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Key staff:	Yara Boubou
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Industry Representative:	Ed Moorhouse
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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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CONTENTS

GROWER SUMMARY

Headline

Soil variability, which can be detected using soil electrical conductivity (EC) measurements, contributes significantly to the variability seen in whole-head lettuce growth and maturity at harvest. Preliminary studies suggest that zones with low EC readings result in low yields at harvest.

Background and expected deliverables

In-field variability in crop maturity and readiness for harvest is a significant issue in field-grown lettuce. The uniformity of whole head lettuce growth is very important for achieving an optimum marketable yield that is suitable for a single-pass harvest. Over-sized and underdeveloped heads result in crop wastage. When production is initiated by transplants, agricultural practices and growing conditions in the field play a key role in achieving lettuce uniformity, mainly because relative plant growth is largely determined by heterogeneity in soil properties.

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), a measure of a material's capacity to transmit electrical current; EC is reported in units of milli-Siemens or deci-Siemens per meter (mS/m or dS/m). This projects overall aim is to identify the key soil factors influencing lettuce crop growth and yield variability and define critical relative values for these factors which would help in demarcating distinctive management zones for growers to implement precision farming techniques.

The objectives are to (i) quantify how much variability in maturity, yield and postharvest quality are accounted for by soil physical and chemical properties (ii) identify the soil factors causing the greatest variability (ii) define the critical relative ranges for these factors that would define specific grower management/treatment zones and (iv) investigate whether variability can be reduced by precision application of inputs or adjusted management for specific zones.

In 2014/2015 work was done to:

1. Test whether field zones identified using EC scans correlated with the variability in lettuce growth and yield.
2. Test whether the zones had underlying differences in soil physical and chemical properties.

3. Test if *smaller scale EC zones* would account for variability in lettuce growth and yields.

Summary

Two experiments were conducted to map the different soil zones within a field in Ely, Cambridgeshire. The field was scanned for soil EC using a Veris E3100 scanner; the scanner was running DGPS (Differential Global Positioning System) so accuracy of locations was within 30cm. Maps were created from the raw data using Gatekeeper software. Multiple soil and plant samples were taken from two successive crops over the summer (June-October 2014) and transferred to HAU for further soils physical and chemical properties analysis and yield assessments.

Objective 1

The first field experiment identified three EC zones within the field using the EC scans, which measured bulk soil conductivity. The zones were demarcated by dividing the raw scanning data into three ranges: low, medium and high:

- Band 1 / Zone A had a '*Low'* EC range of 14.62 - 40 mS;
- Band 2 / Zone B, with a '*Medium'* EC range 40 - 50 mS and;
- Band 3 / Zone C having a '*High'* EC range of between 50 - 68 mS.

The zones that varied in EC varied with up to a 20% difference in total fresh weight at mid growth. Zone A, the lowest EC band had the least total fresh weight. At harvest Zone A continued to be the least with ~50% less fresh weight than Zone B and Zone C (medium and high EC), whereas the difference in yield between the medium and the high EC-Zones was not significant.

Objective 2

In the first experiment, soil zones identified using EC scans varied significantly in clay, sand magnesium (Mg), potassium (K), phosphorus (P) and organic matter (OM). There was no significant difference in acidity level (pH). Zone A had the least levels/concentrations of all the above mentioned parameters except (K) and there was no significant differences in clay percentage between zones A and B.

Simple Linear Regression between the studied soil factors and plants parameters showed correlation between total fresh weight (FW) and levels of OM, K and Mg. Whereas, trimmed-head weight (TW) correlated mainly with magnesium and strongly with fresh weight.

Objective 3

Although objective 3 studies were conducted on a different field with different defined EC zones the experiment showed that there were no significant differences in soil or crop performance when EC ranges were examined on smaller-scale zones, except for the early stage of lettuce growth (the difference disappeared at advanced stages of growth and development).

Financial Benefits

Direct financial benefits cannot be quantified at present. It will be easier to suggest or quantify these after completion of the work planned for years 2 and 3.

Action Points

- Soil EC scans can be used for targeted sampling instead of intensive sampling, this allows a relatively higher density of observations in targeted zones and saves money and time in comparison to conventional and destructive soil sampling.
- Differences in soil EC are associated with differences in soil properties and they may have an impact on lettuce growth and development.

SCIENCE SECTION

Introduction

Previous work regarding precision agriculture has mainly been focused towards cereal crops. No published materials were found on salad crops and particularly lettuce. Yield mapping of cereals or combinable crops is enabled through grain quantity-flow sensors that could be fixed onto the combine. However, lettuce is manually harvested due to the sensitivity of this crop to handling and mechanical damage. This makes its mechanical mapping difficult.

The influence of edaphic factors on lettuce productivity and quality were examined in several old and recent papers without any noting of soil variation. In precision agriculture, soil is a source of variability for plant growth and yield. Hence it should be considered and investigated.

Lettuce crops tend to produce a specific density under specific environmental inducements with a likelihood that this effect will continue to maturity and harvest (Wurr *et al.,* 1992). Reviewed literature showed favourable yield responses in lettuce being induced when standard agronomic inputs were manipulated, indicating a potential for reducing lettuce variation, qualitatively and quantitatively, through variable inducements/inputs.

Soil apparent electrical conductivity (EC) and Soil mapping:

A material's capacity to transmit electrical current is termed electrical conductivity (EC) and is reported in units of milli-Siemens or deci-Siemens per meter (mS/m or dS/m) (Grisso *et al*., 2009). Soil electrical conductivity is stimulated by a mix of physical and chemical factors so it is termed "apparent" (ECa). Factors that affect crop yields and could be estimated indirectly using EC include; soil temperature, clay content, the depth of clayey layers, soluble salts, mineralogy, water content, organic matter, bulk density, water holding-capacity, pH, minerals, the depth of topsoil, depth to water table, compaction and water flow patterns (Corwin and Lesch, 2005; Ma *et al*., 2011; Grisso *et al*., 2009; Zhu *et al.*, 2010; Doolittle and Brevik, 2014).

The importance of EC in soil assessments comes mainly from the fact that different soil types have different levels of electrical conductivity (e.g. clayey soils were commonly noted to have higher EC ranges than sandy soils). Hence, the variability in soil EC is created by the dissimilarity in EC of the substrate's different materials (Doolittle and Brevik, 2014). Soil EC measurements have been recently implemented in a broad range of studies to describe and sometimes define spatial variability in soil properties (Doolittle and Brevik, 2014; Zhu *et al.*, 2010; Corwin and Lesch, 2005; King *et al.*, 2005).

EC maps and precision agriculture (PA):

Precision farming choices were promoted by the expansion of technologies such as; remote sensing, mapping and data-management software and the Global Navigation Satellite System (GNSS) (Doolittle and Brevik, 2014; Corwin and Lesch, 2005).

Literature on PA include two approaches for mapping in-field variability; identifying low-yielding zones within the field (yield approach) (Keller *et al*., 2012) and demarcating in-field homogenous zones (soil approach) (Landrum *et al*., 2015). Parallel studies in precision irrigation have focused on the distribution of water requirements across the field, (Keller *et al*., 2012; Misra and Padhi, 2014 and Daccache *et al*., 2015). Some studies focused on one factor (e.g. saturated soil hydraulic conductivity by Keller *et al*., 2012) others on multiple factors. In general, ECa maps are used for identifying in-field distinctive zones.

Variable management decisions for field Iceberg using EC maps require identification of sources and scales of variation. Since the annual variability is mainly influenced by the current year conditions represented by all the factors that determine the production for that year, this study it will examine seasonal variability and the spatial distribution of lettuce yield from one season to another, taking into consideration the interaction between soil constant edaphic factors and other changing factors within the soil as well as weather conditions.

