European Innovation Partnership (EIP) Wales

Developing a novel method of rapidly measuring the effect of agronomic treatments on grass growth

Interim Report

December 2020

Contents

Introduction

Grass yield is time consuming and laborious to measure because it either involves multiple measurements with a rising plate meter or counting and weighing silage trailers. Some new forage harvester systems allow grass yield to be mapped, but relatively few farmers have access to this technology. This situation contrasts with arable combinable crops for which the majority of farmers have combine harvesters with yield monitors. The upshot of this is that combinable crop farmers can more easily test the effect of different agronomic treatments using tramline/strip scale trials and use this information to optimise crop management. By contrast, grass/forage producers are not able to do this very easily and risk falling behind in terms of the rate of productivity improvement.

Recently an Innovate UK (IUK) feasibility study demonstrated that spectral reflectance of grass crops measured by satellite could be used to accurately measure grass yield (kg dry matter per hectare) with good accuracy of +/- 200 kg/ha). This discovery opens up the prospect of a much simpler method of measuring grass yield that would enable farmers to test the effect of different agronomic treatments in order to optimise their grass husbandry approach. Satellite imagery offers the cheapest and easiest approach but is reliant on a cloudless period to acquire the image. Drone imagery offers a much more reliable method of acquiring the imagery and would provide much finer resolution, but this approach would need to be demonstrated at the field scale.

In order to be confident about whether an agronomic treatment effect is 'real' (as opposed to being caused by natural field variation) ADAS have developed a statistical approach for analysing individual crop yield data points from combine yield maps. The analysis technique is called 'Agronomics'. This approach has been shown to work for combinable crops and has been published in a peer-reviewed scientific journal. It should be possible to apply the same principles to grass yield data points, but this would need to be demonstrated.

The objective of the study is to develop a novel way of rapidly measuring the effects of agronomic treatments on grass yield using images from satellite and drone. By combining new knowledge from an Innovate UK funded feasibility study to develop a method for rapidly testing the effect of agronomic treatments on grass yield. The project will explore whether spectral reflectance information acquired by satellite or drone can be used to rapidly test the effect of agronomic treatments applied to grass in tramline trials.

Experimental approach

Three highly progressive grassland farmers have come together to facilitate the study over a three-year period (data gathering over a 2-year financial period). They are keen to be at the forefront of this science driven project which is extensively farm driven with regards to knowledge and intelligence.

David Jones
Hardwick Farm, Abergavenny

David Morgan
Trostrey Court Farm, Usk,

Russel Morgan
Graig Olway Farm, Usk,

On each farm a tramline trial has been set up to test different agronomic treatments including;

- Variety trial at Hardwick Farm
- Sulphur fertiliser trial at Trostrey Court Farm
- Slurry trial at Graig Olway Farm

Tramline Trial Overview

David Jones – Hardwick Farm

David Jones reseeded the field using three variety mixes. Each treatment received the same amount of fertiliser and management throughout the season. This trial allows David to identify which variety utilised nutrients more efficiently.

The first cut of silage was taken in 25th April, the second cut on 2nd June and a third cut on the 6th July.

Rising plate meter measurements were taken every week from early June through until the third cut was taken. The drone measurement and forage samples were taken on the 6th of July.

Trial description

Tramline 1	Spitfire (Italian/Hybrid/Perennial Ryegrass)
Tramline 2	Spitfire (Italian/Hybrid/Perennial Ryegrass)
Tramline 3	White clover mix
Tramline 4	White clover mix
Tramline 5	Spitfire Pro-Nitro (Italian/Hybrid/Perennial Ryegrass/Red Clover)
Tramline 6	Spitfire Pro-Nitro (Italian/Hybrid/Perennial Ryegrass/Red Clover)

Trial map

David Morgan – Trostrey Court Farm

David Morgan laid out 10 tramlines to investigate the effects of applying different sulphur fertiliser. Each tramline received the same amount of non-sulphur fertiliser and management throughout the season. This trial allows David Morgan to investigate what yield and quality improvements could be made by changing his fertiliser regime. The treatment design also enables us to identify an optimum application rate.

Sulphur fertiliser was applied on 08/05/2020 and 22/06/2020.

The first cut of silage was taken on the 2nd of May, the second cut was taken on 1st June, the third cut on 6th July and the 4th cut was taken on the 30th August.

Rising plate meter measurements were taken weekly from early June through to the third cut. The drone measurement and forage samples were taken on the 6th of July.

Trial description

Tramline	**Treatment application**	**Rate (Kg SO_3/ha)**
Tramline 1	Zero Rate	0
Tramline 2	Half Rate	25
Tramline 3	Full Rate	50
Tramline 4	Zero Rate	0
Tramline 5	Double Rate	100
Tramline 6	Zero Rate	0
Tramline 7	Half Rate	25
Tramline 8	Full Rate	50
Tramline 9	Zero Rate	0
Tramline 10	Double Rate	100

Trial map

Russell Morgan – Graig Olway

Russell Morgan designed nine tramlines to investigate the yield and quality effects of including slurry in his fertilising plan. Each tramline received the same amount of inorganic fertiliser and management throughout the season.

The slurry was applied on 26/06/2020.

The first cut of silage was taken on the 25th of June, the second cut was taken on 23rd of July. The fields were grazed by sheep until the end of spring.

Rising plate meter measurements were taken weekly from late June through to the second cut. The drone measurement and forage samples were taken on the 6th of July.

Trial description

Map	Application	Rate
Tramline 1	Slurry Applied	6000 Gallon/ha
Tramline 3	Slurry Applied	6000 Gallon/ha
Tramline 4	Slurry Applied	6000 Gallon/ha
Tramline 6	Slurry Applied	6000 Gallon/ha
Tramline 7	Slurry Applied	6000 Gallon/ha
Tramline 9	Slurry Applied	6000 Gallon/ha
Tramline 2	No slurry Applied	Zero
Tramline 5	No slurry Applied	Zero
Tramline 8	No slurry Applied	Zero

Trial map

Drone and grass growth data acquisition and analysis

Drone images were acquired for all three farms by Environment Systems on 6th July. Environment Systems carried out the following tasks, including;

- Tasked and acquired red green blue (RGB) and multispectral imagery from a drone
- Capture visible RGB data using 20-megapixel senseFLY SODA camera.
- Capture multispectral (MS) data using 4-narrow band channels (Green, Red, Red Edge and Near Infrared).
- Flying altitude of 120 m was used to achieve the following resolutions:
    - 2 – 3 cm RGB
    - 10 – 15 cm MS.
- Image positional accuracy (2 – 5 cm) achieved using RTK technology onboard the UAV
- Generated ortho-mosaics from raw image tiles
- Geo-referenced ortho-mosaics and applied user-specified projection (e.g. British National Grid)
- Applied radiometric calibration to multispectral imagery
- Delivered analysis-ready ortho-mosaics in *.tif format and associated metadata.

Environment Systems Data Services also acquired satellite images at the closest possible date to the UAV capture including:

- Sentinel -2 cloud free analysis-ready product providing surface reflectance of 10m channels in wavelength order (i.e. Blue, Green, Red, NIR). The data are supplied georeferenced, orthorectified, atmospherically corrected and with ISO19139 metadata

- Vegetation indices derived from the Sentinel -2, such as NDVI are available on request.

- Sentinel -1 backscatter product, a measure of the strength of the radar signal (measured in units of Sigma 0). Band 1 (VV) shows surface scattering; a rougher surface or urban areas with lots of right-angled structures generates higher VV backscatter. Band 2 (VH) relates to volume scattering; randomly oriented volumes, such as forests, generate higher VH backscatter than flat surfaces such as bare soil.

Additionally, ADAS acquired Sentinel-2 data for more dates from the UK Joint Nature Conservation Committee (JNCC) which has been running a pre-operational ARD project to support Sentinel-2 users in the UK. These files were offered as an analytical resource for the whole of the UK processed to bottom-of-atmosphere (or, surface) reflectance. Images could only be collected for dates when the satellite passed over during cloud free periods.

ADAS then analysed the drone data and satellite data to calculate several spectral reflectance indices (SRIs) as described in Table 1 below.

Table 1. Vegetation Indices (VIs) calculated from the drone data.

Vegetation Index	Description	Formula	Wavebands
Canopy Chlorophyll Content Index (CCCI)	The CCCI measures crop nitrogen status.	$CCCI = \frac{\frac{NIR - red\ edge}{NIR + red\ edge}}{\frac{NIR - Red}{NIR + Red}}$	Red Red edge NIR
Canopy Chlorophyll Content Index - alternative (CCCI2)	Another variation of the CCCI used for measuring canopy N content. Derived from NDRE (below).	$CCCI = \frac{\mathrm{NDRE} - NDRE_{min}}{NDRE_{max} - NDRE_{min}}$	Red edge NIR
Chlorophyll Index Red-Edge (CIRE)	This VI estimates canopy chlorophyll or N content.	$\mathrm{CI}RE = \frac{NIR}{red\ edge} - 1$	Red edge NIR
Normalised Difference Red Edge index (NDRE)	Assesses the health of vegetation.	$NDRE = \frac{NIR - red\ edge}{NIR + red\ edge}$	Red edge NIR
Enhanced Vegetation Index, EVI	EVI is sensitive to changes in areas of high biomass. It is also capable of reducing the influence of atmospheric conditions and canopy background signals.	$EVI = 2.5 * \frac{NIR - Red}{(NIR + (6 * Red) - (7.5 * Blue)) + 1}$	Red Blue NIR
Normalised Difference Vegetation Index, NDVI	NDVI is an index of plant greenness or photosynthetic activity.	$NDVI = \frac{NIR - Red}{NIR + Red}$	Red NIR
Normalised Green-Red Difference Index, NGRDI	NGRDI measures surface greenness and are an index that can be used to detect live green plant canopies. The index is suitable to analyse crops in all growth stages.	$NGRDI = \frac{Green - Red}{Green + Red}$	Red Green
Transformed Normalised Difference Vegetation Index, TNDVI	TNDVI is a modified NDVI that provides an improved correlation for the amount of green biomass found in a pixel.	$TNDVI = \sqrt{\frac{NIR - Red}{NIR + Red}} + 0.5$	Red NIR
Wide Dynamic Range Vegetation Index, WDRVI	WDRVI is a modified NDVI that is more sensitive to moderate-to-high LAI values. This allows more robust characterisation of crop physiological and phenological characteristics.	$WDRVI = \frac{0.1 * NIR - Red}{0.1 * NIR + Red}$	Red NIR

Grass growth was measured by ADAS on 6th July using a rising plate meter. Five measurements were made in each treatment strip. The GPS location of each rising plate meter measurement point was recorded with a high degree of accuracy to a few centimetres.

The spectral reflectance values that corresponded with the location of each field rising plate meter measurement were then identified and collated.

Results

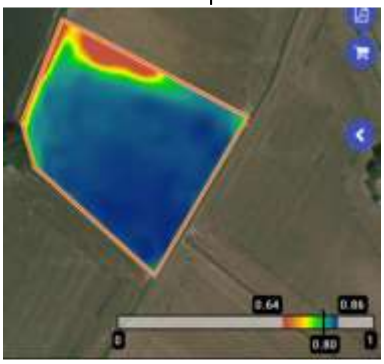
Satellite maps

Satellite images were obtained from the Sentinel-2 satellite during the season to investigate whether the agronomic treatments caused any visual effects. The satellite images measure light reflectance from the land and vegetation in terms of the Normalised Vegetation Difference Index (NDVI). Blue and green areas represent areas of grass with a large and dark green canopy, whereas yellow and red areas represent areas of grass with a small light green canopy or even bare earth. These satellite images have a resolution (pixel size) of 10-20m, so they have quite a low level of resolution.

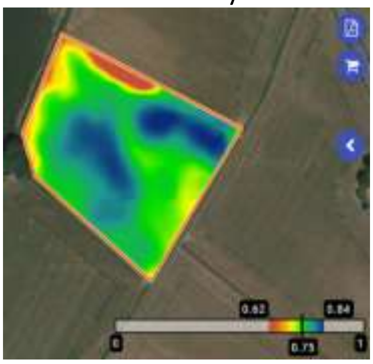
Hardwick Farm

Variety differences started to be apparent from June onwards with the treatment at the south end of the field (Spitfire Pro-Nitro (Italian/Hybrid/Perennial Ryegrass/Red Clover)) having the largest NDVI, followed by the treatment at the north end of the field (Spitfire (Italian/Hybrid/Perennial Ryegrass)) and the white clover mix in the middle having the lowest NDVI.

