Project title:	Towards precision inputs through improved understanding of the underlying causes of in-field variation in Lettuce crop maturity and yield
Project number:	CP 121
Project leader:	Dr Jim Monaghan, Harper Adams University
Report:	Second annual report, March 2016
Previous report:	First annual report, April 2015
Key staff:	Dr Ivan Grove - Supervisor Prof Simon Blackmore - Advisor
Location of project:	Harper Adams University, Newport, Shropshire TF10 8NB and G's Farm Cambridgeshire
Industry Representative:	Ed Moorhouse
Date project commenced:	7th April 2014
Date project completed	7th April 2017

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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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

- Lettuce yield patterns were consistent over 2 seasons, in terms of high or low yielding zones, with no in-season variation.
- EC scans could not be used directly to predict lettuce yields or its zonal variations. However, they are useful for predicting variations in soil properties.

Background

Crop yields are influenced by soil properties, climatic conditions and agricultural practices and their interactions. Understanding the spatial variation of these factors is fundamental when assessing the spatial distribution of 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. The efficiency of a single-pass lettuce harvest is determined by uniformity of the mature heads; 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 contributes significantly to crop variability (Taylor *et al*., 2003). The relationship been 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). As yet, no work has been reported in short season crops such as lettuce. This project aims to improve harvest efficiency in field-lettuce through enhancing yield uniformity or providing targeted solutions. The project focuses on understanding soil heterogeneity and its influence on yield variation in spatial and temporal aspects at a field scale.

The overall aims are to identify:

- how much of the variability in lettuce maturity, yield and postharvest quality is accounted for by soil properties.
- soil factors (edaphic factors) that cause the greatest variability in lettuce growth.
- the critical relative ranges for these factors which allow for the delineation of specific treatment zones.
- whether lettuce variability can be reduced by precision application of inputs or adjusted management for specific zones.

In the second year (2015) aims were to identify factors which correlated most with yield variation.

Hypotheses were that***:***

1. the variability pattern of lettuce yield is consistent over the studied area.
2. underlying soil properties in the area under investigation influence yield distribution.
3. variable field zones could be identified using soil and yield maps.
4. The sand proportion in soil texture affects yield.
5. variation in lettuce transplant size and placement affects subsequent growth.

Summary

In 2015 two field experiments were carried out to map lettuce yield and soil factors for part of the field P57, on G's grower's Ltd farm in Cambridgeshire. In addition a glasshouse experiment investigated the influence of texture (particularly sand proportion) on lettuce biomass production.

Objective 1: To investigate the consistency of the spatial pattern of lettuce yield.

There were no significant differences between two successive yields of Iceberg lettuce (*Lactuca sativa, cv. Kuala cru*) that were harvested from the field P57. Yield maps showed similar patterns for the two yields.

Objective 2: To investigate the influence of the underlying properties of the field soil on lettuce yield.

The yield patterns corresponded with the patterns of a few soil properties. The relationship between factors appeared to differ between the northern and southern zone of the studied area. Overall, the variation in yield was accounted for by differences in soil bulk density, sand proportion, potassium and nitrogen at 30-60cm depth, and phosphorus at 0-30cm depth and soil moisture. None of the measured soil parameters individually correlated with the EC values. A model including soil bulk density, sand proportion, total K, N and P, and soil moisture content at harvest described 42.8% of the variation in lettuce yield averaged over both crops. There were no significant differences in EC between the two depths investigated.

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Objective 3: To identify field zones using the produced maps.

Distinctive field zones were identified of high and low yield. These zones could not be predicted from EC or previous wheat yield maps. The relationship between soil factors changed between the northern and southern portions of the experimental area. Variation in EC correlated with the general level of variations in soil across the field but did not describe amplitude or positional effects at a meaningful crop level. The Formed Variograms showed that data have become largely variable when the sampling points become more than ~100m apart.

Objective 4: To investigate the effect of sand proportion in soil texture on early stage of growth and biomass production.

A glasshouse experiment (GH01) showed significant (negative) correlation between sand proportion and the fresh weight suggesting that the fresh weight of the transplants decreased with greater proportion of sand in the soil.

The sand proportion in a Silty Clay soil obtained from a similar field had a negative impact on lettuce growth.

Objective 5: To investigate the effect of pre-plant transplant variation, and variation of transplants placement on the uniformity of the final yield.

A glasshouse experiment (GH02) looked at the effect of four different placement positions on transplant fresh weight 14 days after planting. The results showed no significant difference between transplants positioned differently in the pots, in terms of biomass production 14 days after planting, which possibly suggested that the visible growth differences might require a bigger number of replicates to be confirmed.

Glasshouse experiment GH03 looked at the degree of variation in fresh weight amongst the transplants inside one commercially propagated tray. The results showed a considerable level of variation amongst propagated transplants of the same tray. This variation could explain partially in-field growth and yield variation.

Financial Benefits

The efficiency of a single-pass lettuce harvest is determined by the percentage of heads which meets the requirement of the buyers, which is in turn determined by the uniformity of the mature heads; oversized/under-developed heads result in crop wastage. Any reduction in variation will increase the proportion of heads harvested and hence return from a crop.

Action Points

- It is not recommended to use EC scans to predict yield variation in lettuce as EC levels did not correlate directly with lettuce yield, or any of the other parameters measured in this experiment.
- Large variation in EC values can be used to predict the general level of soil variations in soil across the field but cannot necessarily explain amplitude and positional effects of individual soil traits.
- EC scans can be used to target soil sampling within zones of variable EC values, as long as the distance between the samples (cores) is less than 100m apart depending on the size of the zone that needs to be sampled.

SCIENCE SECTION

Introduction

This project aims to improve uniformity in lettuce crop yield through understanding soil heterogeneity and its influence on yield variation in spatial and temporal aspects at a field scale. Variability in the growth of lettuce transplants leads to variation in head weight and maturity at harvest and can also affect post-harvest quality. This causes a significant issue in field-grown lettuce where growers wish to harvest heads of a uniform size and weight to meet the demands of the supermarkets. It is known that heterogeneity of soil properties within a field can affect nutrients and water holding capacities which can affect plant growth rates. This soil variability can be detected by scanning its electrical conductivity (Taylor *et al*., 2003).

The overall objectives of this project are to identify:

- How much variability in maturity, yield and postharvest quality can be accounted for by variation in soil properties?
- The soil factors (edaphic factors) that cause the greatest variability in plant growth.
- The critical relative ranges for these factors that can define specific treatment zones.
- Whether variability can be reduced by precision application of inputs or adjusted management for specific zones.

The aims of the work done for the second year (2015) of the project were to identify the factors that showed high correlation with yield variation.

Hypotheses:

1. The variability pattern of the yield is consistent over the studied field.
2. There are underlying soil properties in the studied field that are influencing yield distribution.
3. Variable field zones could be identified using soil and yield maps.
4. Sand proportion in soil texture affects yield.
5. Variation in transplant size and placement affects subsequent growth.

Work objectives for Year 2 were

1. To investigate the consistency of the spatial pattern of lettuce yield.
2. To investigate the influence of underlying properties of the field soil on the variation in lettuce yield.

3. To identify field zones using the produced maps.
4. To investigate the effect of sand proportion in soil texture on early stage of growth and biomass production.
5. To investigate the effect of pre-plant transplant variation, and variation of transplants placement on the uniformity of the final yield.

Statistical analysis:

Glasshouse experiment data were analysed using Dose Response Analysis, field data were analysed using Regression Analysis, ANOVA, T-Test and Variograms in Genstat_17th edition (VSN International) and the Geostatistical Analyst package in ArcGIS (ArcMap 10.2.2, esri).

Collected data were mapped in the Geostatistical Analyst in ArcGIS and the geometric intervals classification method depending the same colour ramp and the number of 10 classes (Bing *et al*., 2006; Krygier and Wood., 2005; Jankowski., 1995). Variograms were formed for several parameters to test the spatial correlation of the data (Oliver and Webster., 1991). Regression analysis (Multiple and linear) and ANOVA were performed to test the variance and the dependence between the two depths of the same trait as well as the correlation between different parameters.

A historic yield map of the same field (provided by the grower) was used to estimate wheat yield and EC values for the referenced sampling locations using GoogleEearth app (Googlearth Ink). This was done to see whether historic yield map can show a certain growth pattern. The values of the nearest 4 data points were averaged.

Objective1: To investigate the consistency of the spatial pattern of lettuce yield (will the low yielding zones remain the same over two different seasons?)

Field experiment 03- (Yield): Materials and methods

Yield sampling

- The experiment was established in field P57, G’s Farm, Cambridgeshire, georeferenced as (52° 27.152'N, 0° 24.184'E)
- Lettuce heads were harvested June 8th 2015 from a first crop (planted on 13/04/2015).
- Sampling was carried out systematically following a 20x25m grid on 63 field sampling points using the Geo 7X handheld GPS unit (accuracy range 1-100 cm).

- A second set of Lettuce heads were harvested from a second crop on September 10th 2015, (planted 29/07/2015)
- Both harvests were done 2-3 days before commercial harvest, by chopping 5 heads in the first-crop and 4 heads in the second crop per location (sampling point) using a sharp harvest knife.
- The total fresh weight was recorded in situ in the first crop and in the lab the second harvest.
- Dry weight was measured for both yields by drying the heads in ovens at 60°C until the weight had become constant.

Yield mapping

The sampling locations were georeferenced using a GPS devise (The Geo 7X handheld GPS unit has a DGNSS accuracy of 1-100 cm). Collected lettuce yield data were mapped in the Geostatistical Analyst in ArcGIS and the geometric intervals classification method depending the same colour range comprised of 10 classes (10 different shades on the map) in conformance with the good guidelines for making maps in GIS. Also, this enables the map readers of seeing distinct boundaries of the traits (Field, 2009). Because any classification of more than 8 classes is considered complex and to make it useful for the grower in practice to see the trait patterns the maps were also classified using 3 categories to represent low, medium and high levels of each trait. These categories do not reflect marketability. They were assigned mainly to show the difference in plant growth over the field. They could be assigned in several different ways to reflect the grower's area of interest. In this experiment the categories were;

a) From 301-440 grams of total fresh weight per head
b) From 44 to 580 g/head
c) From 580 to 719 g/head

A historic and georeferenced wheat yield data from 2014 was provided by the grower mapped using Class combine and Agromap software. The raw data were then mapped and the yield values were estimated for the lettuce sampling locations using the GoogleEarth application. This was achieved by averaging the values of the nearest data points to each sampling location. The historic wheat map from 2014 was compared both statistically and visually to the resulting lettuce fresh weight maps to examine the similarity of yield pattern.

Objective 1 results

Two samples T-test showed no significant difference between the first lettuce harvest (spring yield, Yield 1) and the second lettuce harvest (autumn yield, Yield 2) but the two yields were significantly correlated (Figure 1). When mapping both harvests, yields showed similar patterns but they were not identical. Reducing the number of categories to three, the maps continued to show the highest and the lowest yielding zones in the field (Figures 2 and 3).

The produced historic wheat-yield map for the same field corresponded with lettuce yield at one end of the field only but in general, it did not show a similar yield distribution over the studied area (Figure 4).

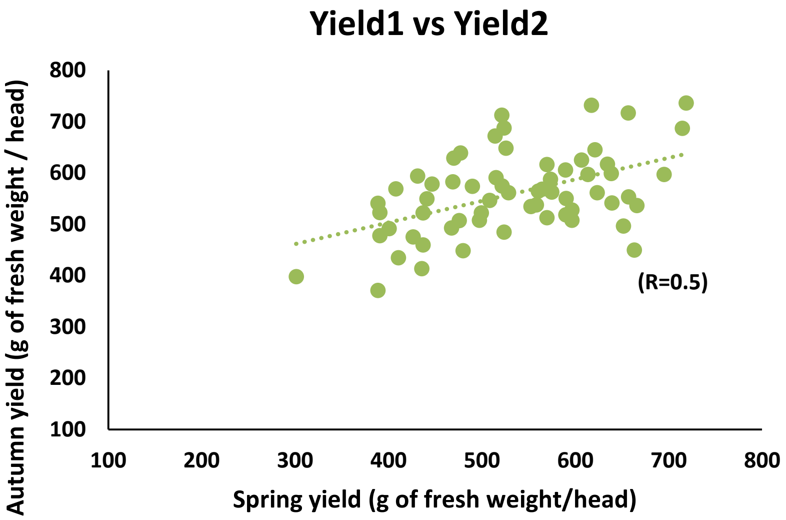

Figure 1. The correlation between Yield1 and Yield2 (P<.001) for n=62 averaged between five heads per location.

