topsoil, AWC ranged from 19% in zone 1c (clay loam) to 16–19% in the heavier clay soil zones (2a, 2b and 2c)

Table 24. Summary of soil moisture availability in the topsoil and lower topsoil

Soil depth	Treatment and (zone number)	Soil texture	Clay (%)	Organic matter (%)	Bulk density* (g/cm^3)	Moisture at field capacity (% v/v)	Moisture at permanent wilting point (% v/v)	Available water capacity (%)
Topsoil (0–5 cm)	1c New drains	Clay Loam	34	4.7	1.39	42	20	21
	2a No drains	Clay	58	7.2	1.23	47	28	19
	2b Old drains	Clay	55	6	1.25	51	29	22
	2c New drainage	Clay	57	7	1.28	46	27	19
Lower topsoil (15–30 cm)	1c New drains	Clay loam+	30	3.8	1.46	41	22	19
	2a No drains	Clay	45	6.3	1.29	45	30	16
	2b Old drains	Clay	51	6.3	1.37	50	32	19
	2c New drainage	Clay	42	5.4	1.38	46	29	17

*Colour coding based on soil heath scorecard scoping study, for topsoil bulk density trigger value based upon land use and SOM content. Note trigger values have only been developed for topsoil horizons. + On the boundary of CL/SCL/SC

Penetration resistance

Penetrologger measurements were taken in March 2023 (Figure 28). Within zone 1c, a layer of firm/partly compact soil was recorded between about 30 cm to 65 cm depth. In zone 2c, soil resistances were optimal for root growth (i.e. between 0.5 and 1.25 MPa) up to about 50 cm depth. Thereafter, the soil was firm/partly compact.

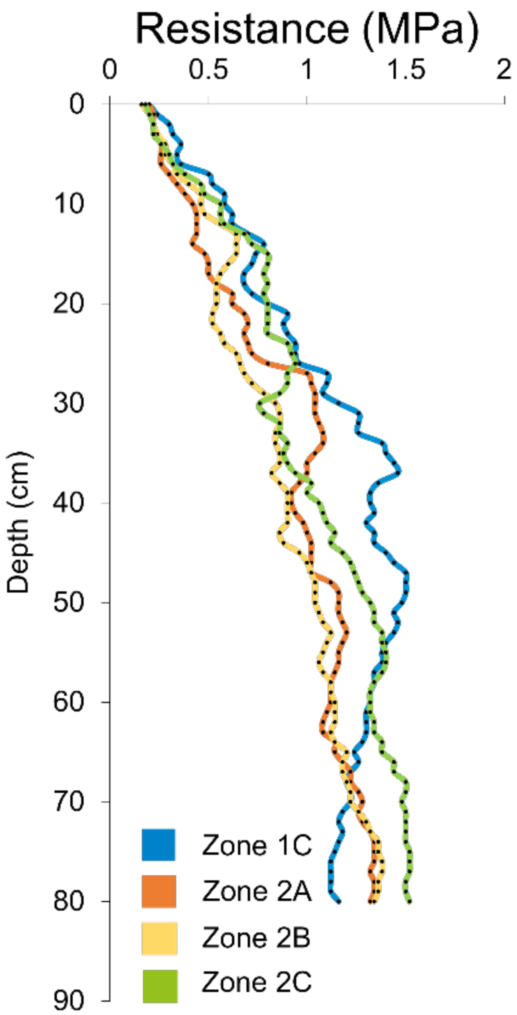


Figure 28. Penetrologger measurements (0–80 cm depth) from each soil zone within Overton 5. Resistances between 0.5 and 1.25 MPa are considered to be optimal for root growth, while those > 2 MPa can significantly impede root growth

Crop disease incidence

Overall disease incidence was low, with no trends in the different drainage and soil type zones. There was a slightly higher incidence of chocolate spot in zones 2c and 2c – old and new drains in the heavier textured soil (Table 25).