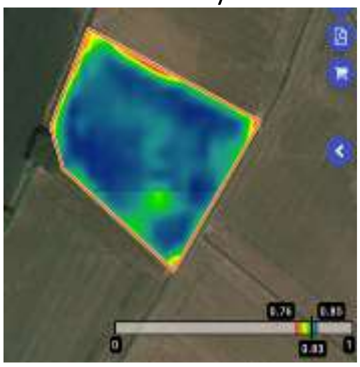
14th April



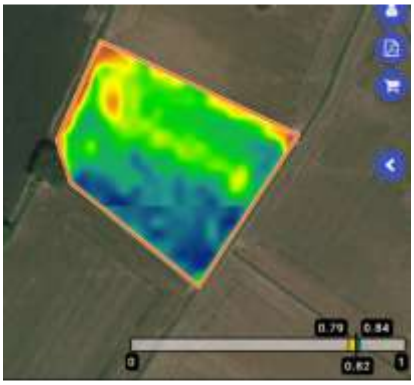
14th May



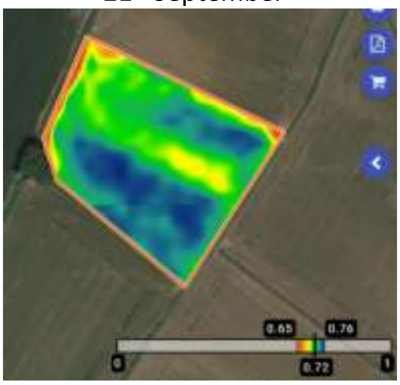
29th May



23rd June



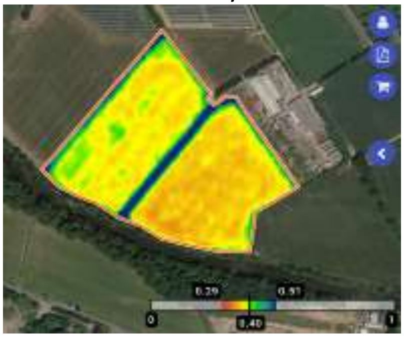
21st September



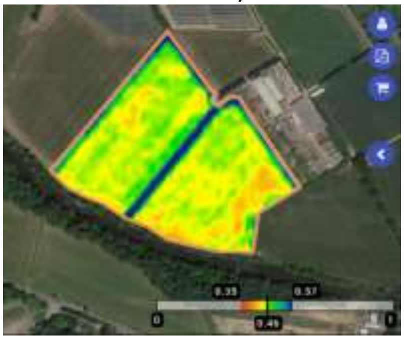
Trostrey Court Farm

Sulphur fertiliser differences started to be apparent from the end of May onwards with the two zero sulphur treatments showing a paler NDVI on 25th June.

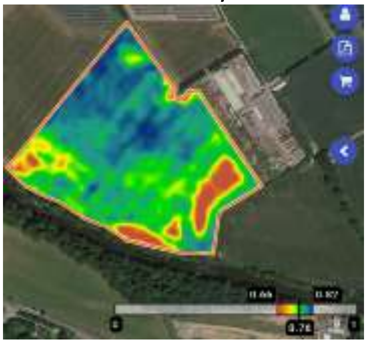
6th May



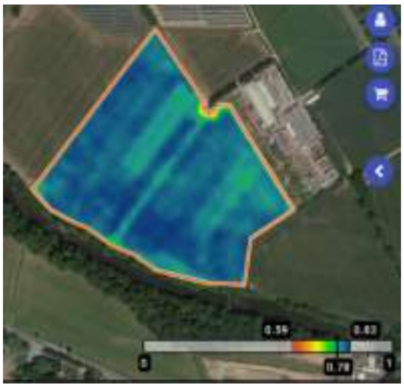
14th May



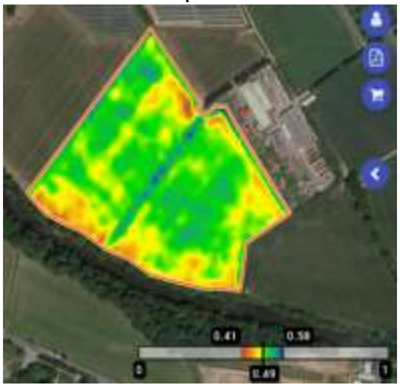
29th May



25th June



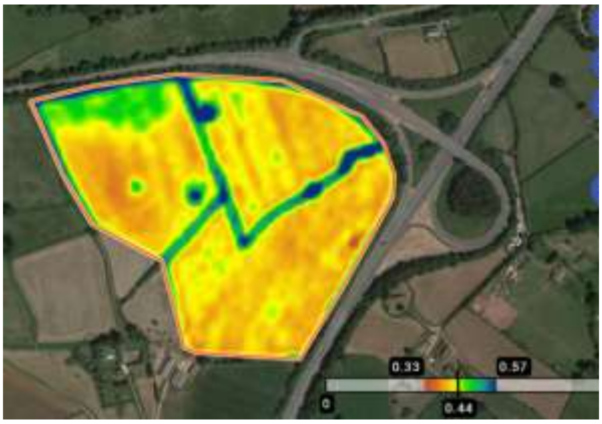
13th September



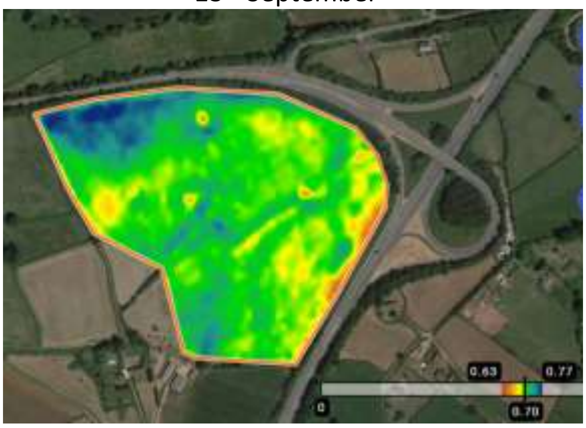
Graig Olway Farm

The effects of the slurry treatments can be seen in terms of different coloured NDVI strips on 25th June.

25th June



13th September



Rising plate meter measurements – Grass Growth Curves

Hardwick Farm – Grass Growth Curves

The perennial ryegrass produced substantially less grass growth on the 19th and 26th June compared with the white clover and the mixture of Italian, hybrid, perennial ryegrass and red clover (Figure 1; Table 2). The most consistent effect on quality measured on 5th July was for the red clover to have a greater crude protein content than the other two grass/clover mixes (Appendix 1).

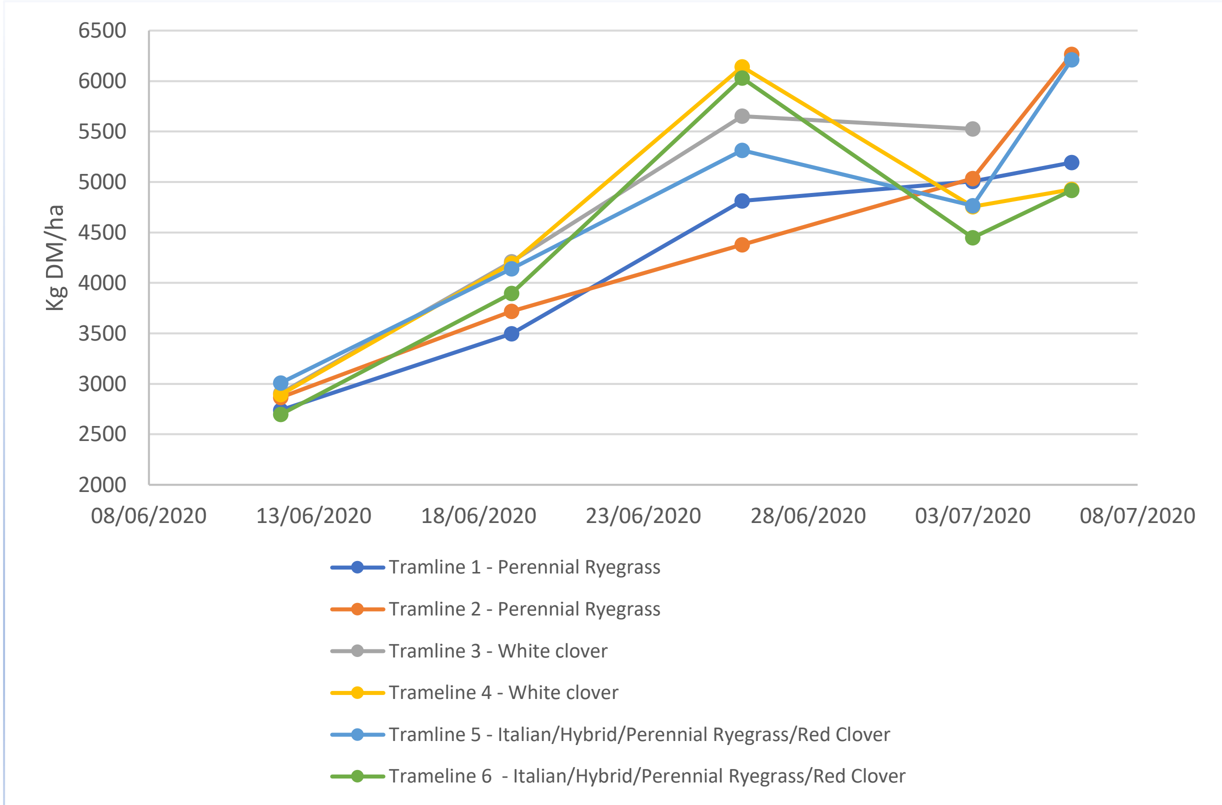


Figure 1. Hardwick Farm grass growth curves

Table 2. Hardwick Farm average grass biomass for each grass/clover treatment (kg/ha).

	Perennial Ryegrass	White clover	Italian/Hybrid/Perennial Ryegrass/Red Clover
12/06/2020	2803	2901	2854
19/06/2020	3608	4203	4018
26/06/2020	4595	5897	5673
03/07/2020	5022	5141	4608
06/07/2020	5730	4927	5566
22/07/2020	2824	2922	2936
Average	4097	4332	4276

Trostrey Court Farm – Grass Growth Curves

The sulphur treatments did not produce any noticeable effects on grass growth as measured by the rising plate meter (Figure 2, Table 3), or on the mineral concentration of the forage on 6th July (Appendix 2).

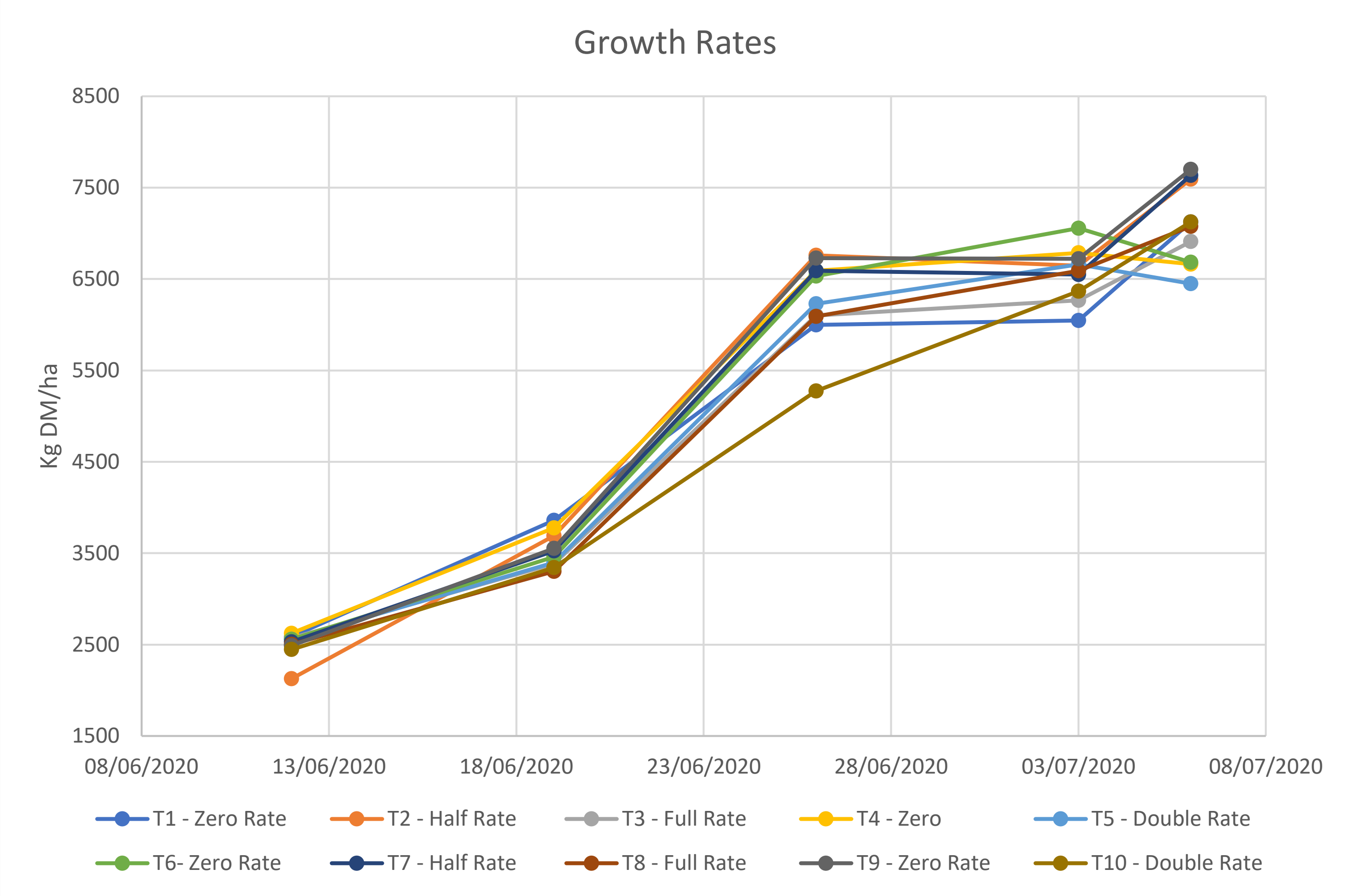


Figure 2. Trostrey Farm grass growth curves

Table 3. Trostrey Farm average grass biomass for each sulphur treatment (kg/ha).

