Defra/UKCEH




# Lowland Peat 2

## Field trial plant health and development assessments

16/03/23

# ADAS GENERAL NOTES

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# 1 WINTER WHEAT

## 1.1 Objectives

To determine if there is an effect of a raised water table on plant health, development, yield and quality of winter wheat in lowland peat areas. This work complements flux tower measurements taken by the UKCEH team.

### 1.1.1 Trial sites

Two sites were selected, for assessments, where the UKCEH team had flux towers installed and were monitoring the GHG emissions. The grower involved was Luke Palmer of Rosedene Farm in Stretham.

The two fields were geographically close to one another:

1. **Business as usual (BAU):** the water table was not modified and kept at usual levels
   Location: What3words: bits.modes.quits, Lat/long: 52.331406, 0.224493
2. **Higher water table (HWT):** the water table was raised.
   Location: What3words: Capillary.massaged.erase, Lat/long: 52.323294, 0.231548

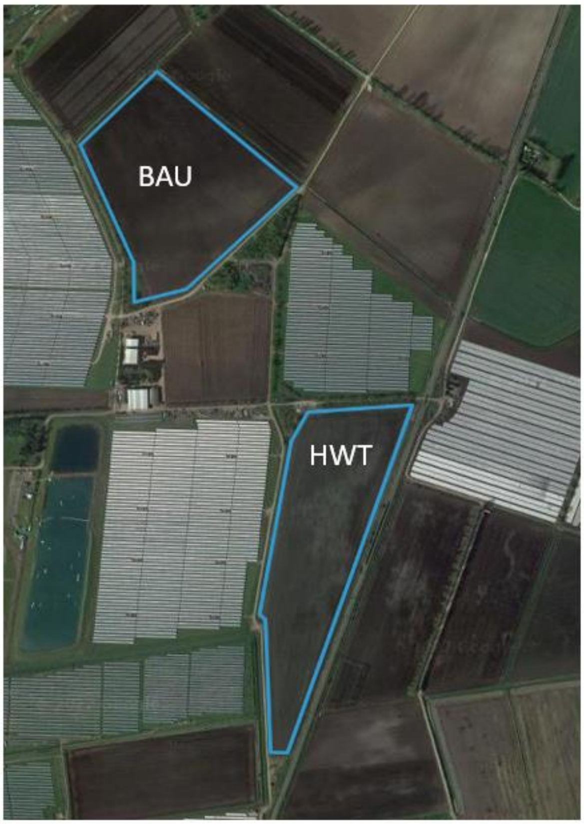


**Figure 1.** Locations of winter wheat trial fields at trial farm to demonstrate geographical proximity of BAU and HWT fields.

## 1.1.2 Assessments

Satellite images of the trial sites, including NDVI, were obtained from Data Farming[1]. These informed how the fields were divided into quadrants to account for potential variation in the field. Each field was divided into four quadrants for assessment, to allow for some spatial variation (**Figure 2**).

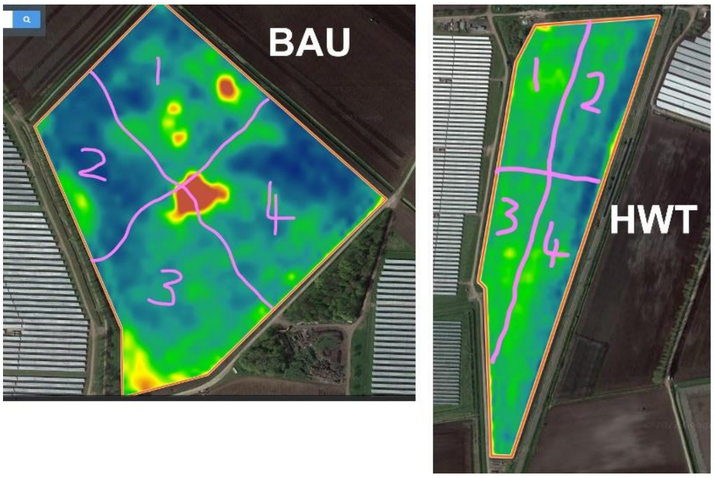


**Figure 2.** NDVI overlays of satellite images of the BAU and HWT field sites, with assessment quadrants (1-4) marked.

### Plant health assessments

Plant health assessment were performed at growth stage 75. Defined as GS75: Medium milk (grain content milky, grains reached final size) in the AHDB Guide to Growth stages of cereals[2]. The growth stage was confirmed by the grower and assessments done by the ADAS field research team on 30/06/23.

Twenty-five tillers were sampled from across a diagonal transect of each quadrant, radiating from the centre to the outside edge of the field. The tillers from each quadrant were assessed for all foliar, root, stem and ear diseases as well as Green Leaf Area. Green leaf area was recorded for each leaf layer until such stage that the leaf layer is completely dead. Green leaf area was assessed on each leaf layer as a percentage. Symptoms of any other diseases were recorded if present.

Formal weed assessments were not made but any marked visible differences in weeds (number and type) in the two fields on a quadrant basis was noted. Pests present were noted but not formally assessed or quantified.

An estimate of the percentage area of each field quadrant affected by lodging and whiteheads was made.

### Pre-harvest assessment

Immediately prior to harvest the fields were assessed using the same quadrants as in the GS75 assessment.

[1] https://www.datafarming.com.au/
[2] https://ahdb.org.uk/knowledge-library/the-growth-stages-of-cereals

Twenty-five tillers were taken from diagonal transects in each quadrant in each field. Both BAU and HWT fields. Tillers were assessed for the following:

1. **Crop height** – measured from base of stem at soil level to top of highest ear.
2. **Lodging** – an estimate of the percentage of stems displaced from their vertical position as a result of stem buckling or root displacement.
3. **Grain heads/fertile ears per m²** – quadrats at 5 points in each quadrant were used to sample the area to count the number of grain heads in the area.
4. **Grains per head** – Each quadrant was sampled as a single plot. Samples were threshed and grains counted in a subsample, using a grain counting machine. The grain number per ear was calculated as follows:

$$\frac{Number\ of\ grains\ in\ subsample\ \text{x}\ weight\ of\ whole\ sample}{Number\ of\ ears\ in\ whole\ sample\ \text{x}\ weight\ of\ subsample}$$

## Harvest and grain quality

A 5kg sample of harvested grain was obtained from the grower and samples were tested to measure the following quality parameters.

1. **Moisture content and specific weight** – using Dickey-John GAC2000 grain analysis computer. Specific weight is a standard of quality in grain trading and intervention, representing the weight of a given volume of grain, expressed in kg/hL. Specific weight measures grain plumpness which is affected by cultivar, growing conditions and husbandry. The GAC2000 is accurate to ± 0.5kg/hL of the readings produced by the UK twenty litre standard instrument. The following conversion was applied to the measured specific weight:

$$Specific\ Weight\ (final) = Specific\ Weight\ (measured) + (0.35 \times (\%MC - 15))$$

2. **Grain quality** – Hagberg falling number and protein content were determined by sending samples to NRM for lab testing (methods S1001 and S1018, respectively). The Hagberg falling number is a measure of alpha-amylase enzyme activity in the sample.

## Post-harvest root sampling

Six root core samples were taken from each quadrant of both BAU and HWT fields. Cores were taken to a depth of 100 cm using a hydrocore, with a 2.6 cm diameter borer/auger. Each core was divided into 20 cm horizons (0-20, 20-40, 44-60, 60-80, 80-100 cm) and the same horizons from each of the 6 replicate cores were pooled. Samples were frozen until analysis.