Table 25. Mean Incidence of crop (winter beans) disease within each of the sampling zones

Treatment and (zone number)	Downy mildew	Leaf spot	Chocolate spot	Bean rust	Green leaf area (%)
	Disease severity (%)				
New drainage, 34% clay (1c)	1.0	0.0	1.3	0.2	95
No drains (2a)	0.6	0.1	1.9	1.1	94
Old drains (2b)	0.4	0.1	2.3	0.5	95
New drainage, 57% clay (2c)	0.1	0.0	3.3	0.3	93

Crop biomass

Crop (winter beans) assessments were only undertaken on the heavier-textured soil type (zones 2a, b and c).

GS10 1st pair of leaves: The zone with no drains (2a) had the lowest NDVI at 0.17, while the zone with old drains the highest NDVI at 0.20 (Figure 29). NDVI, the normalized difference vegetation index, can indicate canopy cover and crop greenness.

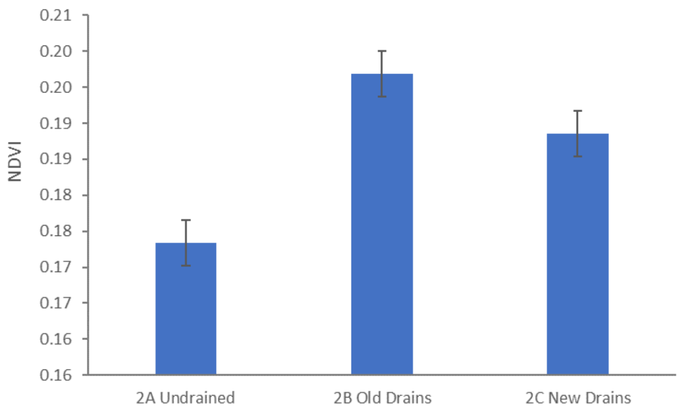


Figure 29. NDVI at GS10, from undrained (2a), old drains (2b) and new drains (2c) sampling zones

GS60–65 flowering:

- At flowering (GS63), the crop had 60 shoots/m^2 on average and there was no significant difference between the treatments
- NDVI at 0.6 was lowest on old drains (2b) compared to the no drains (2a) and new drains (2c) sampling zones (mean NDVI = 0.7) (Figure 30)
- Whole plant tissue analysis indicated that N% and P% was marginally lower on the old drains (at 3.7% and 0.28%, respectively) compared to both the no drains and new drains sampling zones (mean values: N = 4.3% and 4.1 % and P = 0.36% and 0.41%, respectively). Compared to long-term bean YEN dataset (leaf samples), these results are lower than the average of 5.4% N 0.4% P

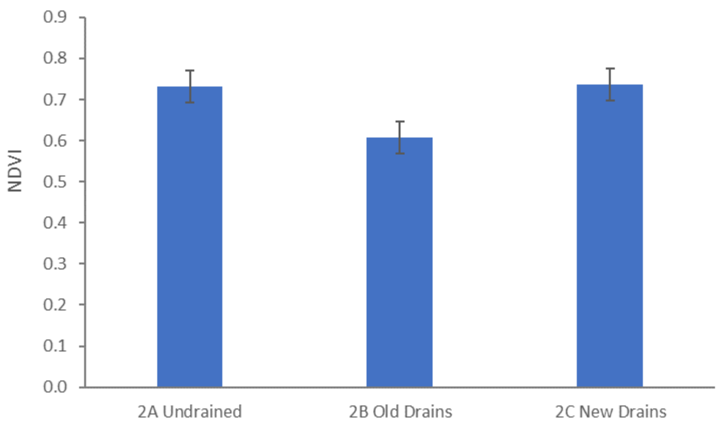


Figure 30. NDVI at GS60–65, from undrained (2a), old drains (2b) and new drains (2c) sampling zones

Pre-harvest biomass:

