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Project number:	CP 121
Project leader:	Dr Jim Monaghan, Harper Adams University
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AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headlines

- Electrical conductivity (EC) measurements can be used to demarcate zones of soil variability but although underlying soil properties are important, particularly soil organic matter, they do not wholly account for the variability that is seen in Iceberg lettuce growth and maturity.
- Transplants in a propagation trays are variable; this project has shown that transplant placement and positioning at planting also impacts on lettuce yields and marketable quality.

Background

Lettuce growth is influenced by soil properties, climatic conditions and agricultural practices as well as the interactions amongst these three factors. Understanding the spatial variation of these factors is fundamental when assessing the spatial distribution of crop yields and making precision farming decisions.

Variability in the growth of lettuce transplants leads to variation in head weight and maturity at harvest and can affect post-harvest quality. This causes a significant issue for growers as they wish to harvest heads of a uniform size and weight. Uniformity of the mature heads determines the efficiency of a single-pass lettuce harvest; oversized and under-developed heads result in crop wastage.

It is known that the availability of soil nutrients and moisture can affect plant growth and that the spatial variability of soil texture, and thus soil properties contribute significantly to crop variability. Variability in growth and development might be explained by dissimilarity in soil properties such as pH, nutrients and water levels. Spatial soil variability can be mapped indirectly by scanning the field soil for electric conductivity (EC). The relationship between soil properties and soil electrical conductivity (EC) has been established and the potential for using EC soil scans to predict yield variation in long season crops has been reported. Yet, no work has been reported in short season crops such as lettuce.

Until recently, growers have treated fields uniformly without considering the natural variation of soil on a field scale. With the promotion of precision agriculture choices, it has become possible to use techniques such as soil EC scanning to identify management zones, target soil sampling and determine variable seeding rates.

The purpose of this project was to understand the causes of in-field variation in lettuce growth as it affects harvest efficiency in lettuce crops. Reducing this variability through agronomic solutions would increase marketable yields. The research work has focused on: a) understanding soil variability and its influence on variation in lettuce growth, spatially and temporally at a field scale; and b) exploring the causes of variability in transplant growth and establishment.

This research investigated in-field variation in lettuce growth by quantifying variation in soil properties and establishing the relationships between soil variation and lettuce growth. Commercial EC scans were used initially to identify soil zones. A few studies have shown that EC scans are useful for targeting soil sampling across a field, as soil EC maps coincide with soil variation. Work in 2014/2015 identified different yield zones; with zone differentiation being guided by soil EC scans which were generated by commercial equipment (Veris3100). The variability in soil properties, and lettuce growth and quality in the zones was investigated further, in order to relate growth responses to a limited number of soil factors.

Summary

Year 1

Two field experiments were carried out in 2014 in the field 'Redmere P36', at G's growers Ltd in Cambridgeshire, to identify different soil zones within the field. Lettuce yields, and soil physical and chemical properties in these zones, were then examined. Multiple soil and plant samples were taken from the zones over two successive crops in the spring with further samples taken over the summer (June-October). Samples were transferred to Harper Adams University (HAU) for further assessments and lab soil analysis. It was concluded from the first-year work that:

- EC scans can be used to identify different soil zones within a field and enable targeted soil sampling.
- Samples from soil zones that varied in EC range varied statistically in percentage clay content and in the nutrients magnesium, Mg; potassium, K and phosphorus, P. However, all samples had a significantly high level of organic matter (above 20%) so they were classified as organic.
- Plant growth varied between the zones mid-season and at harvest.
- Demarcating variable soil-EC zones at a smaller scale (less than 3 m^2) proved inefficient for studying the potential for increasing lettuce crop uniformity through variable management.

Year 2

In 2015, two field experiments were done to map out lettuce yield and soil factors in another field, P57 at a G's Growers Ltd farm in Cambridgeshire. In addition, the influence of texture (particularly sand proportion) on lettuce biomass production was investigated in a glasshouse pot experiment. Conclusions from year 2 work were that:

- The variability pattern of lettuce yields was consistent over the zones, suggesting that yield distribution was mainly influenced by soil properties. Yield variation was mainly driven by underlying soil properties rather than by seasonal variation in moisture and weather conditions.
- Statistical analysis showed that variability in sand proportions and soil organic matter were key soil factors causing yield variation. The data showed that the relationship between the yield and soil properties varied particularly when the organic matter levels varied.
- Although variable field zones could be identified using soil EC scans or soil properties' maps along with the yield maps, there was no statistical correlation of yields with EC scans or conformance with maps.
- A preliminary glasshouse study suggested that the variability that exists in propagated lettuce transplants before they are planted is an important source of variation. This was further investigated.

Year 3

Redmere P57 zones were further examined by excavating four profile pits to investigate soil structure. Two pits were excavated in the high yielding zones and two in the low yielding zone. There was an apparent difference in soil structure between the North and the South regions of the field. The difference was characterized primarily by the depth of the organic matter and the topsoil (red soil) layer (Appendix 1).

Additionally, the third year of the project focused more on the transplant propagation stage and placement of transplants in the field.

Four experiments were done in 2016. The first investigated the impact of varying soil organic matter levels on water holding capacity and soil bulk density.

The second and the third glasshouse experiments investigated variation in transplant sizes at a tray level. The experiment was carried out at Second Willow Nursery, G's, Littleport, Cambridgeshire. The persistency of transplant variation was tracked during growth in a glasshouse experiment at HAU.

Finally, field trials was established at Kenny Hill 44 field, G's growers, Ely, Cambridgeshire to investigate the impact of variable transplant placement (Figure A) at planting on the yield and marketable quality of harvested heads.

Conclusions were that:

- Increasing soil organic matter increases the amount of soil moisture held at field capacity and decreases bulk density.
- There is a considerable amount of variation amongst transplants grown from uniform seeds under uniform conditions.
- Transplants that vary in size (length) within the same tray vary in fresh weight. This variability increases after transplanting.
- Planting position (in terms of orientation, and the depth or the proportion of peat block covered or in contact with soil) affects the marketable yield (Figure B); relatively uniform transplants develop into variable mature heads in terms of head size, fresh weight and marketable quality and particularly appearance when placed differently at planting. The most favourable planting position was the normal position (1) as shown in Figure A.

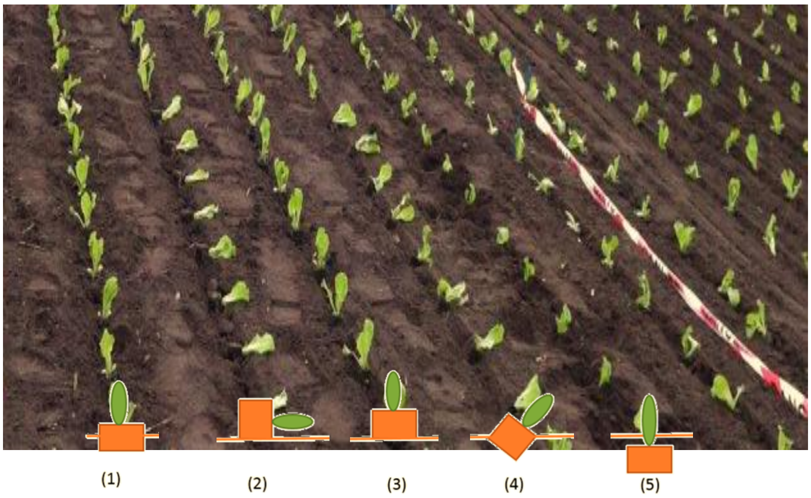


Figure A. Transplants field placement treatments, from left to right; 1) normal, 2) on the side, 3) above soil surface, 4) tilted or 50% of the peat block covered with soil, and 5) buried (approximately 2 cm of the green shoot was underneath the soil).

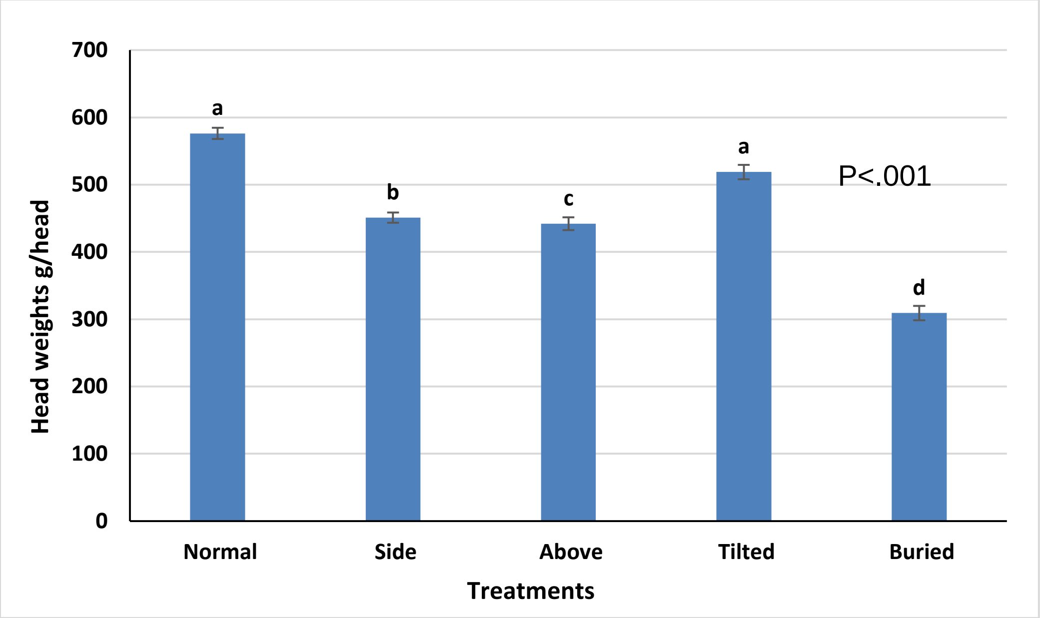


Figure B. Mean trimmed head weights for five different planting positions ($P<.001$) ($n=60$). Error bars show the standard error of the samples for $n=60$.

Financial Benefits

Not quantified but G's opinion is that providing information to manage crops more precisely could result in increased marketable yields of Iceberg lettuce.

Action Points

- EC scans can be used to identify different soil zones within a field and enable targeted soil and crop sampling as a first step to quantify yield variation across the field.
- Zones smaller than 3 m^2 proved inadequate for precision management in lettuce.
- Attention should be given to variability in soil organic matter and sand content across the field. Statistical analysis showed that variability in sand proportions and soil organic matter were key soil factors causing yield variation. The data showed that the relationship between yield and soil properties varied in particular when organic matter levels varied.
- Yield variation in lettuce crops was mainly driven by underlying soil properties rather than by seasonal variation in moisture and weather conditions during plant growth.
- Uniform handling of propagated transplants (growing media, light, and moisture) should be given more attention during propagation at a tray scale, to reduce transplant variability. There were no clear in-tray positional effects. However, excluding significantly small transplants from planting is recommended as the transplants that vary in size (length) within the same tray vary in fresh weight after planting. Moreover, the smaller sized

transplants do not normally catch up larger sized transplants. They either result in smaller heads or do not form marketable heads.

- Planting position requires attention when transplanting, in terms of orientation and the depth and proportion of peat block covered or in contact with soil, as this impacts on marketable yield. Similar or relatively uniform transplants develop into variable mature heads in terms of head sizes, fresh weight, marketable quality and particularly appearance, when positioned differently at planting. Transplants that were planted too deep in the soil, too high, or left tilted in the soil, all resulted in reduced yield due to pest damage or rotting due to contact with moist soil, and they were misshapen.

SCIENCE SECTION

Introduction

Lettuce growth is influenced by soil properties, climatic conditions and agricultural practices as well as the interactions amongst these three factors. Understanding the spatial variation of these factors is fundamental when assessing the spatial distribution of crop yields and making precision farming decisions.

Variability in the growth of lettuce transplants leads to variation in head weight and maturity at harvest and sometimes post-harvest quality. This causes a significant issue in field-grown lettuce where growers wish to harvest heads of a uniform size and weight. Uniformity of the mature heads determines the efficiency of a single-pass lettuce harvest; most oversized/under-developed heads result in crop wastage.