	Zero Rate	Half Rate	Full Rate	Double Rate	Statistical significance
12/06/2020	2564	2328	2537	2502	Not significant
19/06/2020	3662	3608	3342	3370	Not significant
26/06/2020	6464	6675	6095	5752	Not significant
03/07/2020	6653	6597	6429	6513	Not significant
06/07/2020	7042	7615	6994	6788	Not significant
Average	5277	5365	5079	4985	Not significant

Graig Olway Farm – Grass Growth Curves

The slurry treatments applied on 26th July did not have a noticeable effect on grass growth as measured by the rising plate meter (Figure 3, Table 4), but they did tend to increase the crude protein content of the forage (Appendix 3). No consistent effects of slurry treatments were observed for other forage quality measurements (Appendix 3).

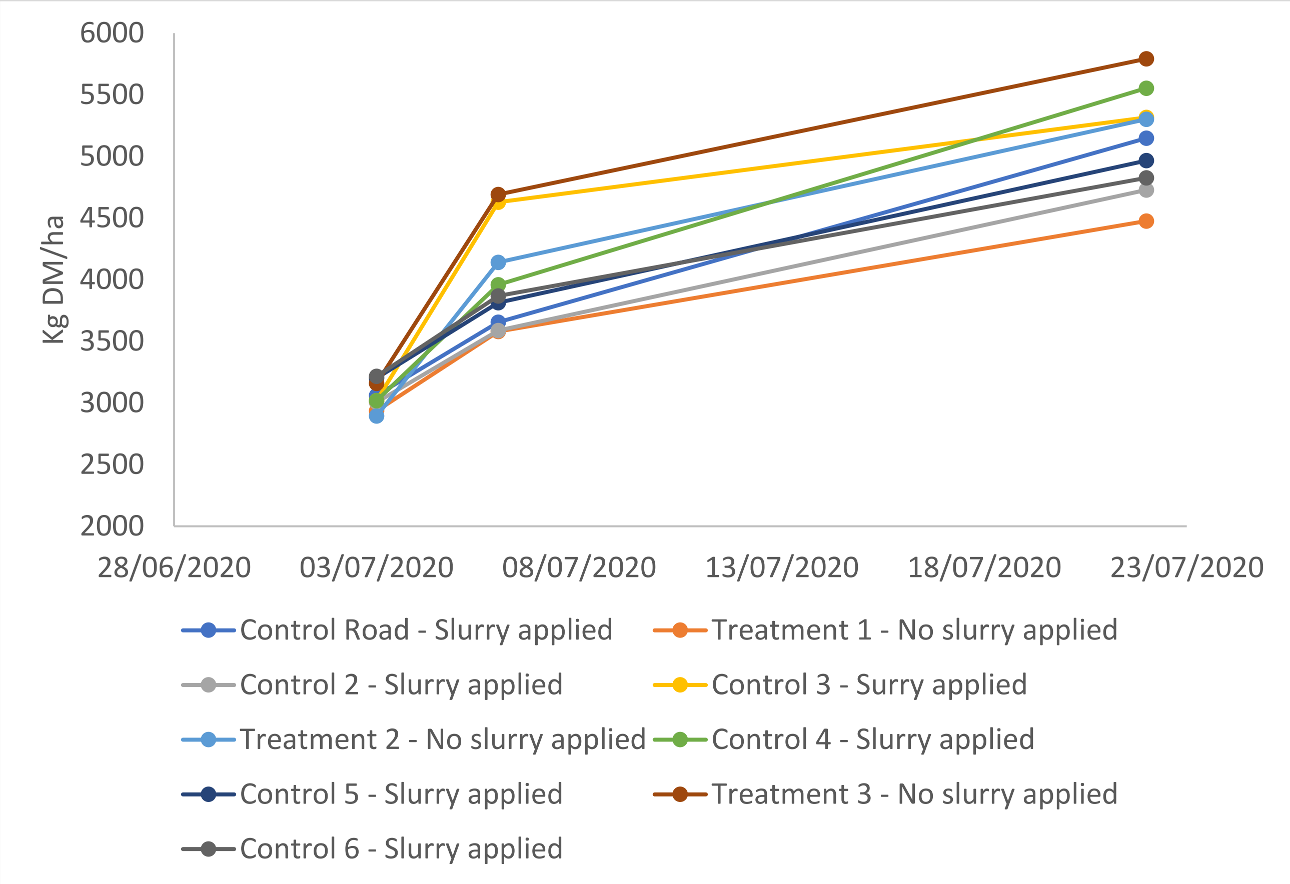


Figure 3. Graig Olway Farm grass growth curves

Table 4. Graig Olway Farm average grass biomass for each sulphur treatment (kg/ha).

	No slurry	Slurry	Statistical significance
03/07/2020	2997	3088	Not significant
06/07/2020	4138	3919	Not significant
22/07/2020	5190	5090	Not significant
average	4108	4032	Not significant

Drone images

The drone images were taken for all the farms on the 6th of July by Environment Systems. The images shown below are RGB images similar to those taken by a normal camera. The drones also collected information about the light reflected at a wide range of wavelengths including wavelengths outside the visible spectrum. These images have a very high resolution with a pixel size of just several cm.

David Jones – Hardwick Farm

Differences between the variety strips can be clearly seen in the image below, with the Spitfire (Italian/Hybrid/Perennial Ryegrass) appearing paler in colour (marked in red).

Figure 4. Hardwick Farm Drone RGB image

David Morgan – Trostrey Farm

Differences between the sulphur fertiliser strips can be seen in the image below, with the two zero sulphur treatments in the middle and southern part of the field appearing paler in colour.

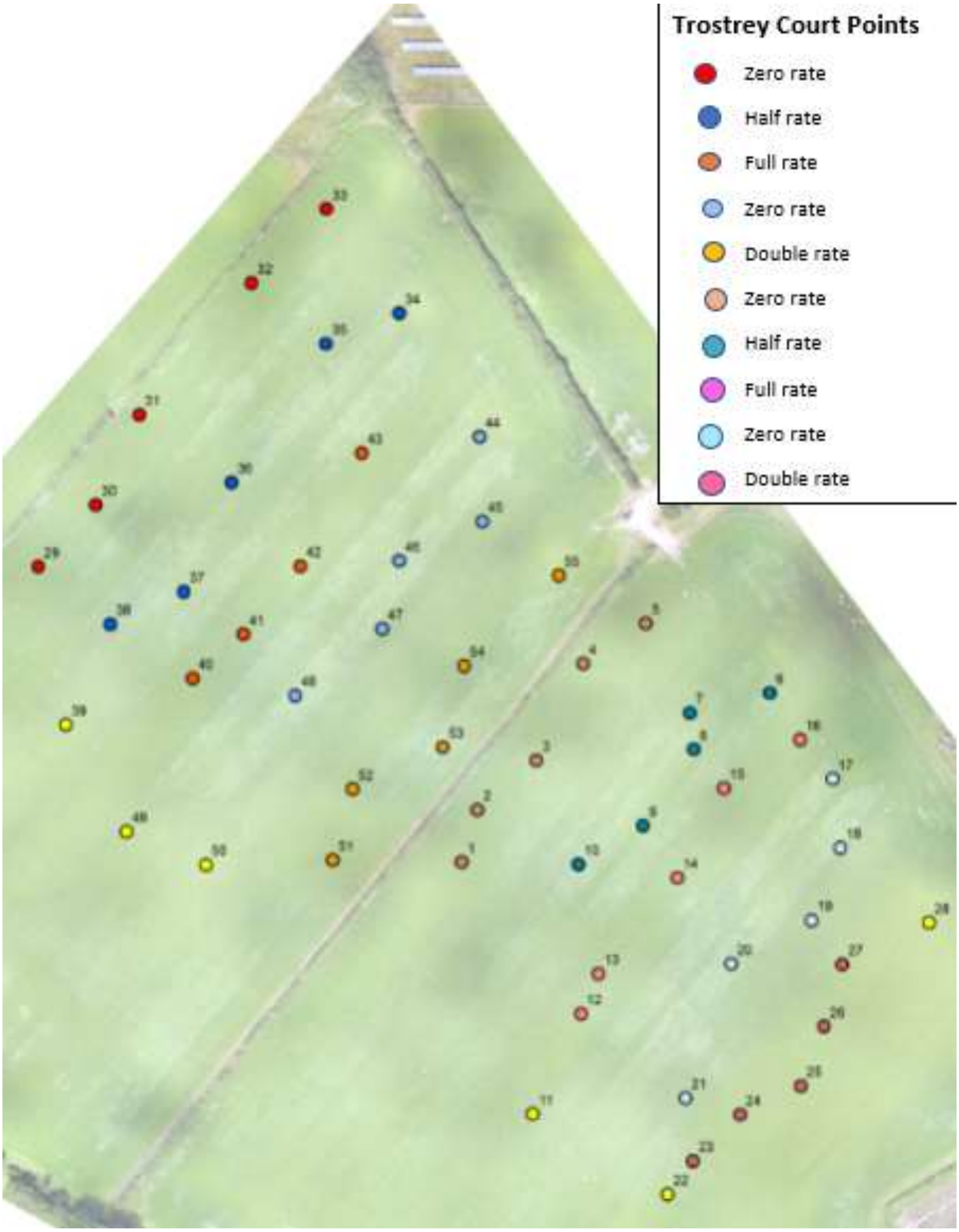


Figure 5. Trostrey Farm Drone RGB image

Russell Morgan – Graig Olway Farm

Visual differences caused by the slurry treatment were not apparent from the drone photo taken on 6th July.

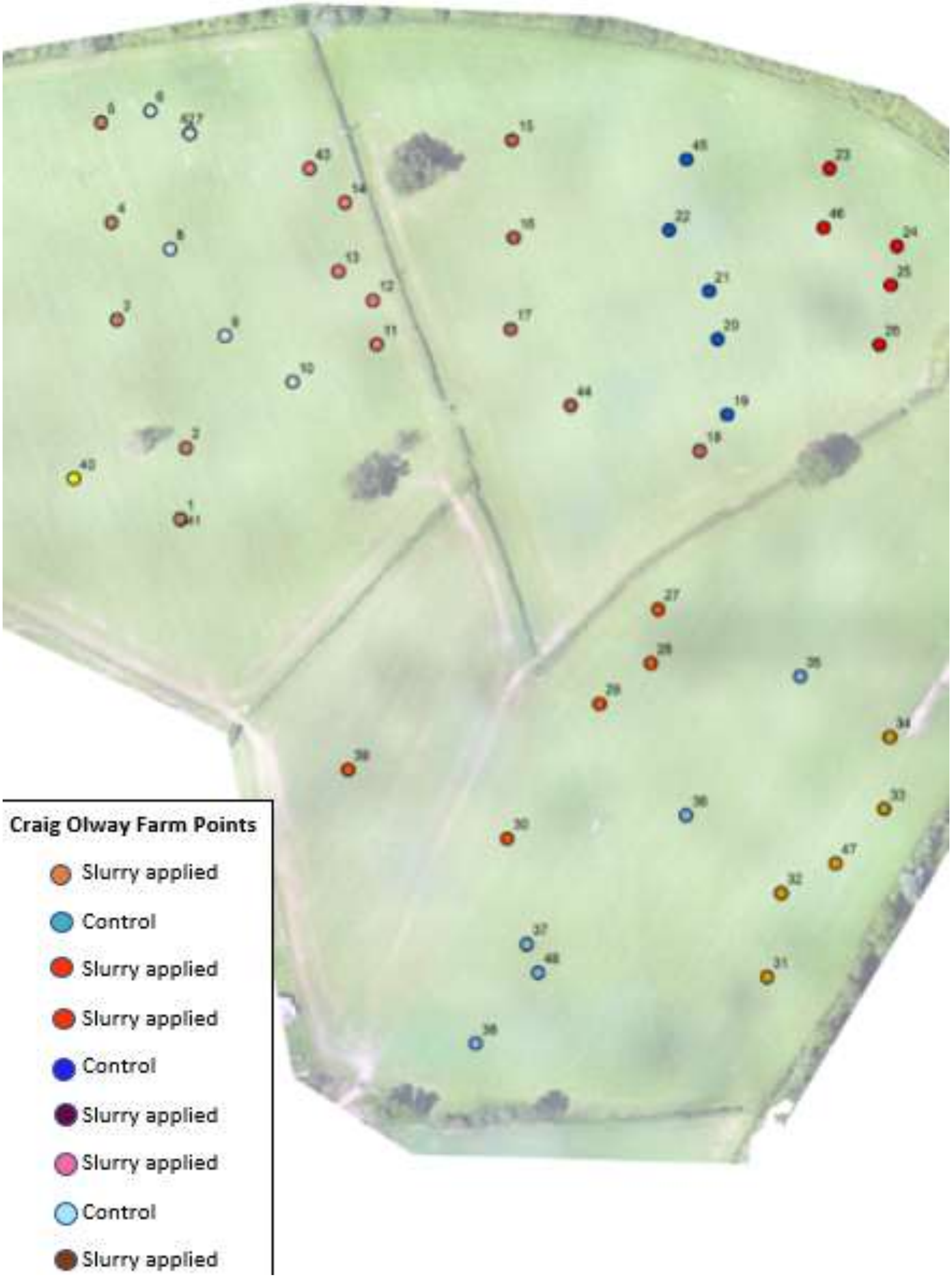


Figure 6. Graig Olway Farm Drone RGB image

Drone & rising plate meter data analysis

Eleven spectral reflectance indices (SRIs) were calculated from the drone data. The degree to which the SRI data correlated with rising plate meter measurements of grass growth is summarised in Table 5 below in terms of the correlation coefficient. A correlation coefficient of one means a perfect positive correlation, whilst a correlation of minus one means a perfect negative correlation between the SRI and the rising plate meter measurement. Across all three farms, the SRIs with the highest correlation coefficient were CCCI, CIRE and NDRE, however, these SRIs did not perform as well as some other SRIs for individual farms and a plot of these SRIs against grass biomass showed that apparent high correlation coefficient results from two distinct clusters of data points (Figure 7). The most promising SRIs were NDVI and WDRVI which had reasonable correlation coefficients for each individual farm and for all data across all 3 farms (Table 5; Figure 7). Figure 7 shows that small changes in NDVI corresponded with large changes in grass biomass. An increase in NDVI of 0.01 units corresponds with an increase in grass biomass of about 2000 kg/ha. An increase in WDRVI of 0.1 units corresponds with an increase in grass biomass of about 1850 kg/ha.