The two deepest horizon samples (60-80 cm and 80-100 cm) for each quadrant and field were thawed and washed using a Delta-T root washing system with 550 micron filters to separate soil and organic material from roots. Each horizon and quadrant was washed separately. Crop debris and non-root material was removed from samples. Clean roots were placed into containers with water for scanning using WinRHIZO root analysis package software (Regent Instruments Ltd. Quebec City, Canada) and a flatbed scanner. Root measurements were (total length, mean diameter and surface area) calculated. After scanning roots were placed into tins and weights recorded. Roots were dried in an oven at 80°C for 48 hours or until no further weight loss. Dry weights were then recorded.

### 1.1.3 Data analysis

Paired t-tests were conducted between root measures to compare the distributions of size roots between treatments.

## 1.2 Results

### 1.2.1 Plant health assessments at GS75

Mean green leaf area at a similar level between BAU and HWT for leaves 1 to 5 but there was a trend towards reduced green leaf area in the high water table samples (**Figure 3**).

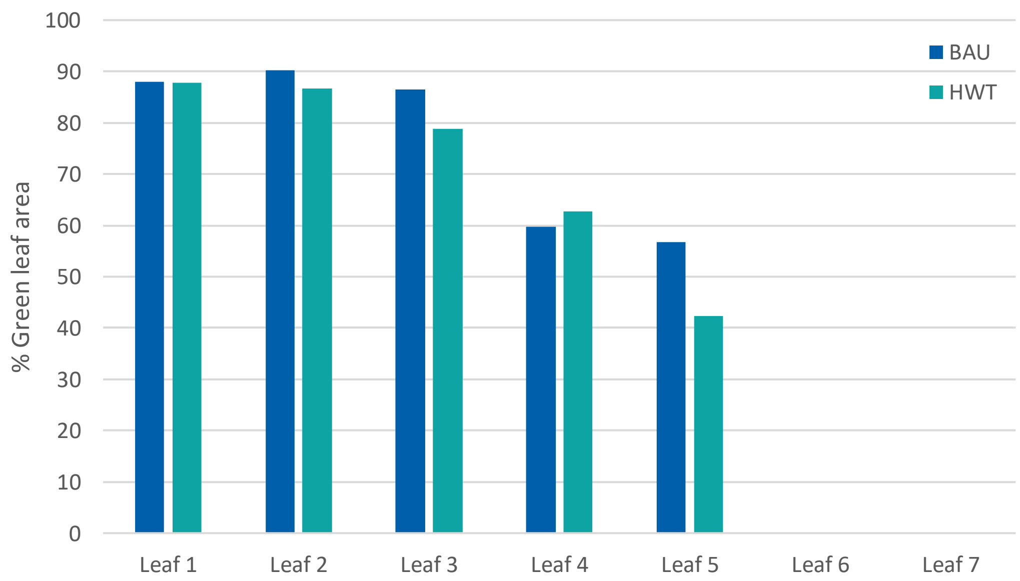


**Figure 3.** Mean green leaf area of 25 tillers sampled from 4 quadrants from winter wheat business as usual (BAU) and high water table (HWT) fields at growth stage 75.

Between 70-90% of leaves sampled from the high water table had some Septoria disease present which was consistent between quadrants. The BAU field was less consistent between quadrants and incidence ranged from under 10 to almost 70% (**Table 1**, **Figure 4**). The severity of disease, where present, was generally low, with less than 10% leaf coverage for all samples. The severity was higher in the HWT samples, compared to the BAU field.

Downy mildew incidence was much lower than that of Septoria. Downy mildew was only present in 2 out of 4 quadrants in BAU, but present in all four quadrants of HWT. The HWT incidence was below 10% for 3 quadrants but in quadrant 3 was 0.36. Severity was under 10% for all quadrants apart from Q1 in HWT which was 22.50% (**Figure 5**).

**Table 1.** Septoria and downy mildew incidence and severity as measured at growth stage 75 in BAU and HWT fields.

| | | Septoria | | Downy mildew | |
|---|---|---|---|---|---|
| Field | Quadrant | Mean Incidence | Mean severity % | Mean Incidence | Mean severity % |
| BAU | 1 | 0.52 | 2.88 | 0.04 | 5.00 |
| | 2 | 0.20 | 5.20 | 0.16 | 8.25 |
| | 3 | 0.04 | 5.00 | 0.00 | 0.00 |
| | 4 | 0.68 | 3.68 | 0.00 | 0.00 |
| HWT | 1 | 0.88 | 7.52 | 0.08 | 22.50 |
| | 2 | 0.76 | 8.76 | 0.04 | 8.00 |
| | 3 | 0.80 | 10.23 | 0.36 | 8.67 |
| | 4 | 0.88 | 3.52 | 0.04 | 2.00 |

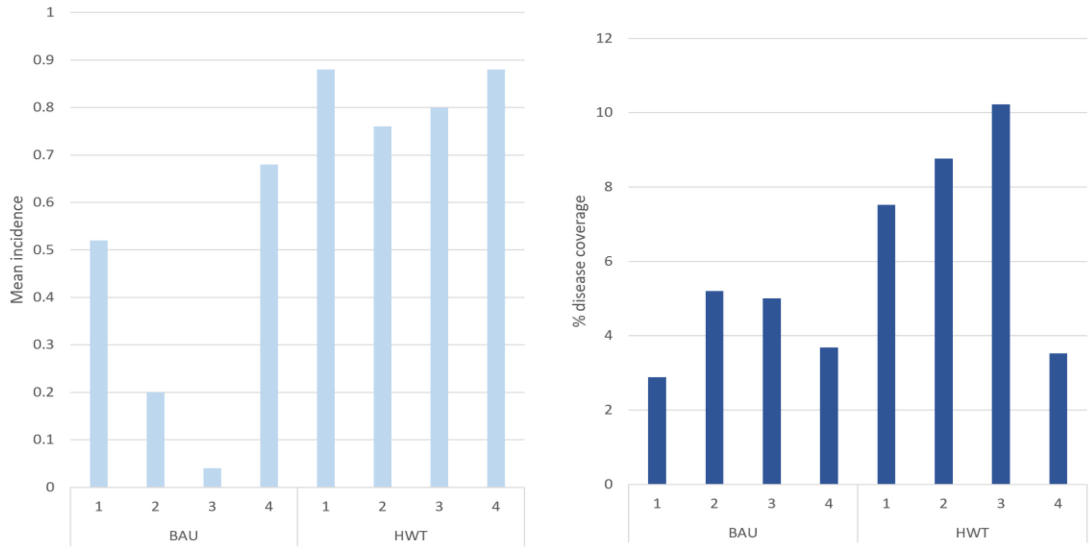


**Figure 4.** Septoria incidence (left) and severity (right) at growth stage 75 assessment of winter wheat in business as usual (BAU) and high water table (HWT) fields.