It is known that the availability of soil nutrients and moisture can affect plant growth and that the spatial variability of soil texture, and thus soil properties contribute significantly to crop variability (Taylor *et al*., 2003). Variability in growth and development might be explained by dissimilarity in soil properties such as pH, nutrients and water levels. Spatial soil variability can be mapped indirectly by scanning the field soil for electric conductivity (EC). The relationship between soil properties and soil electrical conductivity (EC) has been established and the potential for using EC soil scans to predict yield variation in long season crops has been reported (Taylor *et al*., 2003). Yet, no work has been reported in short season crops such as lettuce.

Until recently, growers have treated fields uniformly without considering the natural variation of soil on a field scale. With the promotion of precision agriculture choices, it has become possible to use techniques such as soil EC scanning to identify management zones, determining variable seeding rates and targeted soil sampling.

The purpose of this project was to understand the causes of in-field variation in lettuce growth and ultimately improve harvest efficiency in lettuce crops and enhance yield uniformity through providing targeted solutions. The research work has focused on: a) understanding soil variability and its influence on variation in lettuce growth in spatial and temporal aspects at a field scale; and b) exploring the causes of variability in transplant growth and establishment.

Effect of organic matter on soil water properties

In Year 2 (CP 121 Report Annual 2016), it was concluded that for the studied field, Redmere P57, the variability pattern of lettuce yield was mainly influenced by relatively consistent underlying soil properties and less by soil properties and weather conditions that varied with season. The high and low yielding zones in the first crop remained the same in the second crop. It was suggested that the spatial variation in the first crop could be used to predict possible management zones for the subsequent crop in the same field, if the soil factors that are controlling the yield were to be identified and their way of influencing the crop was understood.

Although EC scans were useful in predicting variable field zones in terms of soil properties, they were not suitable for predicting lettuce yield directly. This suggests that in the field studied, the soil factors affecting EC values differed from those influencing crop yield measurements (Corwin *et al*., 2003).

In year 2 (2015), lettuce yield was mainly correlated with bulk density and sand. A Stepwise ANOVA statistical model analysed the contribution of the following factors to variation in lettuce yield: soil bulk density, sand proportion, total N, P and K, and soil moisture content at harvest. These components described 43% of the variation in lettuce yield. Bulk density and sand accounted for most of this 43% variation. Variable bulk density and sand zones however, did not match with the yield zones when comparing maps of yield to soil properties. From north-east to south west of the field, the yield was higher where there was less bulk density and less sand. However, from the east to the west part of the field, the yield was higher where there was more sand, and the bulk density trend was irrelevant (Figure.1).

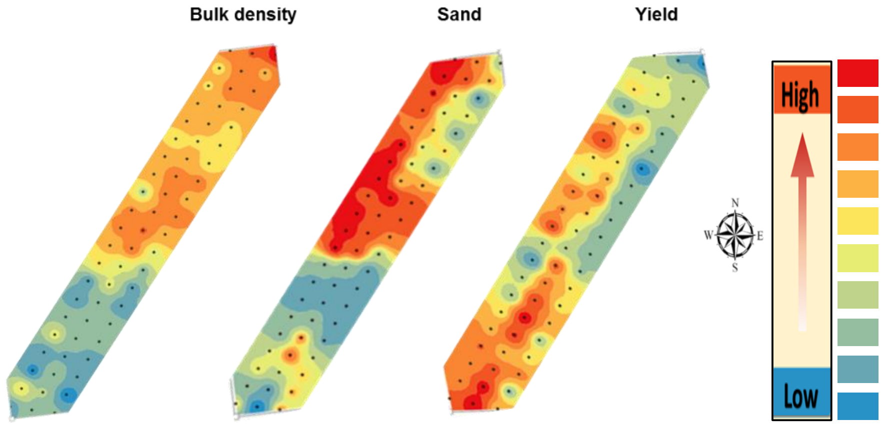


Figure 1. Maps of soil properties (sand and bulk density) and yield (Field experiment 03CP 121 Report Annual 2016) created using the same grid in ArcMap software and the geometric intervals classification method in the geostatistical wizard tool, classified into 10 classes.

Both soil bulk density and sand content (textures) are aspects of soil physical quality, and both were related to the yield as indicated by the statistical model. This suggests that yield is mainly driven by the soil physical quality. Dexter (2003) noted that soil physical quality plays a key role in soil quality due to its significant impact on both the chemical and the biological aspect of the soil. Whilst an increase or decrease in soil bulk density is an indication of the degree of compaction of the soil, soil particle sizes (texture) and organic matter (OM) determine soil compressibility. Arvidson (1998) investigated compaction in over a 100 field experiments in Sweden and concluded that soils with higher levels of organic matter had better yields. He also noted that organic matter reduced soil bulk density, compactness and improved porosity and air content of the soil. A review of literature by Loveland and Webb (2003) on the critical ranges of organic matter in soils stated that there are no "critical" ranges of organic matter that define soil degradation. However, they found that a reduced organic matter was commonly associated with negative soil conditions.

Dexter (2003) investigated the physical parameters of the soil (including organic matter, bulk density and texture) and defined this "physical quality" by the microstructure of the soil and studied its effects on rootability. They argued that soil physical quality is a better indicator of rootability than bulk density, and suggested that organic matter content has a greater impact on soil microstructure than particle size (texture), particularly when clay was lower in the soil. Moreover, he attributed the beneficial physical properties of the soil that are necessary for agricultural production to organic matter due to its association with other factors such as reduced adverse impact of machinery and enhanced rooting intensity.

The texture maps of Redmere P57, 2015, highlighted that there was considerable variation in soil physical quality between the north and the south parts of the field particularly for organic matter and clay (Figure 2).

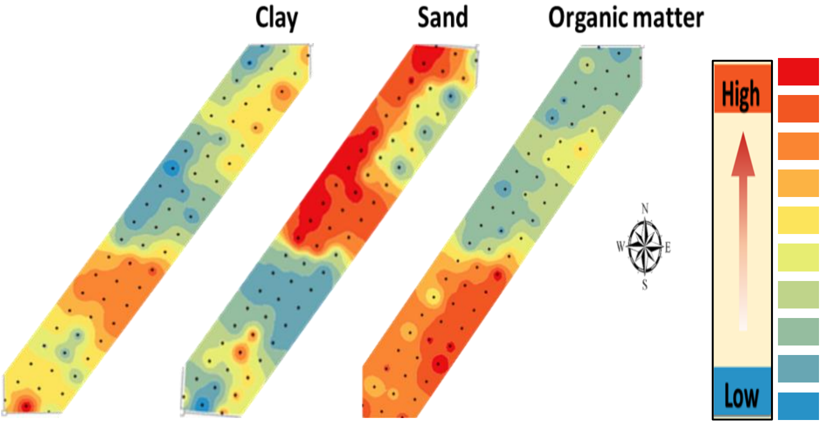


Figure 2. Maps of soil properties (sand, clay and organic matter) (Field experiment 03 CP 121 Report Annual 2016) created using the same grid in ArcMap software and the geometric intervals classification method in the geostatistical wizard tool, classified into 10 classes.

From previous studies, it is evident that organic matter can influence soil physical quality through its impact on soil microstructure and hence, the yield. Moreover, from the results of the 2015 study, further study was required to understand how the change in organic matter influenced the soil water properties through changing the texture and the microstructure of the soil.

Glasshouse Experiment-06: the impact of increasing levels of organic matter on some soil water properties.

Introduction

The field experiment 03 Soil (CP 121 2016 Annual report) showed that OM plays a significant role in crop yields (Loveland and Webb, 2003). Soil OM has a role in several key soil properties affecting water and nutrient availability; e.g. residual nutrient content, cation exchange capacity, water-holding capacity, available water content, bulk density and soil compressibility. This experiment aimed to investigate the influence of different levels of organic matter on water holding properties and bulk density of the soil to establish whether organic matter was the key element in the yield variation across the field. The focus on bulk density was because the statistical model suggested it as a significant factor in yield variation. The focus on water-holding properties was because it was hypothesised that the increased yield zone that conformed with the higher sand zone (east-west trend in the northern part of the field) was due to enhanced drainage.

Hypothesis:

The change in organic matter level in a soil changes field capacity, volumetric water content, bulk density and compressibility.

Materials and methods

Field soil with a very low level of organic matter was collected from Flatt Nook field, Shropshire (52.772710, -2.416932). The soil organic matter was measured by the 'loss on ignition' method (ADAS, 1986) and the average percentage of organic matter in the soil was approximately 1.0%. The collected soil was mixed with pure peat (12 mm), (Bulrush Horticulture Ltd, Magherafelt, UK) to create treatments with different levels of organic matter, with 10% increase of peat between treatments (Table 1). Mixing was done by volume and a cement mixer was used for ensuring soil consistency.

Table 1. Glasshouse Experiment-06 treatments

Number of buckets 100% peat	Number of buckets of Low OM soil	Treatment	Percentage of organic matter	Number of reps
0	10	T1	1%	10
1	9	T2	1%+10%	10
2	8	T3	1%+20%	10
3	7	T4	1%+30%	10
4	6	T5	1%+40%	10
5	5	T6	1%+50%	10
6	4	T7	1%+60%	10
7	3	T8	1%+70%	10
8	2	T9	1%+80%	10
9	1	T10	1%+90%	10

Ten pots (size 0.5 Litres, average weight 14.73 g) were filled with substrate from each treatment. And laid out following a complete randomised block design over six blocks. The glasshouse conditions were daily temperature 15°C and relative humidity 65% on average.

The experiment started 28/01/2017. In the first week, the collected soil was irrigated to saturation every day to improve the disturbed structure after collecting the soil from the field. The soil used in this experiment was removed from the field, sieved and mixed, then mixed further with peat. During this process, the structure was disturbed and soil particles were exposed to dryness. Irrigating the soil brought the soil particles together and improved the uniformity of structure (Brady, 2006). Additionally, irrigating the soil to saturation was done to bring the soil in different treatments to uniform moisture conditions before the start of the experiment. In the beginning of the second week, irrigation was stopped after first saturation and weighing started from saturation for all the pots and continued at regular intervals every two to three hours during daytime to compare the speed of water loss and time to achieving field capacity amongst treatments.

After 72 hours, water loss became negligible for all treatments. At this point the soil moisture was measured using a moisture Field Scout^{TM} TDR 100 Soil Moisture Meter (Spectrum Technologies, Illinois, USA), taking two readings per pot. All the pots were weighed. The soil level slumping from the edge of the pot that occurred due to irrigation was measured using a ruler and the volume of the soil was calculated for each pot. The soil was then oven-dried at 105 C° until constant weight was reached. The bulk density was calculated using the following equation:

Soil Bulk density (g/cm^3) = Dry soil weight (g) / Soil volume (cm^3)

The collected data was analysed using Analysis Of Variance (ANOVA) in Genstat 17th Edition (Payne, 2009).

Results

There was no effect of blocks on the moisture properties of the treatments. Treatments that had higher levels of organic matter lost water slower and to a lesser extent than treatments with low levels of organic matter (Figure 3)

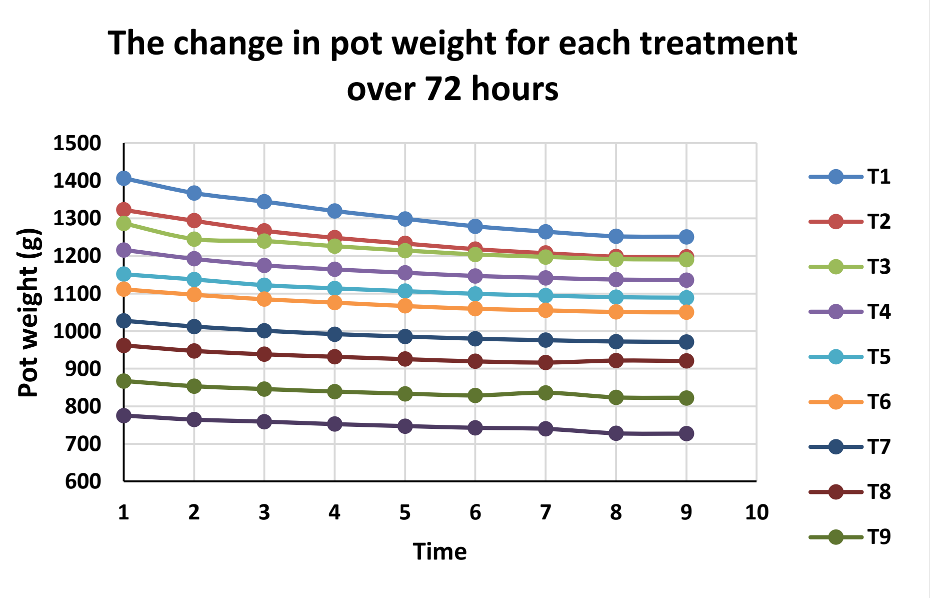


Figure 3. The change in pot weights for the ten treatments over time, as measured regularly starting from saturation status and at 2 hour intervals during day time for 3 days of free drainage. The results are averaged over ten pots per treatment (n=10).