Work in 2014/2015 adopted an approach that aimed at keeping work relevant to practical farming situations, which started by examining the spatial soil and yield variation guided by the commercially available EC surveys. The relationship between the three datasets was also examined. Experiments undertaken have identified different yielding zones guided by soil EC scans that had been generated by (Veris3100). The variability in soil and lettuce quality in these zones was investigated in order to identify potential correlations between the yield responses and a limited number of edaphic factors.

Experiment1:

a) Investigated the in-field differences in yield between zones identified using EC scans

b) Investigated the in-field differences in soil between zones identified using EC scans

Experiment2:

a) Investigated the differences in soil and yield in smaller-scale zones

Experiment 1: Investigating soil and yield variability between zones of different EC values (do EC scans mean anything to the crop or the soil?)

Materials and methods

Site specifications

The studied field (RedmereP36) is located in Ely, Cambridgeshire (52°26’44.86”N, 0°25’08.56”E). It comprises 2.15ha within an 8.45ha field (worked area). Field soil is classified as loamy and sandy soils with peaty texture at the surface and naturally high ground water (National Soil Map and Soilscapes Dataset, 2015). The first crop studied received an average precipitation of 1.5mm over the season and an average temperature of 15.8°C. Agronomically, the crop received the standard inputs uniformly.

EC scans

RedmereP36 was scanned for soil EC on 11/03/2014 commercially using a Veris E3100, The scanner was running DGPS (Differential Global Positioning System) so accuracy of locations was within 30cm. The field was wheat stubble. Maps were created from the raw data using Gatekeeper software by G’s growers Ltd.

The raw data of the scans (comprising co-ordinates and their measured EC values) were processed again, sorted ascending and plotted on Google Earth to locate the EC values on the ground and classify the data into three bands suitable for the study (feasibility in terms of practicality and time required). The area of the field planted with the same Iceberg variety on the same date was selected for study. The bands on the ground are represented by three coloured zones within the field (Figure 1). The bands created were: Band 1 = Zone A (Low EC) from 14.62 to 40 mS, Band 2 = Zone B (Moderate EC) 40-50 mS, Band 3 = Zone C (High EC) 50-68 mS.

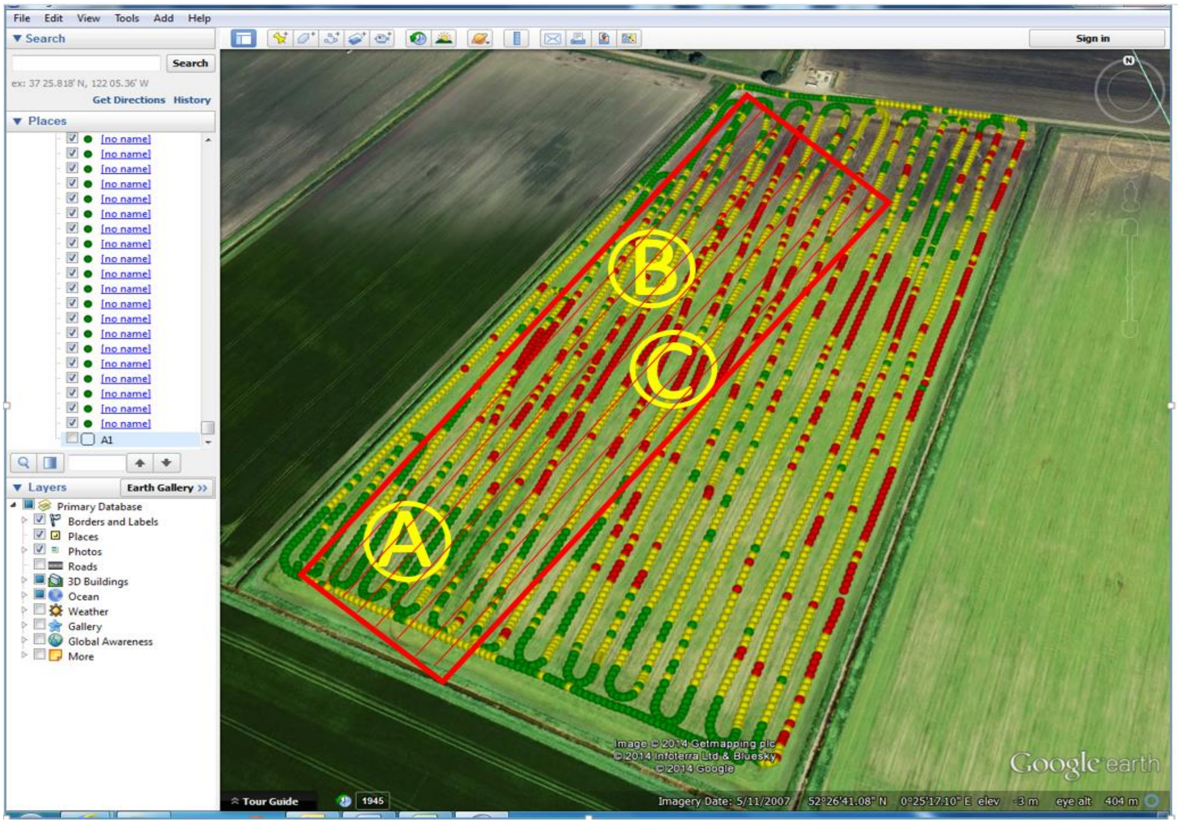

Figure 1: The studied field Redmere P36 with EC bands (green band and Zone A (low EC) 14.62-40 mS, yellow band and Zone B (moderate EC) 40-50 mS and green band and Zone C (high EC) 50-68 mS. The red lines show the planting direction and the red box indicates the targeted area planted on the same date with the same variety (var. Antarctica)

Data collection

From each identified zone, using a GARMIN e-Trex GPS device (accuracy range 10ft=~3meters), the centre point was marked and four locations around it (1m distance from the centre) were marked. All five locations were sampled.

Soil was sampled once at mid-growth. Two soil samples were taken from each location using a hand soil auger at three depths (0-30cm, 30-60cm and 60-90cm), each sample consisted of three sub-samples that were mixed and placed immediately into a sealable and pre-labelled bag. The total number of soil samples was 3 zones x 5 locations x 3 sampling depths = 45 soil samples

Crop was sampled twice:

- Mid-growth (rosette stage): From each location 10 plants (=50 plants per zone) were taken using a sharp harvest-knife. The plants then were weighed onsite and placed inside sealable and pre-labelled plastic bags as per zone, location and head.

Additionally, the diameter and height of two rosettes at each location were measured using measuring tape.

- At harvest: Same pattern was followed by harvesting 5 whole heads per location using a sharp harvest knife and cutting heads horizontally above soil surface, giving 25 plants per zone. Harvest heads were put inside plastic bags and transported to HAU on the same day.

Lab Assessments

a) Soil

All soil laboratory assessments were undertaken at Harper Adams University (HAU) using the standard methods (ADAS, 1986) as displayed (Table1)

Table1: Soil tests carried out on samples from Experiment1.