Statistical analysis of the SRI data showed significant differences for NDVI, WDRVI and TNDVI caused by the agronomic treatments at Trostrey Farm (Table 6) and Graig Olway farm (Table 7). At Trostrey Farm, the double rate sulphur treatment had an NDVI which was 0.010 units greater than the half-rate sulphur treatment ($P<0.05$). This NDVI difference is estimated to equate to an increase in grass biomass of about 2000 kg/ha (according to the relationship in Figure 7). The WDRVI data showed a similar effect with the double rate sulphur treatment having a significantly greater WDRVI than the half rate of 0.051 units, which is estimated to equate to a grass biomass increase of almost 1000 kg/ha.

At Graig Olway farm, there were also statistically significant differences between the slurry treatments for the NDVI, WDRVI and TNDVI SRIs (Table 7). These all indicated that the slurry treatment slightly reduced the observable grass growth. This may have been because the slurry had been applied immediately after the silage cut just 9 days before the drone image was taken and there may have been some slurry on the surface obscuring some grass.

At Hardwick Farm, it was not possible to statistically analyse the results because the replicated tramline strips were adjacent to each other rather than being randomised in different parts of the field. It should be recognised that it is logistically difficult to randomise the position where tramlines of different varieties are drilled. On average the red clover/ perennial ryegrass mixture had the greatest NDVI, WDRVI and TNDVI which indicates this treatment had the greatest growth (Table 8). The most encouraging aspect of this particular trial was that there were positive correlations between measured grass biomass and several SRIs, including NDVI, WDRVI and TNDVI, which demonstrates that these SRIs can be used to estimate grass biomass across red clover, white clover and different types of ryegrass.

Table 5. Correlation coefficients summarising how well each spectral reflectance index correlated with grass biomass measured using a rising plate meter (kg/ha)

Spectral reflectance index	Hardwick Farm	Trostrey Farm	Graig Olway Farm	All farms
CCCI	0.30	0.35	0.28	0.76
CIRE	0.30	0.38	0.33	0.76
GLI	0.17	-0.07	0.18	0.37
NDRE	0.32	0.39	0.32	0.76
NDVI	0.41	0.35	0.51	0.54
NGRDI	0.33	0.17	0.04	0.36
OSAVI	0.24	0.40	0.13	0.50
TGI	0.24	-0.24	0.46	0.21
TNDVI	0.41	0.35	0.51	0.54
VARI	0.34	0.27	0.06	0.32
WDRVI	0.40	0.35	0.52	0.54

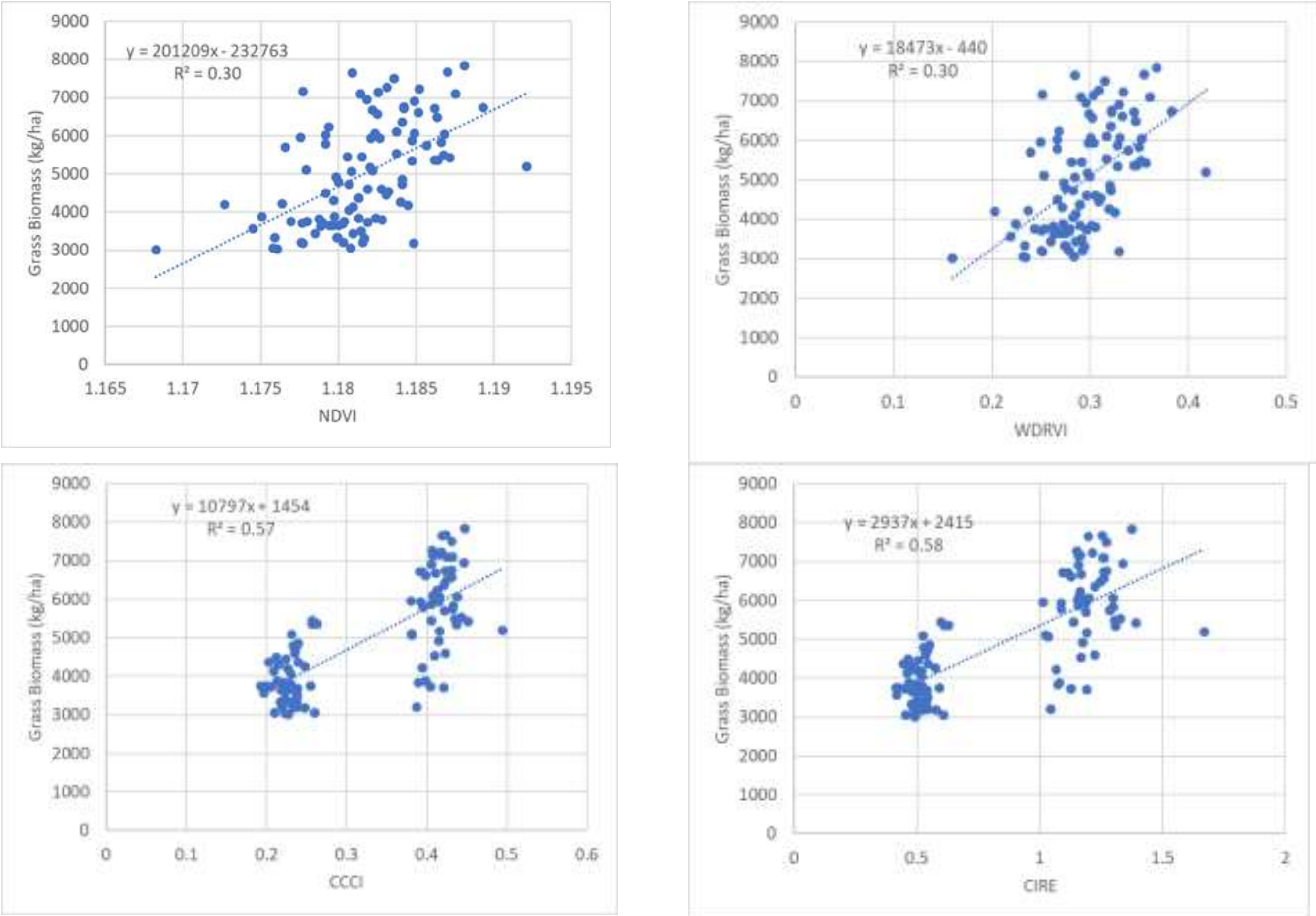


Figure 7. A graphical summary describing how well selected spectral reflectance indices correlated with grass biomass measured using a rising plate meter (kg/ha) across all three farms.

Table 6. Trostrey Farm: Sulphur treatment averages for each spectral reflectance index measured by drone on 6th July.

Spectral reflectance index	Zero Rate	Half Rate	Full Rate	Double Rate	Statistical significance
CCCI	0.420	0.420	0.414	0.416	NS
CIRE	1.221	1.210	1.198	1.212	NS
GLI	0.241	0.236	0.256	0.274	NS
NDRE	0.378	0.377	0.374	0.377	NS
NDVI	0.902	0.896	0.903	0.906	P<0.05
NGRDI	0.140	0.142	0.144	0.154	NS
OSAVI	0.000	0.000	0.000	0.000	NS
TGI	0.633	0.609	0.650	0.665	NS
TNDVI	1.184	1.181	1.184	1.186	P<0.05
VARI	0.191	0.196	0.191	0.201	NS
WDRVI	0.319	0.291	0.325	0.342	P<0.05

Table 7. Graig Olway Farm: Slurry treatment averages for each spectral reflectance index measured by drone on 6th July.

Spectral reflectance index	No slurry	Slurry at 6000 Ga/ha	Statistical significance
CCCI	0.234	0.226	NS
CIRE	0.533	0.508	NS
GLI	0.231	0.231	NS
NDRE	0.210	0.202	NS
NDVI	0.897	0.891	<0.05
NGRDI	0.133	0.131	NS
OSAVI	0.000	0.000	<0.1
TGI	0.643	0.637	NS
TNDVI	1.182	1.180	<0.05
VARI	0.184	0.180	NS
WDRVI	0.295	0.271	<0.05

Table 8. Hardwick Farm: Grass/clover mix treatment averages for each spectral reflectance index measured by drone on 6th July.

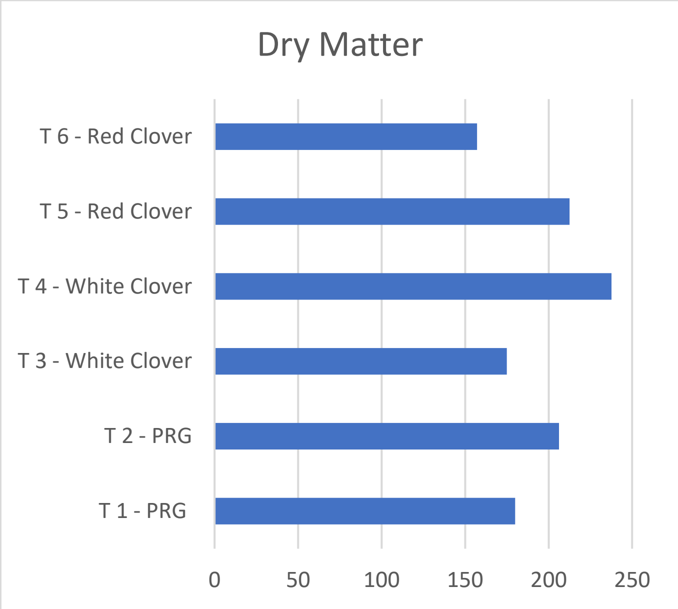
Spectral reflectance index	Perennial Rye Grass	Red Clover mix	White clover mix
CCCI	0.405	0.438	0.409
CIRE	1.134	1.317	1.158
GLI	0.245	0.252	0.271
NDRE	0.361	0.396	0.367
NDVI	0.892	0.903	0.897
NGRDI	0.142	0.145	0.150
OSAVI	0.001	0.001	0.001
TGI	0.695	0.659	0.704
TNDVI	1.180	1.185	1.182
VARI	0.192	0.195	0.196
WDRVI	0.271	0.328	0.295

Preliminary Conclusions

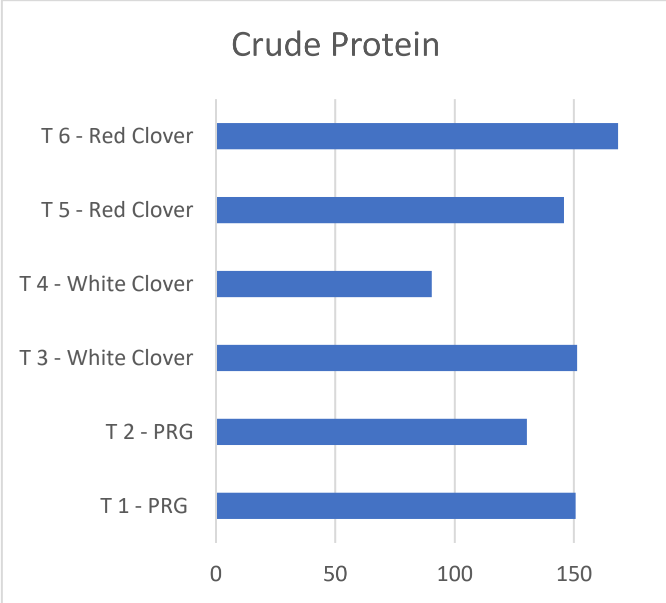
- Agronomic treatment tramline trials were successfully set up on grassland fields on 3 farms testing i) different mixtures of grass and clover species, ii) different rates of sulphur fertiliser, iii) slurry use.
- Grass growth was measured at regular intervals using a rising plate meter. The largest differences in grass growth were caused by a red clover/ryegrass mix compared with white clover and a mixture of ryegrass species.
- Drone images of the fields were collected on the 6th of July. Satellite images were collected on several dates leading up to the 6th of July. These images were used to calculate up to 11 different spectral reflectance indices (SRIs), such as NDVI.
- Analysis of the drone showed that at least three SRIs (NDVI, WDRVI and TNDVI) correlated reasonably well with grass growth measured by the rising plate meter. Importantly, for each SRI the same relationship between the spectral reflectance index and grass biomass worked across all three fields and across swards containing pure grass, red clover grass mixtures and white clover.
- Small changes in NDVI corresponded with large changes in grass biomass. An increase in NDVI of 0.01 units corresponded with an increase in grass biomass of about 2000 kg/ha. An increase in WDRVI of 0.1 units corresponded with an increase in grass biomass of about 1850 kg/ha.
- Statistical analysis of the SRI data showed significant differences for NDVI, WDRVI and TNDVI caused by the agronomic treatments at 2 farms.
- In one trial, the double rate sulphur treatment had a significantly greater NDVI and WDRVI than the half-rate sulphur treatment ($P<0.05$). These differences were estimated to equate to an increase in grass biomass of between 1000 and 2000 kg/ha.
- The discovery that analysis of the SRI data resulted in the detection of several statistically significant differences between the agronomic treatments, whereas analysis of the rising plate meter data did not is important. It probably results from the SRI data being based on many thousands of individual measurements across the whole tramline test area, whereas the rising plate meter relied on 5 measurements per tramline.
- The rising plate meter approach is likely to be adequate for detecting large treatment differences, but the SRI information from the drone image appears to be capable of detecting smaller treatment differences.
- The next steps will now involve i) investigating whether the satellite images can provide equally valuable insights into the effect of agronomic treatments on forage growth as the drone data and ii) testing whether a statistical approach developed for combine yield maps of arable crops can be adapted for drone and satellite data in order to detect even smaller agronomic treatment differences with statistical significance.