The statistical analysis for soil moisture content (SMC), calculated in grams of water per pot showed significant difference amongst treatments (Figure 4). The significance could also be viewed as three levels where from Treatment 1 to Treatment 4 (T1 to T4 or 1% to 31% OM) was significantly different from treatments T5 to T7 (41% to 61% OM) which in turn was significantly different from treatments T8 to T10 (71% to 91% OM).

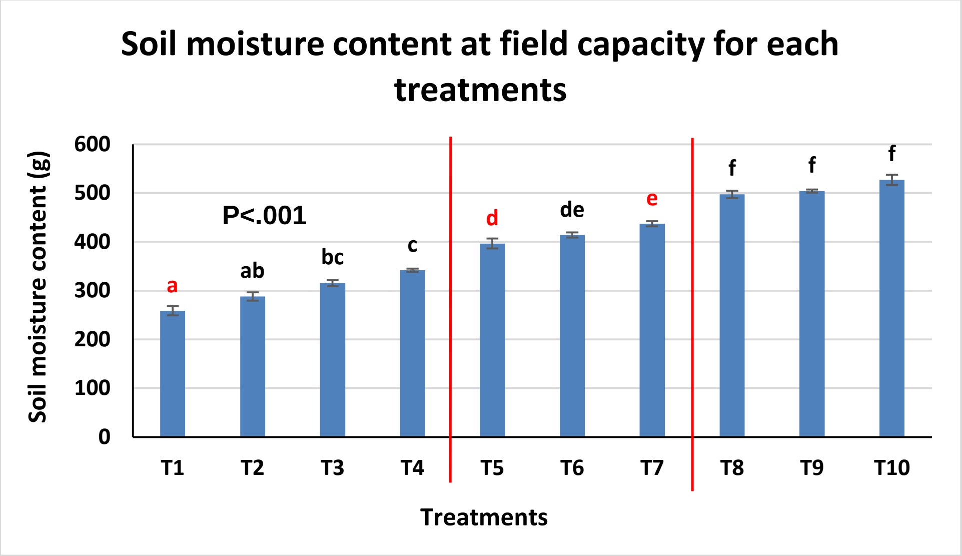


Figure 4. Soil moisture content in grams of water per pot, averaged between ten pots per treatment (n=10). Error bars show standard errors of the samples for n=10.

Soil moisture contents for the ten treatments as a percentage (SMC%) that was measured using the Field Scout^{TM} TDR (Figure 5) differed to some extent from the weight estimate method (Figure 4). However, there was also a significant difference in SMC% amongst the treatments (Figure 5). Soil moisture content SMC% had slightly longer error bars than SMC as weight. There was no significant difference between T1 and T2 for SMC measured by weight (g). Whereas, a 10% addition of peat (T2) to the field soil (T1) caused a significant increase in the amount of moisture retained by the soil after three days of simulated free drainage as measured by the TDR, with a notably longer error bar for T2.

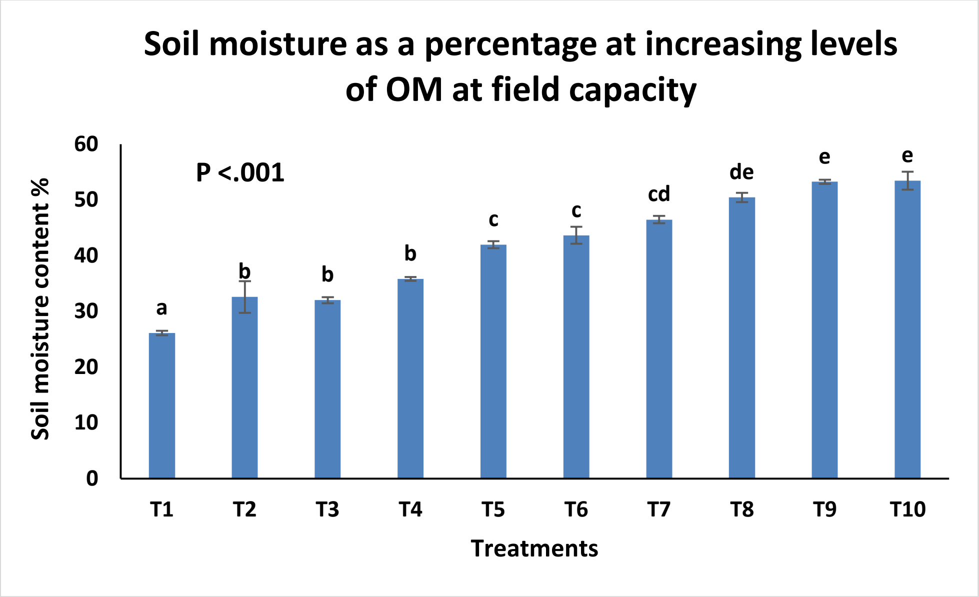


Figure 5. Soil moisture content as a percentage, measured using a TDR probe 3 days after saturation and free drainage. The results are averaged over ten readings (n=10) per treatments and averaged between two readings per pot. Error bars show standard errors for the samples for n=10**.**

Soil bulk density was significantly different between treatments. The treatments that had higher levels of OM had lower levels of bulk density (Figure 6)

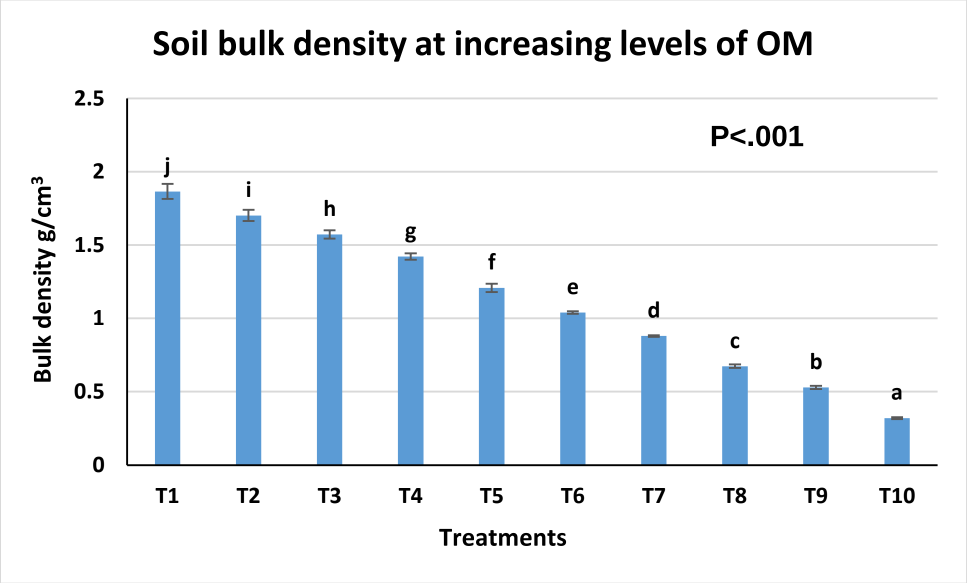


Figure 6. Soil bulk density (g/cm^3) for each of the ten treatments, averaged over ten pots per treatments (n=10). Error bars show standard error for samples for n=10.

Discussion

The treatments in Figure 4 could be grouped into three bands in terms of the significant difference in the amount of water held in the soil at field capacity or after 72 hours of drainage: Band 1 (T1 toT4), Band 2 (T5 to T7) and Band 3 (T8 to T10). After 3 days of free drainage, the treatments in Band 2, which had more than 40% and up to 60% OM organic matter (from T5 to T7) held significantly more water than treatments that had less (T1 to T4). The difference was approximately 100 g on average. After that, at 70-90% OM, the amount of water held in the soil of treatments T8, T9 and T10 was also about 100 g more than treatments that had up to 60% OM. This falls in line with what Dexter (2003) suggested; that increased organic matter in the soil can improve soil microstructure and physical quality. The ranges of organic matter in Band 2 and Band 3 and T4 from Band 1 represent mainly organic and peaty soils. These soils have different properties than the rest of the soils in Band 1. The results here suggest that when organic matter increases by about 15% the soil can hold 100 g more water. This is important for the crop in dry seasons where organic matter can facilitate root growth to access water in deeper layers of soil (Dexter, 2003) and holds more water for more days. However, the rest of soil treatments in Band 1 would lose more water in free drainage more rapidly and roots would be more restricted in terms of growth due to poorer soil microstructure and less water holding capacity This supports Arvidson (1998) who reported that enhanced organic matter content improves soil air content, porosity, reduces compaction and increased the yield.

Bulk density differed significantly amongst treatments and it decreased as organic matter increased. Loveland and Webb (2003) reported that higher levels of organic matter in the soil reduces soil compressibility and mechanical damage resulting from machinery while in some cases increases soil need for compactness (ensuring soil contact with the roots at planting). This experiment shows that each 10% addition of OM to the soil reduced bulk density by 0.2 g/cm^3 (Figure 6). The effect of organic matter on soil bulk density is also related to clay content in the soil. Soil bulk density's relation with clay has been reported as negative (Ruehlmann and Korschens, 2009), which makes organic soils that are rich in clay loose or less prone to compaction. Bulk density data in P57 (2015 experiment) suggested that the soil over the whole field was generally loose. This suggests that bulk density in the field was not a limiting factor but was possibly masking the effect of soil organic matter and soil texture, as soil bulk density is a product of both texture and organic matter content.

Variation at early stages of growth and during transplant propagation

Modern lettuce cultivars (*Lactuca sativa* L.) have shallower and smaller root systems in comparison with their wild relatives, as they have been bred for producing uniform shoots and high yields under high input cropping systems (Johnson *et al*., 2000; Gallardo *et al*., 1996). This makes them underperform when spatial and temporal variability occur in available resources; the smaller root systems for these cultivars make the plants more prone to movement meanwhile they are unable to reach nutrients and moisture in the deeper layers of the soil profile (Johnson *et al*., 2000; Kerbiriou *et al*., 2013).

Variation in lettuce transplant size may contribute significantly to variation in crop yield. Harwood *et al*. (2010) argued that systematic changes in crop development across the field due to soil and microclimate variability is only "superimposed" on the variation caused by the plants themselves (inherited plant to plant dissimilarity). Their experimental work included a number of growers that participated in both transplant and field trials to establish the extent to which yield variation at harvest was accounted for by the variability amongst transplants. However, there was limited data defining the state of soil uniformity or variability and the study relied mainly on comparing the coefficients of variations at early stages of growth to the coefficients of variations at harvest. Nevertheless Harwood *et al*. (2010) suggested that head weight variability at harvest is mostly resulting from inherent plant to plant variation and hence is generated during the transplant production stages. In 2013, Kerbiriou *et al* (2013a) and Kerbiriou *et al* (2013b) carried out a number of glasshouse and field studies, to investigate the variability of transplant size on lettuce biomass and rooting systems, as well as, to investigate the performance of both roots and shoots under limiting supplies of water and nitrogen.

Young plants/transplants of lettuce have small and simple root and shoot systems. It is known that shallow and small root systems are inefficient in extracting moisture and nutrients from deeper soil layers in the field (Johnson *et al*., 2000). This makes exposing seedlings or transplants to stress more harmful than exposing them to stress later on during their production cycle (Kerbiriou *et al*., 2013b). Therefore, Iceberg lettuce transplants are produced commercially under uniform and controlled conditions in order to produce a more robust and uniform young plant that can establish better under field conditions.