Soil test	**Method**
Soil texture	Particle size distribution
Organic matter (OM)	Loss on ignition
Acidity level pH	Measuring the pH in soil suspension extracted by water using pH-meter
Phosphorus (P)	Extracting soil using sodium bicarbonate solution then measuring the blue colour produced using the spectrophotometer
Potassium (K)	Extracting soil using ammonium nitrate and measuring the potassium amount in the filtered extract using the atomic absorption spectrophotometer
Magnesium (Mg)	Using the same extract for potassium, then measuring the Mg amount after adding strontium chloride using the atomic absorption spectrophotometer

(Source: Adapted from ADAS, 1986)

b) Plants

The outer leaves were removed from the whole heads to obtain the closed (marketable) head. Overall assessments made at HAU included; total fresh weight (FW), trimmed (marketable) head weight (TW), dry weight (DW), trimmed heads dry weight (TDW), and circumference. The density of trimmed heads was scored on a scale from 1 to 8 using G's market specifications (Figure 2). All weighing processes were done using digital scales to two decimal places. Dry matter was recorded after drying the plants in the oven at 80°C until obtaining a constant weight (~3days).

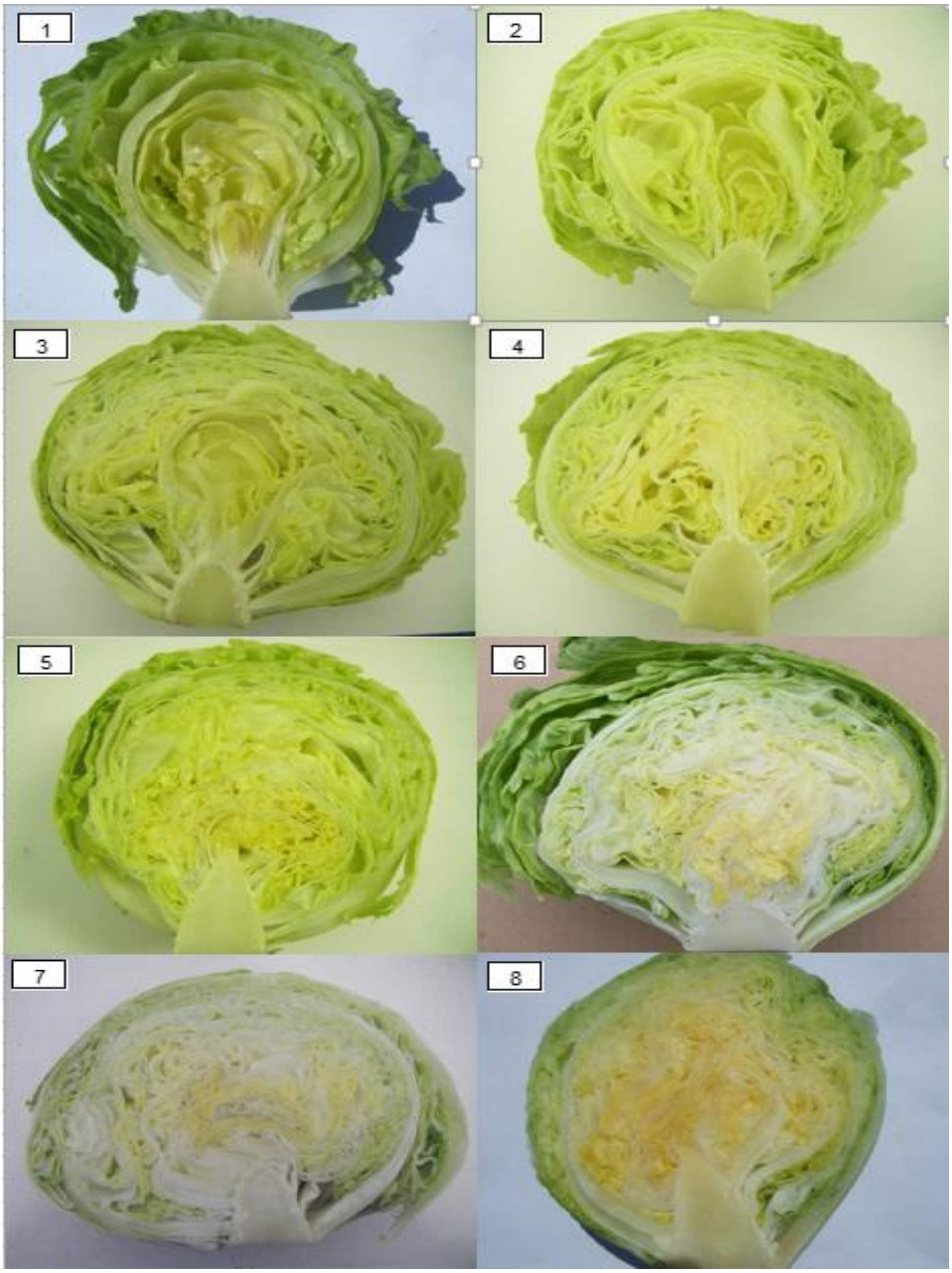

Figure 2: Density scoring scale from 1-8

Statistical analysis

Due to practical limitations such as (field size, scale of EC variation, GPS accuracy range, grower choices of variety and planting date, distance from HAU and labour required) the sampling density of the first experiment (and hence experimental design) was distributed as in (Figure 3).

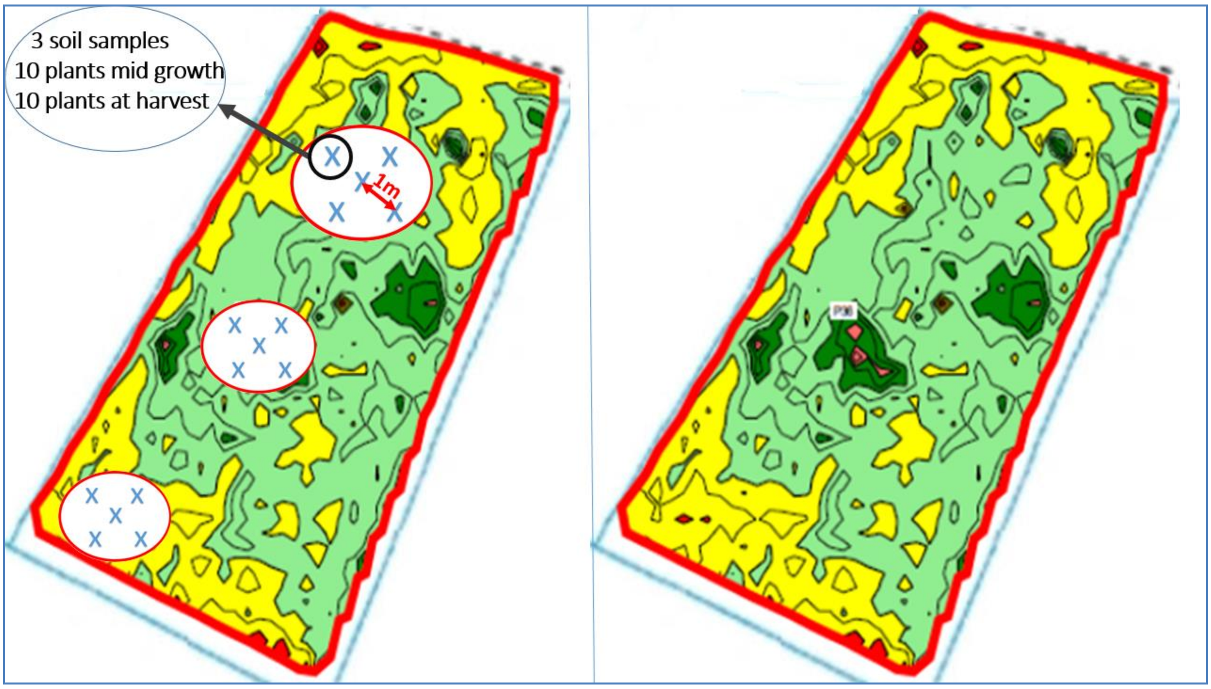

Figure 3: Sampling pattern showing the three zones (A, B and C) with five locations (X) in each.