Appendix 1. Forage Analysis – NIR analysis

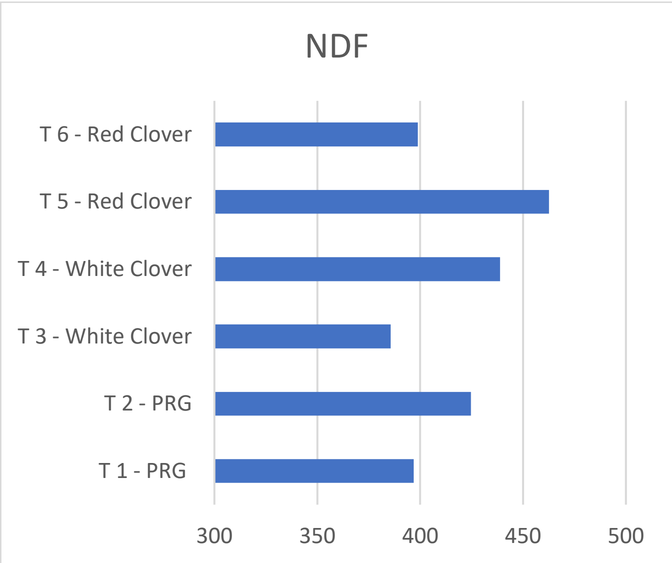
David Jones – Hardwick Farm



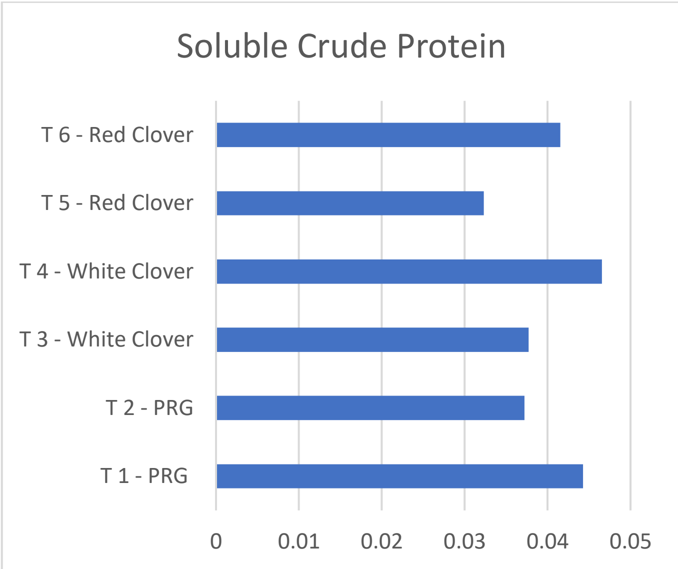
- The white clover treatment yielded the highest Dry Matter content.



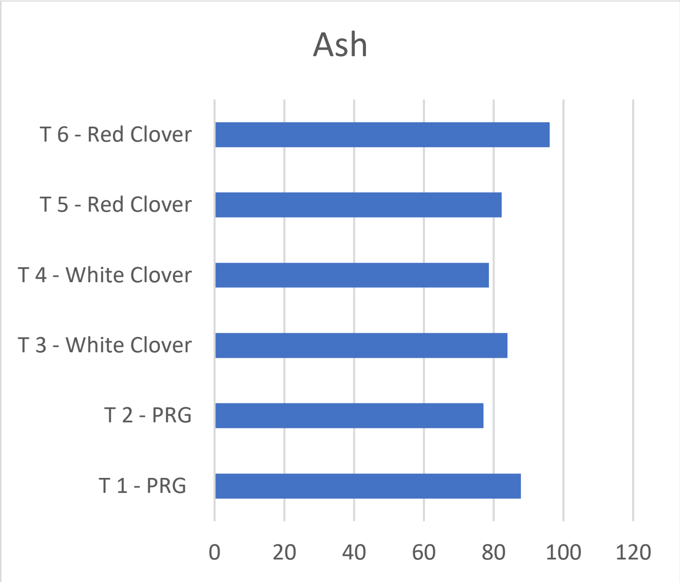
- The red clover treatment contained the highest crude protein content followed by PRG.

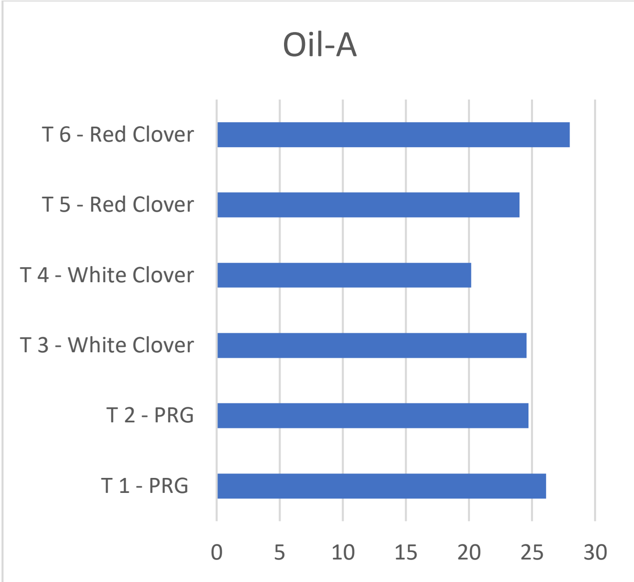


- The red and white clover treatment had the highest content of NDF.

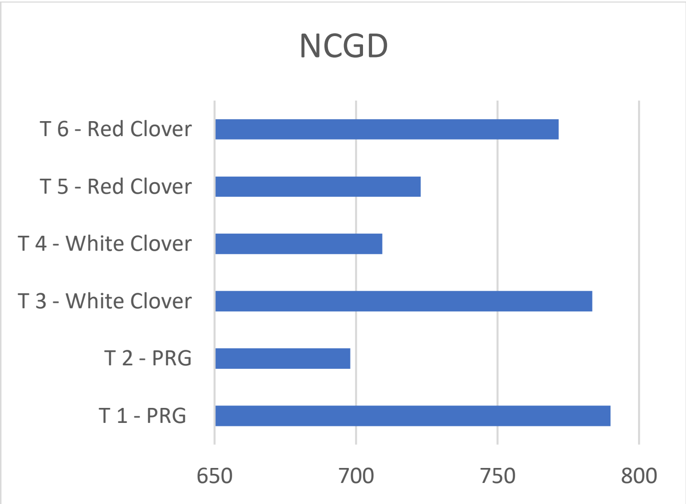


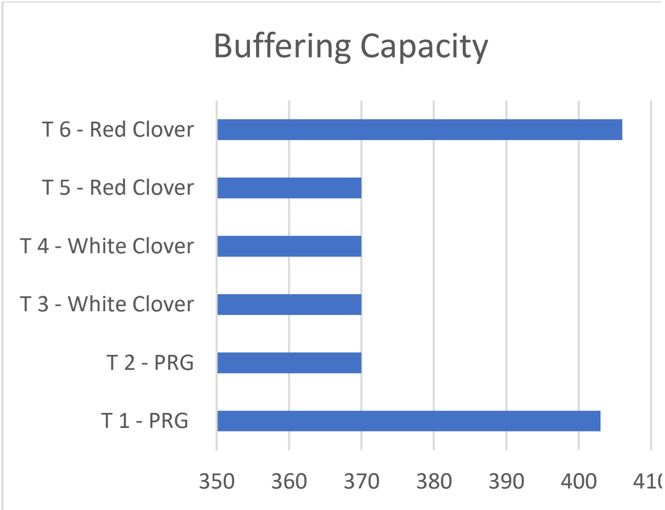
- The white clover treatment had the highest soluble crude protein content.



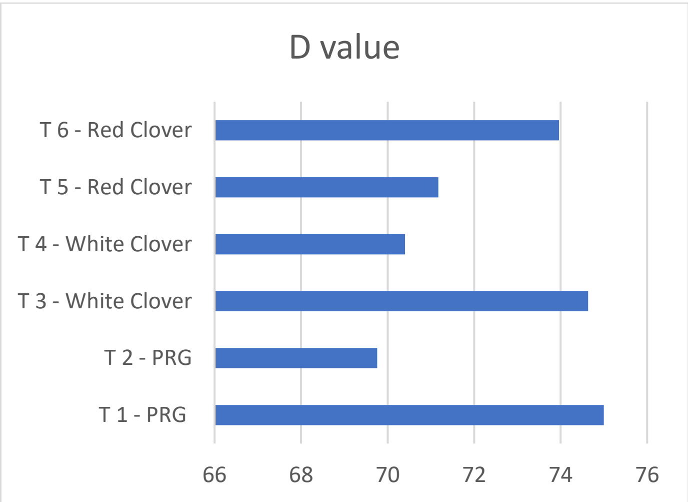


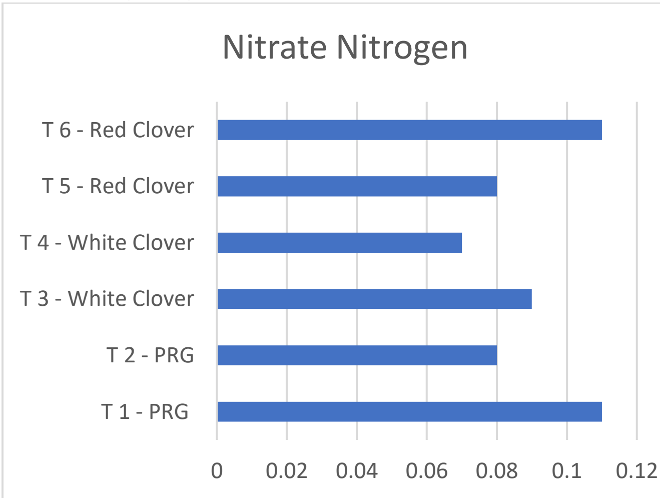
- The red clover treatment had the highest Ash content. White clover and PRG had a similar Ash content.
- The red and white clover treatments had similar Oil-A content.



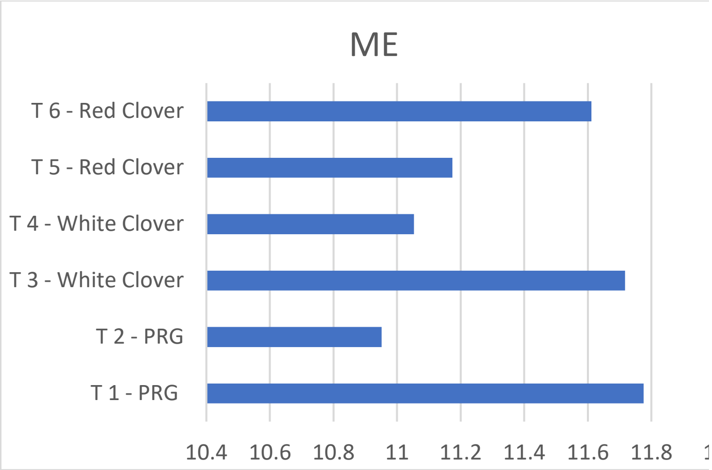


- All three treatments had a similar NCGD value.
- Red clover and PRG had the highest Buffering capacity values.