Harwood *et al*., (2010) suggested that plant to plant variation accounts for most of the final yield variation in lettuce rather than field conditions and suggested that this variability occurs during propagation. Kerbiriou *et al*., (2013a) showed that by planting lettuce transplants of different sizes, the small sized transplants mostly resulted in delayed growth, development and maturity compared to larger transplants.

In this study plant to plant variability was investigated at a tray level, in addition to the effect of this variability on lettuce growth and development in the field and up to the final yield.

The questions this part of the research was aiming to answer were:

- How variable lettuce transplants are within the propagated trays?
- Does this variability follow a certain pattern?
- Does this variability continue to the field?
- Do variable placements in the field result in variability in the marketable lettuce heads?

Introduction

A preliminary study (5b-GH03- A pilot study) showed significant variation in the weights of transplants that were propagated together within the same tray and that were of the same batch (plants that were seeded on the same day and germinated and grown under the same conditions within the same compartment of the glasshouse and germination room). The mean fresh weight ranged between 0.77-0.85 g/plant for the first batch of transplants supplied by PDM produce (approximately 17 days old, cv. SV4896), Shropshire with a co-efficient of variation of approximately 17%. The mean fresh weight ranged between 2.20 to 2.46 g/plant for the second batch of transplants (21 days old) supplied by Second Willow Nursery, G's Growers Ltd, Cambridgeshire, with a co-efficient of variation of approximately 25.3%.

Hypothesis

1a: Transplants from genetically uniform seeds vary in development (weight) within the same propagated tray.

1b: The weight of lettuce transplants varies depending on their location within the tray (edge versus centre).

Materials and methods

Twelve trays of commercially-produced Second Willow Nursery, G's Growers Ltd, Cambridgeshire, UK lettuce (*Lactuca sativa cv. Soleison cru)* transplants were destructively sampled *in-situ* over three successive days starting from 25/05/2016. The top growth was removed at the top of the peat block with scissors and was weighed for each individual plant. The location of each transplant was also recorded. The trays sampled were planted on 06/05/2016 and were sampled at 20, 21 and 22 days after seeding with 3 trays, 5 trays and 4 trays sampled each date respectively. The number of trays is not balanced between dates due to time restrictions.

The seeds were planted automatically one seed per peat-block into trays (using commercial seeding machinery). Each tray included 11 x 16 blocks (176 blocks of transplants in total, block size 3.8 x 3.8 cm) and seeding depth was approximately 5 mm.

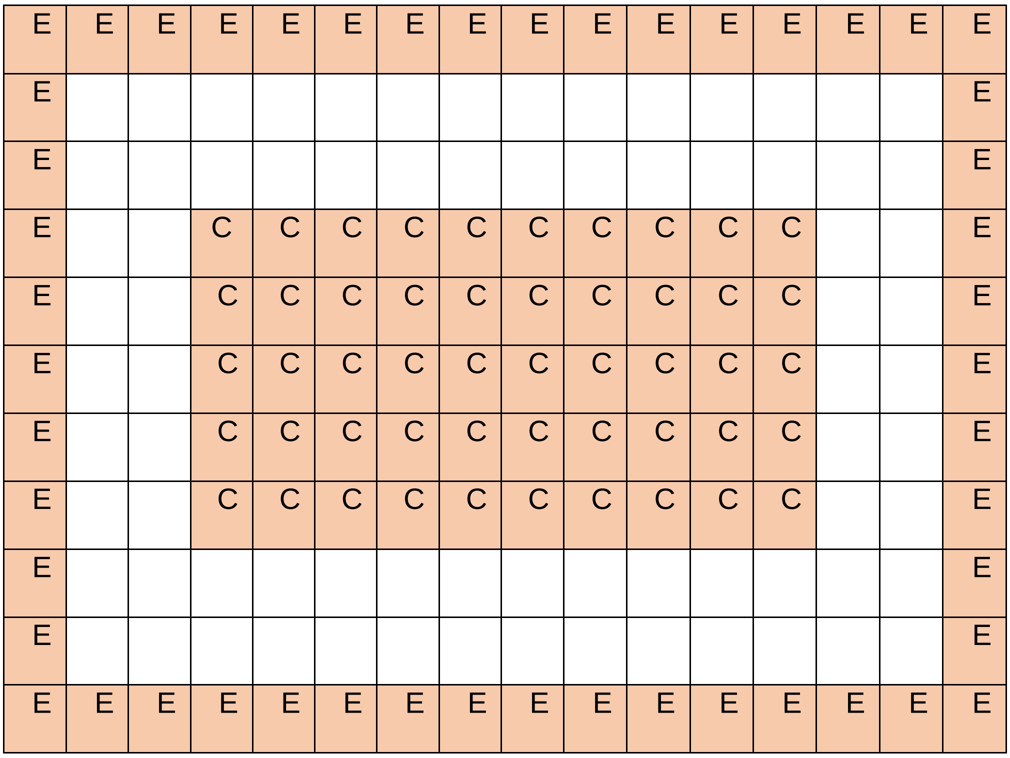
The seeds were germinated in a temperature controlled room at 16°C and high relative humidity (90%) from day 0 to day 3 followed by 17 days of propagation in a glasshouse compartment at around 18°C. At about 20 days old, the transplants were moved to the final glasshouse compartment before being transplanted in the field. The trays were overhead-irrigated throughout glasshouse growth receiving an irrigation rate of about 800 ml/tray per day. This experiment aimed to investigate the uniformity of the transplants that are produced under commercial environment and that are described by the grower as being uniform. However, when transplants were taken for assessment, they were selected from the same area in the glasshouse avoiding edges, roof and side shading, and watering connections/disconnection, to minimise the variability as much as possible.

The data are presented using 3D surface charts of the trays generated using Excel to enable viewing of the trends in fresh weight values across the two dimensions of the tray. The coefficient of variation (CV) was calculated for each tray to estimate the degree of variability within each tray, using the following equation:

(1) CV= (standard deviation/mean fresh weight) x100

The fresh weights of the edge plants were compared to the fresh weights of the centre plants using the Two-sample T-test in GenStat 17th Edition (Payne, 2009). This was done by selecting two equal populations of transplants; 50 from the edge (E) and 50 from the centre

(C) of each tray as demonstrated in the following layout in Figure 7. This was done for the 12 trays.



E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
E															E
E															E
E			C	C	C	C	C	C	C	C	C	C			E
E			C	C	C	C	C	C	C	C	C	C			E
E			C	C	C	C	C	C	C	C	C	C			E
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E															E
E															E
E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E

Figure 7. Tray layout showing two equal populations of transplants from the edge (50 E) and from the centre (50 C) used in a T-test to compare the edge to the centre.

Results

The CV for the 20-day-old transplants was 25.3% averaged amongst three trays, indicating a big variation in the fresh weights of the transplants top growth. The 3D surface chart of transplants fresh weight did not show a consistent pattern of variability across trays, or across days (Figure 7 and Figure 8). The chart's different colour bands represented different weight ranges (trends). The different bands (different weights) were scattered across the tray showing no evidence of a specific spatial pattern.

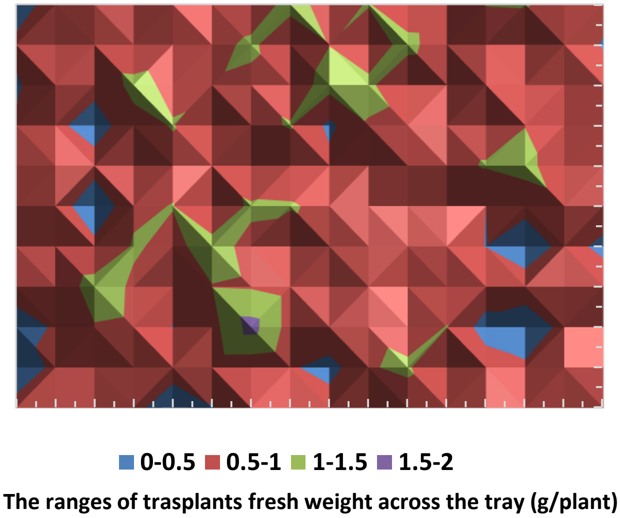

Figure 8. A 3D surface chart with colour bands indicating the difference between the fresh weight data amongst transplants with respect to their locations across a tray of 20 day old transplants (g FW/plant) sampled on Day1, 25/06/2016 (total number of transplants per tray was 11 x 16).

The co-efficient of variation for the 21 and 22 days old transplants were 23.2% and 21.4% respectively, averaged amongst five trays of transplants for the 21 days old and four trays of transplants for the 22 days old. The latter two co-efficient of variations were also considered high (Fowler, 1998) indicating large variability amongst transplants.

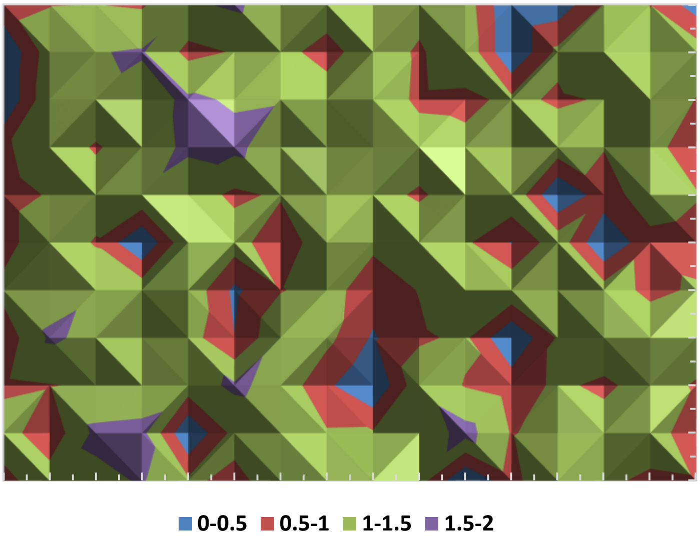

Figure 9. A 3D surface chart with colour bands indicating the difference between the fresh weight data amongst transplants with respect to their locations across a tray of 22 days old transplants (g FW/plant) measured on Day 3 on 27/06/2016.

Comparing trays from Day 1 with trays from Day 3 (Figure 8 and Figure 9) where the transplants have grown two more days, the variability trends were still there, the distribution bands were slightly different where larger transplants occupied more blocks within the trays than smaller transplants. However, no consistent spatial pattern was identified.

The fresh weight increased over the three days as concluded from the means 0.76 g to 1.17 g (Table 2). Although the coefficient of variation values decreased from 25.31 on Day 1 to 21.44% on Day 3, it was relatively high for all the trays, indicating a considerable level of variability in the measured trays. Table 2 summarises the means and the CV%s for the data.

Table 2. Means of fresh plant weight per tray and CV% for each tray.

	Day1 (age 20 days)	Day2 (age 21 days)	Day3 (age 22 days)	
Mean	**0.75**	**1.00**	**1.17**	**Tray1**
	0.79	**0.90**	**1.20**	**Tray2**
	0.76	**0.87**	**1.18**	**Tray3**
	-	**0.93**	**1.14**	**Tray4**
	-	**0.97**	**-**	**Tray5**
Average mean	**0.76**	**0.93**	**1.17**	
CV%	**25.86**	**22.36**	**22.13**	**Tray1**
	25.39	**22.25**	**20.57**	**Tray2**
	24.66	**23.48**	**18.45**	**Tray3**
	-	**24.66**	**24.60**	**Tray4**
	-	**23.45**	**-**	**Tray5**
Average CV%	**25.31**	**23.24**	**21.44**	

The weight of the centre plants was greater than the edge plants at each date however, the differences were not significant ($p<0.05$) at any date (Table 3). The edge weights mean value was 0.9 g whereas the centre weights mean value was 1.0 g for all the trays, averaged between 50 edge and 50 centre transplants per tray. Mean values, differences and degree of significance are presented in Table 3.

Table 3. Means of fresh transplant weights between the edge and the centre of the tray (g/plant) averaged between 50 transplants (n=50).