- Dry Matter Harvest Index (DMHI; proportion of bean dry matter to straw and pod dry matter) was lower ($P<0.05$) at 43% on the new drained (2c) (i.e. larger plants and more straw and pod residue), compared to the no drains (2a) and old drains (2b) sampling zones (i.e. smaller plants and less crop residue), at 48% and 50%, respectively (Figure 31)
- The nitrogen harvest index (NHI; the proportion of nitrogen accumulated in the grain to that accumulated in the whole crop) was significantly lower ($P<0.001$) at 61% on the new drains, compared to the no drains (2a) and the new drains (2b), indicating that less nitrogen was deposited in the beans compared to the whole plant in the new drains. Consistent with DMHI, NHI on the new drains was lower, compared to the undrained and old drains treatments (Figure 32)

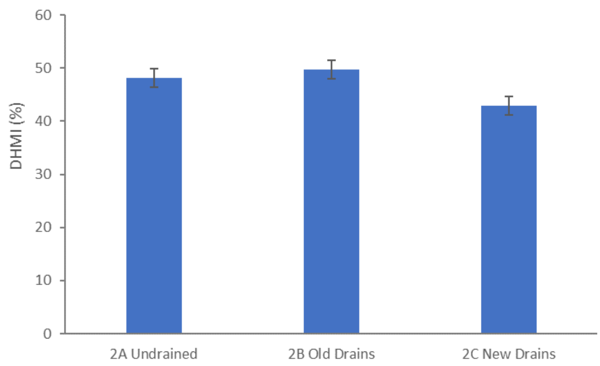


Figure 31: DMHI (%) at pre-harvest, from Undrained (2a), Old drains (2b) and New drains (2c) sampling zones

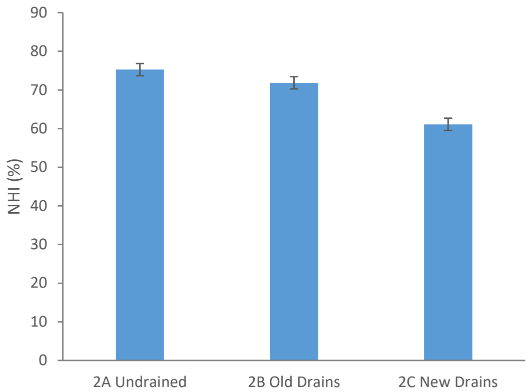


Figure 32. NHI (%) at pre-harvest, from Undrained (2a), Old drains (2b) and New drains (2c) sampling zones

Crop rooting:

Crop rooting was assessed in each of the three treatment zones (2a, 2b & 2c).

Overall, there were few differences in root length density (RLD, cm/cm^3) between drainage treatments (Figure 33). There were a couple of anomalous data points; at 20–40 cm in the old drains treatment and at 40–60 cm depth in the new drains treatment. RLD was markedly lower compared to the other treatments but given the relationship to the other depths these are likely to be 'noise' in the data.

Notably, at the two lower soil depths, the undrained crop (2a) appeared to be slightly less well-rooted compared to both the old and new drained treatments, while there was no difference in RLD between old drains and new drains