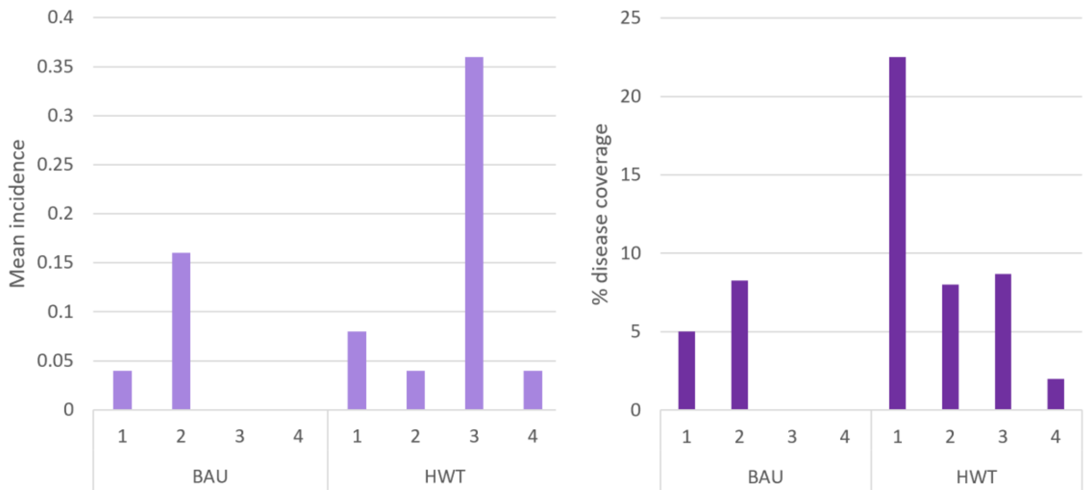


**Figure 5.** Downy mildew incidence (left) and severity (right) at growth stage 75 assessment of winter wheat in business as usual (BAU) and high water table (HWT) fields.

### 1.2.2 Pre-harvest assessment

The pre-harvest assessment showed little difference between BAU and HWT fields and all metrics were within a normal range that might be expected for winter wheat crops. The major difference between the two treatments was in the whole grain weight which was greater in the BAU field (**Figure 6**).

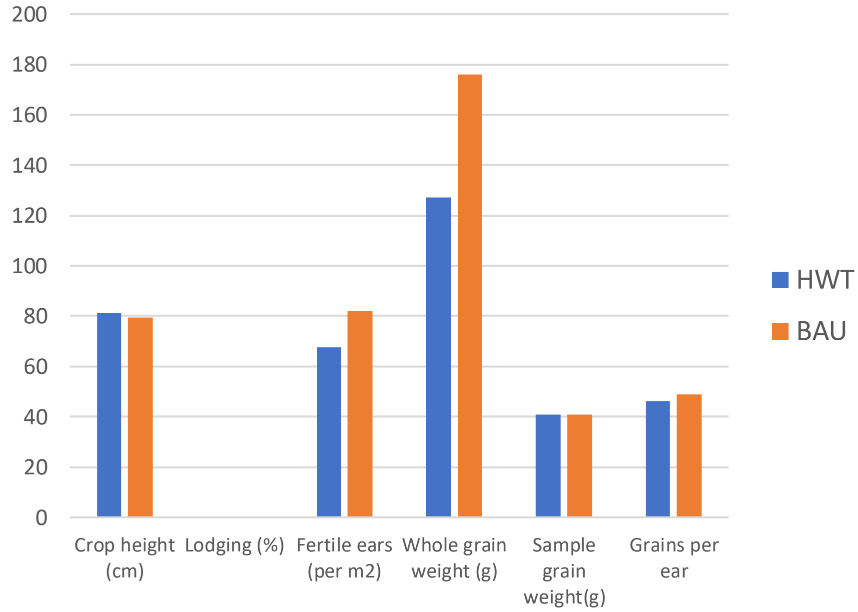


**Figure 6.** Pre-harvest assessment of winter wheat fields for business as usual (BAU) and high water table (HWT) for crop height, lodging, fertile ears, whole grain weight and sample grain weight and grains per ear.

### 1.2.3 Harvest and grain quality

The HWT field had 1.55 tonnes/hectare less yield than the BAU field. Grain moisture and specific weight measures were very similar between treatments and both within normal range. Protein content was greater in the HWT than BAU, but Hagberg falling number was higher in the BAU fields.

**Table 2**. Yield and grain quality measurements for HWT and BAU fields.

| | Yield (t/ha) | Hagberg Falling Number(s) | Protein (%) | Grain moisture (%) | Specific weight (kg/hL) |
|---|---|---|---|---|---|
| HWT | 9.95 | 267 | 12.27 | 13.79 | 82.23 |
| BAU | 11.5 | 360 | 10.9 | 13.73 | 81.7 |

### 1.2.4 Post-harvest root sampling

Mean root length density (RLD) was increased in BAU samples in both horizons when compared with HWT. The deeper 80-100 cm horizon had a lower RLD for both treatments (**Figure 7**) at around 0.2 $cm/cm^3$ for HWT and just below 0.4 $cm/cm^3$ for BAU. The density of roots was greater in the higher horizon of 60-80 cm reaching 1.073 $cm/cm^3$ in BAU and 0.607 $cm/cm^3$ in HWT (**Table 3**).

Root dry weight followed a similar patter to the RLD in both treatments and horizons with the largest dry weighs in the 60-80 cm horizons for both treatments and higher in the BAU than HWT (**Figure 8**).

Average diameter of roots was the same across all horizons and diameters (**Figure 9**).

Specific root length was greater for BAU than HWT in both horizons but the 60-80 cm horizons were greater than the 80-100 cm for both treatments (**Figure 10**).

Distribution of roots was dominated by roots under 0.5 cm length with more than 97% of roots falling into this category for both BAU and HWT in both the 60-80 cm and 80-100 cm horizons (**Table 3**). The 60-80 cm horizons had more 0.5-1 cm roots than the 80-100 cm horizon for both treatments, but BAU had more than HWT in the 60-80 cm horizon at 14.79 cm and 8.23 cm respectively.

Paired t-tests between comparing the 60-80 cm horizon measures between BAU and HWT treatments did not find any significant differences between the metrics, despite the apparent trend towards a difference between treatments.

**Table 3.** Root analysis results for winter wheat post-harvest root core sampling

| Treatment | Horizon Depth (cm) | Root Length Density (cm/cm$^3$) | Root Dry Weight (mg/cm$^3$) | Mean Diam (mm) | Specific root length (m/g) | Percentage of root lengths in different diameter classes (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 0<.L.≤ 0.5 | 0.5<.L.≤ 1.0 | 1.0<.L.≤ 1.5 | 1.5<.L.≤ 2.0 |
| BAU | 60-80 | 1.073 | 0.037 | 0.20 | 301 | 97.8193 | 2.1658 | 0.0146 | 0.0003 |
| | 80-100 | 0.389 | 0.018 | 0.20 | 213 | 98.7585 | 1.2335 | 0.0081 | 0.0000 |
| HWT | 60-80 | 0.607 | 0.026 | 0.20 | 240 | 97.8286 | 2.1429 | 0.0285 | 0.0000 |
| | 80-100 | 0.199 | 0.018 | 0.19 | 106 | 98.3168 | 1.6281 | 0.0551 | 0.0000 |

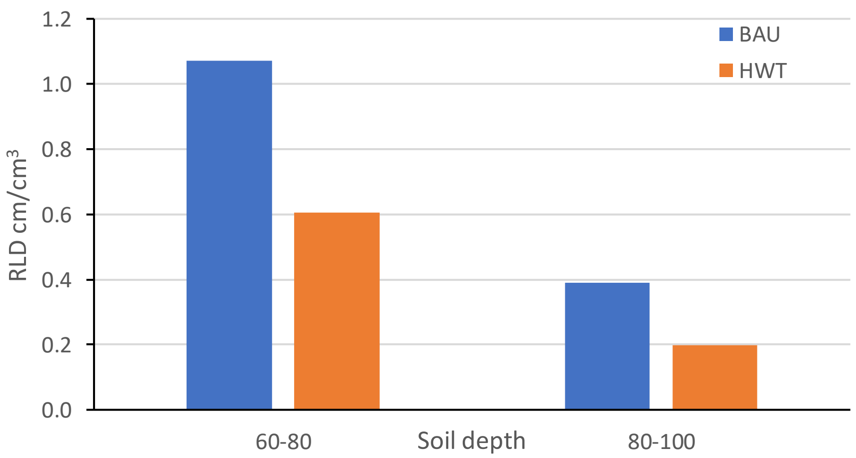


**Figure 7.** Mean root length density (cm/cm$^3$) of roots sampled from winter wheat fields for business as usual (BAU) and high water table (HWT) for 60-80 and 80-100 cm horizons of soil cores.