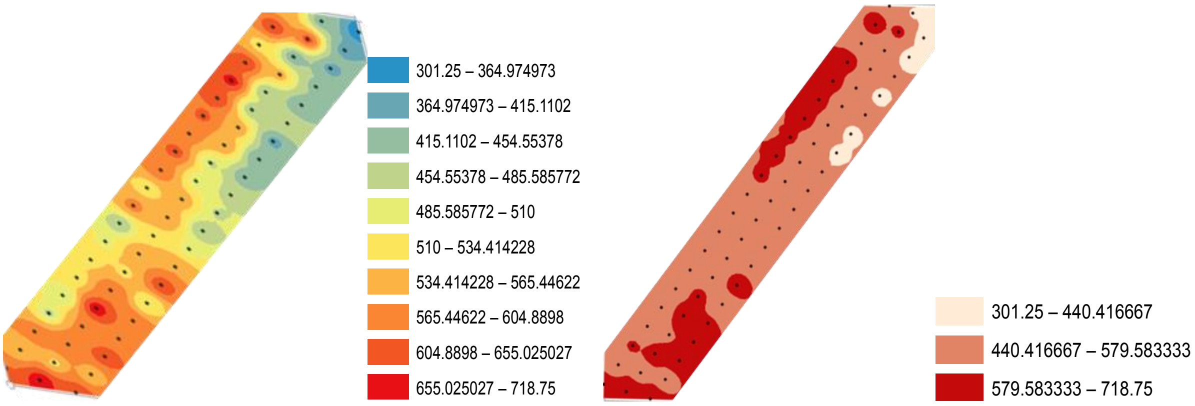

Figure 2. June harvest (Yield1, g/head) mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

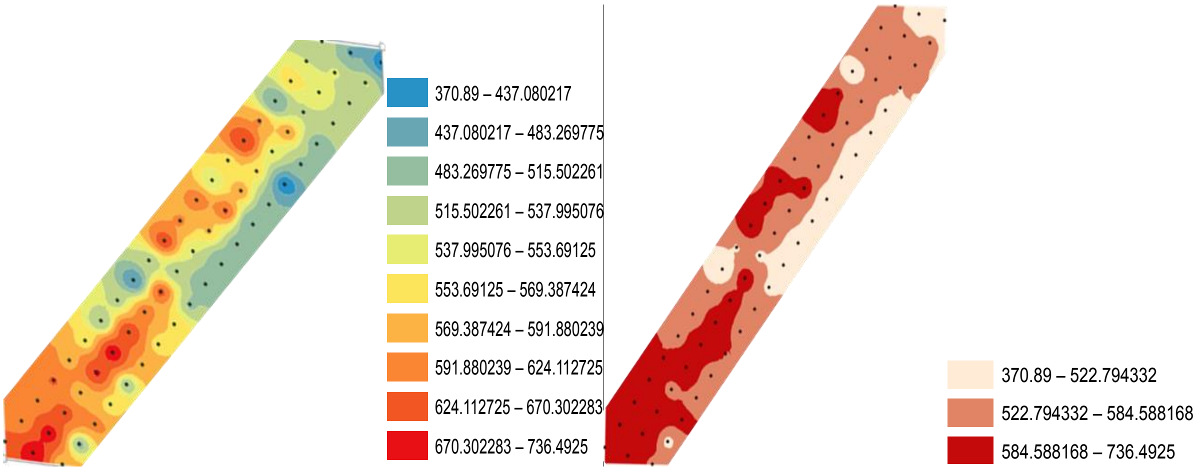

Figure 3. September harvest (Yield2 g/head) mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

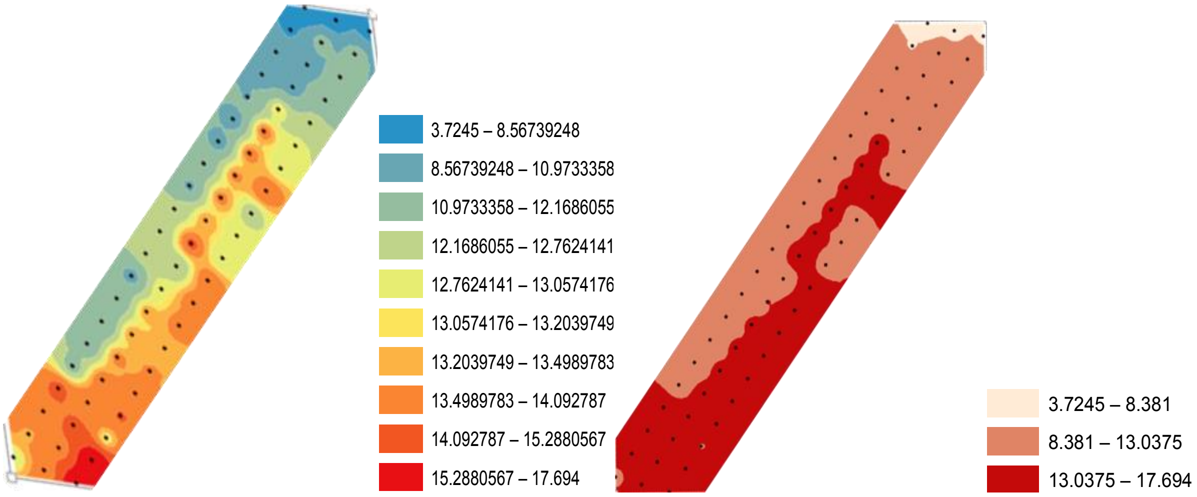

Figure 4. Historic wheat yield t/ha for the sampling locations, estimated using GoogleEarth from historic data of the whole field and mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

Objective2: To investigate the underlying properties of the field soil and the relationships amongst them and between them and soil EC scans and the yield.

Field experiment 03- (Soil); Materials and methods

- Using two different soil augers (0-30cm and 30-60cm) and bulk density cylinder (10 X 11cm), three types of soil samples were taken from each location: a bulk density sample at the depth of 10-20 cm, a soil sample at 0-30 cm and a third sample at 30-60cm.

- *Bulk density* samples were placed in a sealable plastic bag, weighed in the lab and dried to calculate the bulk density as the weight per the volume of the sample (Rowell, 1994).
- *Soil samples from the depths 0-30cm and 30-60cm* were transferred into sealable bags and taken to the lab at HAU, air dried, milled using pestle and mortar and sieved (2.0mm sieve). Subsamples were taken from each of the 63 bags of each depth for analysing for the organic matter and the texture. The remaining were sent for nutrient analysis (total N, P, and K) at NRM Laboratories, Berkshire.
- *Organic matter* was estimated by loss on ignition method after burning the oven dried soil at 500 °C for 6 hours (Schulte and Hopkins, 1996)
- *Texture*: After digesting the soil organic matter using hydrogen peroxide, particle size distribution was determined for the mineral part of the soil via the Laser Diffraction method and using Mastersizer2000 instrument with measurement range between 0.5µ to 3000µ (Eshel *et al*., 2004). A summary of the measured parameters is shown in (Table 1).
- The field P57 was scanned commercially for soil ECa on 11/03/2014, using VerisE3100 scanner. The scanner was running DGPS (Differential Global Positioning System) so accuracy was within 30cm. The field was a wheat stubble. Repeating the scans was not possible at the time of the study, however it is know that soil EC scans are relatively consistent. Grisso *et al*., 2009).
- The raw scanned data (comprising value's coordinates) were processed and plotted on Google Earth to locate the ECa values on the ground. Thereafter the data were mapped ArcMap in GIS using the same method explained in yield mapping.

Table 1. A summary of the measured soil parameters.

Parameters measured	**Samples and methods**
Bulk density	Bulk density cylinder (10 X 11cm) - measuring soil weight per volume.
Soil moisture	TDR field scouts (20cm)
Soil nutrients 0-30cm	Soil auger- lab analysis for N, P, K
Soil nutrients 30-60cm	Soil auger- lab analysis for N, P, K
Soil EC shallow 0-30cm	Obtained from the raw scanning data at 0-30cm
Soil EC deep 30-60cm	Obtained from the raw scanning data at 30-60cm
Soil texture 0-30cm	Soil auger- analysed using laser diffraction method (Mastersizer2000, measurement range 0.5µ to 3000µ)
Soil texture 0-30cm	(Mastersizer2000)
Soil penetration resistant	Three readings were logged per location using Ejkelkamp penetrologger
Organic matter	Soil auger-loss on ignition technique.

Objective2 results:

Soil electric conductivity (EC) for the sampling locations:

T-test showed no significant difference between EC-shallow and EC-deep samples. The two levels of EC have significantly correlated (Figure 5). The two layers of EC maps showed similar pattern for both the shallow and the deep EC (Figures 6 and 7). Soil EC however, did not correlate with the yields or with any other measured parameters.

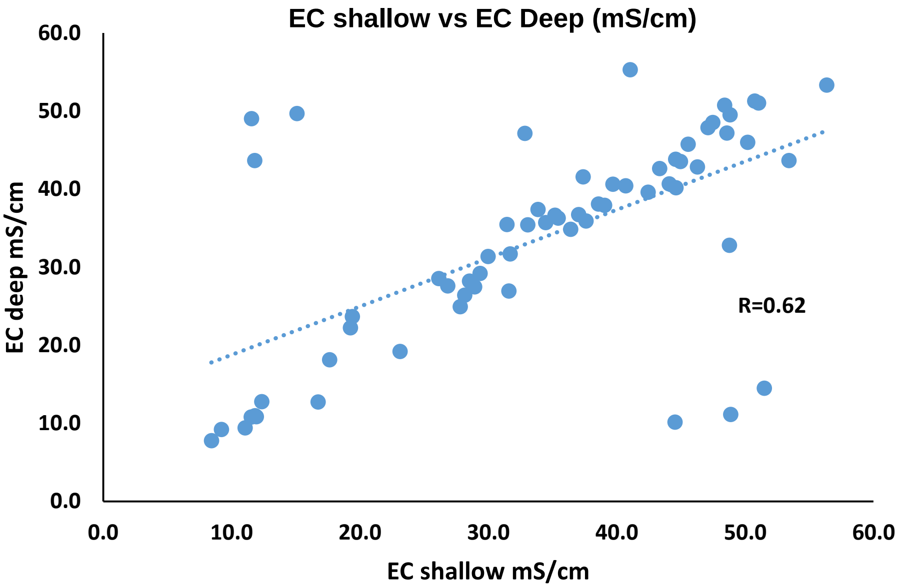

Figure 5. The correlation between the shallow and the deep EC of the soil (P<.001) for n=63 averaged between the 3-4 nearest points per location (georeferenced and estimated using GoogleEarth.

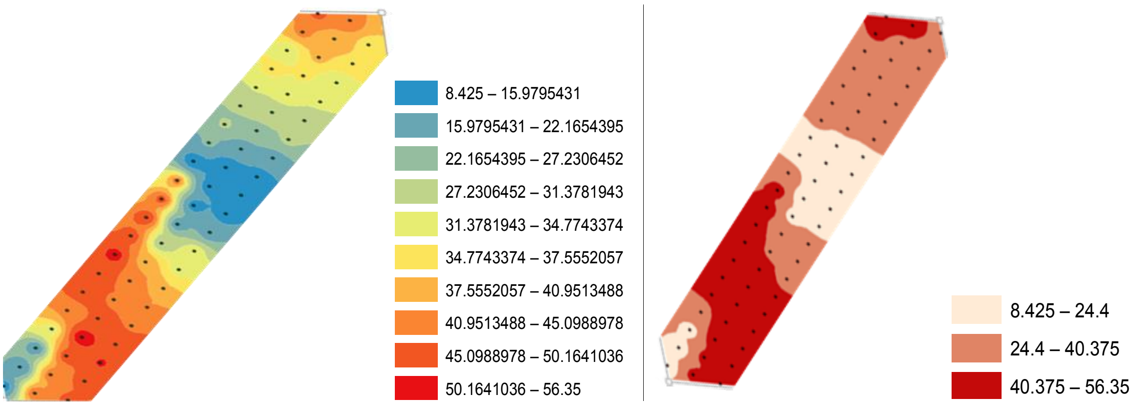

Figure 6. The shallow EC (covering 0-30cm) of the soil mS/cm for n=63 averaged amongst the 3 to 4 nearest points per location, estimated using GoogleEarth from the raw scanning data as georeferenced and measured over the whole field.

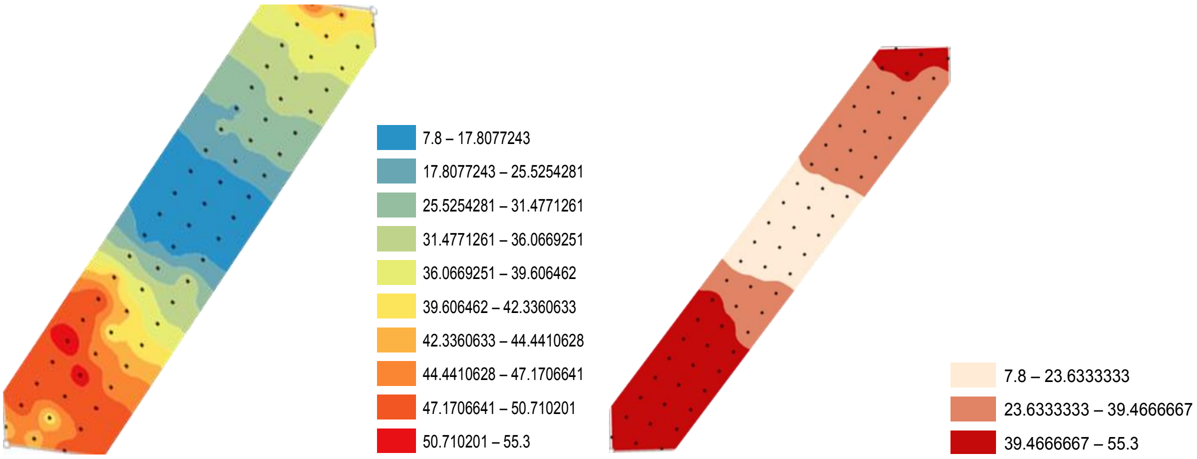

Figure 7. The deep EC of the soil (covering 30-60cm) mS/cm for n=63 averaged amongst the 3 to 4 nearest points per location estimated using GoogleEarth from the raw scanning data as georeferenced and measured over the whole field.