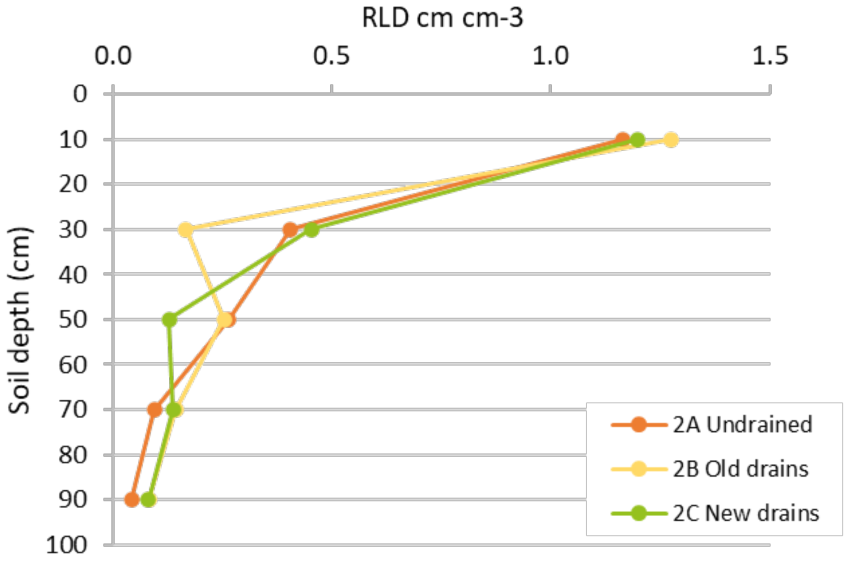


Figure 33. Root length density (cm/cm^3) just after harvest from the different drainage treatments

The average root diameter (across all soil depths) was slightly different between the treatments, with the undrained crop having the narrowest roots (at an average of 0.20 mm), the crops in the new drained treatment had the widest roots (at an average of 0.23 mm), and the old-drained crops had an average root diameter of 0.21 mm.

There were also differences between treatments in the length of roots, which fell into different diameter classes (0–0.5 mm, 0.5–1. mm and 1.0–1.5 mm) expressed as a percentage of the total root length (Figure 34). On average, across all soil depths and treatments, over 95% of roots were between 0–0.5 mm thick. The undrained treatment had 97.7% of root length in this diameter class, while the new drained had less root length in this class (95.2%) and the undrained was between the two (96.7%). This meant that crops grown on the new drains and old drains had more thicker roots.

Figure 35 shows the percentage length of root (of the total length) in the two thicker classes (0.5–1.0 mm and 1.0–1.5 mm). The main differences are that only the old drains and the new drains treatments have roots that were between 1.0 mm and 1.5 mm thick and there were slightly more of these in the new drains compared to the old drains. The undrained treatment had no root above 0.5 mm thick below 60 cm soil depth. Older roots tend to be thicker, with root tips being the narrowest point.

The root dry weight in the top 0–20 cm corresponded to the root length density, the undrained samples had the lowest at 0.07 g/cm^3, with the new drains at 0.11 g/cm^{3}and the old drains at 0.15 g/cm3. We were not able to obtain dry weights for the lower horizons.

Overall, the RLD and root length by diameter class results indicate that in the two drained treatments the crops root systems were able to better explore the soil below 60 cm compared to the undrained treatment.

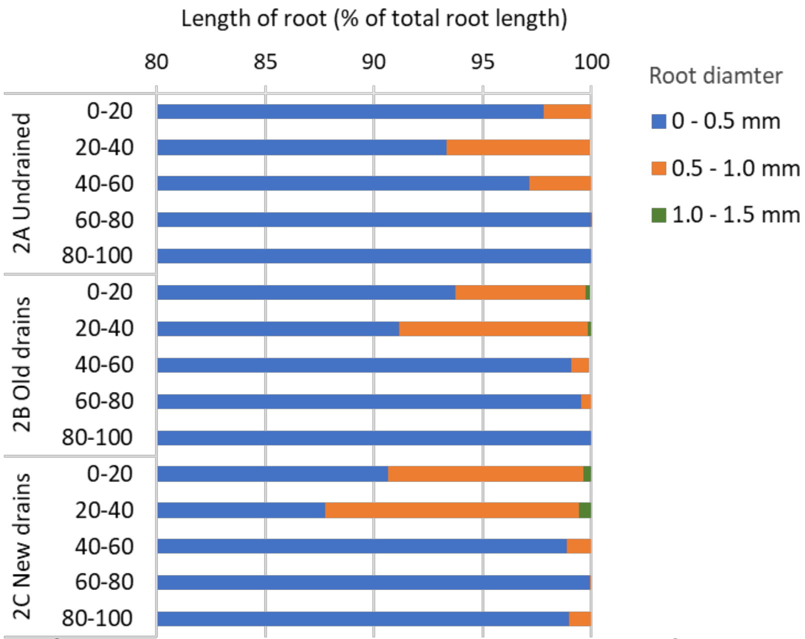


Figure 34. The length of root in each diameter class, as a percentage of total root length for three diameter classes