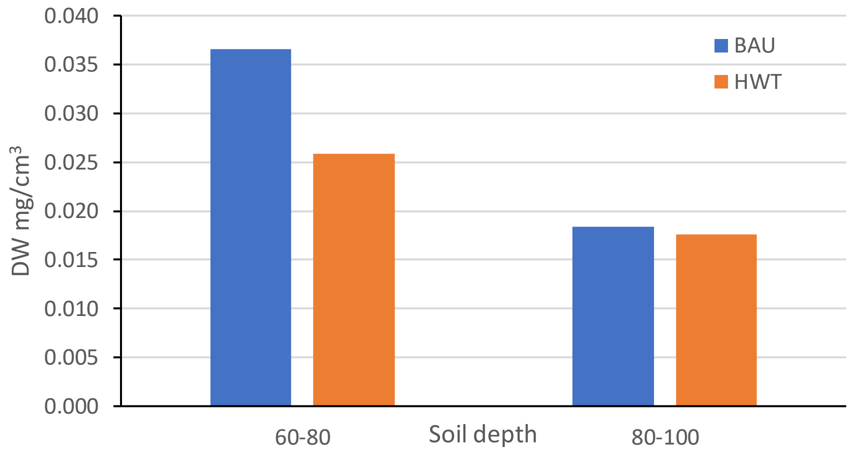


**Figure 8.** Mean dry weight for roots (mg/cm$^3$) sampled from winter wheat fields for business as usual (BAU) and high water table (HWT) for 60-80 and 80-100 cm horizons of soil cores.

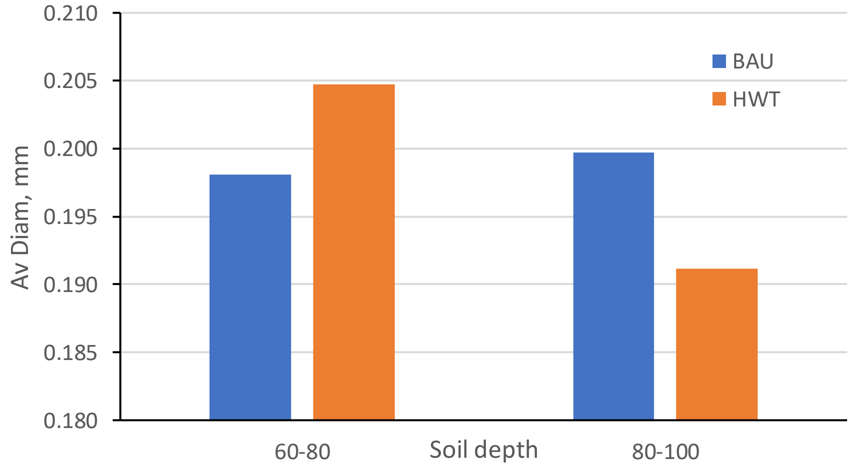


**Figure 9.** Mean root diameter for winter wheat fields for business as usual (BAU) and high water table (HWT) for 60-80 and 80-100 cm horizons of soil cores.

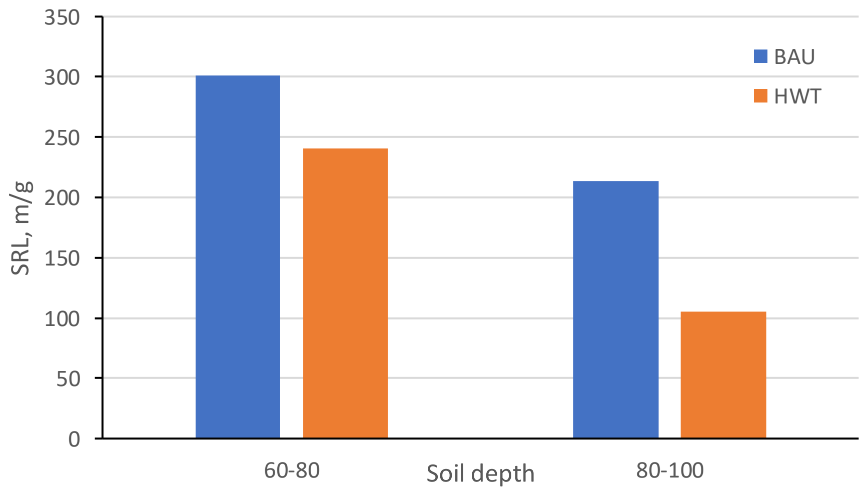


**Figure 10.** Mean specific root length for roots sampled from winter wheat fields for business as usual (BAU) and high water table (HWT) for 60-80 and 80-100 cm horizons of soil cores.

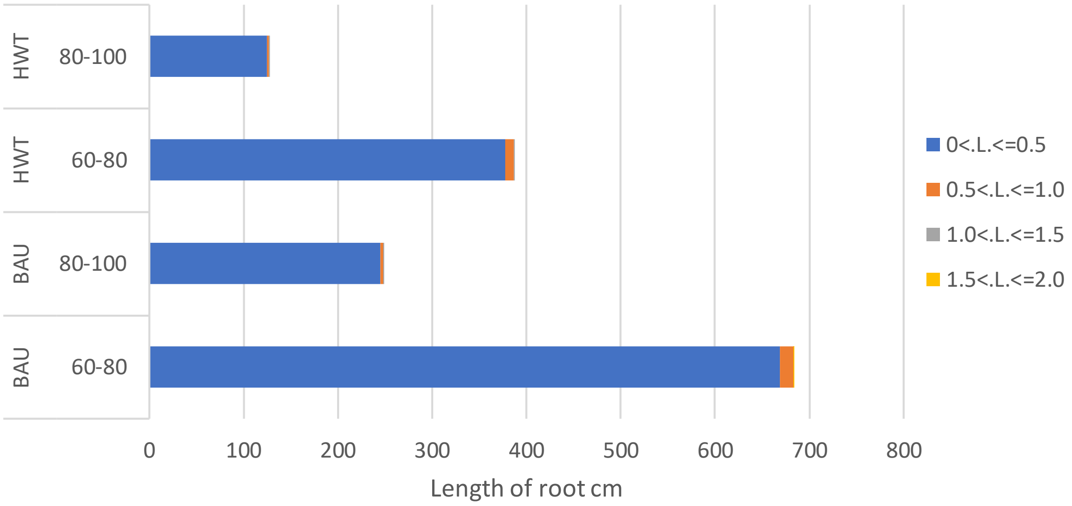


**Figure 11.** Distribution of root size for winter wheat fields for business as usual (BAU) and high water table (HWT) for 60-80 and 80-100 cm horizons of soil cores.