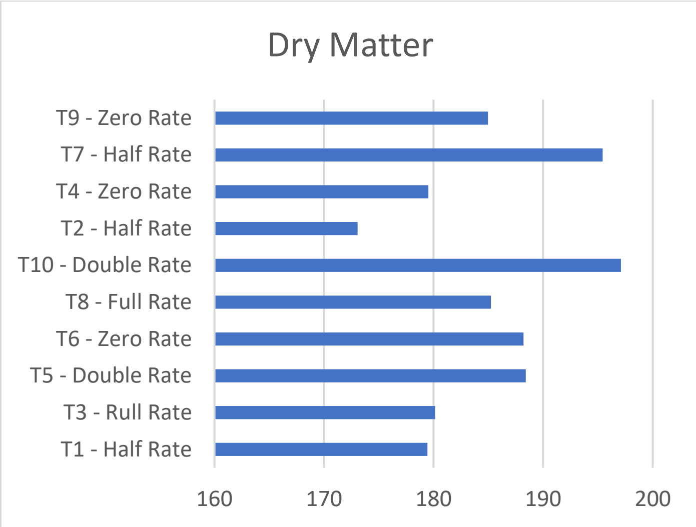


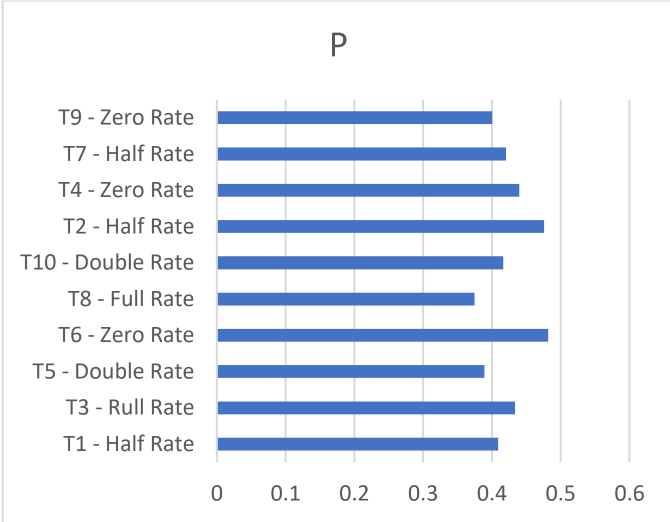
- The three treatments had a similar D value.
- PRG and Red clover had the highest Nitrate Nitrogen content.

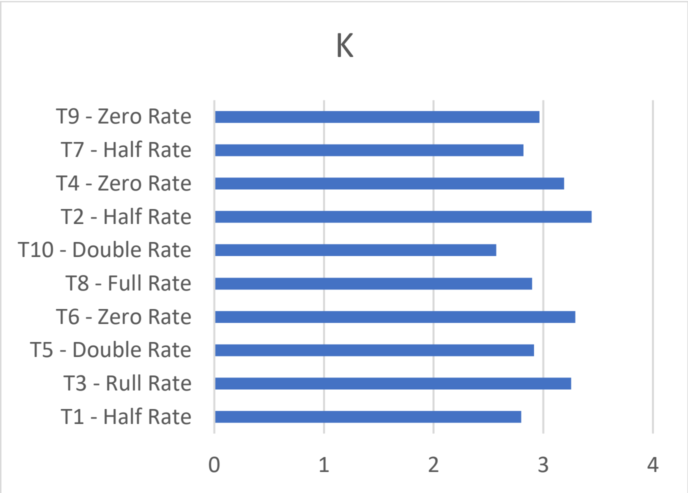


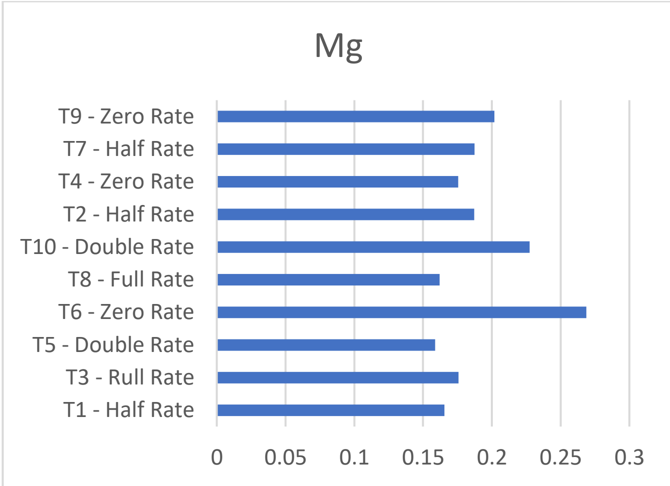
- The ME value was very similar for the three treatments.

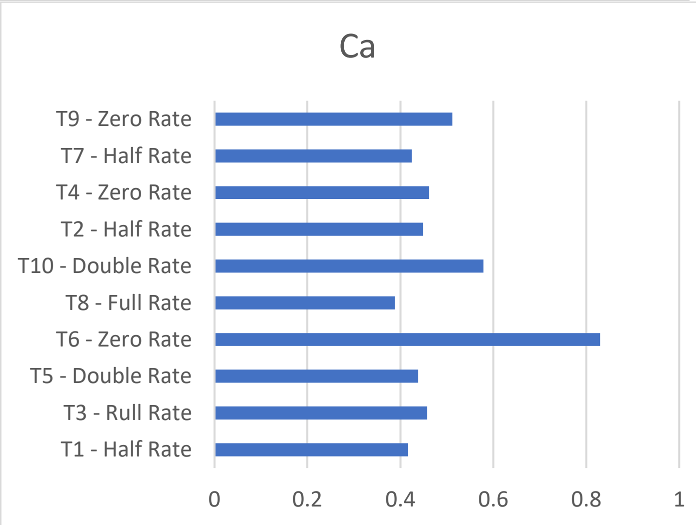
Appendix 2. Forage Mineral Analysis – David Morgan – Trostrey Court Farm

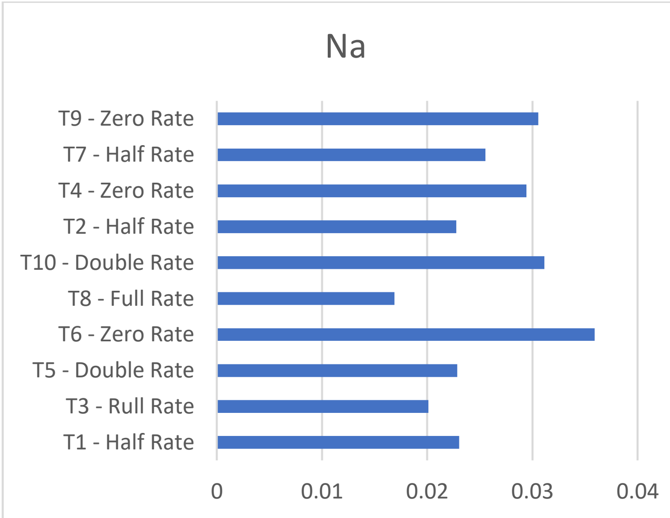


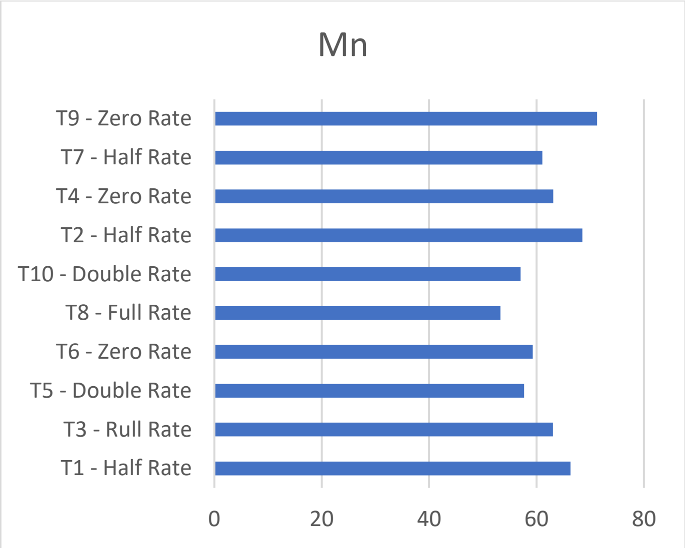


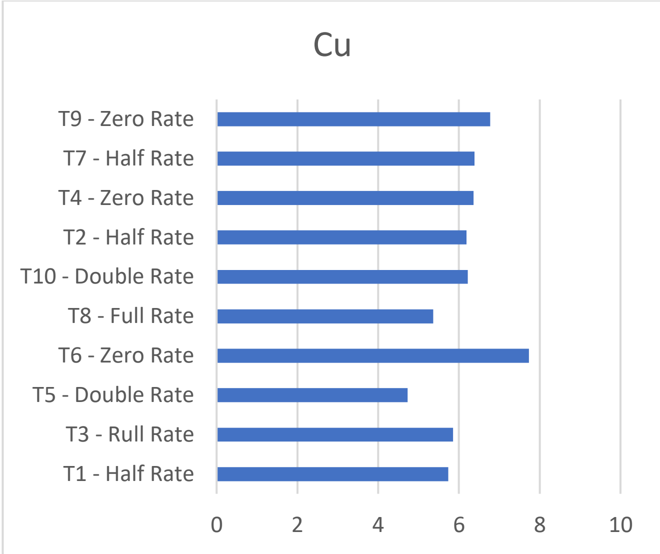


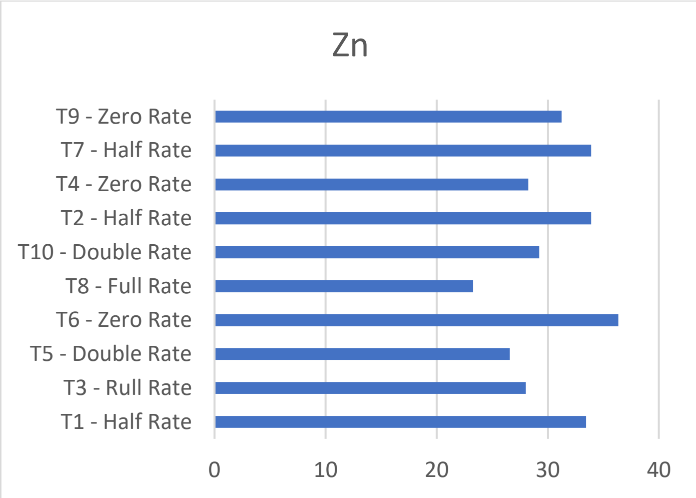


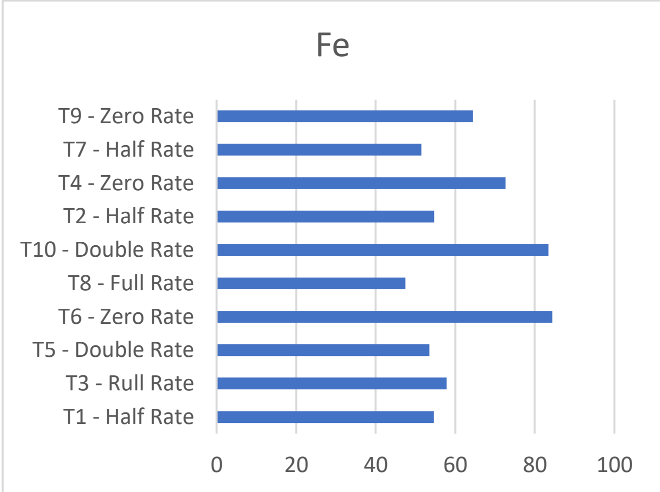


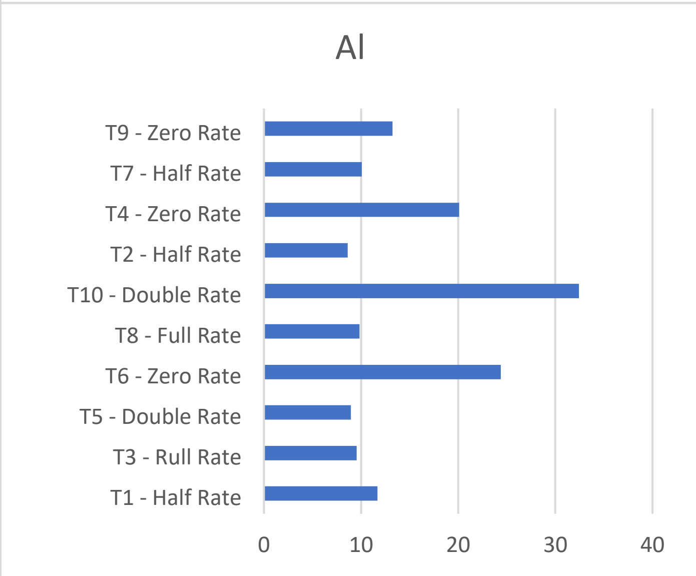



Mn
T9 - Zero Rate
T7 - Half Rate
T4 - Zero Rate
T2 - Half Rate
T10 - Double Rate
T8 - Full Rate
T6 - Zero Rate
T5 - Double Rate
T3 - Rull Rate
T1 - Half Rate
0 20 40 60 80


Cu
T9 - Zero Rate
T7 - Half Rate
T4 - Zero Rate
T2 - Half Rate
T10 - Double Rate
T8 - Full Rate
T6 - Zero Rate
T5 - Double Rate
T3 - Rull Rate
T1 - Half Rate
0 2 4 6 8 10