Nutrients

When comparing the nutrient levels between the two depths of the soil, a significant difference was found between the two total nitrogen depths 0-30cm and 30-60cm (Figure 8) as well as between the two levels of total potassium (depths 0-30cm and 30-60cm) (Figure 9). There was no significant difference in total phosphorus at the two depths. A correlation was found between the two levels of N (Figure 10) as well as between the two levels of K, where K level in the second depth was higher than in the first depth (Figure 11). Phosphorus concentrations did not correlate.

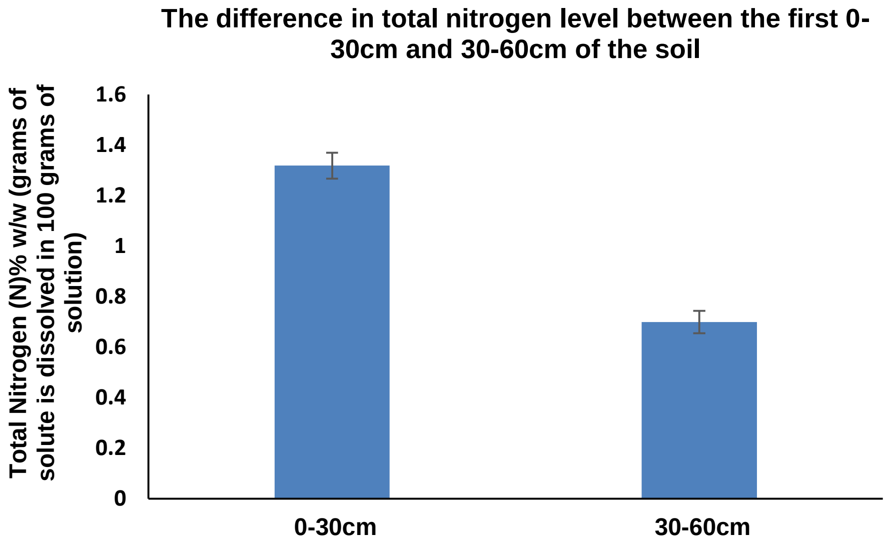

Figure 8. The difference in Nitrogen level between 0-30cm depth and 30-60cm depth of the soil (P<.001) for n=63.

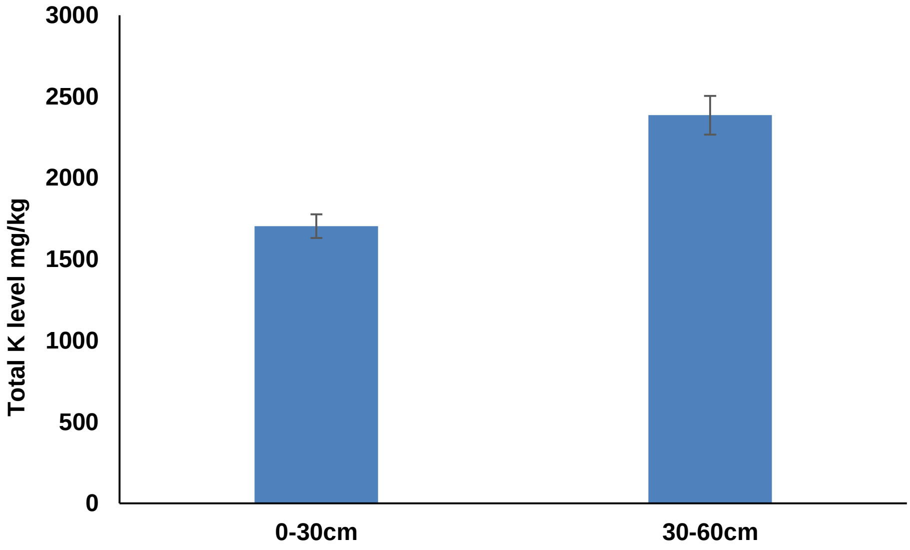

Figure 9. The difference between total K levels at the first and the second depths (P<0.001)

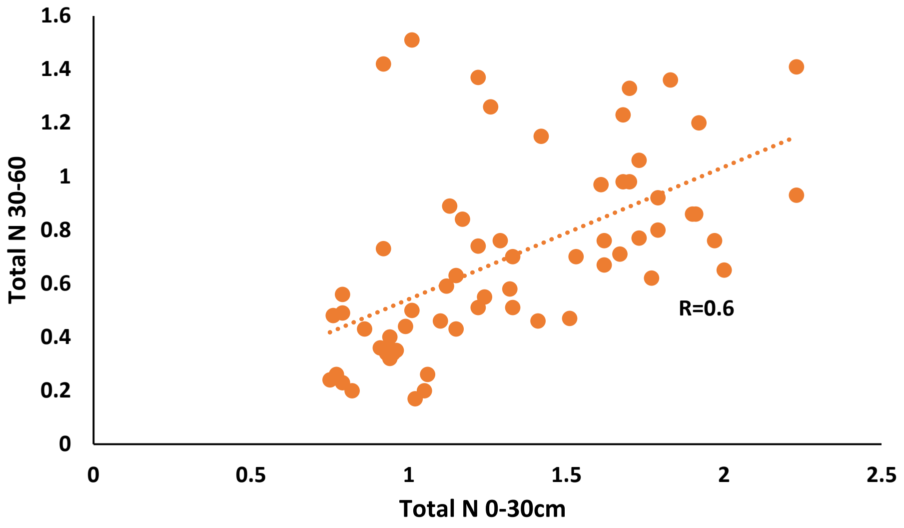

Figure 10. The correlation between total N levels at 0-30cm depth and 30-60cm depth of the soil (P<.001) for n=63.

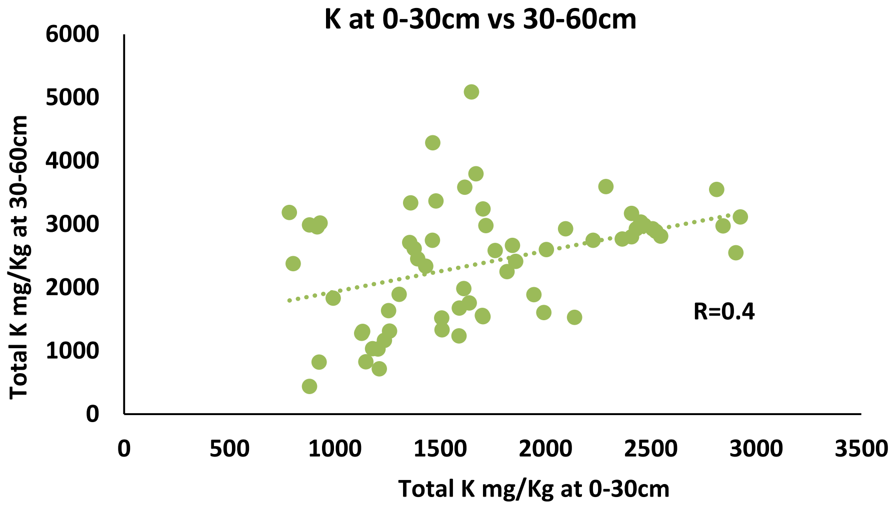

Figure 11. The relationship between total K levels mg/kg at 0-30cm and 30-60cm of the soil showing P<.001 for n=63.

Similarly, the distribution pattern on the produced maps was relatively similar between the two soil depths for N (Figures 12 and 13) and less similar between the two patterns for K (Figures 14 and 15) and was different for P maps (Figures 16 and 17).

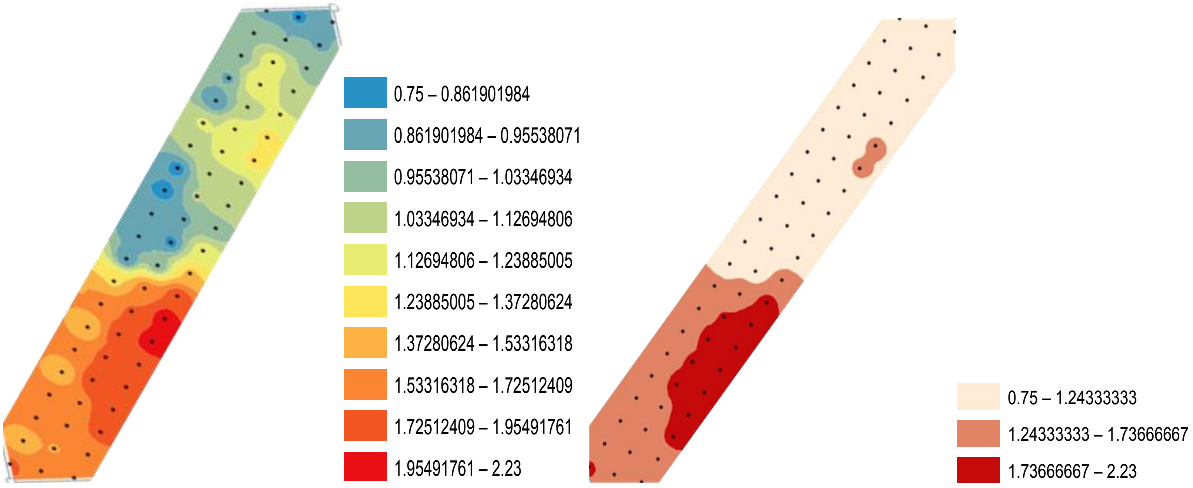

Figure 12. Nitrogen level (N) % w/w (grams of solute is dissolved in 100 grams of solution) at 0-30cm of the soil mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

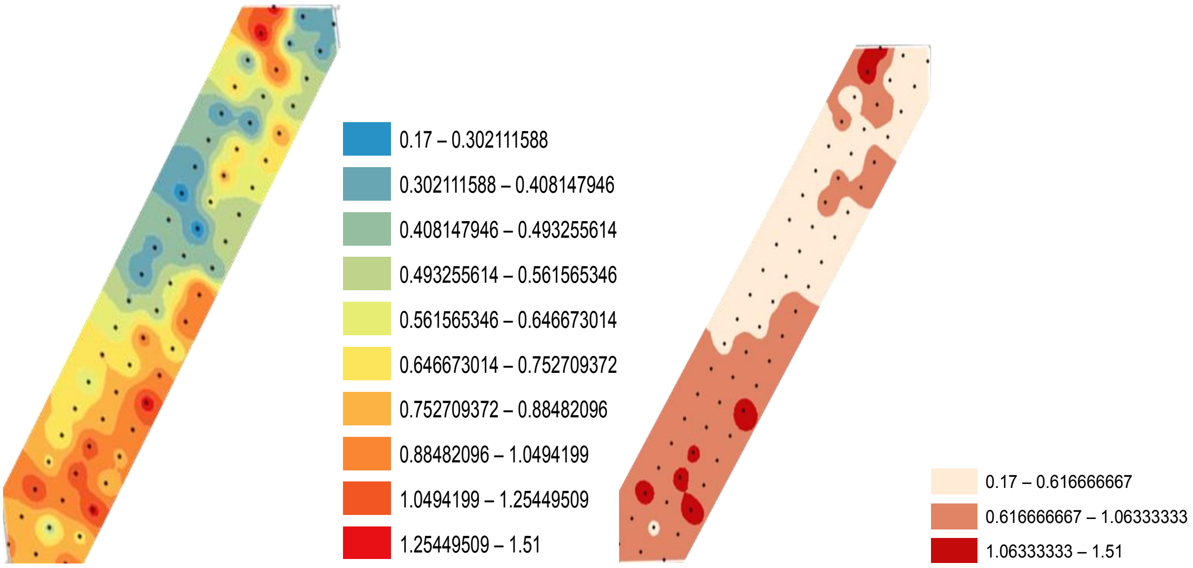

Figure 13. Nitrogen level (N) % w/w (grams of solute is dissolved in 100 grams of solution) at 30-60cm of the soil mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

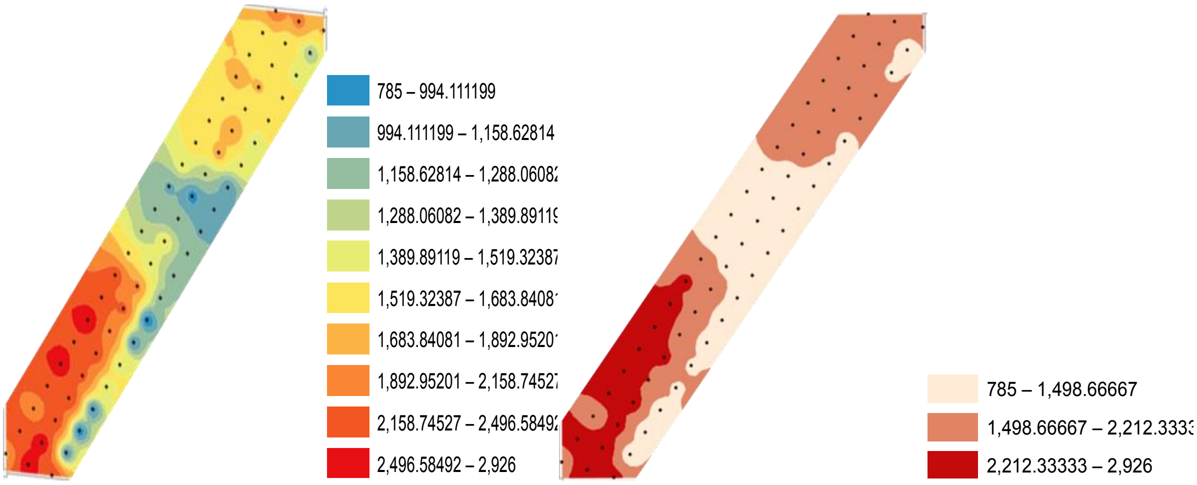

Figure 14. Potassium levels mg/kg at 0-30cm of the soil mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