To test each band (zone), five locations were selected within each zone. Each location was initially set to be treated as a replicate. In practice, it was difficult to replicate the zones within the same field as other parts of the field were planted with different varieties on varied dates and had different soil EC levels.

This experiment would have benefitted from a spatial statistics design and/or data clustering techniques. However, due to lack of resources at the time of the experiment, data were analysed using ANOVA on Genstat 16th Edition with zones as a treatment (n=50 or n=25 depending on the assessments). A limitation of this approach was that there was a lack of real replication (pseudo replication). However, the data can be treated as preliminary studies and has identified trends of interest for further study. The statistical design of the field studies will be addressed in the planning for Year 2 field experiments.

Results

a) Plants

When visiting the field at mid growth, the variable leaf surface area, growth and weed infestation were visible (Figure 4)

Zone A (the lowest EC conductivity EC 14.26-40 mS/m

Visual Observations:

- Lots of weeds
- Small heads
- Little crop cover/LSA

Zone B (A higher EC conductivity EC 40-50 mS/m (B)

Visual Observations:

- No or very little weeds
- Big heads
- Good crop cover/LSA

Figure 4: Visual observation of plant growth and leaf surface area of two different zones in the field as identified using the EC map.

(Source: Author's own)

Fresh weight: Samples collected at mid-growth showed significant differences in yield between the three zones with Zone A having the lowest yield. At harvest Zone A continued to have the lowest yield between the zones but no significant differences between Zone B and Zone C were observed. (Figure 5).

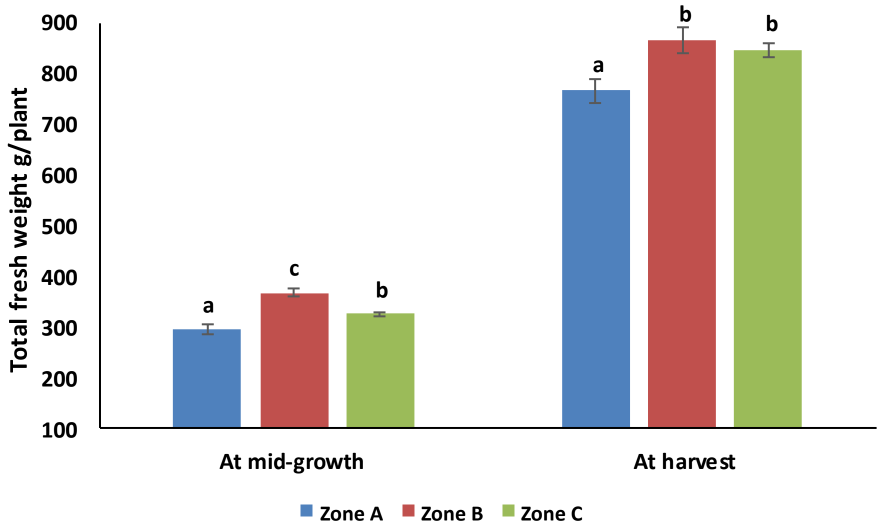

Figure 5: Total fresh weight of the three zones at mid-growth (n=50) and harvest (n=25). Error bars show standard errors for samples, where lower case letters differ values are significantly different (P<.001 and P<.05 respectively).

Trimmed head weight (marketable yield): There was a similar pattern for the fresh weight at harvest with Zone A displaying significantly lower yield than Zones B and C (Figure 6)

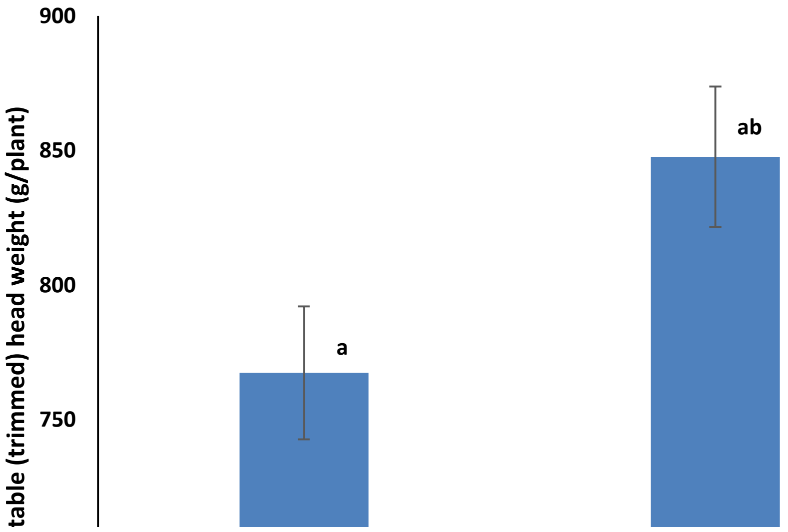

Figure 6: Marketable (trimmed) head weights of the three zones (n=25). Error bars show standard error for samples n=5, where lower case letters differ values are significantly different (P<.05), statistical analysis was undertaken on logged data.

Dry weight: At mid-growth Zone A significantly differed from Zone B with larger difference being noted at harvest than at mid-growth where Zone A became significantly different from both B and C. In both cases, Zone A had the lowest dry weight (Figure 7).

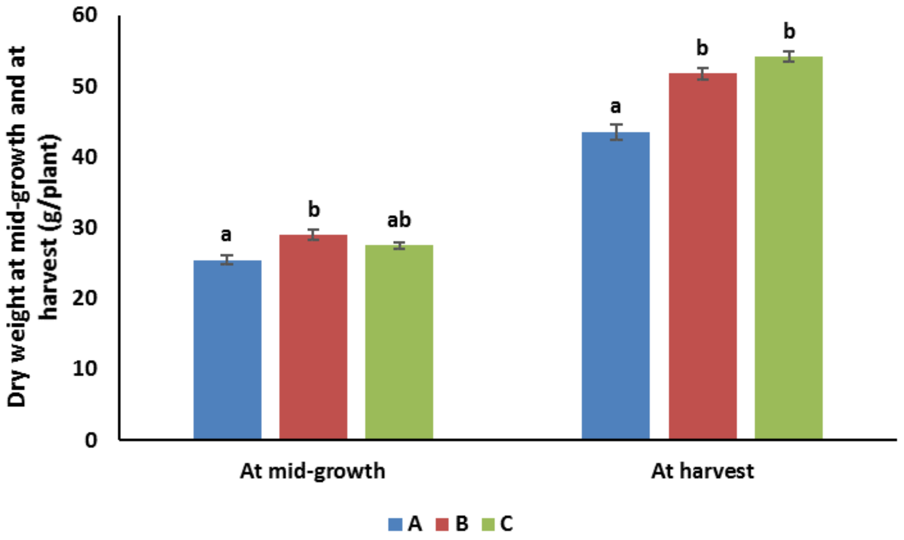

Figure 7: Dry weight at mid growth (n=25, P<.001) and at harvest (n=25, P<.001). Error bars show standard error for samples, where lower case letters differ values are significantly different.