## 1.3 Discussion

The development of the plants in both BAU and HWT fields was generally comparable but with a trend towards reduced green leaf area for HWT indicating that the higher water level may have had some impact on development and put the plants under some stress that impacted their development.

Disease levels were generally low overall for both Septoria and downy mildew. The growing season of 2022 was generally very hot and dry which is not conducive to a high disease pressure. However, the trend towards more Sclerotinia symptoms, albeit at a relatively low level, in the high water table field incidates that this increased moisture below the soil did create an enhanced environment for disease development. The stems of wheat can wick moisture up and create a microclimate suitable for disease to develop. The hot summer is likely to have stressed the plants and then higher water table may have made them more susceptible to this low level disease than the BAU.

The gross yields for the two treatments were within acceptable levels but there was a yield penalty of the HWT treatment. It might be expected that better access to water would be beneficial for development but this was not what was observed. However, there were some unfortunately unavoidable issues with the management of the HWT field which may have confounded some of the results. The grower reported that the water from the HWT field was drained by the Environment Agency without warning just before harvest which dried the field down immediately and would have halted development. This would have had a yield impact, but the crops were also at full development with ears already formed so it is unlikely that all of the yield reduction in the HWT fields was down to this incident. The quality of the grain was generally good and within normal ranges. The lower Hagberg falling number in the HWT field could be caused by pre-harvest sprouting caused by an uneven crop or lodging. Although there was no lodging recorded the HWT field did have some inconsistencies and there were issues with water drainage. Hagberg falling numbers can be increased via crop nutrition and it may be that these plants were compromised in their nutrient uptake by the higher water table, giving a variable soil nitrogen supply.

Root development was as might be expected with higher root length density in BAU field plants, indicating more exploration of roots to go deeper and wider to seek water. This difference between treatments was observed at both 60-80 and 80-100 cm but the densities at the deeper horizons were lower - indicative of the roots reaching the water, but that the BAU roots were putting more resources into accessing water via a more elaborate exploratory root system. Root diameter was similar across treatments and depths. When plants are putting a lot of resources into exploration for water they can tend to size down the diameter of roots to put resources into length of root rather than thickness to extend its root network to seek water. This trend was observed in the 60-80 cm horizon where the BAU roots were thinner indicating that there was more resource put into exploration than HWT. However, this trend does not persist at the deeper horizon, suggesting that some of these differences may be due to natural variation between samples rather than a stress affect.

This trial was conducted in an unusually hot and dry growing season, which would have put the plants under more extreme stress than in a normal growing season. It would be valuable to look at this effect again in other fields with raised water tables in a 'normal' year, to understand the relationships better. The relationship of the underground development of roots in relation to fluxes has not been explored but could be something for future trials, to look at root development over time.

# 2 LETTUCE

## 2.1 Objectives

To determine if there is an effect of a raised water table on the plant health and marketable yield of lettuce. This work was to complement flux tower measurements taken by the UKCEH team via a Skyline installed above the trial plots.

## 2.2 Materials and Methods

### 2.2.1 Trial site and set up

The trial site was located on Rosedene Farm, Severalls Road, Methwold Hythe. Trial site location was located here: What3words: ///cubed.strong.greet

Thirteen plots approximately 1.5 x 1.5 m square, with barriers sunk into the ground surrounding each plot to help maintain water level were set up by UKCEH.

Three irrigation levels were used:

(i) Business as usual (BAU) – no additional irrigation
(ii) Medium irrigation
(iii) High irrigation

Irrigation was supplied from above regularly to maintain consistent levels of moisture in the different treatments.

Plots were planted in early July with up to 16 lettuce plug plants planted in each plot. Plots 1, 5, 8 and 9 were half size plots with up to 8 plants in each.

Three plants were planted within a collar in the centre of each plot where the skyline apparatus would lower the chamber over the lettuce. The remaining plants were planted outside (**Figure 13**).

| **Plot** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **BAU** | **High** | **High** | **High** | **High** | **Medium** | **Medium** | **Medium** | **Medium** | **BAU** | **BAU** | **BAU** | **BAU** |
| **No. Lettuce** | 7 | 14 | 16 | 16 | 8 | 15 | 16 | 15 | 8 | 16 | 16 | 15 | 8 |

**Figure 12**. Plot map for lettuce trial.

**Figure 13**. Lettuce planting in plots to demonstrate the location of the inner area planting and plants outside and how the chamber lowers to measure GHG emissions.

Shortly after planting plots were sprayed following a commercial spray regime. Crops were sprayed on two occasions:

20/07/22: Spray 1: Kerb flo 1.875l/ha + stomp 0.5l/ha herbicide
Spray 2: Movento 0.5l/ha + Hallmark 0.075l/ha + Switch 0.8l/ha + $MnSO_4$ 2kg/ha + $MgSO_4$ 2kg/ha + Headland Complex (Nutrient mix @3kg/ha)

27/07/22: Movento 0.5l/ha + Decis Protech0.42l/ha + Revus 0.6l/ha + $MnSO_4$ 2kg/ha + $MgSO_4$ 2kg/ha + Headland Complex (Nutrient mix @3kg/ha).

### 2.2.2 Assessments

#### Plot and plant selection

Three plots from each treatment were assessed for marketable yield (wet and dry weights), disease incidence and severity on the 27th August 2023. This was aligned with the harvest window for the commercial crops grown in the same area by the same grower.

Only full plots with 14, 15 or 16 plants (**Figure 12**) were assessed as below:

- High irrigation: plots 2, 3, 4
- Medium irrigation: plots 6, 7, 8
- BAU: plots 10, 11, 12

#### Marketable yield

At harvest all plants within the plot were cut at the base and outer leaves trimmed as would be done during commercial harvest. For those plants that were growing outside of the test collar the trimmed marketable heads were counted and weighed. The trimmed leaves were combined by plot and weighed. All samples were taken to the laboratory for dry weights to be calculated.

The three plants per plot that were growing within the collar were harvested and trimmed in the same way but the trimmed basal leaves were left on the ground, as would be done during a commercial harvest. The marketable heads were weighed separately from those that were growing outside of the collar.

## Disease incidence

At harvest each marketable head was visually inspected for the presence of disease and if present scored as follows:

**Downy mildew** – percent disease severity per plant looking at the underside after it is cut using the guide from EPPO standard PP 1/65 (4) Downy mildew of vegetables.

**Botrytis cinerea** – Each individual plant assessed using 0-5 scale:

0 = no attack;
1 = slight attack, infection of basal petioles only;
2 = moderate attack, stem lesion not girdling stem;
3 = heavy/severe attack, stem lesion girdling stem, or upper leaves infected, lettuce unmarketable (including plants completely destroyed by Botrytis during the trial).
4 = total plant collapse/dead

**Sclerotinia** – Each individual plant assessed using 0-4 scale:

0 = no attack;
1 = slight attack, plant wilted, mycelium of Sclerotinia spp. present on lower leaves
2 = moderate attack, infection of upper leaves
3 = heavy/severe attack,
4 = total plant collapse/dead

Diseases were identified according to their symptoms. Samples were not taken for culturing to confirm the cause of the visual symptoms.

## Root core analysis

Soil cores were taken manually using a 2-6 cm diameter borer to a depth of 60 cm. Four cores were taken from 2 plots per treatment from the area immediately after lettuce harvest. High irrigation (plots 2 and 3), medium irrigation (plots 7 and 8), BAU (plots 11 and 12). Cores were separated into 20 cm horizons and amalgamated for each plot by depth.