	Tray	Edge	Centre	Difference	Significance
Day1	**Tray1**	**0.72**	**0.78**	**0.06**	**Ns**
	Tray2	**0.73**	**0.82**	**0.10**	**Ns**
	Tray3	**0.70**	**0.82**	**0.12**	**Ns**
Day2	**Tray1**	**0.93**	**1.11**	**0.18**	**Ns**
	Tray2	**0.80**	**0.99**	**0.19**	**Ns**
	Tray3	**0.79**	**0.89**	**0.10**	**Ns**
	Tray4	**0.89**	**0.96**	**0.07**	**Ns**
	Tray5	**0.90**	**1.05**	**0.15**	**Ns**
Day3	**Tray1**	**1.10**	**1.27**	**0.17**	**Ns**
	Tray2	**1.08**	**1.29**	**0.21**	**Ns**
	Tray3	**1.14**	**1.18**	**0.04**	**Ns**
	Tray4	**1.04**	**1.14**	**0.10**	**Ns**

Ns = not significant at $p<0.05$

Transplant size difference

Introduction

Previous work has shown that the relative size of transplant influences the relative size of the lettuce at harvest (Kerbiriou *et al*., 2013). The previous experiment showed that transplant weight varied significantly within trays at the block stage, with transplants of the same age weighing between 0.5 to 2.0 g FW. This experiment aims to investigate whether this difference in transplant growth results in subsequent variation in growth and development at 14 days after transplanting. This is the time range that the grower reported being able to predict yield variation, distinguishing visually the young plants that are expected to develop into mature heads of marketable size in time for harvest and the ones that are too late to develop in time.

Materials and methods

Five trays of commercially raised lettuce transplants (cv. *Soleison cru*) were produced by Second Willow Nursery, G's Growers Ltd Cambridgeshire, UK. The production process was described above. The trays were sown on 29/06/2016, and all conditions experienced were the same for all the trays i.e. within the same compartment and the area inside the commercial glasshouse. The trays were delivered to Harper Adams University on 15/07/2016. The trays were held in a glasshouse at about 17°C and 63% RH for 3 days before the experiment started.

On 15/07/2016, 15 transplants (three from each tray) were randomly selected and destructively sampled for length and weight, in order to establish the relation between the size and the weight of the transplants. This was done by cutting the transplants at the surface of the peat block, weighing the whole fresh biomass using a digital two decimal places balance and measuring the length of the plant from the cutting edge to the top of the oldest leaf. The weights and the sizes were plotted against each other to obtain the relationship equation as demonstrated in Figure 10.

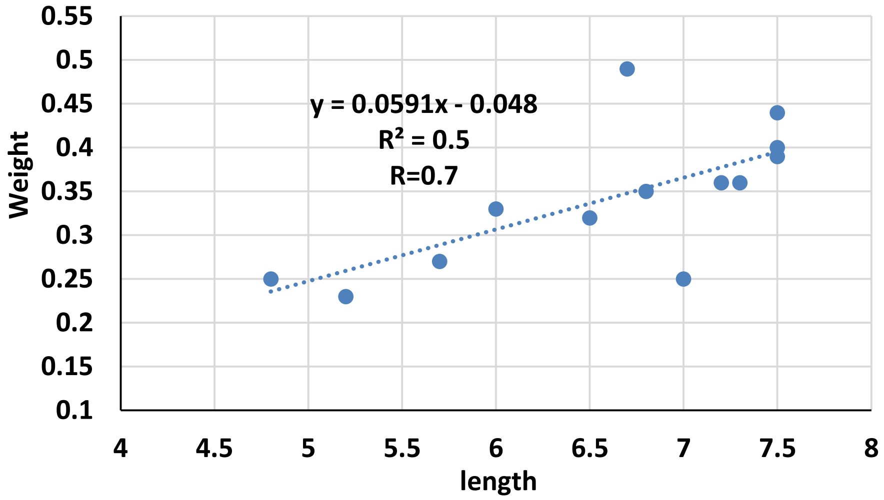

Figure 10. The relationship between the length (cm) and the weight of transplants (g)

Thereafter, two group sizes of transplants (small and large) were created by visually selecting the smallest and the largest transplants across the five trays (20 of the largest and 20 of the smallest transplants from each tray = five groups of small 20 transplants and five qroups of large 20 transplants = 200 plants in total in total)

Nine plants were selected from each 20 (from size group of each tray) in order to create two sub-groups to be incorporated into two treatments of 45 replicates each (45 small plants and 45 large plants) = 90 experimental units (plants) in total.

The sub-groups were measured in length to estimate the starting weight using the equation derived from correlation analysis (Figure 10)

(2) Transplant starting weight (g/plant) = 0.0591 X Transplant length - 0.048

Ninety plastic pots (Deep Rose pots 8 X 11 X 18 cm supplied by LBS Horticulture Ltd, Lancashire) were filled with John Innes No.2 (supplied by K G Loach, Cheshire). The field capacity for the compost, was established for three pots using the gravimetric water content by weight method, following the protocol demonstrated in Glasshouse Experiment-06.

The 90 pots were each placed on the top of an inverted saucer that had fine raised lines on the top to allow free drainage. The pots were irrigated slowly to saturation immediately before planting.

The selected transplants were planted individually one per pot to a normal depth and position as done in the commercial field (soil surface adjacent to the peat block). The pots were labelled and randomised using GenStat 17th editions. The planting was done inside the glasshouse at Harper Adams University on 18/07/2016 after irrigating the soil until saturation to simulate the planting process in the field.

The glasshouse mean temperatures during the experiment were 17 °C at night and 24 °C in the day with mean relative humidities of 73 % at night and 52 % in the day.

The plants were grown for 14 days and harvested by cutting at the soil surface using a sharp knife. Each cut transplant was weighed using a digital 3 decimal places scale. Data were analysed using the Two-Sample T-test in GenStat 17th edition.

After determining the soil wet weight at field capacity, soil moisture content at field capacity (SMC) was calculated using the following equation:

SMC= (Soil wet weight at FC-Soil dry weight) / (Soil wet weight at FC)*100

Soil moisture content at field capacity (pot capacity) was on an average 55% of the weight.

Irrigation was carried out every 3 days where the calculations were repeated at every irrigation event. Estimating the irrigation requirements was based on returning soil moisture back to field capacity, by calculating the loss in weight due to plant uptake over time. This was calculated by subtracting current pot weight (at the time of irrigation) as averaged between four pots (two pots of each treatment) from the average pot weight at field capacity. Irrigation water was added using a measuring cylinder and a syringe.

Irrigation requirements = Pot weight at FC – pot weight at the time of irrigation (current)

All pairs of groups were compared using two-sample T-test in Genstat17th Edition (Payne, 2009).

Results

The correlation between transplant weights and lengths for the destructively measured group (DMG) in Figure10, enabled estimation of the starting weight of transplants for each of the visually selected group sizes (large and small) by measuring the length of these transplants and using equation (1) (Figure 11).

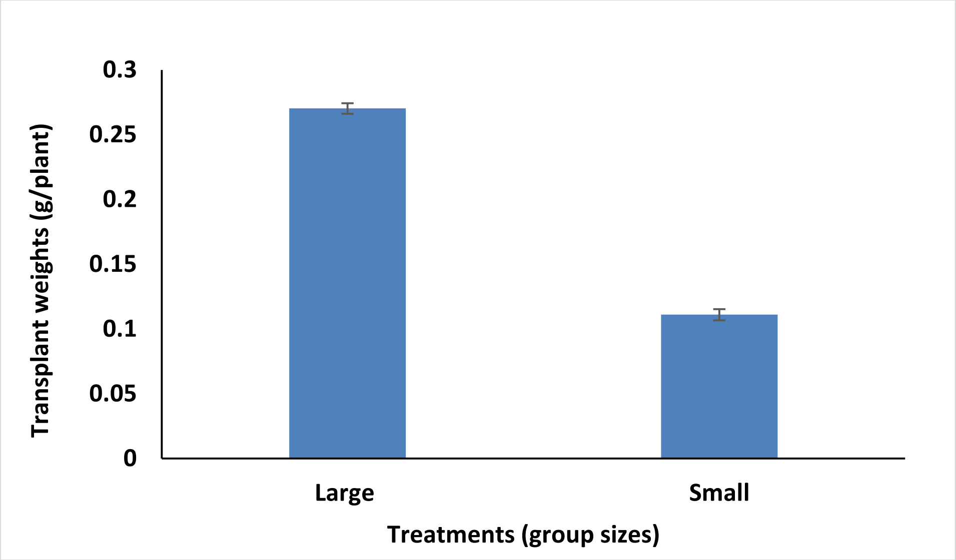

Figure 11. Estimated starting fresh weights of large and small groups of transplants as calculated (n=45) by measuring the length and using equation (2). Blue bars show the means and the error bars show the standard error for n=45.

The ranges of the values and the averages of all groups are demonstrated in Table 4.

Table 4. Lettuce transplant data for small and large groups (n=45), before planting and 14 days after planting

	Range	Mean
DMG* Length (cm)	4.8 -7.5	6.5
DMG Weights (g)	0.2 - 0.5	0.3
Starting Length (Small) cm	1.8 - 3.4	2.7
Starting Length (Large) cm	4.7 - 6.4	5.4
Estimated starting weight (Small) g	0.1 - 0.2	0.1
Estimated starting weight (Large) g	0.2 - 3	0.3
Weight 14 DAP* (Small) g	4.9 - 28.5	20.1
Weight 14 DAP (Large) g	23.4 - 39.2	33.029

*DMG: Destructively Measured Group
*DAP: Days After Planting

The small group differed significantly (P<.001) from the large group of transplants at the start of the experiment in both weights and lengths (Figure 2) with a 2.7g difference in length as an average and 0.2 g in weight as an average.

When the young plants were harvested 14 days after planting in separate pots, the weights of the small group of transplants also differed significantly (P<001) from the weights of the large group of transplants (Figure 12). The weights of the large group were 13 g more than the small group on average.

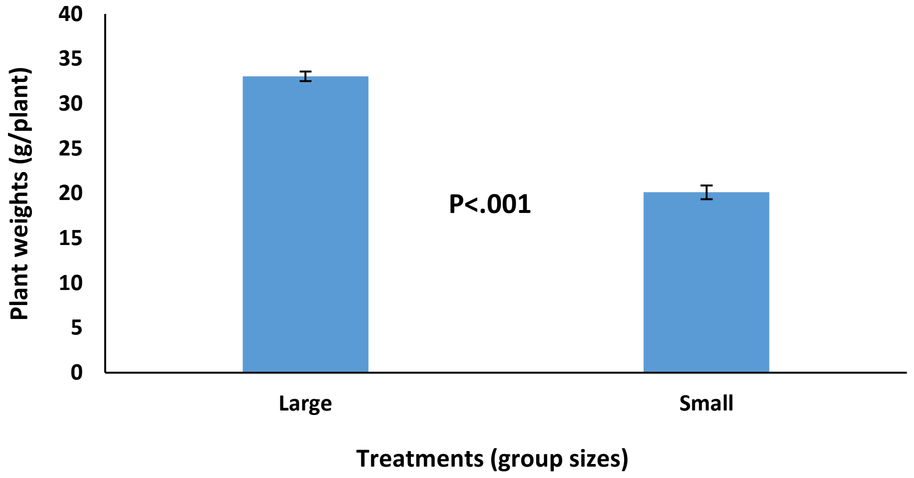

Figure 12. The difference in fresh weight between the large and small group-size of transplants, 14 days after planting (n=15).

The difference in weight between the two group sizes was larger than the difference in weight between the two group sizes at the start of the experiment suggesting an amplification in the difference over time.

Experiment to determine the effect of transplant placement on yield

Introduction

The variability in soil nutrients, moisture and soil texture creates variability in the conditions for growth and development of plants. These conditions are particularly important at early growth and establishment of the crop life cycle where the plants are still young and vulnerable. Variable placing of transplants in the field (such as planting depth, direction and spacing) results in variable orientations of the growing plants in response to the variation in accessibility to the surrounding resources (light, moisture, etc.). Variability of access may include the degree and the strength of soil contact with the root (and hence, the establishment of the rooting system), exposure to light and the effect of gravitropism on plant texture and appearance; all of these conditions create additional sources of variation.

In a preliminary glasshouse experiment in 2015 (Experiment 6a-GH02, CP 121 Annual Report 2016) plant growth after 14 days did not vary significantly when lettuces were planted in varied positions and orientations. Transplants of Iceberg lettuce of similar size and shapes from the same tray were planted in four different positions,

(1) Normal: soil surface adjacent to the peat block of the transplant.