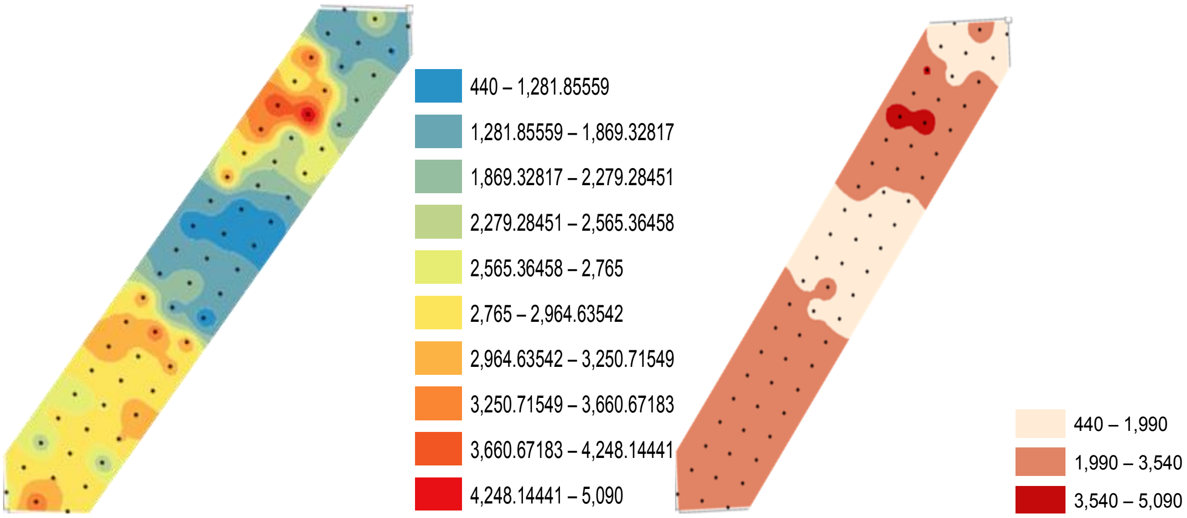

Figure 15. Potassium levels mg/kg at 30-60cm of the soil mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

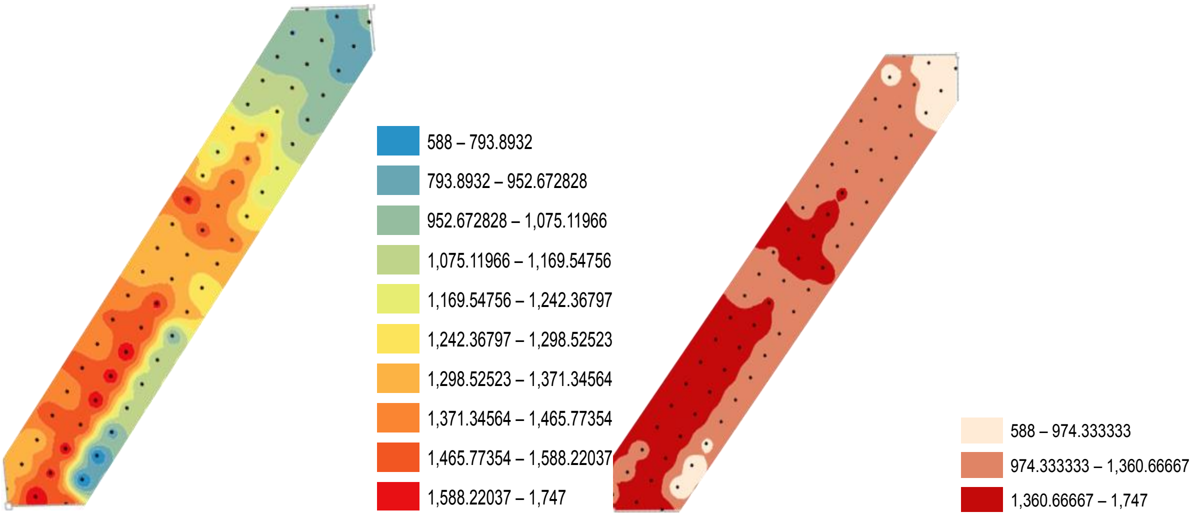

Figure 16. Phosphorus levels (mg/kg) at 0-30cm of the soil mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

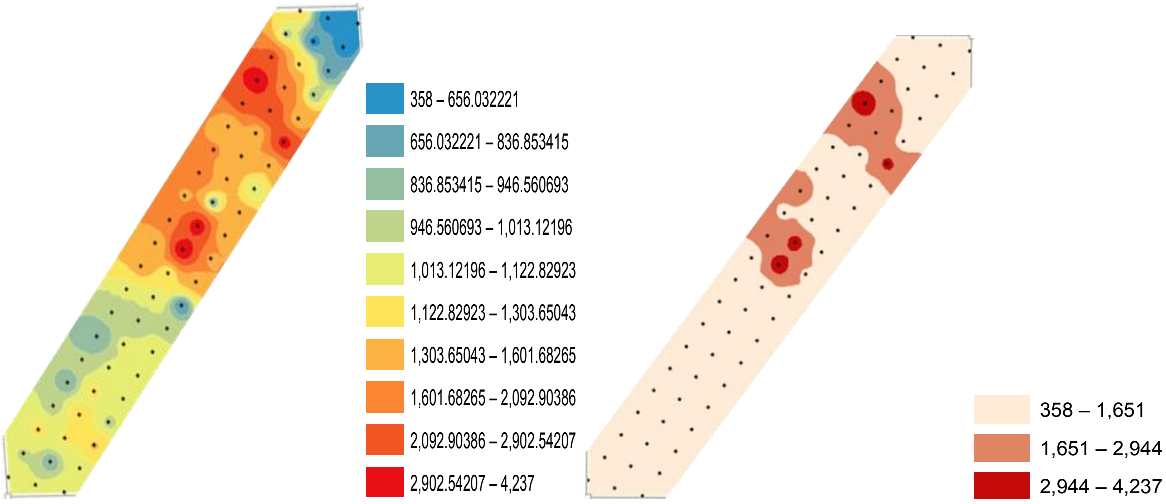

Figure 17. Phosphorus levels mg/kg at 30-60cm of the soil mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

Organic matter

The two samples T-test analysis showed significant difference in organic matter between 0-30cm (35.3%) and 30-60cm (19.5%) depths, where surface OM was significantly higher than subsoil OM (Figure 18). However the two correlated significantly (Figure 19).

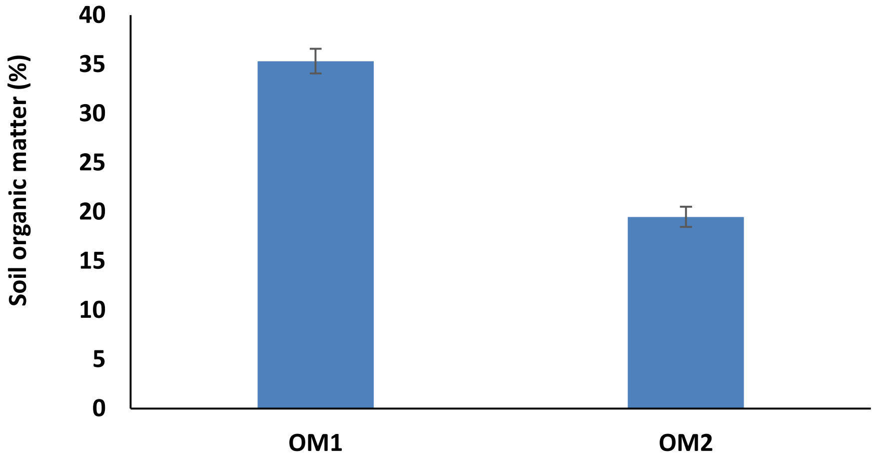

Figure 18. The difference in organic matter levels between the depths 0-30cm and 30-60cm of the soil (P<.001).

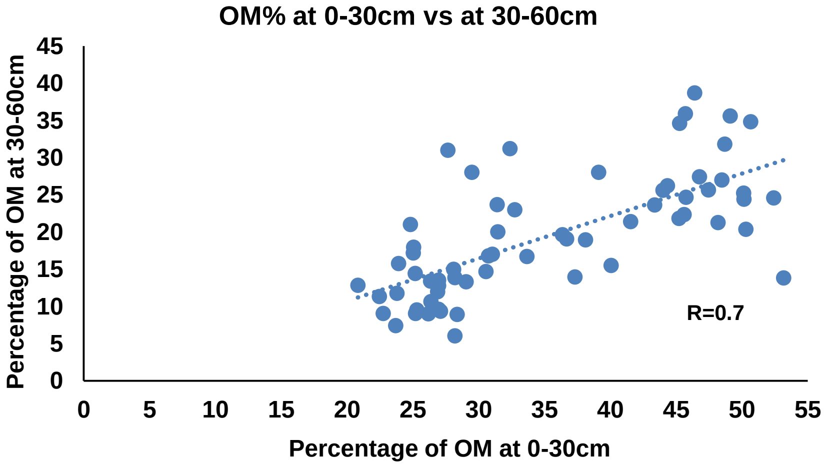

Figure 19. The correlation between organic matter at 0-30cm and OM at 30-60cm of the soil for n=63.

Mapping the data for each depth showed similar distribution pattern across the two layers (Figure 20) and (Figure 21).

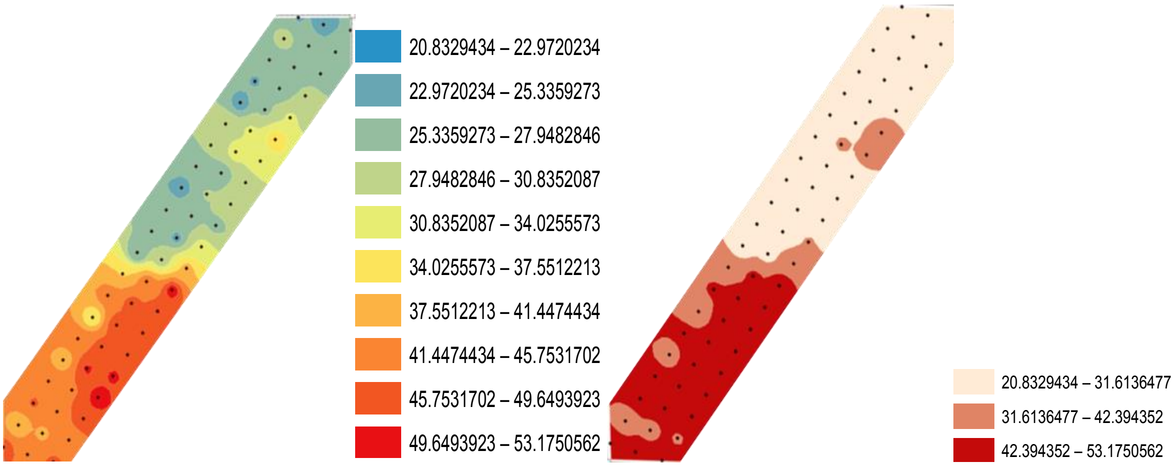

Figure 20. Organic matter map at 0-30cm, mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

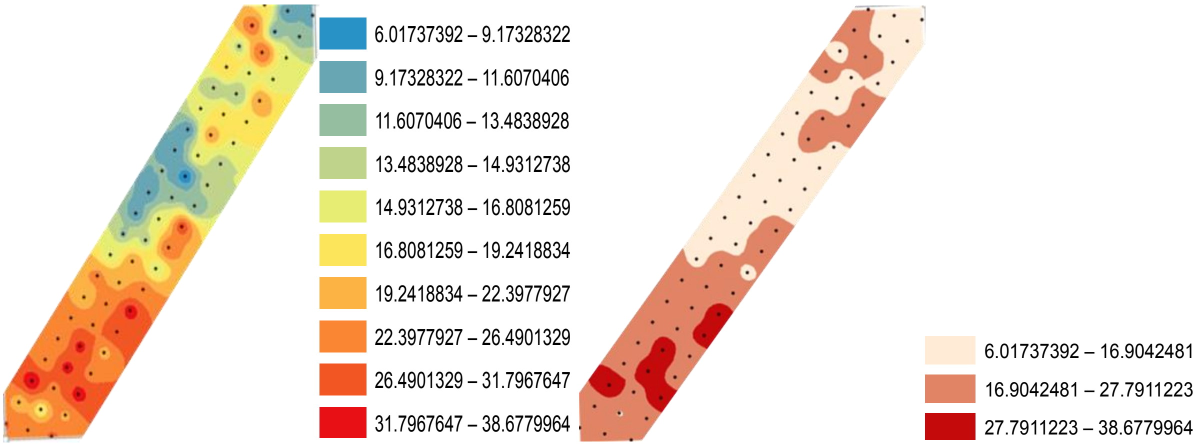

Figure 21. Organic matter map at 30-60cm, mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

Soil physical characters (*Texture, Moisture, Bulk density and Penetration resistance*)

The overall results of the field soil particle size distribution analysis using the Laser Diffraction method are shown in (Table 2) and (Figure 22 and 23). Clay and silt maps distributed similarly in the field, however, the sand had an opposite trend to the silt and clay (Figures 24, 25 and 26). The soil is classified as organic soil (Natural England, 2008). Soil resistivity was measured to investigate the variability in soil looseness or compaction using digital penetrometer where no significant difference was found across the field. The soil resistivity on the map (Figure30) was slightly higher towards both ends of the field however the very low values of bulk density do not suggest that this could be explained by compaction.