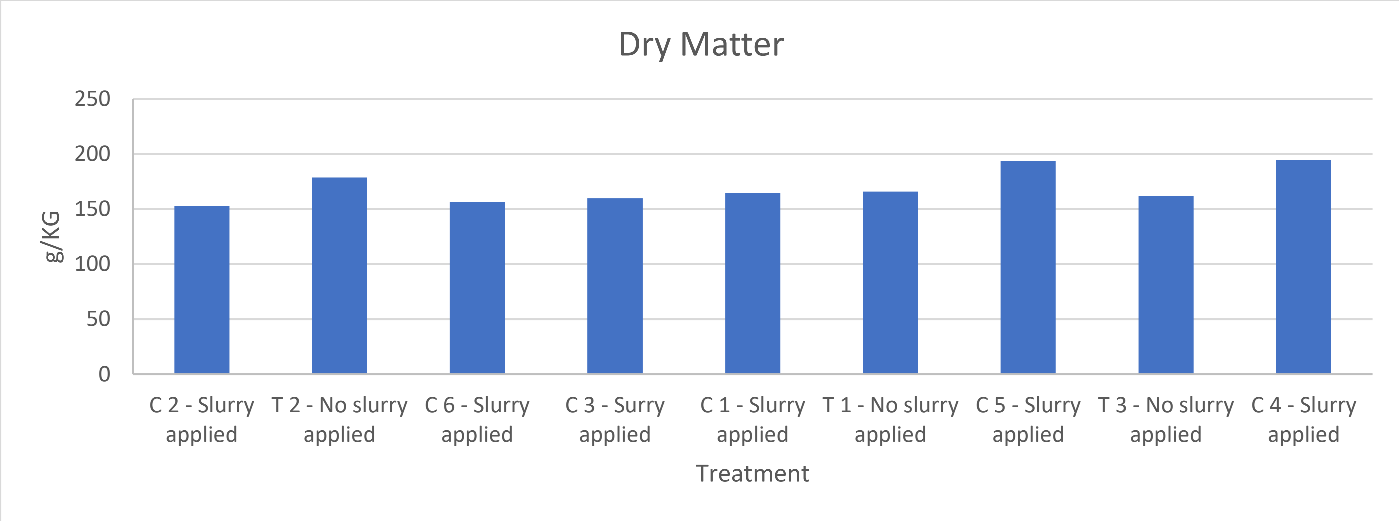

Zn
T9 - Zero Rate
T7 - Half Rate
T4 - Zero Rate
T2 - Half Rate
T10 - Double Rate
T8 - Full Rate
T6 - Zero Rate
T5 - Double Rate
T3 - Rull Rate
T1 - Half Rate
0 10 20 30 40

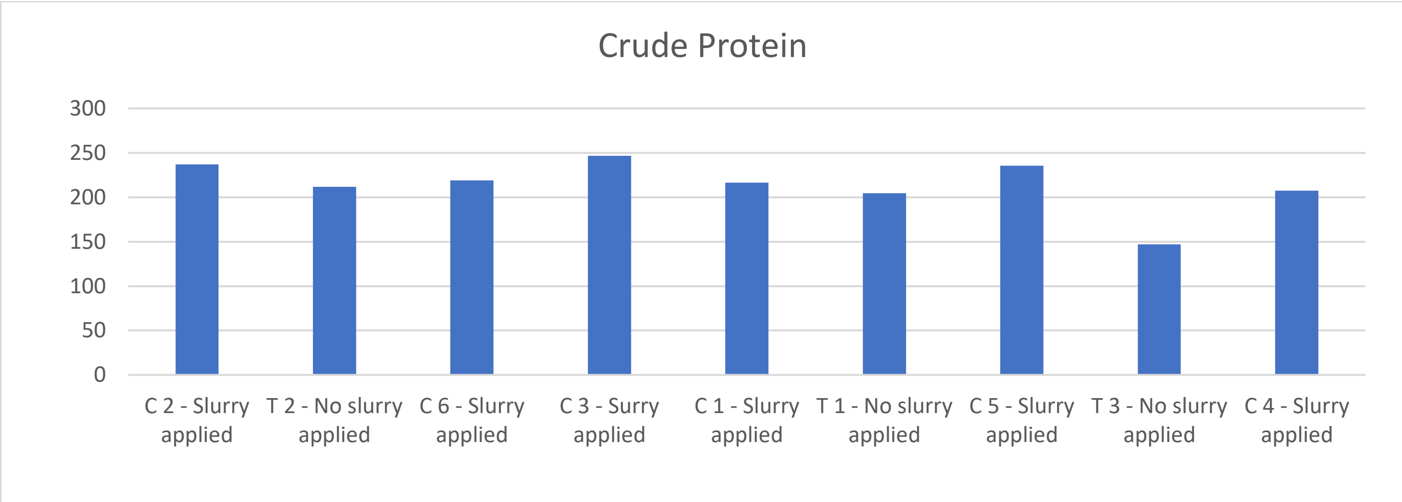

Fe
T9 - Zero Rate
T7 - Half Rate
T4 - Zero Rate
T2 - Half Rate
T10 - Double Rate
T8 - Full Rate
T6 - Zero Rate
T5 - Double Rate
T3 - Rull Rate
T1 - Half Rate
0 20 40 60 80 100


Al
T9 - Zero Rate
T7 - Half Rate
T4 - Zero Rate
T2 - Half Rate
T10 - Double Rate
T8 - Full Rate
T6 - Zero Rate
T5 - Double Rate
T3 - Rull Rate
T1 - Half Rate
0 10 20 30 40

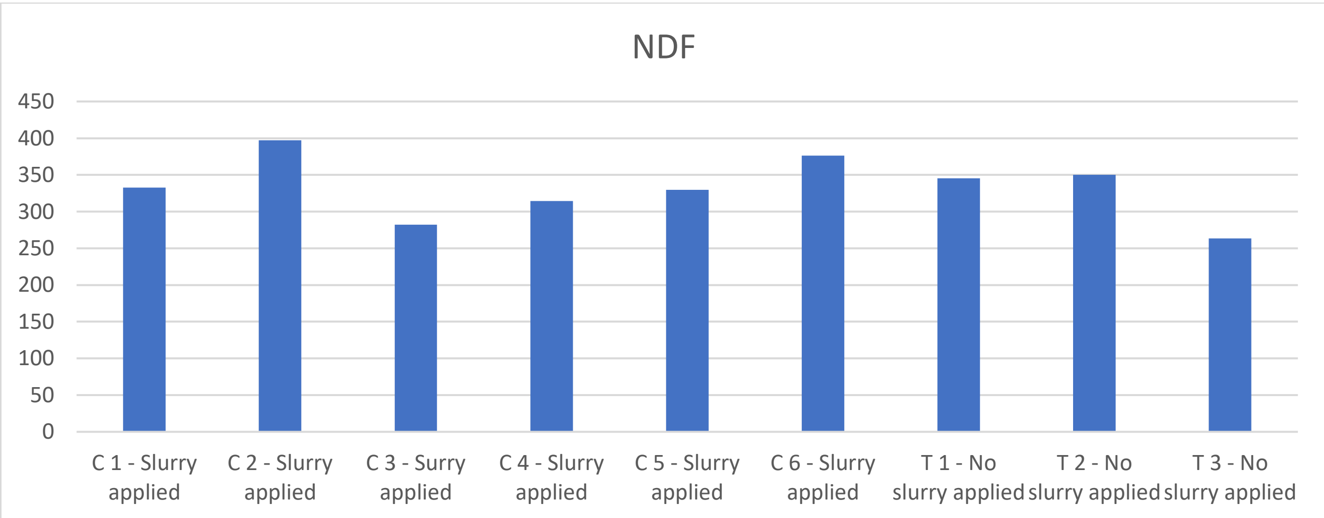

S
T9 - Zero Rate
T7 - Half Rate
T4 - Zero Rate
T2 - Half Rate
T10 - Double Rate
T8 - Full Rate
T6 - Zero Rate
T5 - Double Rate
T3 - Rull Rate
T1 - Half Rate
0 0.1 0.2 0.3 0.4

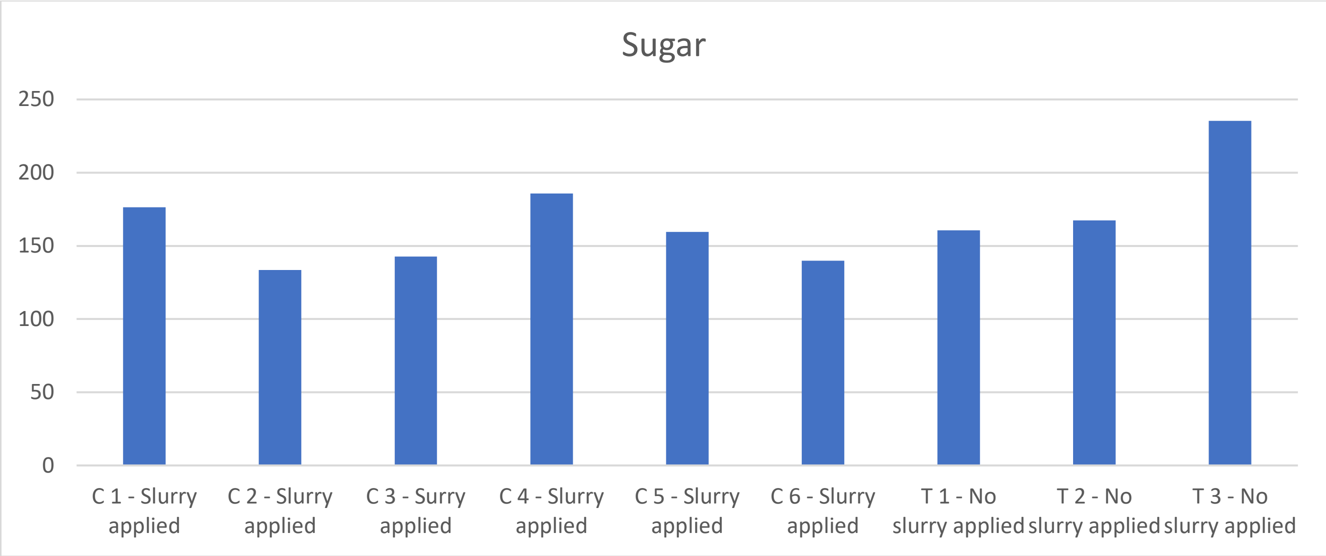
Appendix 3. Russell Morgan – Graig Olway



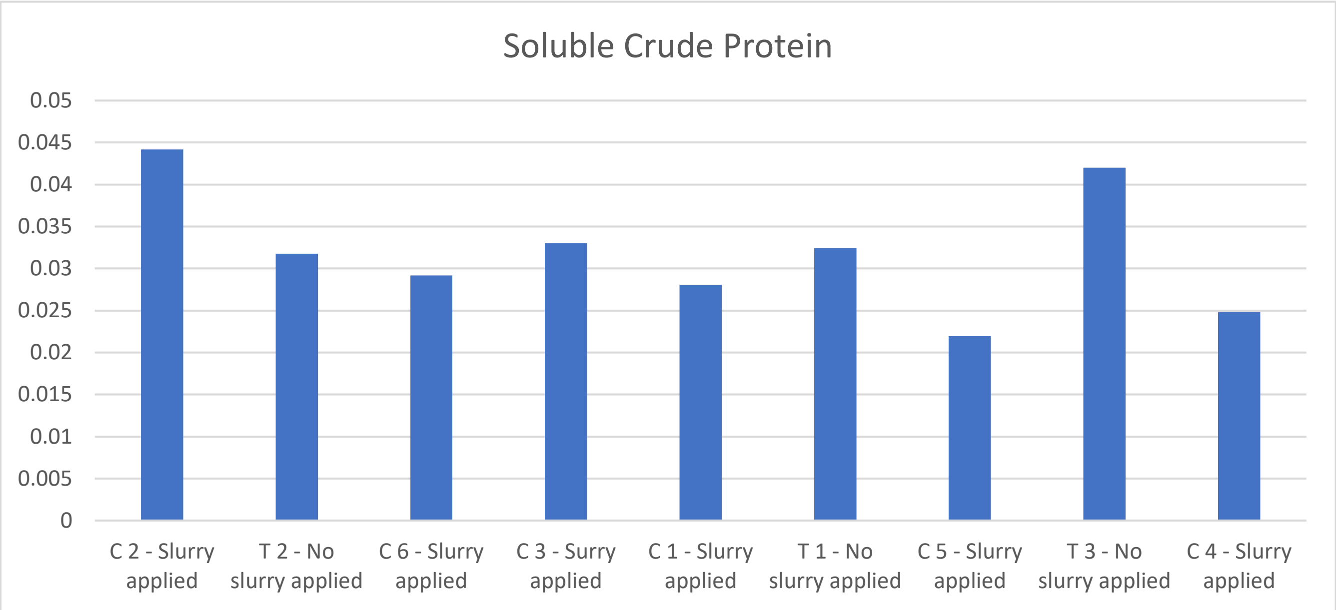


- The tramlines that received slurry tended to have a higher Crude Protein value.