(2) Side: transplants were placed on one side, above the soil surface.

(3) Above; transplants were placed above the soil surface

(4) Tilted; the transplants were positioned at an angle with the soil surface and quarter of the peat-block was covered by soil.

(5) Buried under the soil surface; green leaves were half-covered with soil

In 2016, the following experiment examined growth responses at maturity to transplant placement in the field under commercial conditions.

Hypothesis:

Variable placement of transplants in the soil results in variation in lettuce head qualities at harvest.

Materials and methods

Six plots of iceberg lettuce transplants (*Lactuca sativa* cv. *Soleison cru*) were established along with the commercial planting on the 10/08/2016 in Kenny Hill 44 field at G's farm, Ely, Cambridgeshire (grid reference TL 6680/3505), and received commercial crop inputs as for the rest of the crop. The transplants used for this trial were seeded on the same date and propagated under controlled commercial conditions at G's Second Willow Nursery (for propagation conditions at G's Second Willow Nursery see propagation Experiment 1). The planting crew was followed so the plants were checked for visual size uniformity, re-placed and repositioned in conformance with each designated treatment. Five treatments were planted as shown in Figure 1. Each treatment had 10 replicates and there were 6 blocks in total in the field.

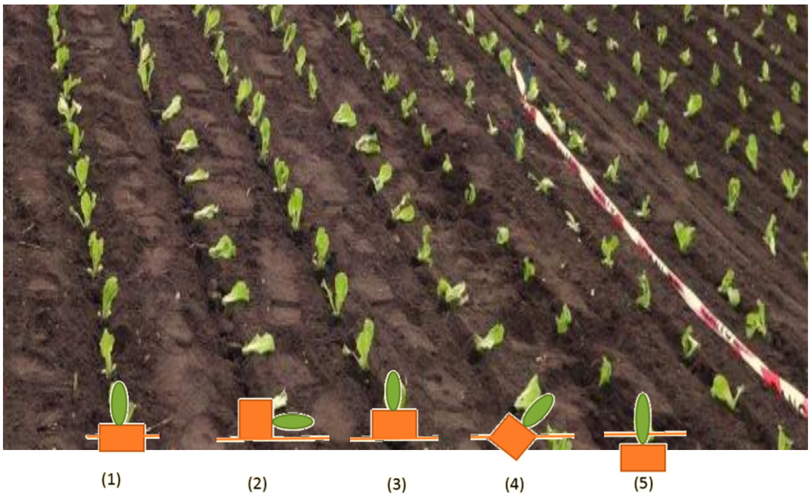

Figure 13. Transplants field placement treatments, from left to right; i) normal, ii) on the side, iii) above soil surface, iv) tilted or 50% of the peat block covered with soil, and v) buried (approximately 2 cm of the green shoot was underneath the soil).

All the plants within the trial were repositioned manually, including the “normal treatment” (1) (Figure 12).

Experimental plot locations within the field were chosen in homogeneous zones as recommended by the grower. EC scans were not available for this field. Therefore, soil samples were taken from each block for analysis to ensure soil uniformity. Two soil samples were taken from two depths of each one of the six blocks; (2 samples from 0-30 cm + 2 samples from 30-60 cm) X 6 blocks = 24 soil samples in total.

The soil samples were analysed for particle size distribution, total nitrogen, total phosphorus and total potassium in addition to one sample of organic matter from each block from each depth. The soil analysis were done at NRM Laboratories, Berkshire using standard methods.

All lettuce heads from the experimental plots were harvested at maturity (1 day after commercial harvest) by cutting the heads using a sharp knife just above the soil surface. The heads were packed in labelled plastic bags and brought back to the cold store at Harper Adams University, Shropshire and stored at 4 °C until the next morning.

In the laboratory, on Day 1 after harvest, the external leaves of the heads were removed and the heads were measured for trimmed head fresh weight using a digital scale of 2 decimal places. The head circumference was measured using a measuring tape that was held horizontally parallel to the base (the stem cut) about 4-5 cm above the cut surface. Visual market specification guides were used to score the heads for density (the density of trimmed heads was scored on a scale from 1 to 8 using G’s market specifications) (Figure14). Pest and moisture damage were also scored on a 0 or 1 basis (0 for absent and 1 for present).

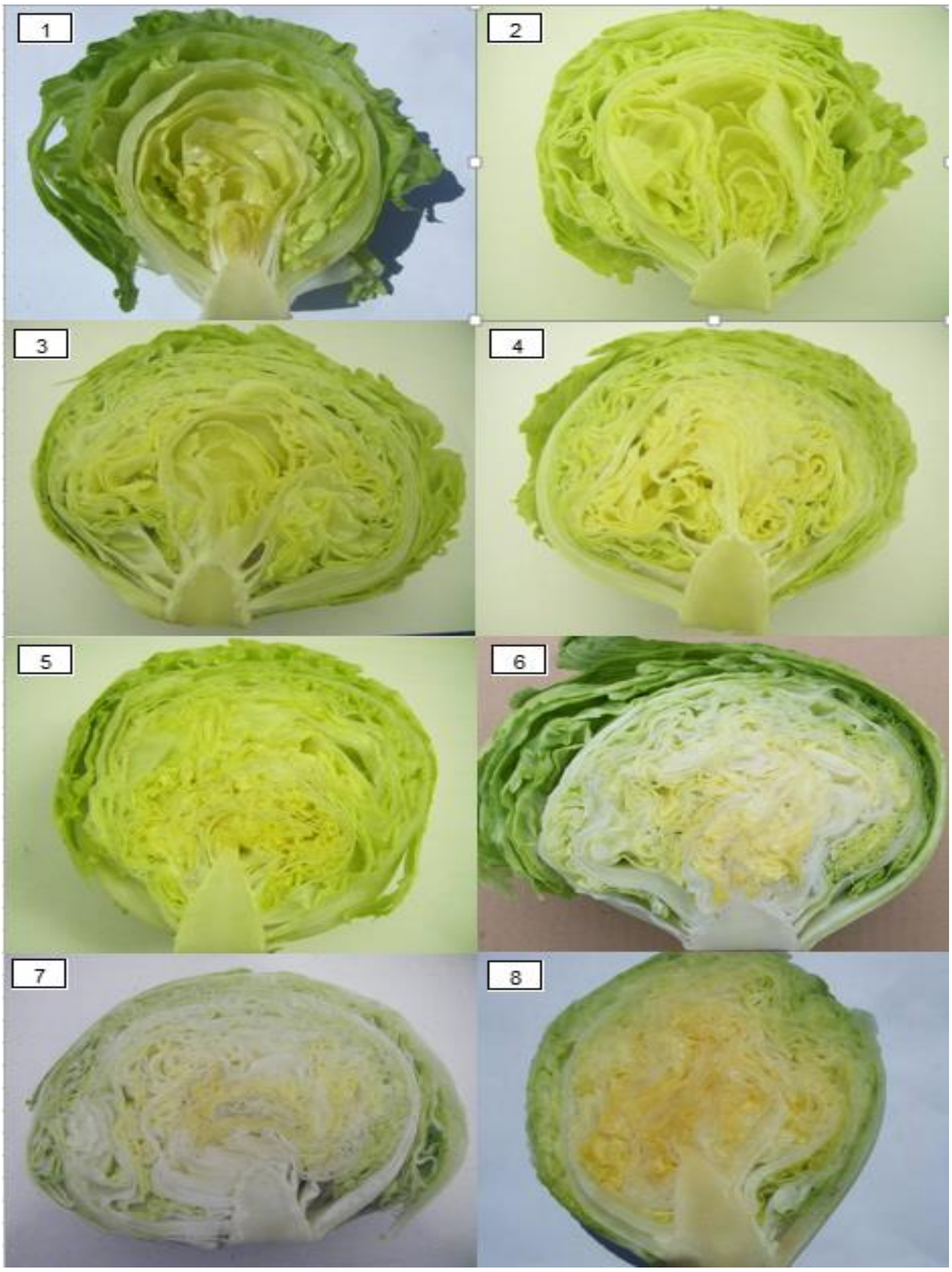

Figure 14. G's head density scoring guide showing a scale from 1-8

Results

a) Soil Analysis Results

Organic matter for the trial plots area was about 17.3% for the top soil (0-30 cm) and 11.2% for the subsoil (30-60 cm) averaged between 12 samples for each depth. Soil texture analysis showed that the top soil classified as Sandy Loam at 0-30 cm and the subsoil classified as Sandy Clay Loam at 30-60 cm. Statistical analysis showed no significant difference in the measured soil properties between the six blocks (silt%, sand%, Clay%, total N, total P, total K, and OM%).

Table 5. Soil analysis results for the top soil (0-30cm) of the experimental plots area

Block	Sample	Depth cm	Total N %W/W	Total P mg/kg	Total K mg/Kg	Sand	Silt	Clay	Soil Texture classification
1	1	0-30	0.68	922	368	62	15	23	Sandy loam
1	2	0-30	0.67	956	352	61	16	23	Sandy loam
2	1	0-30	0.72	1017	435	60	22	18	Sandy loam
2	2	0-30	0.81	1048	391	61	16	23	Sandy loam
3	1	0-30	0.67	977	378	62	19	19	Sandy loam
3	2	0-30	0.3	513	443	78	8	14	Sandy loam
4	1	0-30	0.7	857	905	61	15	24	Sandy loam
4	2	0-30	0.69	994	428	63	18	19	Sandy loam
5	1	0-30	0.73	905	350	64	14	22	Sandy loam
5	2	0-30	0.74	1035	416	65	13	22	Sandy loam
6	1	0-30	0.71	908	316	64	20	16	Sandy loam
6	2	0-30	0.65	867	418	64	14	22	Sandy loam

Table 6. Soil analysis results for the sub-soil (30-60 cm) of the experimental plots area

Block	Sample	Depth cm	Total N %W/W	Total P mg/kg	Total K mg/Kg	Sand	Silt	Clay	Soil Texture Classification
1	1	30-60	0.17	505	339	86	5	9	Sandy Clay loam
1	2	30-60	0.83	1031	412	60	17	23	Sandy Clay loam
2	1	30-60	0.82	883	324	60	16	24	Sandy Clay loam
2	2	30-60	0.64	1097	499	65	14	21	Sandy Clay loam
3	1	30-60	0.11	576	382	87	5	8	Sandy Clay loam
3	2	30-60	0.69	994	428	63	18	19	Sandy Clay loam
4	1	30-60	0.69	726	712	67	11	22	Sandy Clay loam
4	2	30-60	0.32	659	547	69	15	16	Sandy Clay loam
5	1	30-60	0.73	712	657	69	14	17	Sandy Clay loam
5	2	30-60	0.45	766	476	75	10	15	Sandy Clay loam
6	1	30-60	0.81	744	320	60	24	16	Sandy Clay loam
6	2	30-60	0.38	1130	456	78	9	13	Sandy Clay loam

b) Marketable head results

There was no significant difference between the trial blocks in terms of the marketable fresh weight (trimmed head weights) and the quality specifications. Whereas, there was significant difference in the trimmed head weights between the five treatments (Figure 15). The normal treatment had the highest marketable head weight as well as the tilted treatment. The buried treatments had the lowest head weights of all the treatments.