Table 2. Particle size distribution for the mineral part of the soil averaged between samples for n=63. Each value (n_1…..n_{63}) was averaged between the detected results of 0.58-3.698µ for clay, 4.034-59.835µ for silt and 65.273-2750.045µ for sand (equivalent of the standard particle sizes in mm according to the USDA system (United States Department of Agriculture).

Clay%	Silt%	Sand%
8	48	44

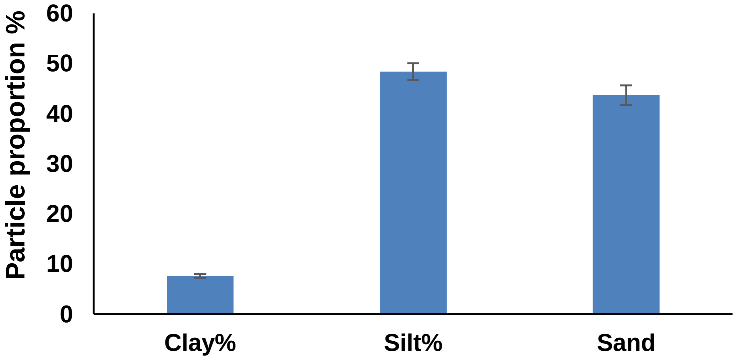

Figure 22. Particle size distribution chart that demonstrates as a percentage of the mineral soil fraction.

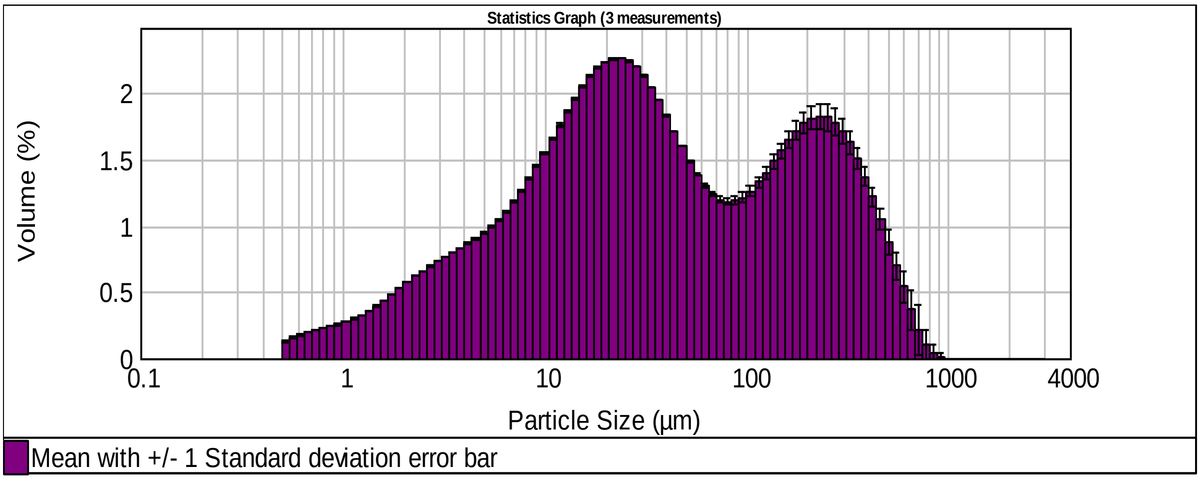

Figure 23. A sample picture of Laser diffraction analysis of soil particle distribution (soil texture for location number one/field sampling point number1).

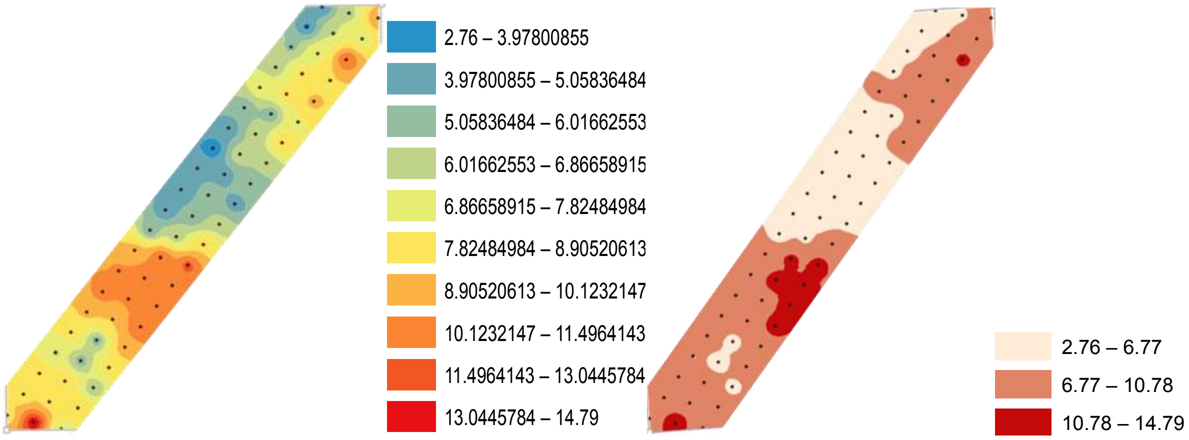

Figure 24. Clay map at 0-30cm, mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

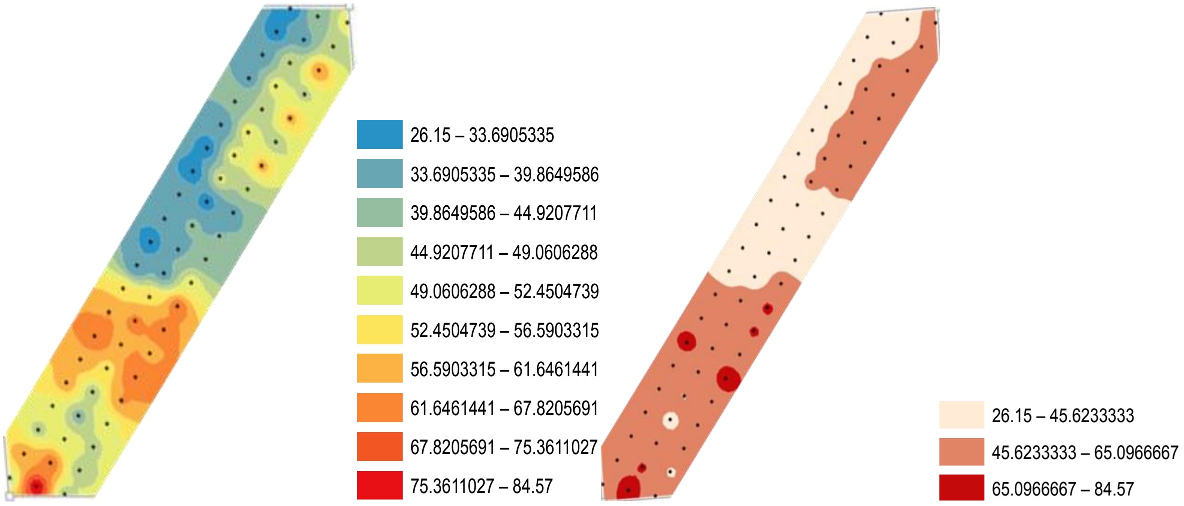

Figure 25. Silt map at 0-30cm, mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

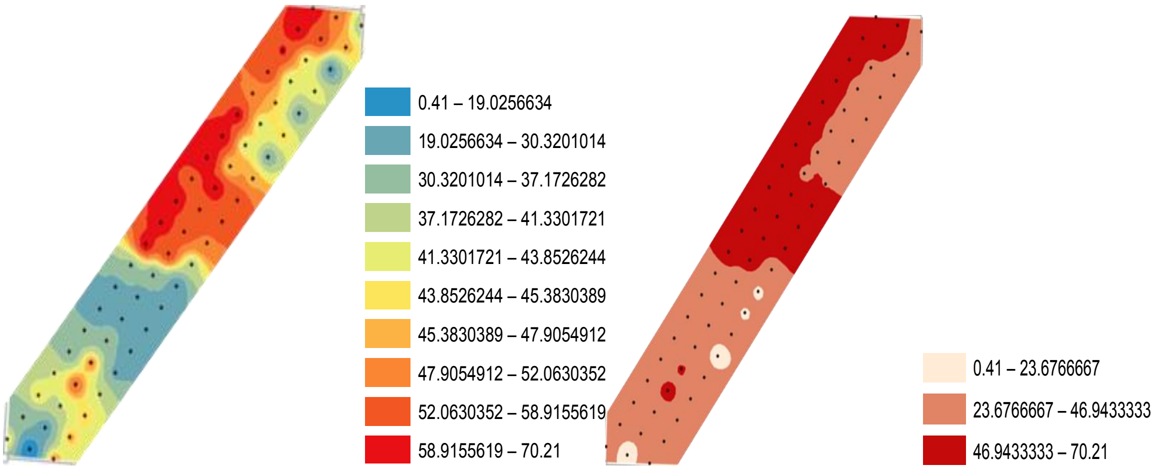

Figure 26. Sand map at 0-30cm, mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

Moisture map (Figure27) conformed to the on-site observation and differed in pattern to all the other texture components (OM, clay, silt and sand).

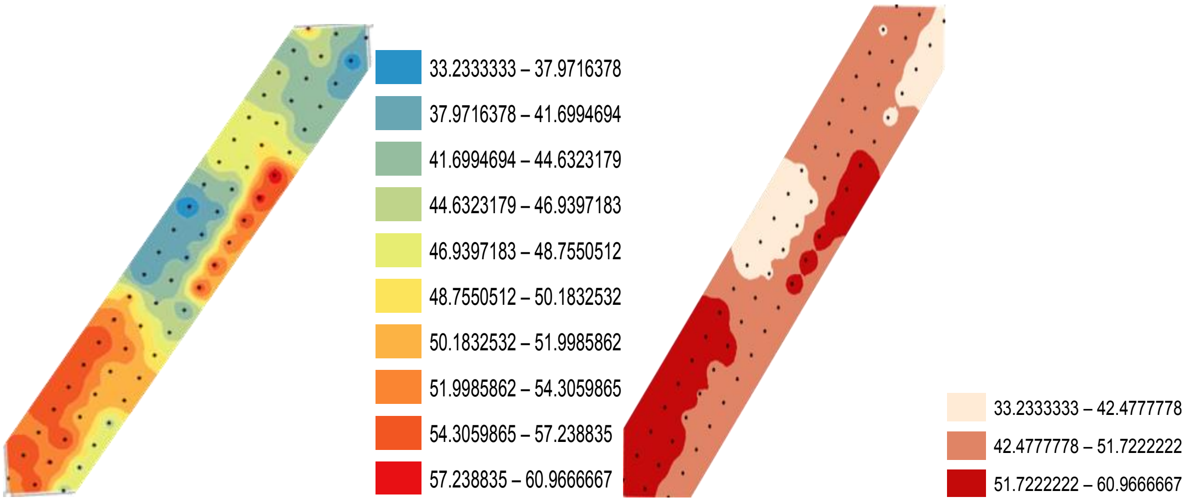

Figure 27. Soil moisture map at 0-30cm, mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

Bulk density over the field mostly split into low and high zones, which was clearer on the three-category map (figure28) in nearly an opposite trend to the organic matter (see figures 20 and 21). Bulk density also correlated negatively with yield (as averaged between the two yields) (Figure 29).

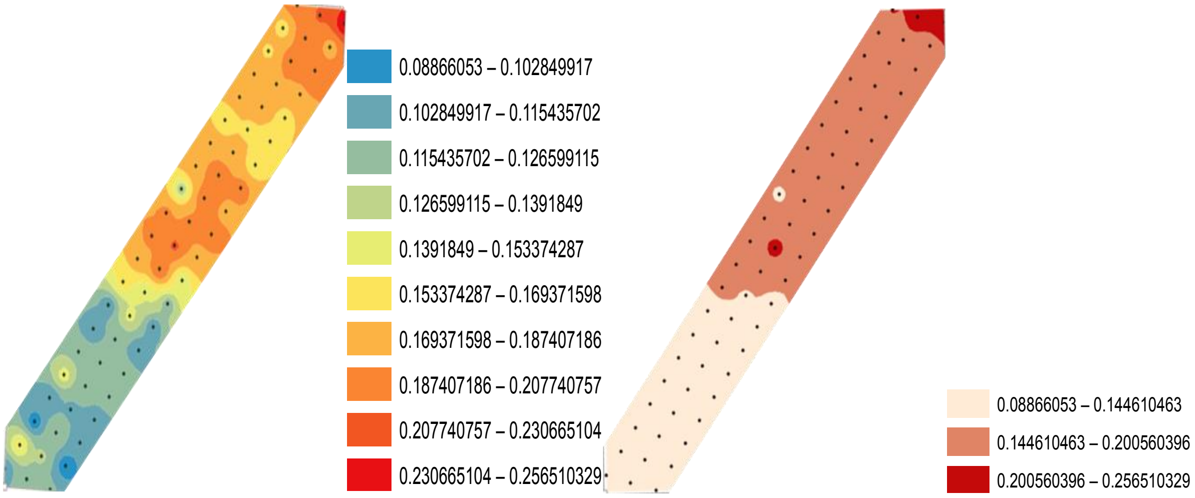

Figure 28. Soil Bulk density map at 10-20cm, mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

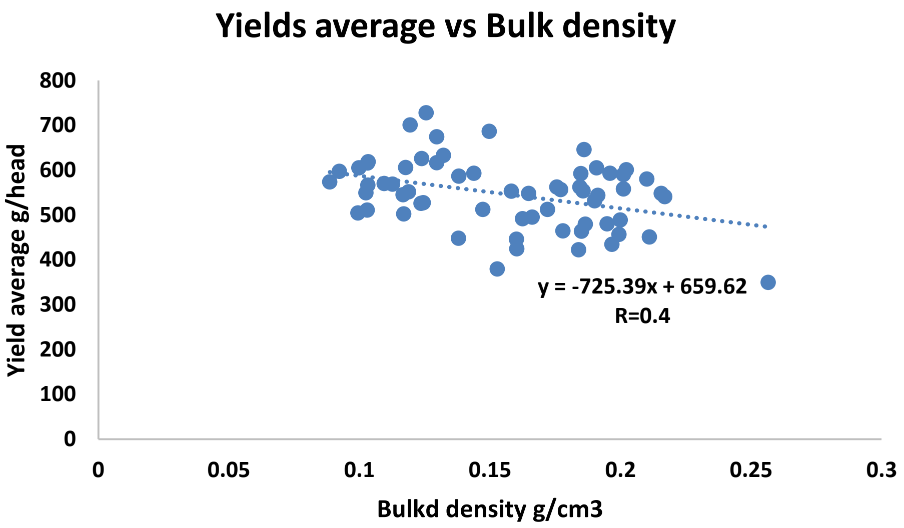

Figure 29. The correlation between bulk density g/$cm^3$and yield for n=63, (P<.001).