Rosette dimensions: plants differed significantly in diameter between the three zones. Whereas, height only differed between Zone A and B

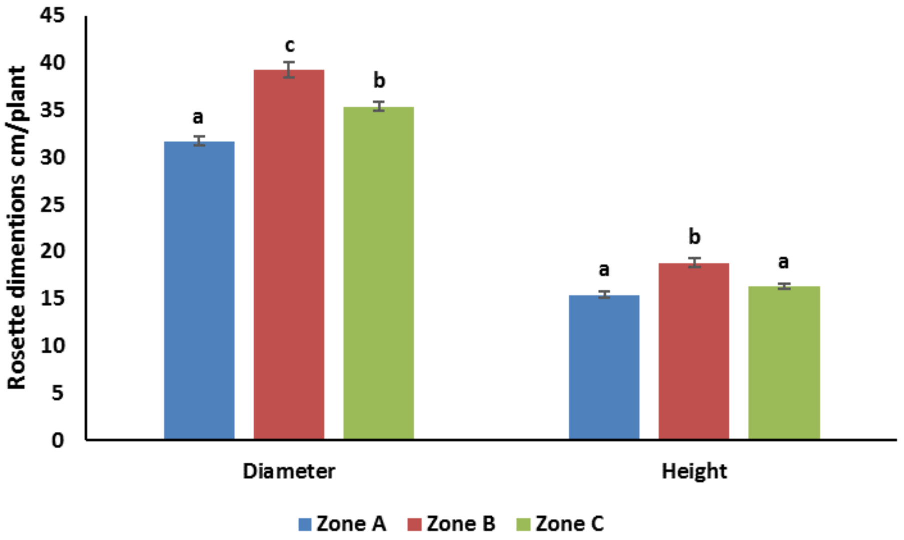

Figure 8: Rosette dimensions (diameter and height). Error bars show standard errors for the samples (n), rosette diameter (P<.001, n=10), rosette height (P<.001, n=10), where lower case letters differ values are significantly different.

Trimmed head circumference and density: There was no significant difference in the trimmed head circumference. However, Zone C showed significantly higher density than Zones A and B (P=0.008) (Figure 9).

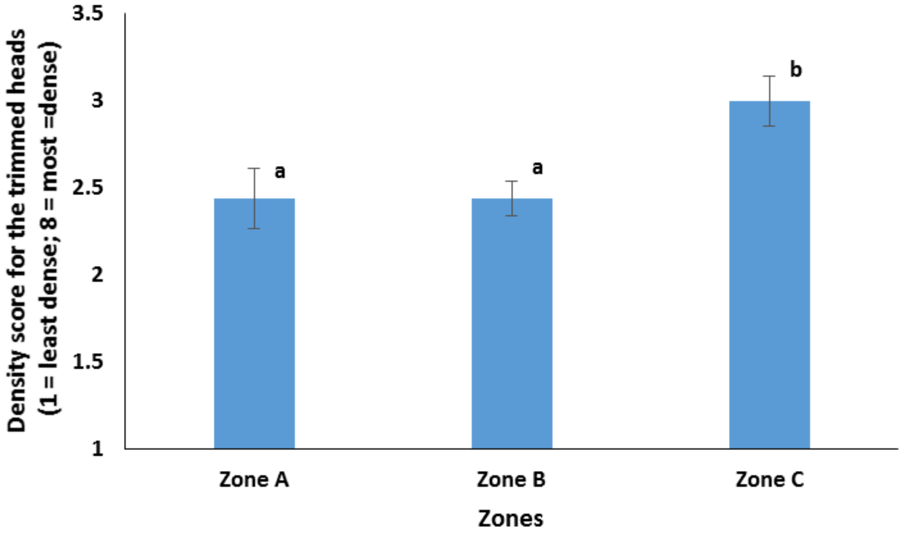

Figure 9: Trimmed-heads density score for samples (n=25). Error bars show standard error for samples (n=25) where lower case letters differ values are significantly different ($p<0.05$).

b) Soil

In the field, soil texture and moisture of the EC-identified zones were visually different. Zone A for example looked drier and had lighter colour and a more friable texture than zones B and C, whereas Zone C looked dark and muddy to some extent.

Texture: The use of soil texture triangle soil at Zones A and B resulted in classifying the soil as silty clay loam at the three sampling depths. However, the soil of Zone C fell on the silty clay area on the texture triangle at the surface and on the silt loam area for the third depth (Table 2)

Table 2: Soil type determined using soil particle size distribution test and texture triangle.

Samples depth	Zone A	Zone B	Zone C
0-30cm	Silty clay loam	Silty clay loam	Silt clay
30-60cm	Silty clay loam	Silty clay loam	Silty clay loam
60-90cm	Silty clay loam	Silty clay loam	Silt loam

The proportion of soil particles calculated as averaged percentages showed clearer differences (Table 3).

Table 3: Soil type (using texture triangle) and the percentages of clay, silt and sand of each zone at each depth averaged between the samples (n=5).

Zone	Depth	Soil type	Sand %	Clay %	Silt %
A	0-30cm	silty clay loam	14.2	32.9	52.9
	30-60cm	silty clay loam	8.5	35.6	56
	60-90cm	silty clay loam	6.6	29.8	63.5
B	0-30cm	silty clay loam	20	37.2	42.8
	30-60cm	silty clay loam	7.9	33.4	58.6
	60-90cm	silty clay loam	17.3	29.2	53.5
C	0-30cm	silty clay	5.5	42.8	48.5
	30-60cm	silty clay loam	14.5	32.4	53.1
	60-90cm	silt loam	20	53.5	58.8

Whereas, statistical analysis for clay content showed significant difference between Zone A and Zone C (P<.05), with Zone A being significantly lower in clay than Zone C (Figure 10).

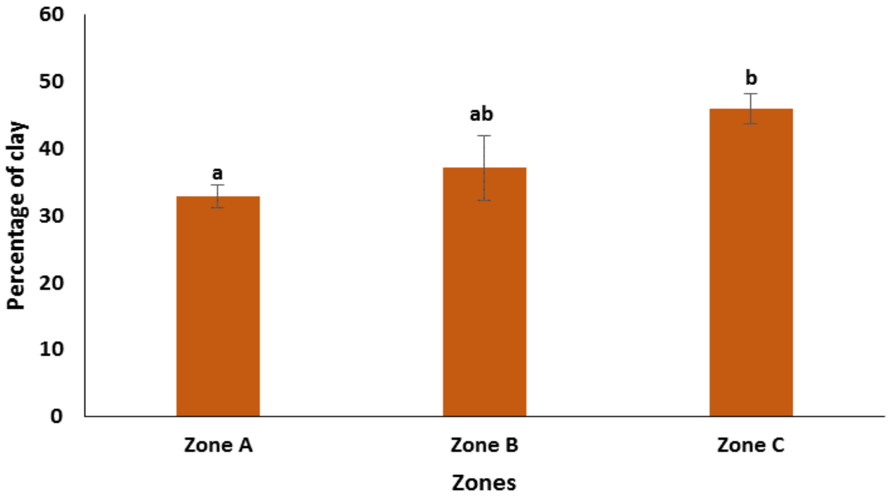

Figure 10: The difference in clay proportion between the zones (n=5) error bars show standard errors for samples (n=5), where lower case letters differ values are significantly different (P<0.05).

Organic matter: Zone A was significantly lower in organic matter content than Zone B and C (p<.001) (Figure 11).