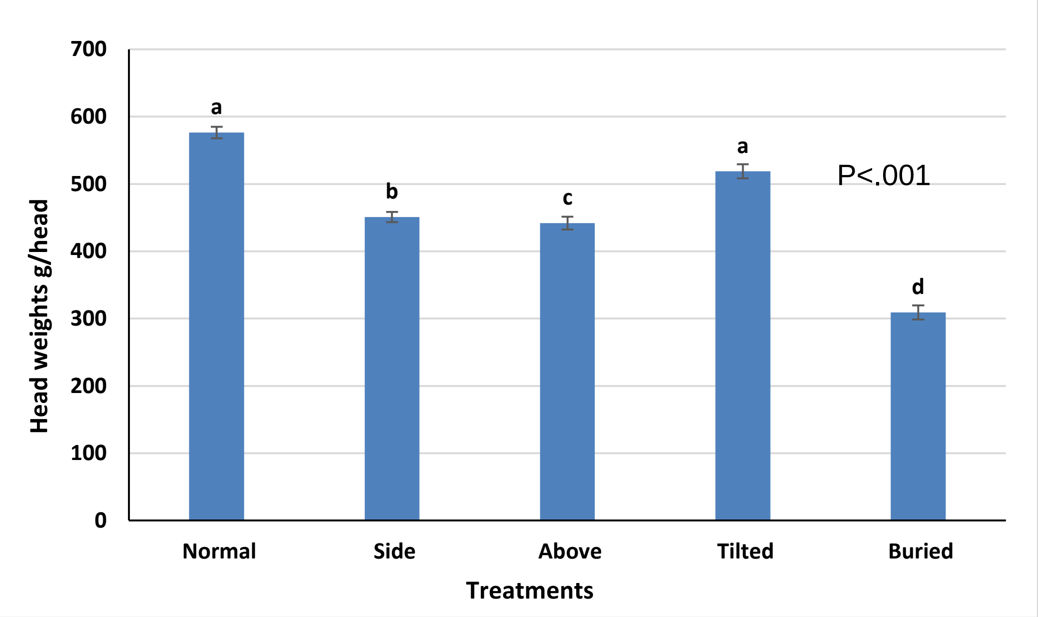

Figure 15. Mean trimmed head weights for five different planting positions (P<.001) (n=60). Error bars show the standard error of the samples for n=60.

Moreover, there were significant differences between the treatments in terms of marketable quality specifications such as head circumference, misshaping and head density (Figures 16-19). The normal, side, above and tilted treatments were relatively close to each other in terms of the head circumference (Figure 16) whereas they varied more in terms of head density. The side and the above treatments were significantly less dense than the normal and the tilted (Figure 17). The buried treatment had the smallest head circumference and the highest head density of all treatments, showing a small dense head (Figures 15, 16 and 17).

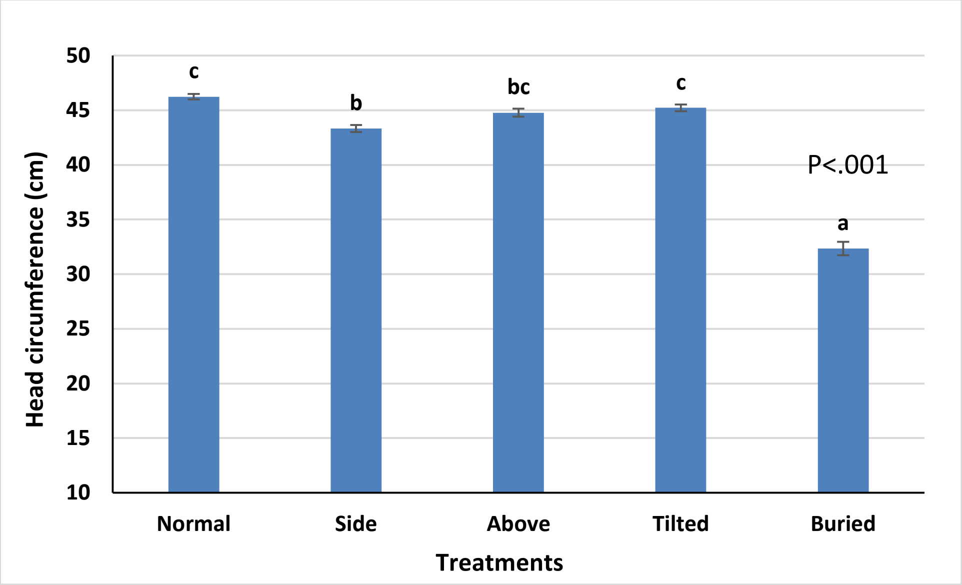

Figure 16. Mean trimmed head circumferences for five different planting positions (P<.001) (n=60). Error bars show the standard error of the samples for n=60.

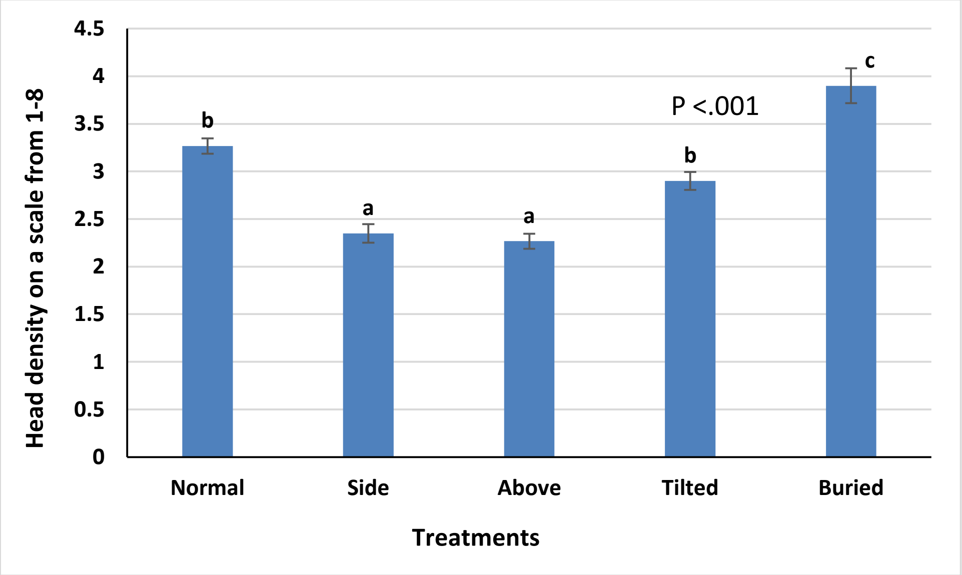

Figure 17. Mean density scores for mature trimmed heads for five different planting positions (P<.001) (n=60). Error bars show the standard error of the samples for n=60.

Figure 18 shows different unfavourable appearances in lettuce heads that are considered unmarketable. These conditions can resulted from abnormal orientation at planting. For example, Fig. 18a shows an extremely misshapen head where all of the head falls to one side of the central line (the stem) as a result of the side treatment. Fig. 18b shows a marked degree of ‘ribbiness’ on a very loose trimmed head that was considered unmarketable, from the above treatment. Fig. 18c shows a failed head from the tilted treatment. Fig. 18d was a small, dense elongated head from the buried treatment. Fig. 18e shows an ideal head in terms of the density, circumference, shape and formation, from the normal treatment.

a. Halved head from the Side treatment showing degree of misshaping

b. Head from the Above treatment showing degree of ribbiness

c. Head from the Tilted treatment failed to form

d. Small dense head from the buried treatment

e. Ideal head in terms of size and density from the Normal treatment

Figure 18. Pictures showing variability in the marketable quality for positioning treatments.

Heads were categorised as 'misshapen' if their appearance would negatively affect marketability (following commercial guidelines). The percentage of misshapen heads was notably different between upright positions (buried, above and normal) and the sideways treatments (side and tilted). Most of the heads that were harvested from the upright positions were formed more evenly around the stem situated in the middle of the head than the side or tilted positions (Figure 19).

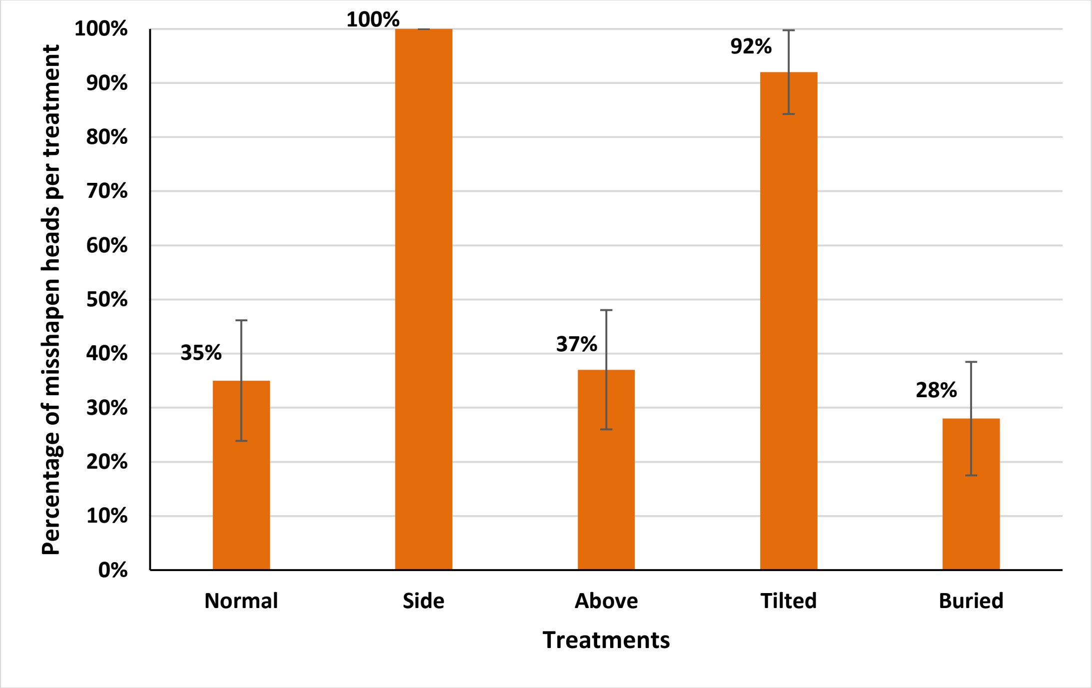

Figure 19. The percentage of misshapen heads for each of five planting positions. Presented using the sum of 60 head scores per treatment (n=60). Score: 0 = head shape does not affect marketability, 1 = too misshapen to market. Error bars show the standard error of the samples (n=60).

The proportion of heads with external breakdown damage per treatment were accounted for using a scoring system based on a score of 1 for intact heads and 2 for heads that had any signs of breakdown damage similar to the head in Figure 20.

Figure 20. External breakdown in Iceberg lettuce head. Source: G's – Tesco market specification guide.

The results showed that the side treatment had the highest level of breakdown damage of all treatments (Figure 21).

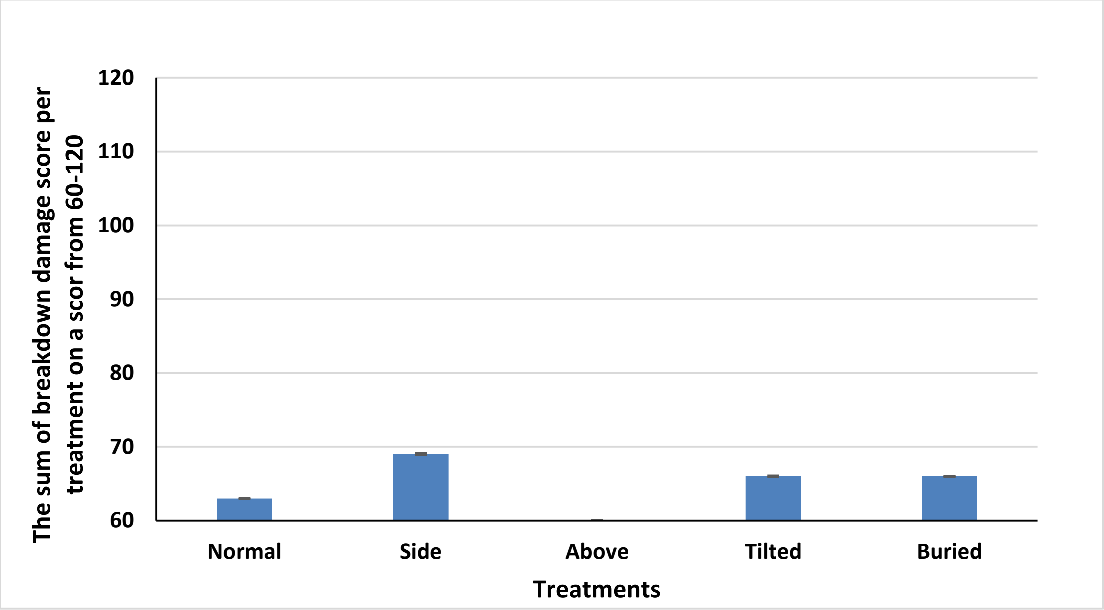

Figure 21. The proportion of heads with external breakdown damage per treatment. Presented using the sum of 60 head scores per treatment (n=60). Score: 1 = breakdown absent, 2 = present. Error bars show standard error for the samples.