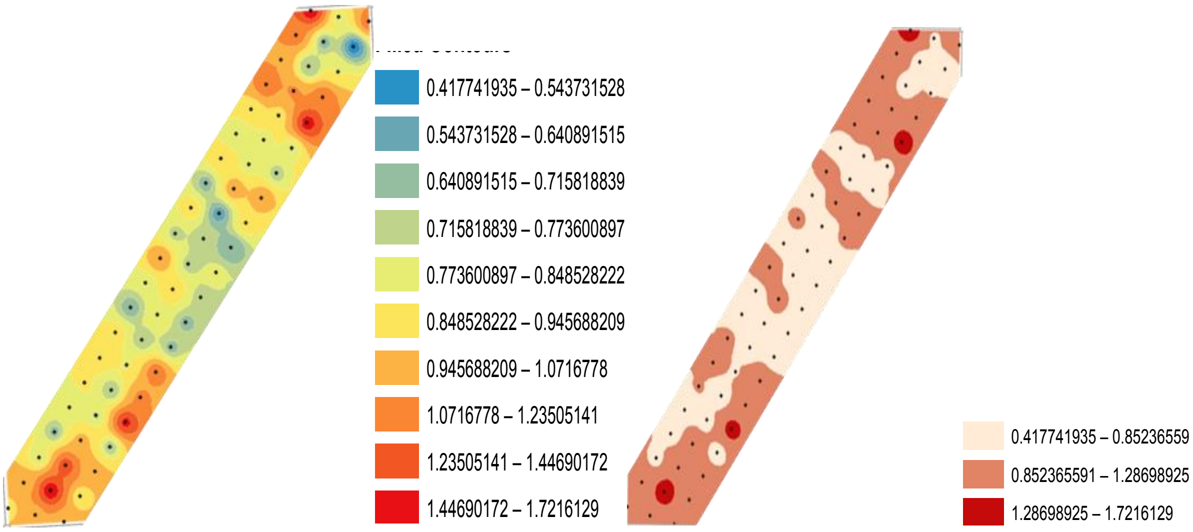

Figure 30. Penetration resistance map for the top 20cm, mapped using ArcGIS, classified into 10 classes (left) and 3 classes (right).

Yield1 was analysed against all parameters using Stepwise (forward) Analysis Of Variance (Yield1 samples were collected simultaneously with soil samples). The analysis showed that bulk density, silt, K2, P1, TDR and N2 are the key factors that influence yield variation as per the resulted model:

Constant + Bulk density + silt + K2 + P1 + TDR + N2

Multiple linear regression analysis (MLRA) between the yield and the factors comprised within the model showed that these factors together were accounted for 42.8% of the variance. Repeating the same procedures using Backward Stepwise ANOVA gave the same model but replaced silt with sand. In other words, both analysis showed the same important effect of soil texture on lettuce growth either through silt or sand proportion.

Objective3: To identify field zones using the produced maps.

Distinctive field zones of high and low yield were identified on the yield maps. These zones could not be predicted from EC or previous wheat yield maps. The variation in EC was associated with a general variations in soil properties across the field but did not describe amplitude or positional effects at a meaningful crop level. Individual soil properties mostly differed between the northern and southern portions of the experimental area possibly due to the change in organic matter between these two parts of the field.

Objective3- Materials and methods

This objective was studied through reviewing the various soil maps displayed in objective2 results. Additionally, Variograms were formed to study the autocorrelation between sampling points and how each pair of sampling points will vary depending on the distance between the two points. In other words, this was done to see whether the primary EC map can be used to predict variable field zones in the field and how the sampling process of these zones could work.

Objective3- Results

The Formed Variograms showed that data becomes more variable when the sampling points are more than ~100m apart as shown in Figure 31. Variograms were formed for a few other traits and they also showed that the autocorrelation declines when the distance between each pair of sampling points becomes greater than ~125-150cm.

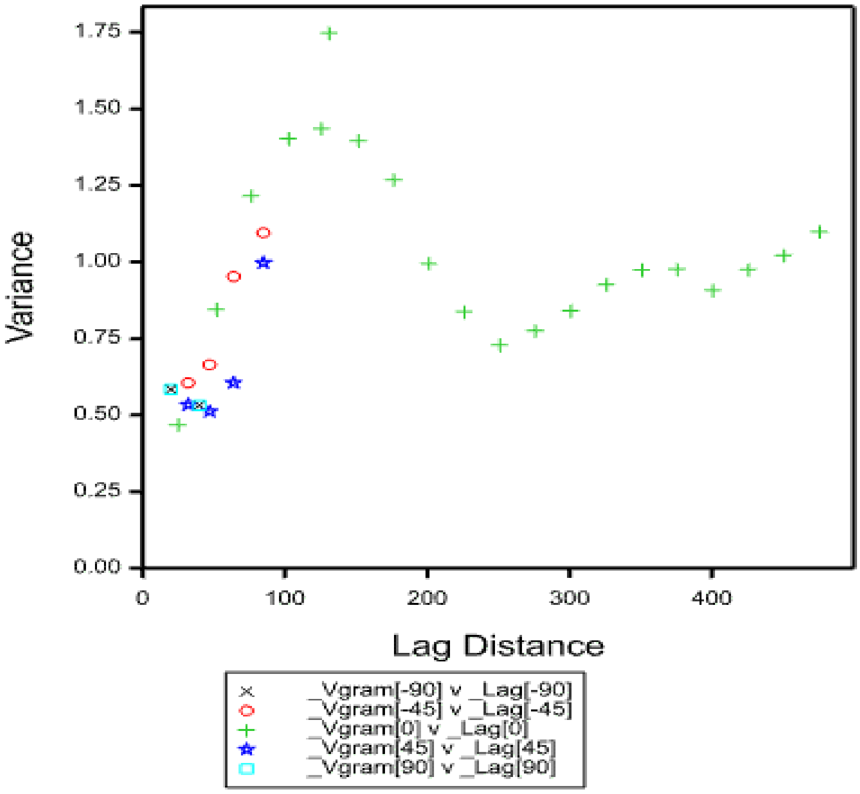

Figure 31. Variograms for Clay% in the soil, showing the decline in autocorrelation between sampling points after ~125cm distance between each pairs of point

Objective 4: To investigate the effect of sand proportion in soil texture on early stage of growth and biomass production.

Objective 4- Materials and methods

It is well known that texture plays a significant role in crop growth and development. It was anticipated from the first year results that the texture was the key influence on lettuce yield through its interactions with soil moisture and nutrients holding capacities (Dexter, 2004), which in turn suggests that texture has also an effect on the mobility and the availability of the plant nutrients.

A glasshouse experiment investigated the effect of sand proportion on plant growth and how this effect could be altered under two different soil moistures. The experiment was carried out on field soil that was brought from Redmere P36 field, from the location of the highest yield in experiment1 (Field01- 2014). The soil was collected from Zone C which had the highest clay content, least sand content, highest EC and highest yield.

The soil was shredded using soil shredder to remove big large aggregates and mixed by volume, using cement mixer, several times to improve homogeneity, then the texture treatments were made by adding sand (horticultural sand/J Arthur Bowers, sharp sand, 3 mm down nominal) (Table3). All the five treatments were mixed in a cement mixer again before potting up.

Texture treatments are shown in Table 3

Table 3: Texture treatments including sand and field soil proportion.

Treatment	Soil%	Sand%	Number of soil buckets	Number of sand buckets
A	100	0	10	0
B	90	10	9	1
C	80	20	8	2
D	70	30	7	3
E	60	40	6	4

Texture of the two extreme treatments was analysed after mixing to check the success and the homogeneity

Irrigation treatments

M1: Normal irrigation by re-watering up to field capacity (FC).

M2: Over irrigation by re-watering up to field capacity + 20% of FC

1) Establishing field capacity for all the five textures

Five pots were filled with soil A. The pots were put on the top of a reversed saucer with fine lines on the top to imitate free drainage. The pots were irrigated slowly to saturation and Weighed (Sw), covered and left to drain.

The pots were weighed regularly and the weight was recorded until the change or the weight loss became negligible. After the last weight was recorded (day6), the soil was dried in the oven at 65°C for 48 hours to calculate the soil dry weight.

The recorded weights were plotted to identify when the soil in the pots had reached field capacity (Figure32)

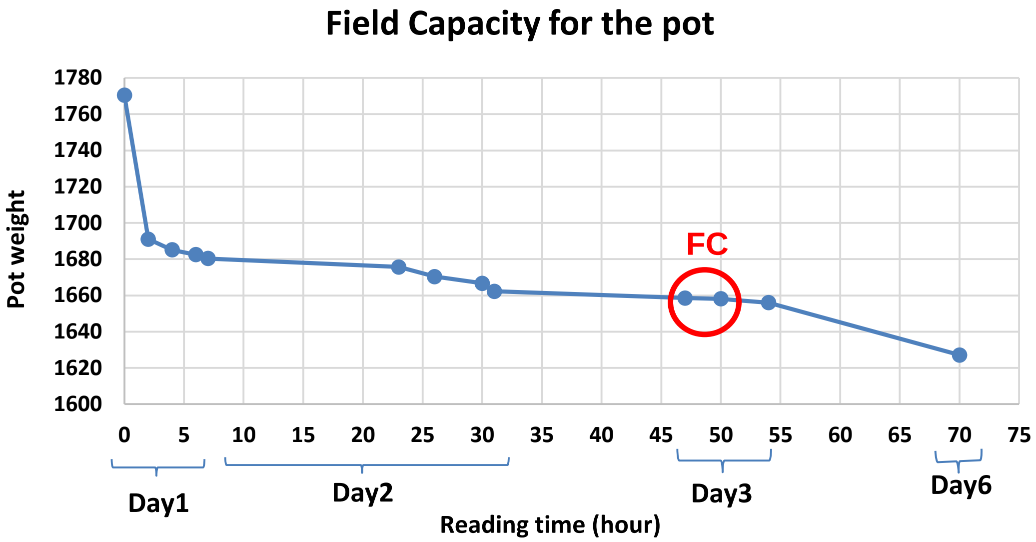

Figure 32. Field capacity for the control treatment (A/100%field soil) expressed as pot weight loss overtime.

After the pot weight at field capacity was determined, soil wet weight at field capacity was calculated by subtracting the pot weight and the averaged result was **861** g of water. Using the following equation:

$$MC = \frac{\textbf{Soil wet weight at FC} - \textbf{Soil dry weight}}{\textbf{Soil wet weight at FC}} * 100$$

Soil moisture content at field capacity (Pot capacity) was (as an average) 55% of the weight. Using the same method, pot capacity was established for the 4 remaining texture treatments (Figure33)

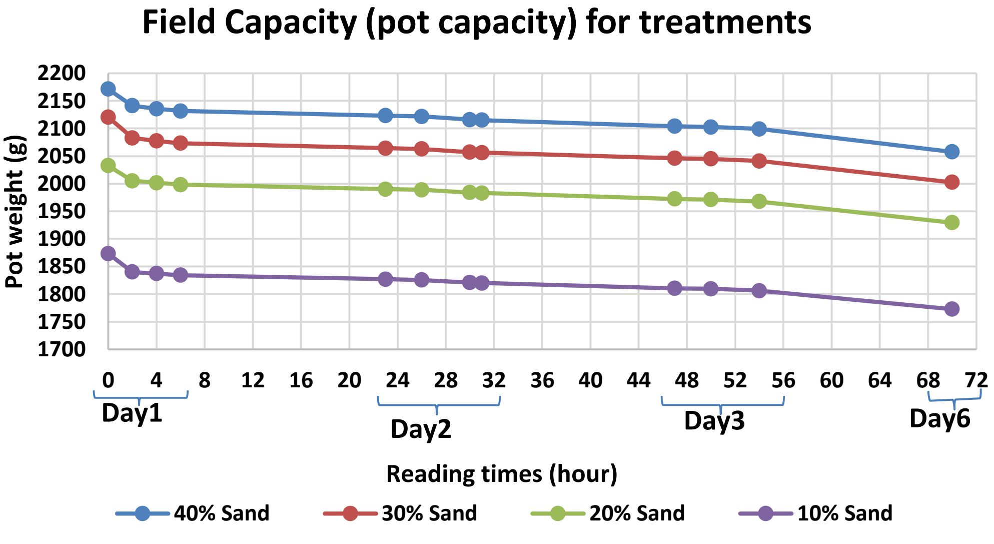

Figure 33. Field capacity for the four texture treatments B, C, D, E that were diluted with 10, 20, 30 and 40% of sand successively.