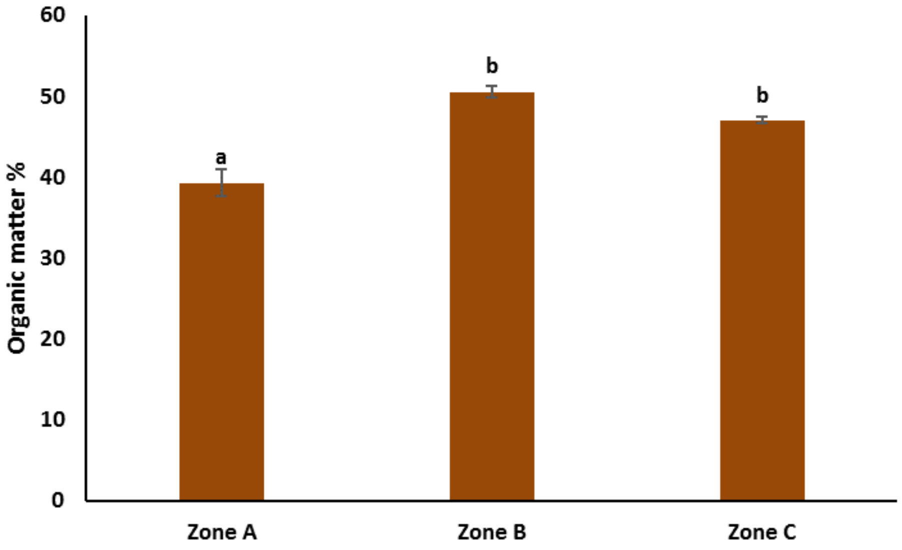

Figure 11: The difference in OM percentage between the zones (n=5) error bars show standard errors for samples (n=5). Where lower case letters differ values are significantly different (P<0.001).

Nutrients concentration and indexes: Analysing soil samples for Mg, K, P and pH showed significant differences between the three zones in all three nutrients (P<.001), (Figure 12), but no significant difference was found in pH levels.

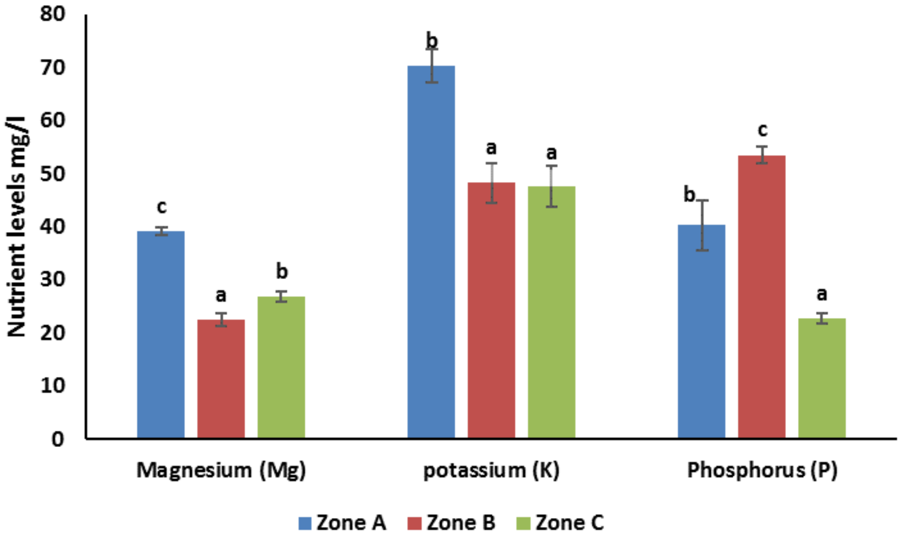

Figure 12: Mg, K, and P concentrations in the soil of the three zones (A, B and C) for soil samples (n=5) error bars show standard errors of the samples (n=5). Where lower case letters differ values are significantly different (P<0.001).

Similarly, variable nutrient concentrations resulted in different indexes for fertilisers recommendations (Table 4).

Table 4: Soil indexes for the analysed nutrients of each zone

Zone	Mg index	K index	P index
A	1	1	3
B	0	0	4
C	1	0	2

Simple Linear Regression between soil factors and plant parameters showed a correlation between total fresh weight (FW) and OM, K and Mg. Whereas, trimmed-head weight (TW) correlated mainly with magnesium and strongly with fresh weight (Table 5).

Table 5: Correlation matrix for FW, TW and soil factors (n= 5)

	OM (%)	*Mg (mg/L)*	*K (mg/L)*	*P (mg/L)*	*pH*	*FW (g/plant)*	*TW (g/plant)*
OM	1						
Mg	**	1					
K	**	**	1				
P	NS	NS	NS	1			
pH	NS	NS	NS	NS	1		
FW	*	**	*	NS	NS	1	
TW	NS	*	NS	NS	NS	**	1

Experiment 1 Discussion

Examining soil properties in soil zones identified using different EC ranges showed significant differences in most properties agreeing with published studies that have mostly showed coincidence between variable EC and variable soil zones across the field (e.g. Earl *et al*., 2003; James *et al*., 2003 and Taylor *et al*., 2003). The density of soil samples taken and analysed was higher than the density adopted by James *et al.* (2003) where he showed strong correlation between EC zones and soil variability at a sampling density of 4-8 samples per hectare. This probably supports the results of this study where the number of samples was increased to build up a higher density of observations.

Defining the soil texture from soil-texture triangle based on the results of soil particle size distribution test did not show differences in soil types. Despite the visually observed difference in appearance and moisture, the texture triangle gave the same type of soil at three zones across three depths except for minor differences for Zone C where it was silty clay at the surface (0-30cm) instead of silty clay loam as in Zone A and Zone B. However, when comparing the clay content between zones, Zone C was significantly higher in clay content as a percentage than Zone A (13% higher). It was not significantly different from Zone B but there was 8% difference between the two averages, showing a similar trend to the difference between these two zones in total FW and TW weights at harvest that was not statistically different but the difference was present. The significant difference in clay% indicates that the precision of using soil texture triangle for determining zonal soil-type is not adequate for this approach. Clay content is a more reliable measurement for soil in-field variability as also indicated by De Benedetto *et al*., (2012) due to the importance of clay content in determining soil hydraulic properties and water holding capacity as well as its strong correlation with EC surveys under uniform soil water conditions (De Benedetto *et al*., 2012).

There were significant differences in the yield between the three zones in FW at mid-growth. This difference was reduced at harvest between Zones B and C. Similar pattern was observed for the marketable head weight where Zone A was significantly lower than Zones B and C. This could be because the variability in size between young plants declines in time particularly for the overdeveloped plants in comparison to the normal one as noted by Kerbiriou *et al*., (2013). Or, it could also be attributed to reducing the number of samples from 10 samples per location at mid-growth to 5 per location at harvest, which caused a loss of precision.

However, the proportion of variation that was picked up at mid-growth stage and continued to harvest (in particular between Zone A and both of Zones B and C) could indicate a variation in growth and development that starts at early stages of growth and affects the biomass acquired by harvest.

In most studied crop parameters, Zone A (the lowest EC range) was significantly different from Zones B and C. Whereas the significant difference between Zones B and C was picked up less frequently (medium and high EC). Density score at harvest was the only crop parameter in this experiment in which Zones A and B were similar and significantly different from Zone C. The density results could possibly mean that soil factors that changed between zones A and B were having no effect on density. However, all samples showed low density in general (the highest density score given was four out of eight of all locations and that was only for very limited number of samples (8 samples out of 75). The low density in lettuce is normally attributed to environmental conditions. This parameter could have benefited from a greater number of samples per zone as the difference to be detected is small.

Obtaining soil indexes from nutrients concentrations for the three zones showed different fertilisers recommendations for the three zones for each of Mg, P and K, which shows that some areas of the field were receiving extra or reduced amounts of fertilisers.

The trend that was observed between total FW and marketable weight at harvest from one side and soil clay and OM from the other suggests a possible relationship between lettuce and these factors. Hence, further investigation is proposed

Linear regression amongst the studied soil factors and plant parameters showed that FW correlated with OM and K and more strongly Mg, whereas, the marketable weight correlated with Mg although the trend of these nutrients was not similar to fresh weights. Part of this this coincidence with Mg and K could be explained by the trend of OM and clay% as these nutrients are known to be strongly interactive with clay minerals and organic matter, which in turn determine their availability (Brady and Weil, 2006 and Marschner, 2012) as nutrient concentrations results from chemical analysis of soil does not necessarily mean their availability to the plants, but how mobile are the nutrients and strongly they are held is more important and this is strongly affected by OM and clay minerals.