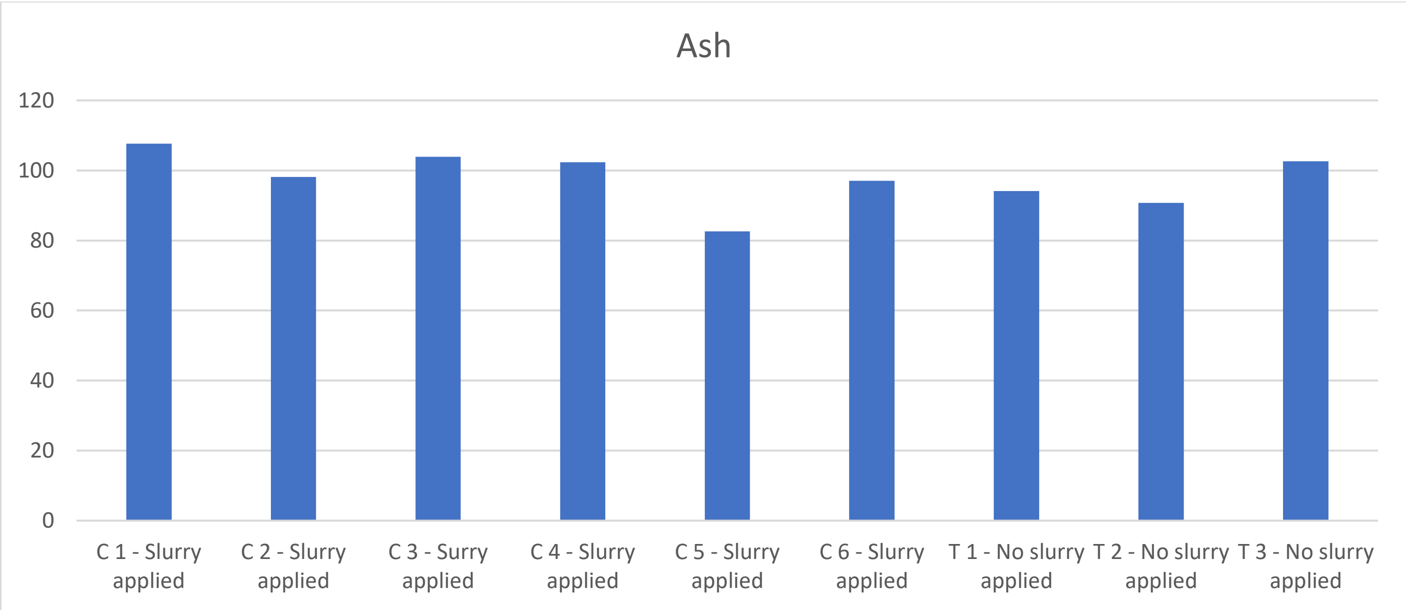




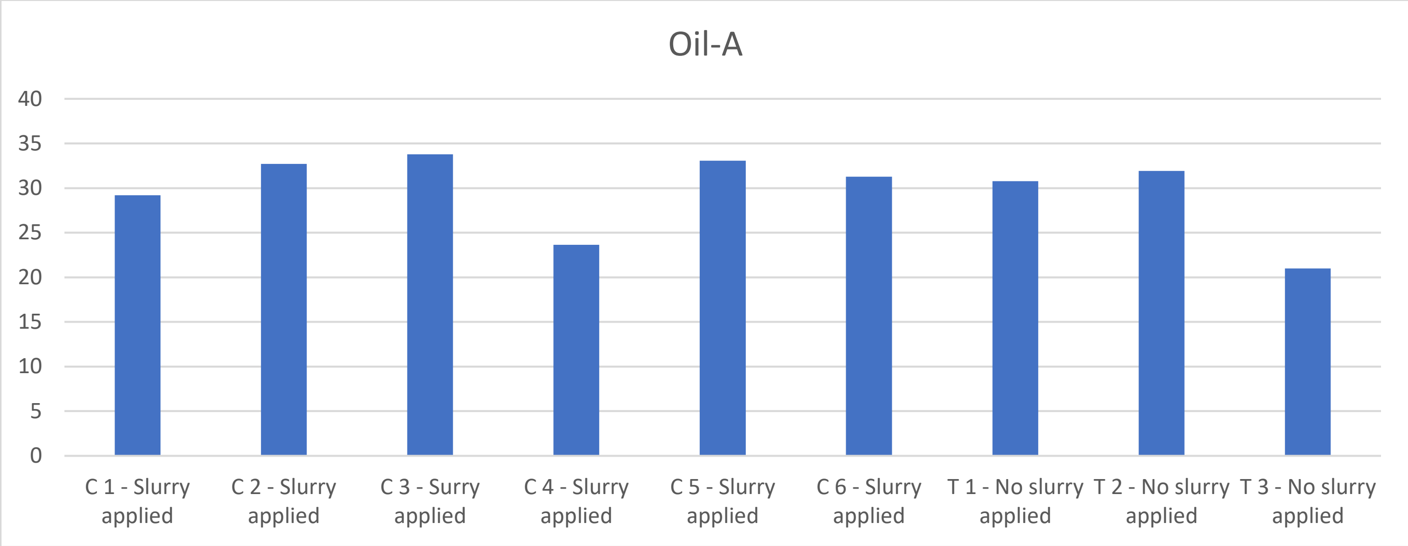
- Tramline T3 did not receive slurry and recorded the highest content of sugar.



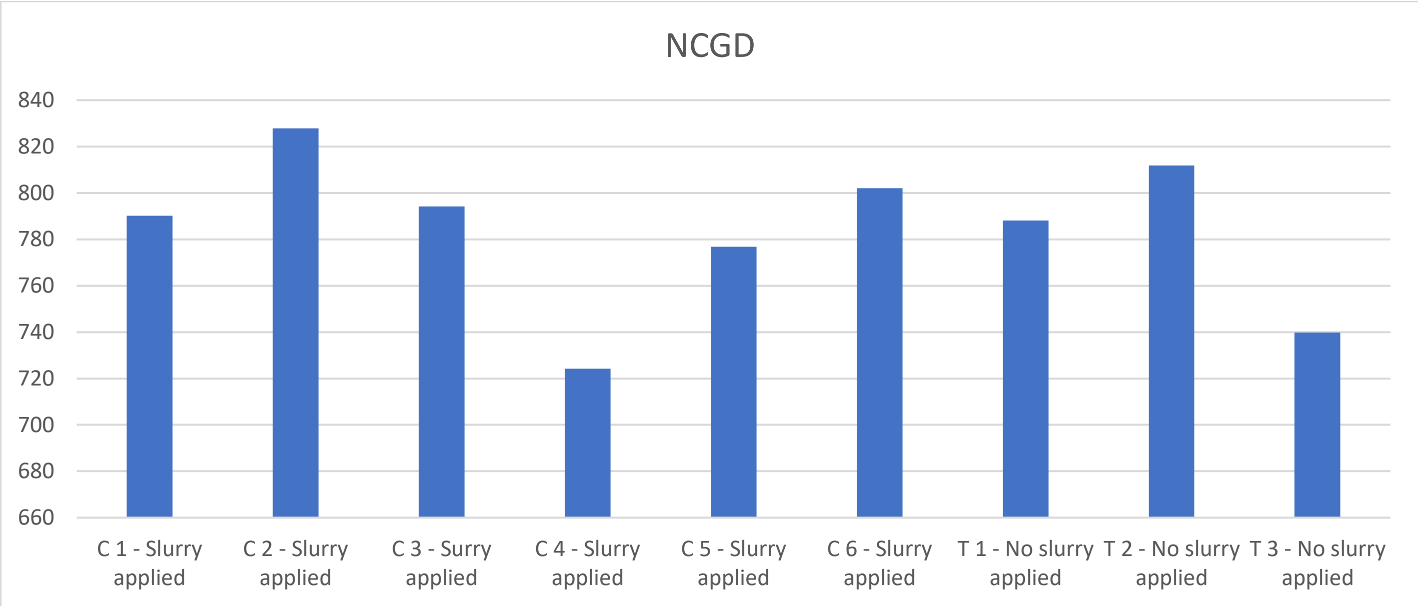
- C2 received slurry and recorded the highest Soluble Crude Protein. T3 did not receive slurry and recorded the next highest content level. C5, C4, C1 and C6 received slurry and recorded the lowest content.



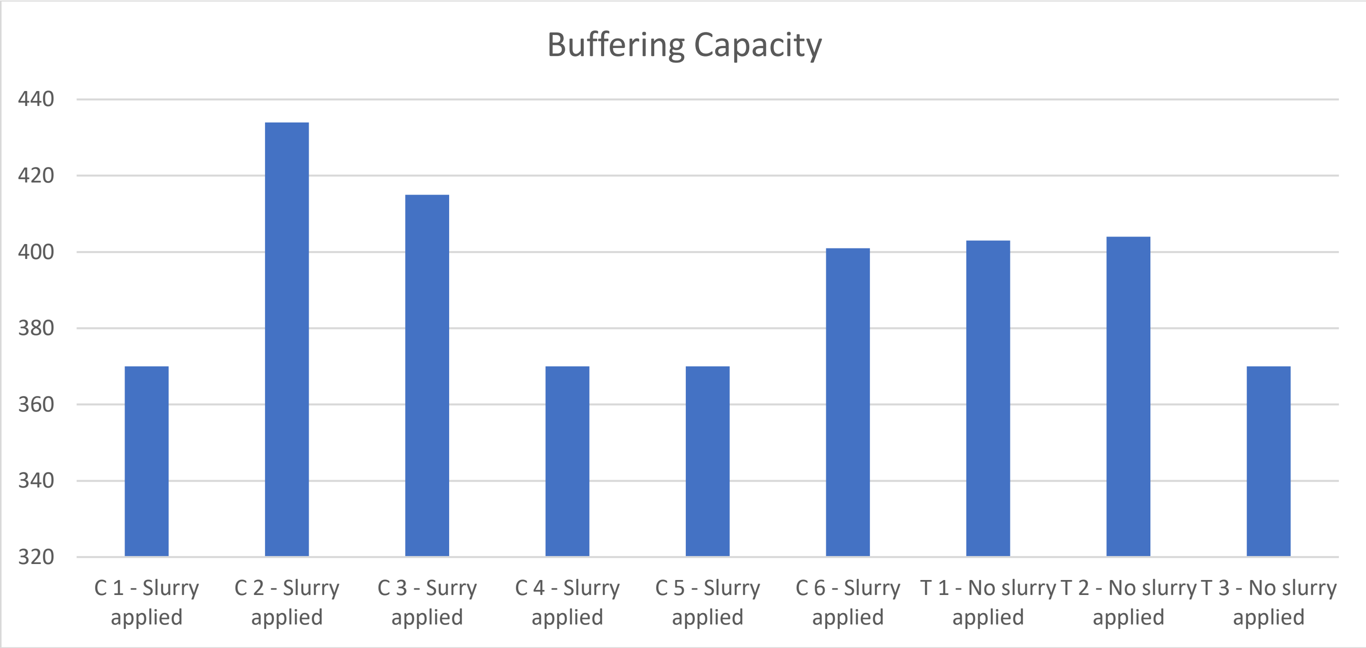
- Tramlines C1 and C3 received slurry and they recorded the highest Ash content.



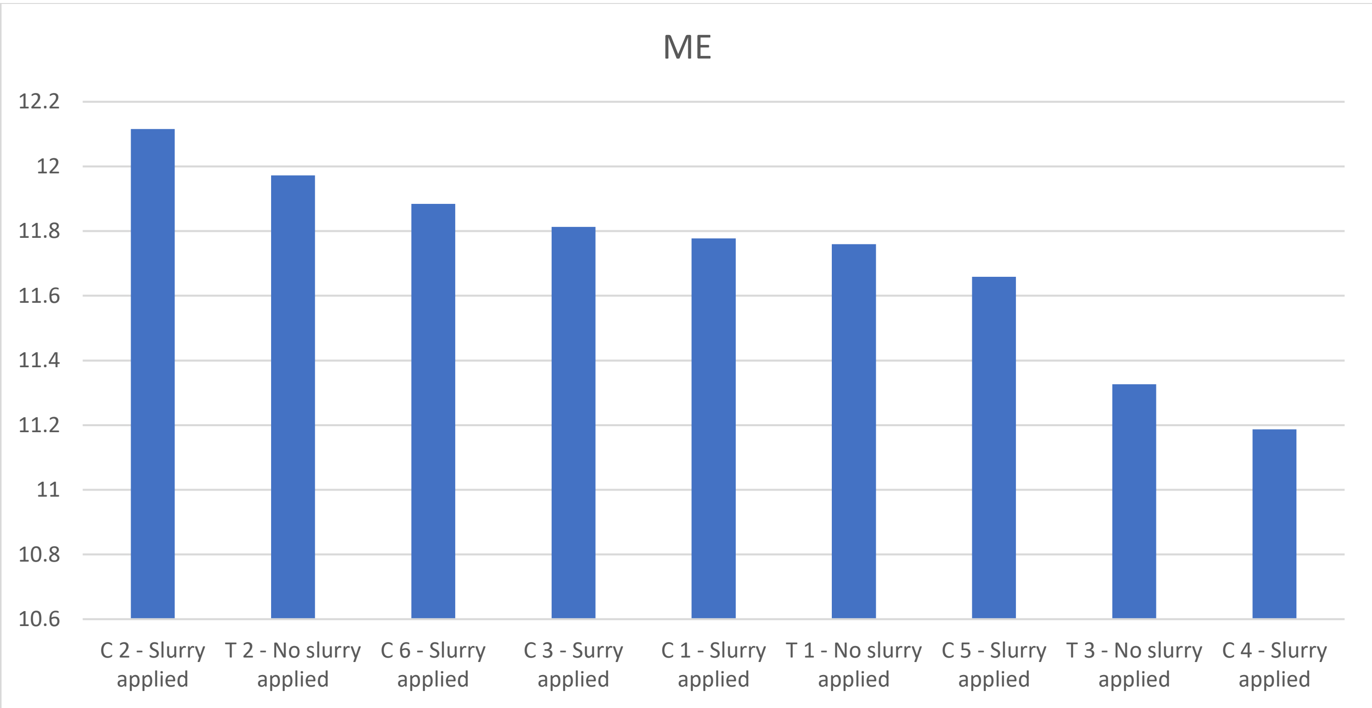
- C3, C5 and C2 received slurry and recorded the highest Oil-A content.



- C2 received slurry and T2 did not receive any and both recorded the highest content of NCGD.



- Tramlines C2 and C3 received slurry and they recorded the highest Buffering Capacity. The tramlines that received slurry also recorded the lowest values.



Tramlines C2 received slurry and recorded the highest ME value.