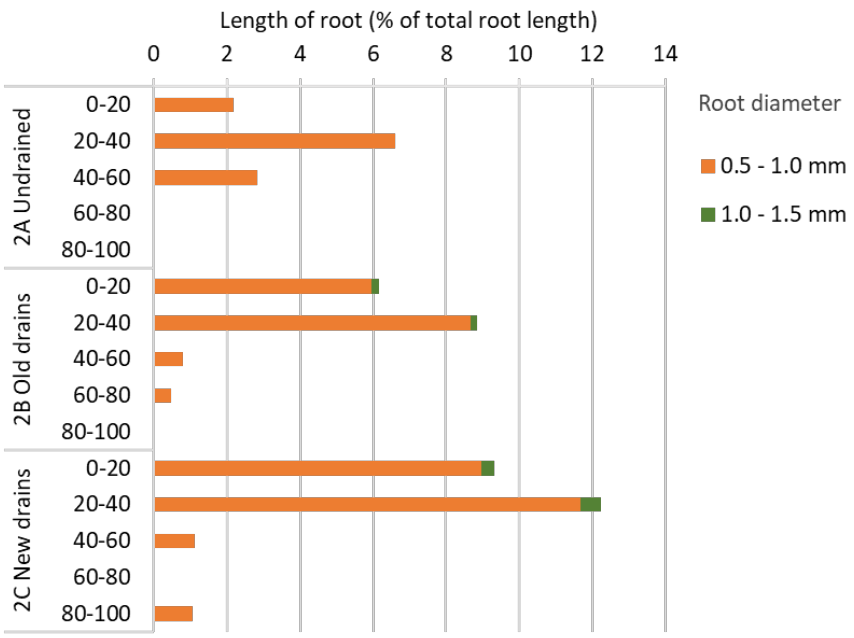


Figure 35. The length of root in each diameter class, as a percentage of total root length, for 0.5 – 1.5 mm diameter roots

Grain nutrition results

The grain nutrition results are summarised in Table 26. The grain samples were entered into YEN (Yield Enhancement Network) nutrition. There will be further analysis and interpretation for these samples via the YEN nutrition reports.

- Across all zones, beans had a low concentration of N (ranging from 3.79 to 4.02 N%). The new drains had a low concentration of calcium (at 0.11 Ca%), and the old drains and new drains had a low concentration of molybdenum (ranging from 0.58 to 0.83 mg/kg) and the new drains area just below the YEN-low threshold for Mo.

- In the bean YEN, grain potassium (K) concentration has been associated with high yields, with the top 25% of entrants for yield having an average of 1.19 % K in the bean. Across all zones, the bean K concentration was around this average (with a range of 1.19 to 1.22%).

Table 26. Mean grain nutrition results, highlighted cells indicate those nutrients which are below YEN-low values (i.e., below 75% of all previous YEN results for this crop type)

Zone	N	P	K	Mg	S	Ca	B	Cu	Fe	Mn	Mo	Zn	N:P ratio	N:S ratio
	%						mg/kg							
2a no drains	4.02	0.61	1.22	0.17	0.22	0.14	11.6	15.9	80.2	13.8	0.58	62.3	6.59	18.3
2b old drains	3.79	0.57	1.22	0.15	0.19	0.13	11.9	14.6	70.5	12.8	0.83	57.9	6.65	19.9
2c new drains	3.96	0.58	1.19	0.15	0.19	0.11	10.4	16.6	67.7	13.2	1.10	51.7	6.83	20.8

Harvest

Winter bean yield was highly variable across the whole field, ranging from <2 t/ha to >5 t/ha with an overall average yield of 4.1 t/ha (after cleaning data and removing headlands). The results show that crop yield varied with soil texture, as such comparison between drainage treatments were made on the heavier clay soil (Figure 36).