The two deepest horizon samples (20-40 cm and 40-60 cm) for each quadrant and field were thawed and washed using a Delta-T root washing system with 550 micron filters to separate soil and organic material from roots. Each horizon and quadrant were washed separately. Crop debris and non-root material was removed from samples. Clean roots were placed into containers with water for scanning using WinRHIZO root analysis package software (Regent Instruments Ltd. Quebec City, Canada) and a flatbed scanner. Root measurements were (total length, mean diameter and surface area) calculated. After scanning roots were placed into tins and weights recorded. Roots were dried in an oven at 80°C for 48 hours or until no further weight loss. Dry weights were then recorded.

## 2.3 Results

### 2.3.1 Marketable yield

At harvest there was a visible difference between different treatments with the BAU plants visibly smaller than those with high and medium irrigation. The medium irrigation plants appeared to be the largest of all treatments in all plots (**Figure 14**). These visible differences were mirrored in the fresh and dry weights of the marketable yield (**Figures 15** and **16**). Plants harvested from outside of the collar within the plot had on average a higher marketable weight in the medium irrigated plots but at a similar level to the high irrigation which was slightly lower. The BAU plots had substantially lower marketable yield, approximately half that of the high and medium irrigated plots. Plants harvested from within the collar area (inner) were generally smaller for all treatments than those outside of the collars, but the pattern between treatments remained consistent with the medium irrigated plots having the largest plants. Trimmed leaves followed a similar pattern to fresh weight but with the high irrigation appearing to require more leaves to be trimmed to bring the head to marketable specification.

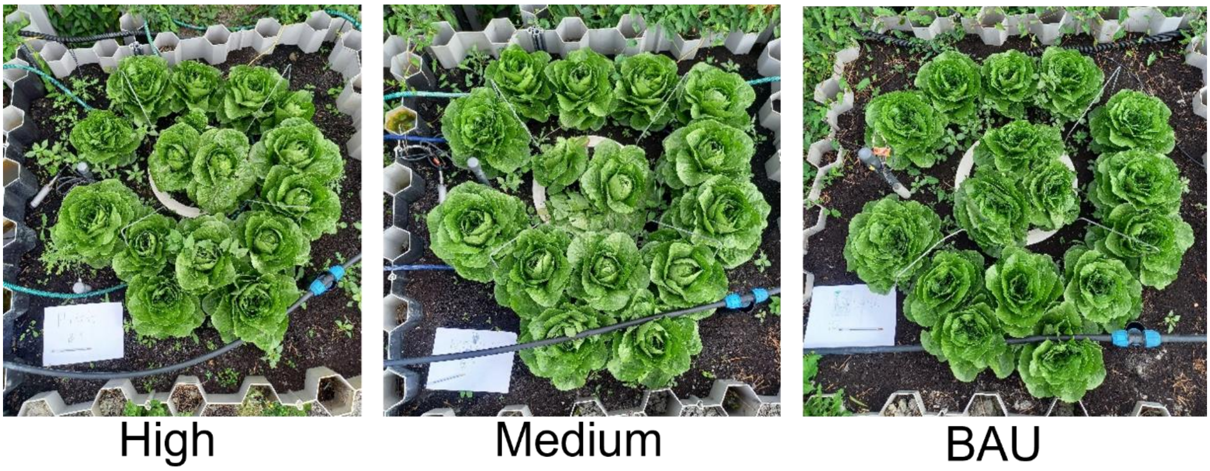


**Figure 14.** Example of lettuce head growth in different treatment plots at harvest.

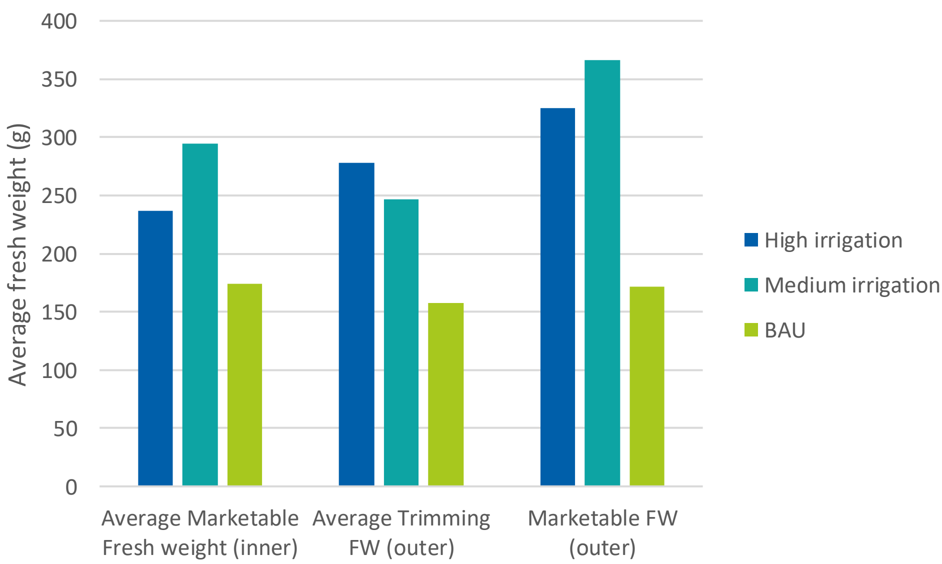


**Figure 15.** Average fresh weight of lettuces at harvest for the three irrigation treatments (3 plots per treatment).

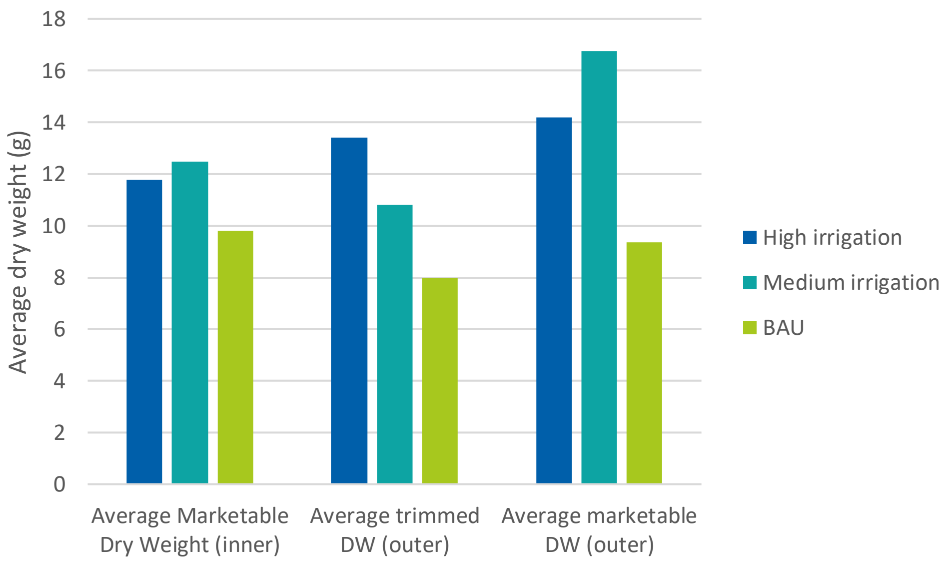


**Figure 16.** Average dry weight of lettuces at harvest for the three irrigation treatments (3 plots per treatment).

### 2.3.2 Disease incidence

There was very little disease incidence recorded in the plots with no downy mildew or botrytis observed in any of the plots. Very low levels of Sclerotinia were detected with no plants scoring more than a 1 on the disease severity scale with no more than 1-5% coverage of leaf symptoms for any one plant. Each of the three plots with high irrigation had some Sclerotinia affected although the majority of the plants were unaffected. A single plant in plot 8 with medium irrigation had some symptoms and a single plant in plot 11 with BAU.