A similar approach was used to score for pest and disease damage, where intact heads were given a score of 0 and heads that showed signs of pest or disease damage (whether pests were present or absent) were given a score of 1. The pictures in Figure 22 were used as examples to identify damage in the lettuce heads. As with external breakdown, the side treatment was most severely affected by pest or disease damage (Figure 23).

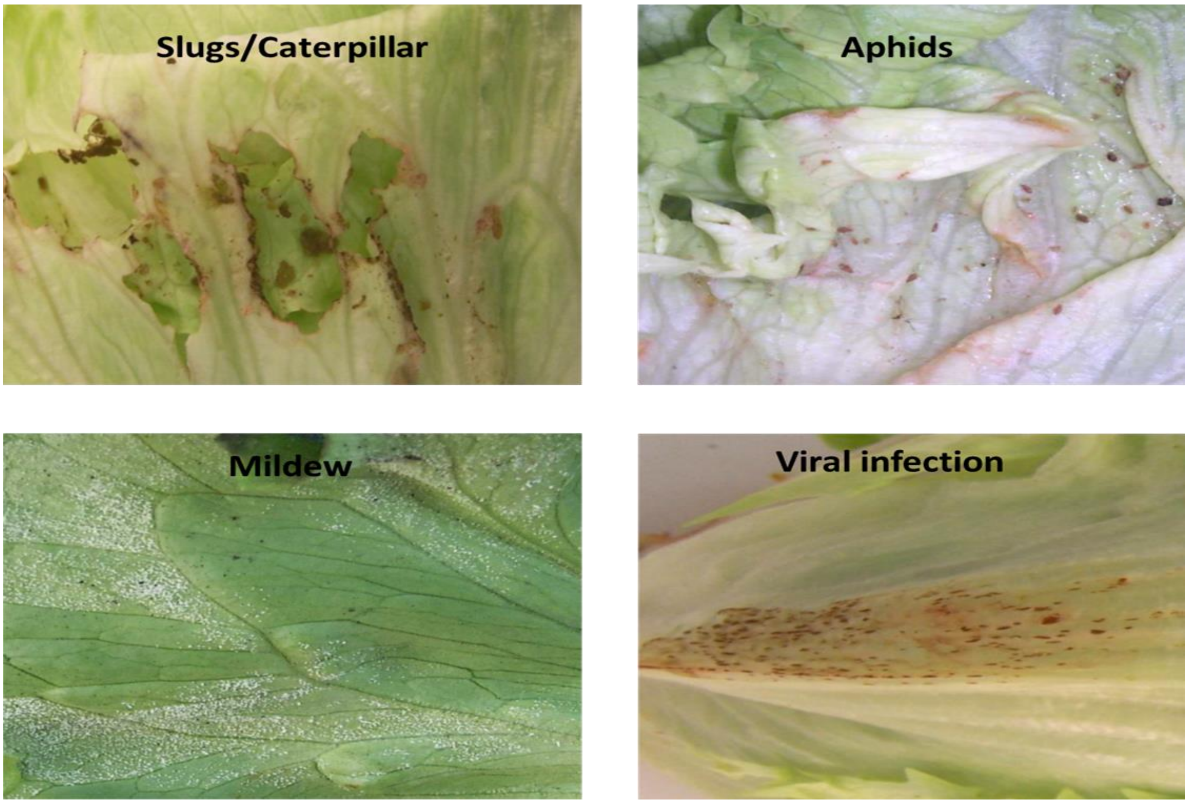

Figure 11. Examples of pests/pathogen damage in Iceberg lettuce heads. Source: G's – Tesco market specification guide.

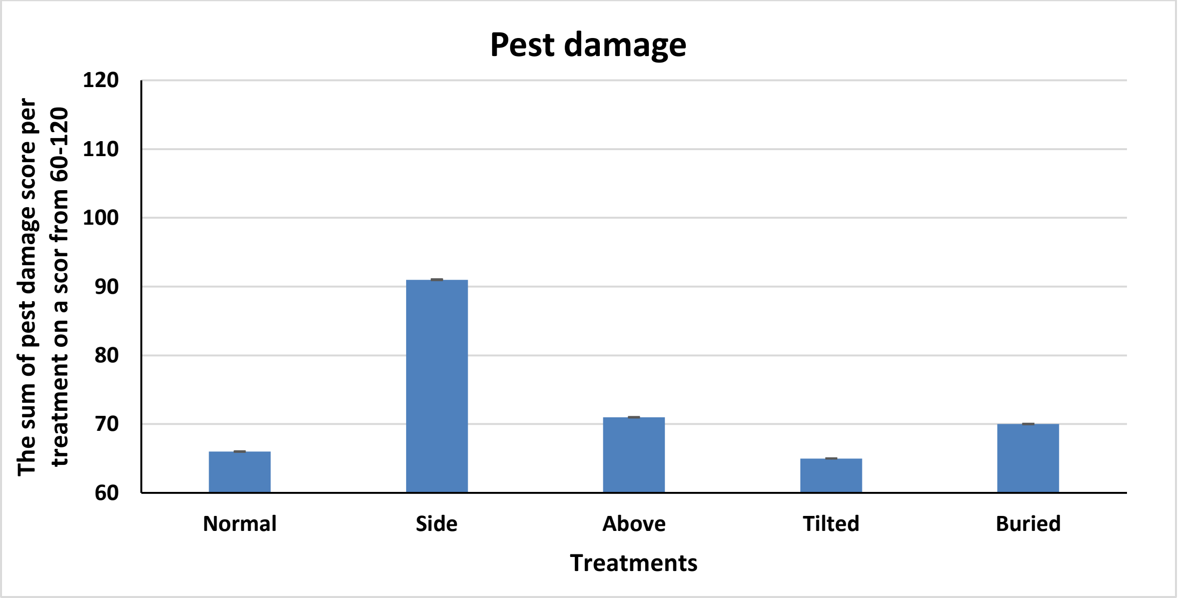

Figure 23. The proportion of heads with pest or disease damage per treatment. Presented using the sum of 60 head scores per treatment (n=60). Score: 0 = pest damage absent, 1 = pest damage present. Error bars show standard error for the samples.

Discussion

The yield variability amongst transplants that are grown from genetically uniform seeds under the same controlled conditions within the same trays can be partially explained by the inherited plant to plant variation. Harwood *et al*. (2010) suggested that this natural variation accounted for most of the variation in transplants. Although modern lettuce varieties have been bred for optimum yield under high input systems (Johnson *et al*., 2000; Gallardo *et al*., 1996 and Kerbiriou *et al*., 2013), the small size of seedlings makes them highly sensitive to minor fluctuations in the micro-climate i.e. temperature, light, moisture, etc. This study showed that over 3 days of growth, the coefficient of variation, although decreased in value, remained relatively high, indicating substantial variation amongst transplants. This inherent variation has the potential to be reduced through manipulating the micro-conditions or improving the management of the growing environment. Therefore, the effect of micro-climate conditions on transplant growth at a tray level and during the propagation stage requires further investigation.

There was no difference in fresh weights for transplants between the edge and the centre of trays so the hypothesis that transplants on the tray edge were smaller than the plants in the centre of the tray was not supported. Although the mean values were always smaller on the edge than in the centre, the individual plant values were not always smaller at the edge. This could be supported by the suggestion of Harwood *et al*. (2010) that the inherited natural plant to plant variation is the major cause of transplants variability. However, the large value of the CV% necessitates investigating the reasons behind this variability and how could the micro-conditions be used to affect this variation (eg. peat block size, tray size, temperature and moisture distribution, shading from tray edges or glasshouse poles, etc.)

In the transplanting field experiment, soil analysis results suggested a general level of homogeneity (consistency) of the soil properties within the plot areas in P58 and there was no effect of blocking on results. The orientation of the transplant had a significant effect on plant growth and quality at harvest. Between 92% and 100% of the trimmed heads of the tilted and the side treatments were misshapen compared with 35% in the normal treatment. This could be possibly be explained by the plants growing back towards the light after being planted in a tilted or horizontal position.

The highest fresh head weight achieved in the normal treatment suggests that the proportion of the peat block covered by soil in the normal treatment was sufficient to cover the rooting system and give the small plants access to soil nutrients and moisture, in comparison with the side and the above treatments. In each of the latter treatments, the peat block was in contact with the soil from one side only (Figure 13, treatments (2) and (3)). This is also supported by the fact that the peat-block in the tilted treatment was in contact with soil with a larger surface area (a total of three sides) and the fresh weight of tilted plants was also high and did not differ significantly from the normal treatment. The buried treatment was significantly smaller in head circumference (Figures 16 and 18), however, it had the densest heads (Figure 17). Although the normal and the tilted treatments were statistically similar in terms of head weight and size, the marketable quality of the tilted treatment was considerably poorer in terms of the percentage of the misshapen heads and appearance (pest damage and deterioration).

Conclusions

Years 1-3

- EC scans can be used to identify different soil zones within a field and enable targeted soil sampling.
- Demarcating variable soil-EC zones at a smaller scale (smaller than 3 m^2) proved inefficient for studying the potential for increasing lettuce crop uniformity through variable management.
- Although variable field zones could be identified using soil EC scans or soil properties' maps along with the yield maps, there was no statistical correlation of yields with EC scans or conformance with maps.
- Plant growth varied between the zones mid-season and at harvest.
- The variability pattern of lettuce yields was consistent over the zones, suggesting that yield distribution was mainly influenced by soil properties. Yield variation was mainly driven by underlying soil properties rather than by seasonal variation in moisture and weather conditions.
- Samples from soil zones that varied in EC range varied statistically in percentage clay content and in the nutrients magnesium, Mg; potassium, K and phosphorus, P. However, all samples had a significantly high level of organic matter (above 20%) so they were classified as organic.
- Statistical analysis showed that variability in sand proportions and soil organic matter were key soil factors contributing to yield variation. The data showed that the relationship between the yield and soil properties varied particularly when the organic matter levels varied.

- Soil organic matter has significant influence on soil moisture properties and bulk density; increasing organic matter increases the amount of soil moisture held at field capacity and decreases bulk density.
- The study suggests that organic matter variability is the key factor affecting yield variability in the studied field through its influence on soil physical quality and water -holding properties of the soil.
- A preliminary glasshouse study suggested that the variability that exists in propagated lettuce transplants before they are planted is an important source of variation. This was further investigated.
- During propagation, there is significant in-tray yield variation amongst transplants grown from uniform seeds under uniform conditions. There were no clear in-tray positional effects, and it is suggested that inherent genetic variability and differences in micro-climate may be contributory factors to yield variation.
- Transplants that vary in size (length) within the same tray vary in fresh weight and these two variables are directly proportional. This variability amplifies after transplanting separately
- Planting position, in terms of orientation and the depth or proportion of peat block covered or in contact with soil, affects the marketable yield; similar or relatively uniform transplants develop into variable mature heads in terms of head size, fresh weight and marketable quality and particularly appearance when they are planted differently. Transplants that are planted too deep in the soil, too high, or left tilted in the soil without adjustment, all result in reduced yield due to the resulting pest, disease or moisture damage from the soil, as well as misshaping due to abnormal growth direction.

Knowledge and Technology Transfer

- Undergraduate and postgraduate student lectures in Precision Farming in Fresh Produce and Innovation in Horticulture (x3) (Harper Adams University,2016)
- Research presentation for industry representatives and academics (Harper Adams University, 2016)
- Research presentation at the Sixth International Conference for Food studies (The University of California at Berkeley, USA, 2016)
- PhD Research presentation for the AHDB studentship conference (Warwickshire,2016)
- Research presentation for the British Leafy Salad Association (BLSA) annual meeting (Peterborough, 2017)

- Published article: Improving harvest efficiency by reducing lettuce variability, LEAF IFM Bulletin, 2017

Glossary

DMG: Destructively Measured Group

DAP: Days After Planting

ECa: apparent electrical conductivity of the soil

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Appendices

Appendix 1. Profile pits in two differently yielding zones derived from the map (centre; high in red and low in blue)