Data analysis by agronomics shows:

- A yield benefit of new drains in (2c) over old drains (2b), both areas analysed being in the clay soil texture: 0.67 t/ha ± 0.49 (95% confidence interval), $P<0.001$
- A yield benefit of new drains (2c) over none in (2a) both in clay soil texture zone: 0.77 t/ha ± 0.31, $P<0.05$
- No significant difference between no drainage (2a) and old drains (2b) (0.08 t/ha ± 0.54, $P=0.761$)
- The greatest variation in crop yield was seen in zone 1c

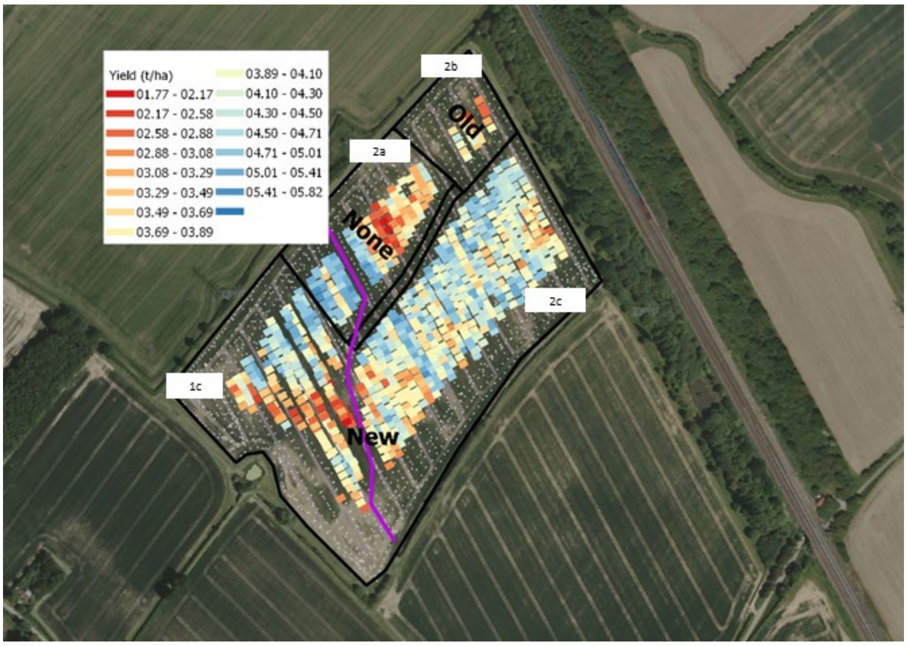


Figure 36. Winter wheat yield map of Overton 5. The pink line marks the approximate boundary between the two soil texture zones

Next steps

In this first year, drawing comparisons on the effectiveness of new and old drainage systems between the different sampling zones is difficult, due to: a) variations in soil texture; and b) the physical disruption due to drain installation.

This work will continue as a long-term trial. The field will be in winter wheat for harvest 2024 and assessments will focus upon quantifying the impact of drainage on crop nitrogen use efficiency.

As it takes time for clay soils to restructure following changes in wetting and drying cycles (due to improved drainage), we will assess soil health in harvest year 2025.

5.5. Action points for farmers and agronomists

It is important to assess fields to see if there is evidence of poor drainage, this may be obvious from the soil surface as surface ponding or saturated topsoils. Equally, waterlogging below the surface may not be obvious at the surface but may be evident by poor crop yields. Refer to the AHDB Field drainage guide on how to monitor and improve soil drainage.