**Table 4**. Sclerotinia incidence at harvest

| Treatment | Plot | No. plants affected | Average per plant disease score |
|---|---|---|---|
| High irrigation | 2 | 5 | 1 |
| | 3 | 1 | 1 |
| | 4 | 2 | 1 |
| Medium irrigation | 6 | | |
| | 7 | | |
| | 8 | 1 | 1 |
| BAU | 10 | | |
| | 11 | | |
| | 12 | 1 | 1 |

### 2.3.3 Root core analysis

Root length density (**Figure 17**) was increased in the 40-60 cm horizon compared to the 20-40 cm horizon but with very little difference between the three treatments in both horizons. RLD for 20-40 cm was 0.13-0.28 cm/cm$^3$ and 40-60 cm was 0.87-1.22 cm/cm$^3$. Mean dry weight followed a similar pattern (**Figure 18**). Mean root diameter (**Figure 19**) was relatively consistent between horizons and treatments ranging between 0.162 – 0.2 mm. Distribution of roots (**Figure 21**) was similar across all treatments with the highest proportion (of roots in the smallest size category 0-0.5 cm for the 20-40 cm horizon. There was a slight increase in the proportion of the larger category 0.5 – 1.0 cm in the 40-60 cm horizon samples for all treatments.

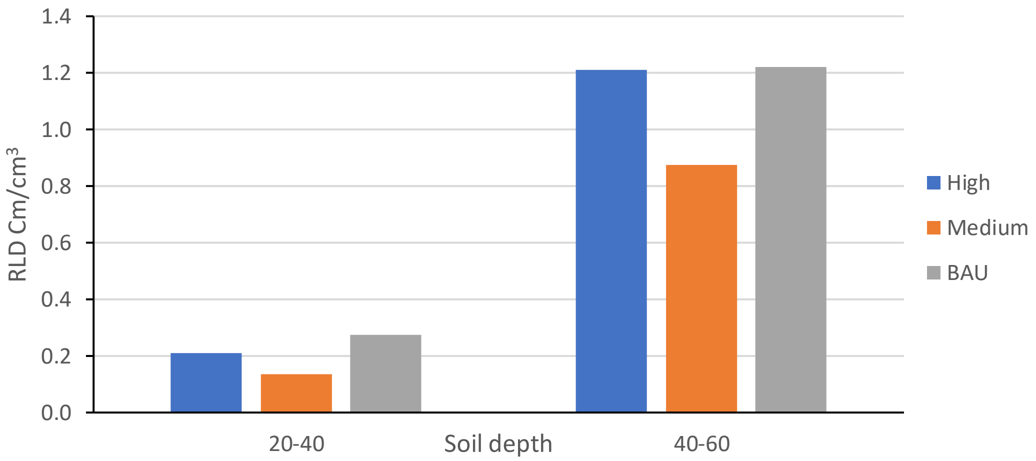


**Figure 17.** Mean root length density (cm/cm$^3$) of roots sampled from lettuce plots with high and medium irrigation or BAU for 20-40 and 40-60 cm horizons of soil cores.

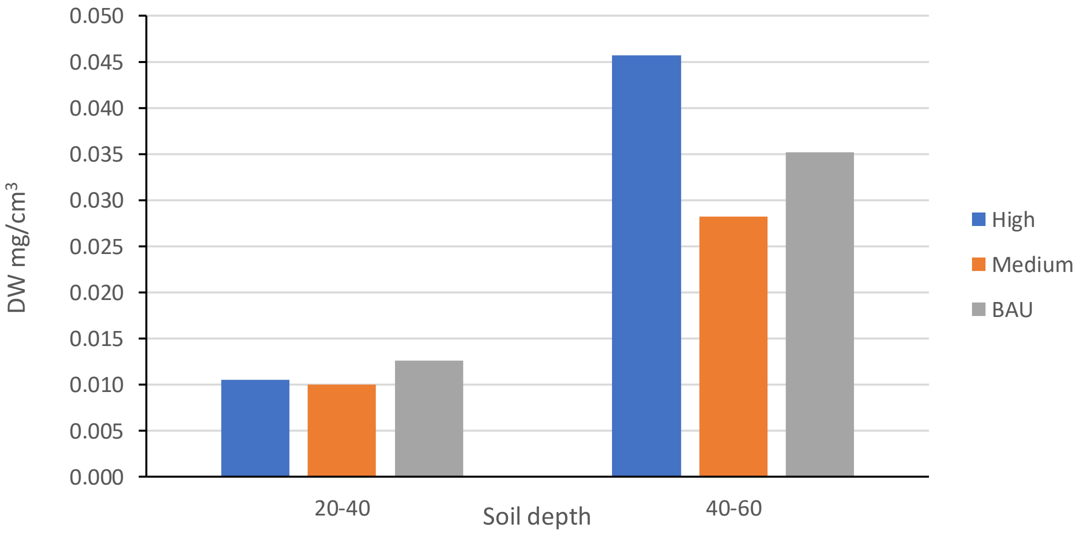


**Figure 18.** Mean dry weight (mg/cm$^3$) of roots sampled from lettuce plots with high and medium irrigation or BAU for 20-40 and 40-60 cm horizons of soil cores.

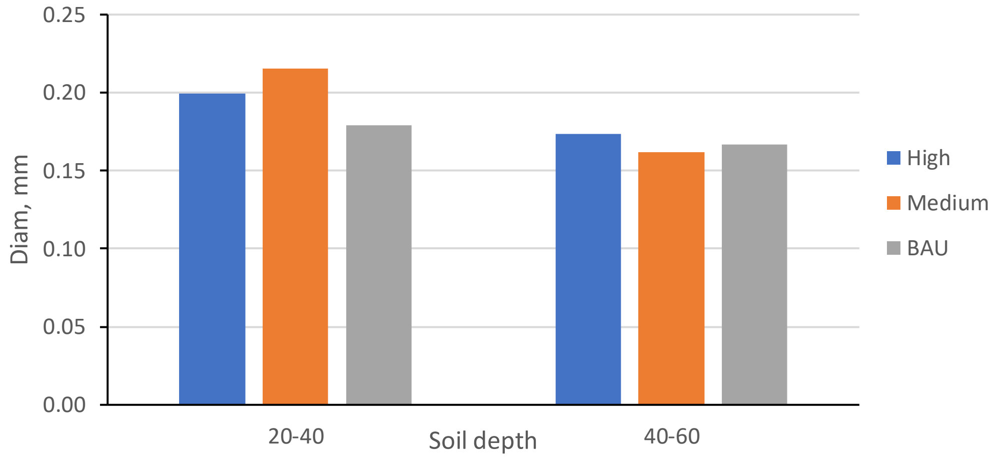


**Figure 19.** Mean root diameter (mm) of roots sampled from lettuce plots with high and medium irrigation or BAU for 20-40 and 40-60 cm horizons of soil cores.