1) *Potting and experimental design*

- 200 pots were filled with the texture treatment soils to the same level (20 pots/treatment), labelled and randomised using Latin-square design in GenStat.
- Transplants, that were provided by commercial propagators, were planted inside the glasshouse 30/07/2015 one transplant per pot after irrigating the soil till saturation to simulate the planting process in the field.
- Extra transplants were also grown the same way to estimate the accumulation in the biomass production.
- Irrigation was carried out every 3 days where the calculations were repeated at every irrigation event. Water was added using measuring cylinder and syringe.
- The extra 20% of field capacity was added after a period of six hours from the application of normal irrigation, to allow the soil (in irrigation treatment2) to absorb the first supply of water and avoid losing the extra added water immediately by direct drainage from the bottom of the pots.
- Plants were harvested 14 days after planting by cutting plants off at the soil surface and then weighed.

2) Estimating the irrigation requirements

Normal irrigation treatment:

Estimating normal irrigation requirements was based on returning soil moisture back to field capacity, by calculating the loss in weight due to plant uptake over time. Therefore, the following weights were accounted for:

- The average pot weight at field capacity 1625.4 g
- The current weight of the pot at the time of irrigation as averaged between six pots of treatment A)
- The starting weight of the transplants (biomass +peat block)
- Biomass and peat block weights were also recorded individually at the beginning to be used in estimating the accumulation of plant growth at every irrigation.
- The current biomass; 3 young plants were cut off the pot-soil surface and weighed to estimate plant growth between irrigations

Irrigation need= Total pot weight at FC – (the current pot weight- (the accumulation in plant growth + the starting weight of transplants))

The accumulation in plant growth is the difference in biomass weight between the current and the starting weight.

Average starting weight of transplant (total: plant + peat block) = 46.92 g

Average starting weight of the transplant biomass = 0.75 g

Average pot weight at FC (excluding saucers) = 1625.4 g

Over-irrigation treatment:

Over-watering was intended to simulate rainfall after irrigation or similar conditions as in wet zone of the field that was over-irrigated due to its lower requirements than the rest of the field that was irrigated conventionally. In this experiment, over-irrigation was done by watering the pots up to FC + 20% of FC.

3) Statistical analysis

Data were analysed by carrying out Dose Response Analysis in Genstat (VSN International).

Objective 4 results

Analysis showed that 16% of the natural variance was accounted for by the treatment (the added sand rate). 85% of the variance accounted for by sand fitted a straight line (13% of the total variance) (Figure 34). Irrigation treatment had no effect on plant fresh weight.

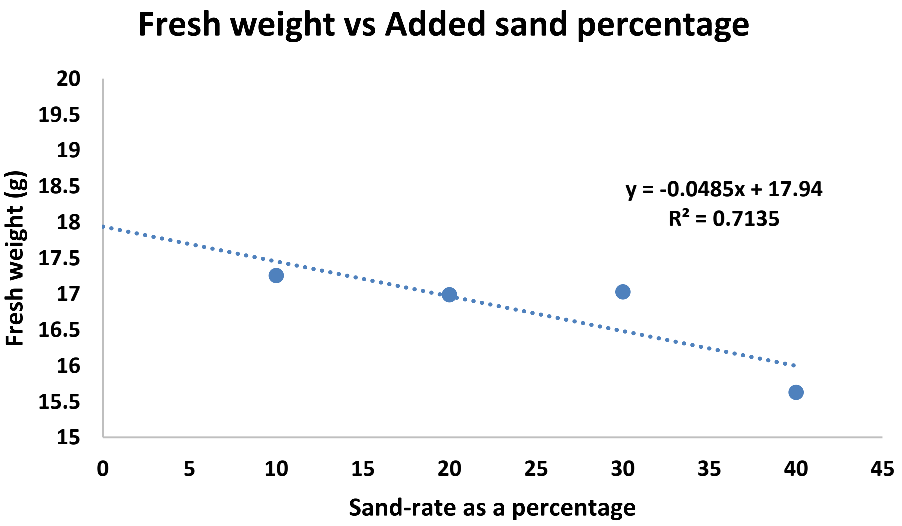

Figure 34: The effect of diluting field soil collected from a high-yield zone of the field with increasing amount of sand on lettuce growth production at early stages of planting.

Objective 5: To identify field zones using the EC scans and other produced maps.

Testing this objective was done through all the previous field work mentioned above.

- *EC zones and predicting yield and soil properties*: There has been no significant difference between EC shallow (0-30cm) and EC deep (30-60cm) (Figures 6 and 7). Soil EC did not correlate with yield1, yield2 or any of the measured soil properties.

- *Yield zones*: Comparing the zones on the two different maps, high yielding zones and low yielding zones were consistent in two different seasons in both the10 and the 3 categories classifications.

- *Zones of soil properties*:
  - There was a general trend of most of the measured soil properties that was found on the maps between the two ends of the field.
  - One end of the field seemed to have higher level of most measured soil properties than the other end of the field.
  - Bulk density and sand proportion showed an opposite trend (pattern) in comparison with the rest of the factors.

Objective 6:

a) To investigate the extent of variation resulting from transplants placements and

b) The variability of plants coming from the commercial propagators

Objective 6a-GH02- Introduction:

Studies showed that rapid establishment of transplants affects the size of Iceberg marketable and total fresh weight acquired at harvest (Wurr *et al*., 1992). Rapid establishment of the transplants in the field could well be affected by planting depth and positioning by the planters (Figure 35) as well as the growing conditions.

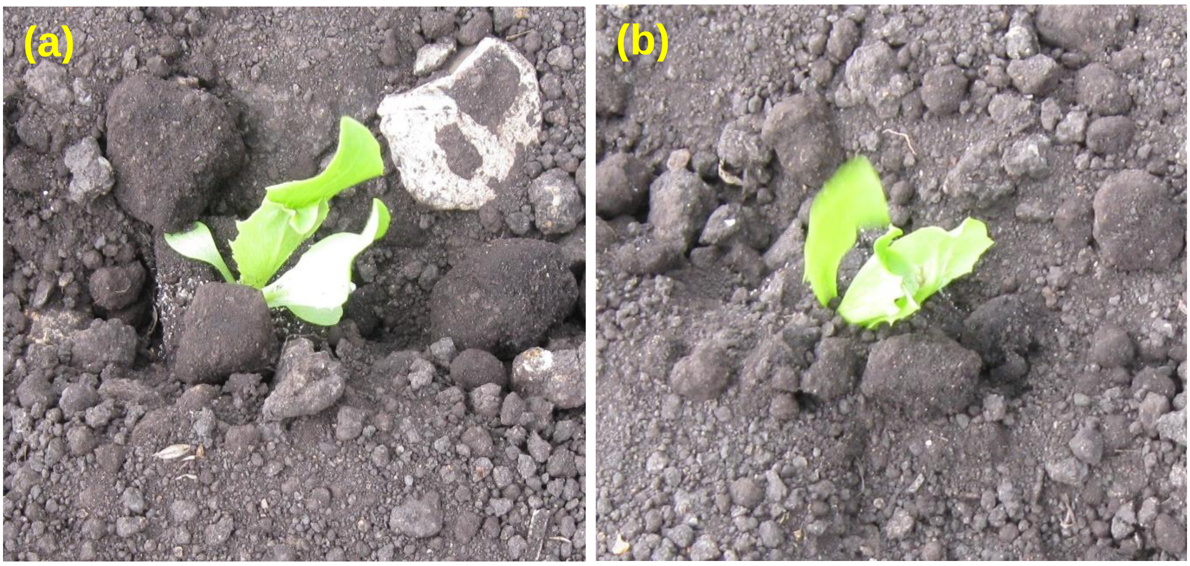

Figure 35. shows a transplant with lack of contact with the soil from one side and the stem is covered with a stone (a) and a transplant over-covered with soil (b).

Objective 6a-GH02- Materials and methods:

Forty four pots size (18x10x11cm) were field with field soil (Zone C) to the same level. Transplants of Iceberg lettuce were selected for this experiment of similar size and shapes from the same tray and they were planted in 4 different positions each to represent a placement treatment (11 per treatment) (normal position or control, under soil surface, above soil surface and tilted). Each position is described in Table 4 and shown in Figures 36 and 37. The pots were laid out in a Latin Square experimental design. The glasshouse temperature over the experiment time was (as an average) 16.8 °C at night and 23.6 °C in the day with a relative humidity was, also as an average, 74.1 % at night and 54.1 % in the day.

Table 4: The different transplants positions/treatments

Treatment	**Description**
Normal middle or soil surface **(M)**	Soil surface fell in the middle of the peat block of the transplant.
Under soil surface **(U)**	green leaves are half-covered with soil
Above soil surface **(A)**	Transplants were placed above soil surface.
Tilted in the soil **(T)**	Quarter of the peat-block is covered by soil

Irrigation was done through capillary mat and plants were harvested 14 days after planting and weighed

Figure 36. Four pots representing the three transplants positioning treatments

Figure 37. Transplants of different placement positions 14 days after planting.

All the plants were harvested on day 14 after planting using a sharp knife and by cutting the green part of the plants off at the soil surface. The plants thereafter were weighed in grams using a digital scale with 2 decimal places and the fresh weight was recorded.

Objective 6a results:

The difference in weight between the 4 treatments was not significant. Although the transplants that were planted under the surface of soil had the lowest mean fresh weight.

Table 5: The means of the different transplants mean (P= 0.338)

Treatment	**Under**	**Above**	**Middle**	**Tilted**
Mean g/plant	10.79	11.09	11.14	12.3
SE	0.0436	0.0343	0.0422	0.0340

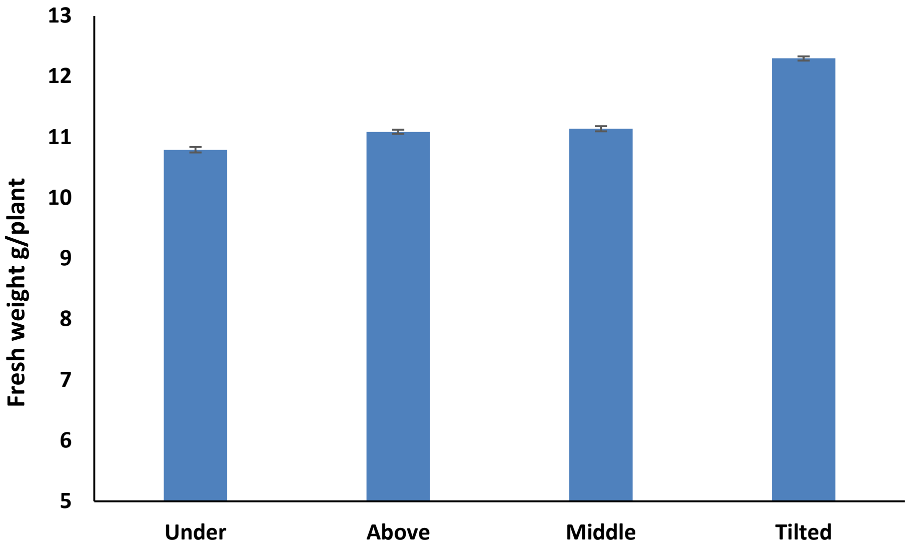

Figure 38. The difference in transplants fresh weight between different positioning treatments for n=11 and P=0.338.

Objective 6b-GH03- A pilot study

What if the variation in size is already determined during propagation?

Field studies of the first year concluded that there is a certain amount of the variation that can be detected at the early stages of growth that continue to exist until maturity and harvest stage. This conclusion conformed to literature, where (Kerbiriou *et al*., 2013) Concluded that smaller size transplants do not catch up with bigger ones at harvest, in other words they resulted in smaller heads. In addition to this, the uniformity of the transplants coming from the commercial propagators has been a question for both science and industry.

Therefore, a small experiment was conducted on 7 trays of transplants from 2 different propagators to examine the level of variation within the trays (Figure 39).

Objective 6b-GH03- Materials and methods:

All transplants of each tray were harvested (cut) off at the soil surface and weighed individually for each plant of each tray.

Data were analysed by calculating the tray mean, Standard deviation and the coefficient of variation (CV %) using the equation:

$$CV\% = \frac{\text{Standard deviation}}{Mean} * 100$$

Figure 39. Propagated transplants ready to be transferred to the field.

Objective 6b-GH03- Results

The transplants' trays showed high CV% values which are displayed in Table 6.

Table 6: Descriptive statistics results for 6 trays of transplants that came from two different propagators.

Tray number	Mean of fresh weight g/plant	Standard deviation	CV%	Tray source
1	2.53	0.83	32.6	Source1
2	0.84	0.14	16.3	Source1
3	0.77	0.13	16.9	Source1
4	2.28	0.55	24.1	Source2
5	2.47	0.66	26.7	Source2
6	2.20	0.55	25.2	Source2

Discussion

Field work

The yield patterns were consistent for two successive lettuce crops, where the high yielding zones remained high yielding and the low yielding zones remained low yielding. This implied that there are some underlying soil properties influencing yield distribution regardless of moisture and weather conditions. This eliminates the seasonal variation in lettuce yield as a key investigation of this project. The results of 2014 showed strong correlation between the total fresh weight and the trimmed head weights, so results of total fresh weight could possibly be used as an indication of the marketable head weights.