Earl *et al.* (2003) found in their study that both P and Mg were above the limiting thresholds for cereals and reported variability in their concentrations between sampling dates. However, they did not discuss further, which highlights the importance of carrying out similar research on lettuce due to the difference in limiting threshold of nutrients.

Experiment 2: Explore soil and yield differences at a smaller-scale zones

Materials and Methods

Site

Second experiment was undertaken in the same site (Redmere P36) as in Experiment1. The part of the field selected for this experiment depended on the uniformity of lettuce variety and planting date. In order to minimise the variation (the largest part of the field planted with the same variety on the same date was chosen. This required the creation of new EC ranges/bands and hindered repeating the first experiment, as the ranges used for the first experiment were not present in the new part of the field. This crop had received an average precipitation of 0.67mm over the season and an average temperature of 14.15°C

EC scans

Using the same scans used for Experiment 1, soil EC bands/ranges were selected based on the scale of the EC variation present within cv. Kuala cru planting area. Bands are shown in distinctively-coloured dots on the ground (Figure 13) and they were as follows:

EC-Band1 G (green dots) = low conductivity 9.1-24.9 mS)

EC-Band2 BC (blue dots) = medium conductivity; EC 25-29.9 mS)

EC-Band3 RC (red dots) = high conductivity (EC from 30-57.1)

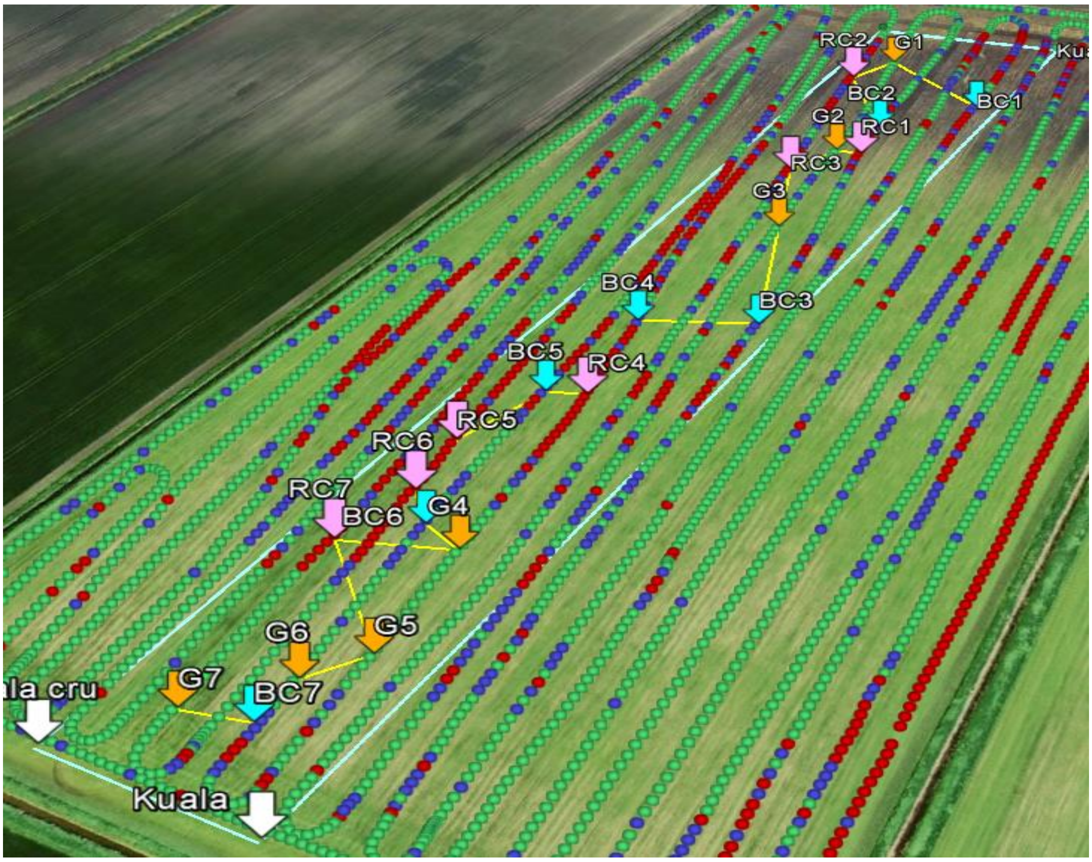

Figure13: sampling design for experiment 2, shows sampling locations belonging to same EC range indicated by arrows of the same colour. Yellow lines on the ground are the distance between locations as measured via Google Earth for increasing the accuracy. The blue box on the ground is the part of the field planted with cv. Kuala cru on the same date.

Data collection

In order to increase the number of samples, each range (band) was sampled at seven locations (instead of five as in the first experiment).

Soil

Soil was sampled once at mid growth. From each sampling location one sample was collected each sample consisted of three subsamples that were mixed together inside a sealed bag giving seven samples per band and 21 samples in total.

Assessments were undertaken using the standard methods as in Experiment1 and included texture, organic matter and pH.

Crop

- ***Harvest (a), early satge,14 days after planting***

  Ten young plants were sampled at each location and brought back to HAU for further assessments, which included:

  - Leaf count (counted all visible leaves from the biggest to the tiniest one)
  - Fresh weight (FW) (to 3 decimal places) was recorded next morning after sampling and where plants were put in the cold-store overnight
  - Dry weight (DW) (using the same balance) obtained after drying the young plants in the oven at 100 °C for 48 hrs.

- ***Harvest (b), mid-growth, 35 days after planting***

  Ten plants/rosettes were sampled at each location and transported to HAU on the same day for assessing FW and DW as in Harvest (a)

- ***Harvest (c), at maturity***

  Ten whole heads where harvested at each locations following the same protocol as in Harvests (a) and (b). Assessments included:

  ✓ *Total FW*

  ✓ *Trimmed-heads FW or TFW*

  ✓ *DW*

  ✓ *TDW*

  ✓ *Trimmed head circumference*

  ✓ *Density score*

  ✓ *Quality scores on Day 10 after harvest*

  ✓ *Quality Scores on Day 20 after harvest*

Quality assessments:

After recording the total fresh weight of the heads, outer leaves were trimmed to obtain the marketable head of Iceberg. The marketable weight (the trimmed-head fresh weight TFW) was recorded and the head circumference was measure at a horizontal level parallel to the base of the head and using a measuring tape.

Four measured heads from each location were then wrapped in plastic bags and stored at a 4°C.

DAY10 after harvest two heads from each location were removed from storage scored for quality.

DAY20 after harvest the remaining two heads of each location were scored for quality.

Quality scorings were undertaken using lab methods for FW, DW, TFW and TDW. In addition heads were scored to market specifications for both internal and external quality parameters including; breakdown, tip burn, mildew, pest damage, viral infection, delamination, ribbiness, rib-cracking, butt-pinking, rib pinking, pinking, density scoring, bolting and misshaping.