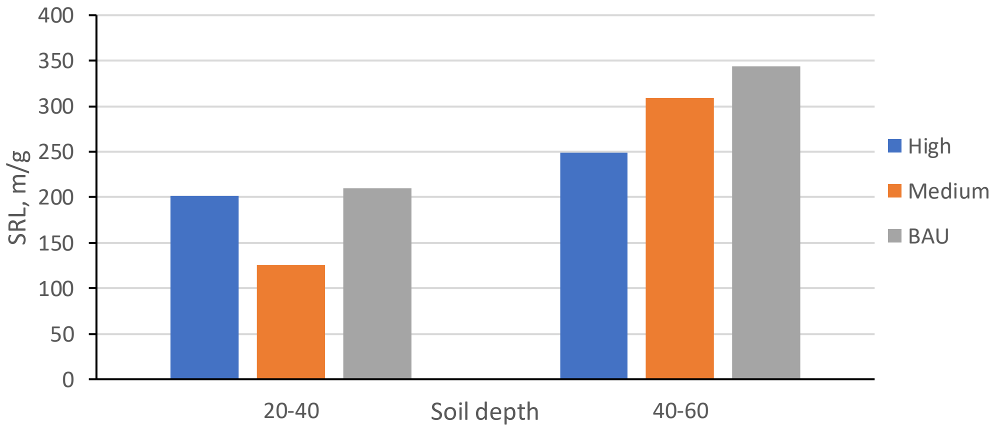


**Figure 20.** Mean specific root length (m/g) of roots sampled from lettuce plots with high and medium irrigation or BAU for 20-40 and 40-60 cm horizons of soil cores.

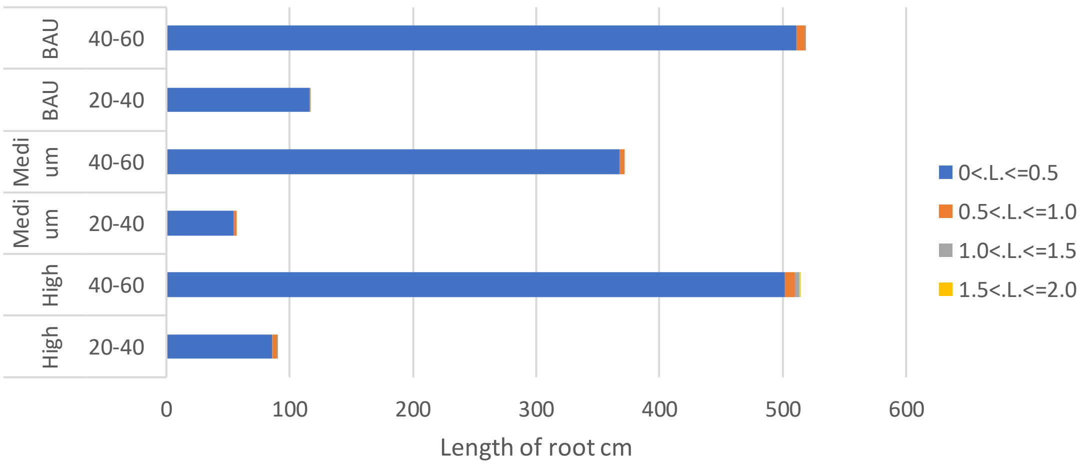


**Figure 21.** Distribution of root size for lettuce plots with high and medium irrigation or BAU for 20-40 and 40-60 cm horizons of soil cores.

**Table 5.** Root analysis results for soil cores taken for lettuce plots immediately after harvest.

| Treatment | Depth (cm) | RLD ($cm/cm^3$) | Root DW ($mg/cm^3$) | Mean Diam (mm) | Specific root length (m/g) | Percentage of root lengths in different diameter classes (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 0<.L.≤ 0.5 | 0.5<.L. ≤1.0 | 1.0<.L. ≤1.5 | 1.5<.L. ≤2.0 |
| High irrigation | 20-40 | 0.21 | 0.01 | 0.20 | 202 | 95.8570 | 4.1018 | 0.0412 | 0.0000 |
| | 40-60 | 1.209 | 0.046 | 0.173 | 249 | 97.7019 | 1.5220 | 0.7376 | 0.0385 |
| Medium irrigation | 20-40 | 0.13 | 0.01 | 0.22 | 126 | 95.3895 | 4.6105 | 0.0000 | 0.0000 |
| | 40-60 | 0.876 | 0.028 | 0.162 | 309 | 98.9779 | 1.0221 | 0.0000 | 0.0000 |
| BAU | 20-40 | 0.28 | 0.01 | 0.18 | 210 | 99.2726 | 0.7274 | 0.0000 | 0.0000 |
| | 40-60 | 1.220 | 0.035 | 0.167 | 344 | 98.7249 | 1.2655 | 0.0097 | 0.0000 |

## 2.4 Discussion

The higher irrigation treatment resulted in the highest marketable yield of the three treatments tested. The medium treatment had a similar marketable yield to the high irrigation, albeit slightly lower. The BAU treatment was both visibly and in terms of marketable yield smaller than those with the supplemental irrigation. This indicates that the supplemental irrigation was beneficial especially in the growing season of 2022 which was exceptionally warm and dry in the East of England. Growers were using all of their available water in this season and this grower had recently built a supplementary reservoir, which was almost empty by the end of the season. Although this enhanced irrigation was necessary and beneficial in this case, if the hot drought conditions continue then such high levels of irrigation might not be viable. This above ground irrigation however was used because attempts to raise the water table and maintain it at those levels in the test plots proved to be very difficult.

Despite a slightly increased incidence of Sclerotinia in the high irrigation treatment plots the overall disease level was very low. This is in part due to the very hot, dry growing season that was experienced which was not conducive to disease development and growers elsewhere experienced similarly good years for disease. The growing season for lettuce from planting to harvest was also relatively short so very little time for disease development to occur.

The root analysis was perhaps as expected for a lettuce crop where roots developing relatively shallowly and spreading laterally. The deepest 40-60 cm horizons across all treatments had higher root length density than the shallower 20-40 cm horizon which indicates that these deeper roots were in an exploratory habit seeking water. This would fit with the above ground irrigation that was applied whereby the higher roots had more access to water, whereas the lower roots sought to reach deeper water, which we know to be draining from the base of the plots. The root diameters were similar in both horizons, across all treatments.

Roots that are in an exploratory phase can tend to be lower diameter as the plant puts less energy into producing thicker roots in favour of sending out longer roots to seek water. In this case this effect was not seen between horizons perhaps because the need to seek water was not so great. In a more water deprived/drought condition plot perhaps we would see this effect, but in these plots although there was difference in water availability all of the lettuces developed well, so did not appear to under extreme stress that might trigger this root diameter difference. However, the higher root density in the deeper 40-60 cm horizon does indicates that more exploration at the deeper level was taking place. The relatively uniform root diameters across treatments and horizons suggests that although some exploration was taking place the plants had adequate water and did not need to use reduced diameter as a strategy to seek more efficiently.

There was some variation between treatments but these were mostly likely due to natural variation or noise in the data. It would have been optimal to take more cores per plot and all plots to be able to test these differences statistically, but logistically it was not possible. In future trials more cores would be taken and perhaps even deeper at 60-80 cm to explore further, although the average lettuce is known to have roots to about 60 cm, which is why deeper cores were not taken.

The conclusion is that the higher water level was beneficial in terms of marketable yield, but in a year with conditions more conducive to disease development the higher water level could have a negative impact. The development of roots under the ground indicates some exploratory strategies were employed. The impact of below ground plant development on emissions is an area that would warrant further exploration.