It does not appear to be possible to locate high or low lettuce-yield areas using a historic wheat yield map in these experiments. The biological differences between the two crops probably did not support this comparison; Wheat is a long season and non-irrigated crop and Lettuce is a short season, irrigated crop with intensive inputs. Costigan and McBurney (1983) clarified this very well when they highlighted the difference between crops in terms of growth patterns before harvest and the stages at which each crop achieves its high dry matter content; mature lettuce stands in the field for a very short time, therefore it is more likely for the final yield to be determined by earlier stages of growth and very unlikely for mature heads to be very dependent on the subsoil water. For long season crops such as cereals, the yield is more dependent on the sufficient extraction of subsoil water than on early stage of growth (Costigan and McBurney., 1983).

Lettuce yield was mainly associated with soil bulk density, sand proportion, total K at 30-60cm, total N at 30-60cm and total P at 0-30cm as a result of Backwards Stepwise ANOVA. The average of bulk density in general was low (0.2 g cm^{-3}) and it ranged from 0.1 to 0.3 g cm^{-3} which could be explained by the high level of organic matter which reduces the soil compressibility (Ruehlmann and Korschens., 2009). This was also apparent on the maps as bulk density was the lowest where organic matter.

Variation in yield, after the relationship with bulk density was accounted for, was significantly correlated with sand proportion in the mineral fraction of the soil. Sand has been shown to be an influential factor on lettuce growth both in the glasshouse and in the predictive model and it distributed similarly to bulk density when comparing the two maps. Previous studies have found a significantly negative relationship between soil bulk density and clay content (Ruehlmann and Korschens., 2009). Sand has a higher density than clay which could have reflected on the dry weight of the soil bulk sample reflecting in turn on the bulk density value. However this suggestion is not supported by the positive trend between the sand and yield.

In contrast to the field data, sand proportion correlated negatively with the yield in the glasshouse. The field experiment showed a different scenario where the yield was higher where sand levels were the highest. Considering the difference in the two studied soils; the field (Redmere P36) soil that was studied in the glasshouse was silty clay with a high levels of clay and silt ~46% and 49% respectively and a low level of sand (~6%). Whereas, the soil of studied field (P57) was loam soil with high levels of silt and sand 48% and 44% respectively and a low level of clay ~8%.

This underlines the importance of considering the specific conditions of each field when attempting to make precision farming decisions. Sand's effect in these two different studies could possibly suggest that the sand proportion has a different effect depending on the levels or the combination of the other two soil mineral components (silt and clay). In the glasshouse experiment where the soil had high level of both silt and clay, sand resulted in growth reduction by either nutrient dilution, reduced nutrient holding capacity or reduced water retention. In the field there has been two different scenarios where the field could be divided into two areas

1) Field area 1; the area where both silt and clay where high (the bottom left of the maps), the lower level of sand was associated with higher yield similarly to the glasshouse scenario. In this part of the field organic matter was also high.

2) Field area 2; the other half of the field had more complicated results that do not support a simple explanation of the crop performance. Although organic matter was lower on the shallow map at that part of the field, the blue to yellow colours still indicated between 21-31% organic matter content, which is still considered as fertile soil (Loveland and Webb., 2003). Similarly, silt was lower in that part of the field however, total potassium was higher.

Based on general reviewing of all mapped and measured soil properties, it could be useful to view the influence of each trait in the light of the levels of other elements or the levels of the most interactive attribute with the studied feature. For example, Total K distribution at 30-60 cm (which was included in the predictive model of the yield) seems to be associated with higher yield when sand concentrations were extremely high, which requires further research.

Although the nutrients analysed for this study were total nitrogen, potassium and phosphorus and do not reflect the availability of these elements, these measures can be used to indicate a general nutrient status of the soil especially with favourable levels of organic matter (Costigan and McBurney. 1983).

There were significant differences between surface and subsoil nitrogen. The level of total N was higher in the top 30 cm of soil, possibly due to fertiliser application, improved aeration and mineralisation in topsoil (Brady and Weil., 2006). Although N tends to leach towards deeper layers of soil with drainage water, the two sets of data have correlated strongly. The N maps at the two depths showed similar patterns with slightly different trend in field Area 1 but not the Area 2. Unlike total N, total K was significantly higher in the subsoil than in the surface soil with strong correlation between the two levels of K. The low level of total K in the middle of the field at both surface soil and subsoil could be attributed to the native K in the field soil, whereas the difference in K between the two depths and the lower K level in the surface soil could be a result of crop roots uptake and farming practices or manipulation to adapt to crop needs (Brady and Weil., 2006). Maps showed similar distribution across the field for both depths with a clearly distinctive zone of low K in the middle of the field. Total P levels did not differ significantly between the two soil depths, and P distribution between the two depths was different.

EC did not correlate statistically with yield differences or with any of the other measured soil parameters. It was higher where most measured soil properties were higher (Area 2). There has been no significant difference between shallow EC and deep EC and the two levels of EC correlated significantly. The two patterns (shallow and deep) of EC distribution looked similar. This suggested that the two scans could be treated similarly for this field. Since the scans did not correlate or correspond to yield maps or other parameters' maps, this might imply that EC scans cannot be used directly to predict lettuce yield or its variations. Or that they are based on distribution of consistent soil properties, however these properties are not correlated with lettuce yield, such as the depth of top soil, the depth of water table (Corwin and Lesch, 2005) in addition to the possibility of other soil properties that have not been measured yet.

Organic matter was significantly higher in the surface soil than the subsoil, the two levels were strongly correlated and the two maps were similar. It is well known that organic matter is normally higher in the surface (top) soil than the subsoil due to enhanced aeration and other farming activities such as ploughing and incorporating crop residue with the soil and other farming practices (Brady and Weil., 2006). This in turn explains part of the higher N levels in the top soil. Organic matter levels within the top 30 cm of the soil ranged between 21 and 53%, which is considered as fertile soil (Loveland and Webb., 2003). Hence, Organic matter did not represent a limiting factor in this field. The relationship between the increase in organic matter levels and yield response needs further research.

The field soil is classified as organic. The soil had a high level of silt and low level of clay in general. On the maps, silt and clay proportions had very similar distribution unlike the sand proportion which showed an opposite trend. Moisture map did not conform well to any of the texture components maps. However, it appeared similar to EC deep, OM 0-30, silt and clay in Area 2. It could possibly be explained by clay or OM map where sand proportion was not very high.

The digital-penetrometer readings showed that penetration resistance was slightly higher towards both ends of the field. Although headlands were avoided in this experiment (more than 20meters of both ends of the field were avoided and the rest of the studied grid located in the middle of the field), this slightly higher level of resistance could possibly be a result of a greater farming traffic leading to compression of the soil.

Glasshouse work

In GH01, the difference in irrigation treatments was not big enough to influence plant fresh weight within the first 14 days after planting. Added sand showed a significantly negative effect on plant fresh weight, 14 days after planting in the glasshouse. It is still unclear whether the reduced fresh weight of the plants resulted from reduced water holding capacity of the substrate or from the dilution of the nutrients and hence, the decreased cation exchange capacity of the soil and nutrient leaching. No analysis was done on the substrate leachate on this occasion.

Variable transplant placement in GH02 resulted in no significant effect on the biomass weight acquired 14 days after planting, where the first plant roots started to appear at the bottom of the pots. This stage of growth was particularly focused on in the glasshouse experiments as several studies reported that the growth variation happens early in the young plants resulting in subsequent variation in the final (mature) heads (Kerbiriou *et al*., 2013).

There was a small visible difference between the tilted treatment and the rest of the treatments however this was not detected statistically possibly due to the lack of replicate number or the short period of growth. The tilted treatment had the highest mean fresh weight value. It is very likely that gravitropism could have had a role in this where the rigidity of plant cell walls increase in response to gravitational-resistance (Hoson and Wakabayashi., 2015).

The visible variation noted within the propagated transplants trays in GH03 was supported by the high values of the coefficient of variation for all the tested trays. The CV% value ranged from 16 to 33%. This represents a significant source of variability in the field that has the potential to explain why it has been difficult to pick up variation resulting from other sources such as EC and other soil factors. This area of work will be explored further in Year 3.

Conclusions

- Lettuce yield pattern was consistent in terms of the high and low yielding zones between two seasons in Year 2, which suggest that the yield variation is mainly driven by soil underlying properties rather than seasonal variation in moisture and weather conditions.
- EC scans could not be used directly to predict lettuce yield and its zonal variations. It can be used to predict variable field zones in terms of soil properties. But cannot necessarily explain the amplitude and positional effects. This requires further research.
- Considering the effect of the interaction between various soil properties. The study recommends that each soil trait or element studied should be viewed in the light of other or the highly interactive soil properties, as the difference in yield could be due to one reason in one part of the field and another in another part of the field.

- A model including soil bulk density, sand proportion, total K, N and P, and soil moisture content at harvest described 42.8% of the variation in lettuce yield averaged over both crops.
- Sand proportion in soil texture has a negative impact on lettuce growth in Silty Clay soil obtained from a similar field.
- Variability in propagated transplants (before planted) is an important source of variation that requires further investigation.

Knowledge and Technology Transfer

- Harper Adams University postgraduate research colloquium November,2015
  (1st prize for best poster presentation)
- AHDB-Smart Agriculture conference, Birmingham. Poster presentation September, 2015.
- AHDB horticulture studentship conference – Poster presentation September, 2015.
- The Tomato Growers Association conference – Oral presentation September, 2015.
- Harper Adams University/BLSA meeting- Lettuce Research Update February,2016.

References

- Bing, Z., XiuPing, J., ZhengChao, C. and QingXi, T. 2006. A patch-based image classification by integrating hyperspectral data with GIS. International Journal of Remote Sensing, 27 (15), pp. 3337-3346.
- Brady, N. C.andWeil, R. R. 2006. *The nature and properties of soils / nyle C. brady, ray R. weil.*Harlow : Prentice Hall, 2006; 14th ed.
- Corwin, D. L. and Lesch, S. M. 2005. Apparent soil electrical conductivity measurements in agriculture. *Computers and Electronics in Agriculture,* 46 (1), pp. 11-43.
- COSTIGAN, P. A. and McBURNEY, T. 1983. Variation in yield between two similar sandy loam soils. II. causes of yield variation in cabbage and lettuce crops. *Journal of Soil Science,* 34 (3), pp. 639- 647.
- Dexter, A. R. 2004. Soil physical quality: Part I. theory, effects of soil texture, density, and organic matter, and effects on root growth. *Geoderma,* 120 (3–4), pp. 201-214.
- Field, K. 2009. Gis cartography: A guide to effective map design. *Cartographic Journal,* 46 (3), pp. 276-277.
- Eshel, G., Levy, G.J., Mingelgrin, U. and Singer, M.J., 2004. Critical evaluation of the use of laser diffraction for particle-size distribution analysis.*Soil Science Society of America Journal*, *68*(3), pp.736-743.

- Grisso, R. Wysor, M,A. Holshouser, D and Thomason, W. 2009. Virginia Co-operative Extension, Precision Farming Tools: Soil Electrical Conductivity. [On-line]. Virginia State University. Available from: http://pubs.ext.vt.edu/442/442-508/442-508.html [Accessed on 06/04/2016].
- Hoson, T. and Wakabayashi, K. 2015. Role of the plant cell wall in gravity resistance. *Phytochemistry,* 112 pp. 84-90.
- JANKOWSKI, P. 1995. Integrating geographical information-systems and multiple criteria decision-making methods. International Journal of Geographical Information Systems, 9 (3), pp. 251-273.
- Kerbiriou, P. J., Stomph, T. J. and Bueren, E. T. a. P. C. S. 2013. Influence of transplant size on the above- and below-ground performance of four contrasting field-grown lettuce cultivars. *Frontiers in Plant Science,* 4 (article 379), pp. 1-16.
- Krygier, J.andWood, D. 2005. *Making maps :A visual guide to map design for GIS.* New York; London:Guilford Loveland, P. and Webb, J. 2003.
- Is there a critical level of organic matter in the agricultural soils of temperate regions: A review. *Soil and Tillage Research,* 70 (1), pp. 1-18.
- Oliver, M. A. and Webster, R. 1991. How geostatistics can help you. Soil use and Management, 7 (4), pp. 206-217.
- Rowell, D. L. 1994. *Soil science: Methods and applications.* Harlow; UK:Longman Group Limited, Longman Scientific & Technical.
- Ruehlmann, J. and Korschens, M. 2009. Calculating the effect of soil organic matter concentration on soil bulk density. *Soil Science Society of America Journal,* 73 (3), pp. 876-885.
- Schulte, E. E. and Hopkins, B. G. 1996. Estimation of soil organic matter by weight loss-on-ignition. *SSSA Special Publication,* (46), pp. 21-31.
- Taylor, J. C., Wood, G. A., Earl, R. and Godwin, R. J. 2013. Soil factors and their influence on within-field crop variability II: Spatial analysis and determination of management zones. *Biosystems Engineering,* 84 (4), pp. 441-453.
- USDA, Not dated
- Wurr, D. C. E., Fellows, J. R. and Hambidge, A. J. 1992. Environmental factors influencing head density and diameter of crisp lettuce cv. Saladin. *Journal of Horticultural Science (United Kingdom),* 67 (3), pp. 395-401.