Results

Crop

Fresh weight and dry weight: analysing FW and DW data from the three harvest data showed significant difference between the three bands at the first harvest date (14 days after planting) as shown in (Figure 14) and (Figure 15) respectively

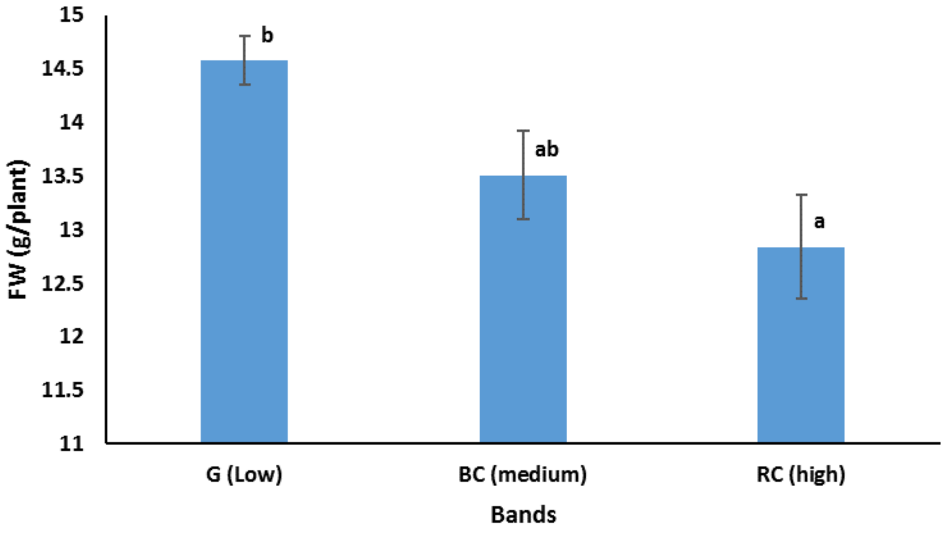

Figure 14: Total FW of young plants g/plant on day14 after planting. Error bars show standard error for averages (n=7) as averaged between the samples (n=10). Where lower-case letters differ values are significantly different (P<.05).

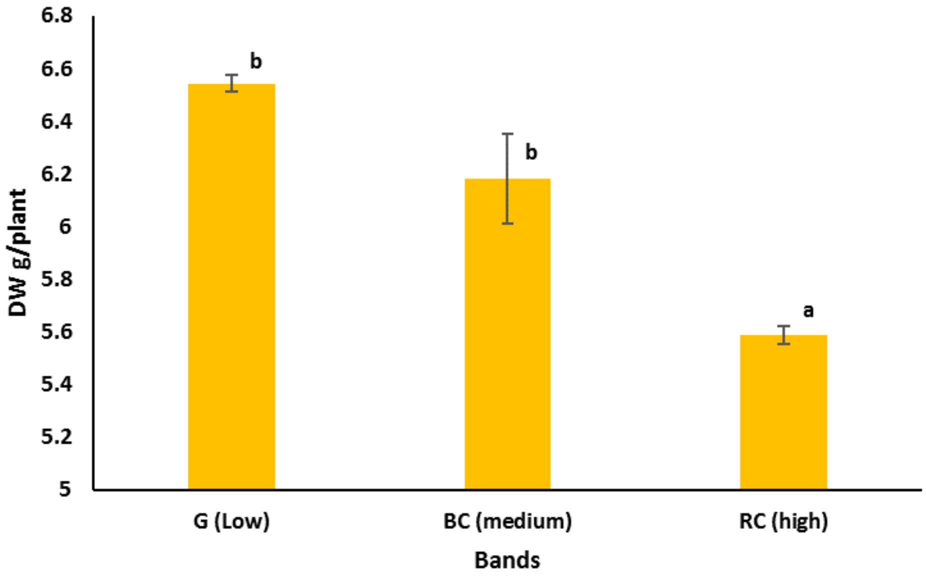

Figure 15 Total DW of young plants g/plant on day14 after planting. Error bars show standard error for averages (n=7) as averaged between the samples (n=10 per location). Where lower case letters differ, values are significantly different (P<.05)

However samples collected on the following two harvest dates (35 DAP and Maturity) did not show any significant difference between the bands at any of the examined parameters as displayed in the (Table 6)

Table 6: Examined crop parameters and the significant difference (S) or non-significant difference (NS) between the bands on each sampling or examining date.

	Day14 after planting	Day35 after planting	Maturity (at harvest)	Day10 post-harvest	Day20 post-harvest
FW	**Sig**	**NS**	**NS**	**NS**	**NS**
DW	**Sig**	**NS**	**NS**	_	_
Leaf count	**NS**	_	_	_	_
T-head circumference	_	_	**NS**	_	_
Density score	_	_	**NS**	**NS**	**NS**
Quality score	_	_	_	**NS**	**NS**

Soil

Soil texture analysis and soil type determination using texture triangle showed only a slight or no difference in type (Table 7)

Table 7: Soil bands, their type according to soil texture triangle and the proportion of clay, sand and silt as percentages as averaged between the samples (n=7).

Band	Type	Sand%	Clay%	Silt%
G (low)	Silty Clay	9.5	39.8	50.8
BC (medium)	Silty Clay Loam	14.1	33.3	52.6
RG (high)	Silty Clay Loam	6.5	36.4	57

Statistical analysis for the soil particles proportions did not show any significant differences between the bands as displayed in (Table 8)

Table 8: results from Analysis Of Variance the difference between the bands was not significant.

Soil particles content	Clay%	Sand%	Silt%
Difference between the bands	NS	NS	NS

Experiment 2 Discussion

In this experiment, EC bands were tested using smaller-scale zones than the zones tested in the experiment 1.

These zones showed only significant differences in FW and DW for young plants when the crop was sampled 14 days after planting. Zone RC (the highest EC range) was the lowest in both parameters. This was opposite to what was found in Experiment1 where medium or high EC range showed the highest FW. This could be explained by the soil texture. Zone RG was the highest in both silt and clay contents, which makes the soil surface possibly harder to penetrate by the fragile root of the newly-established transplants in dry conditions. Soil in this case might have larger size aggregates that reduce contact with the small transplants roots and hence access to moisture.

Later on, when the plants became bigger at the 35 DAP and at maturity sampling dates there were no significant differences in FW, DW, circumference, density or other measured parameters, which could be explained by the larger roots that are farther reaching to moisture and nutrients than the small roots of young transplants, overcoming by this the small-scale of soil variability. Repeating such an experiment is essential before discussing the outcomes.

The lack of differences found in FW, DW and the rest of soil parameters indicates that the small-scale variation in soil EC is not adequate for detecting soil or yield variation

The relationship between the scale of the variation and determining the size of the management zone was noted by Stafford *et al*. (1999) being a complicated process due to the complexity of the factors involved (soil-crop-season). Hence, it is not possible to adopt the results at this stage without further investigation

Conclusions

- Different soil zones within the field could be identified through targeted soil sampling guided by soil EC surveys.
- Soil zones that varied in EC range varied slightly in soil type when plotting the results on texture triangle but varied statistically in clay content as a percentage, nutrients; Mg, K and P.
- The studied zones similarly varied in crop performance at mid-growth and harvest. Part of the variation in growth and development could be detected at early stages of growth and could continue to be seen at harvest.

- Small scale variation of soil properties is not adequate for studying the potential of increasing lettuce crop uniformity through variable management or management units.

Knowledge and Technology Transfer

November 2014	Presentation at Harper Adams University’s annual PhD/MPhil Student Colloquium
November 2014	Poster presentation for Student & Early Career Researchers Day, a Focus on Policy.
January 2015	Grower visit and presentation- G’s Growers, Barway.
February 2015	Presentation at the IAgrE South East Midlands Branch Student Evening A presentation for an audience of growers, farmers and academics from HAU and CU, (won the prize for best presentation).
February 2015	Meeting at Cranfield University with G’s remote sensing technologist for discussing data exchange and mapping software.
March 2015	Abstract submitted and accepted for a poster presentation at the UK Plants Science Conference taking place at Harper Adams 14th-15th April

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