European Innovation Partnership (EIP) Wales

Developing a novel way of rapidly measuring agronomic treatment effects on grass growth

Final Report

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ADAS GENERAL NOTES

Title: Developing a novel way of rapidly measuring agronomic treatment effects on grass growth

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1 SUMMARY

- The objective of the study was to develop a novel way of rapidly measuring the effects of agronomic treatments on grass yield using images from drone and satellite.
- This objective was investigated by setting up five field-scale strip trials in grass and grass/clover fields in 2020 and 2021 testing a wide range of agronomic treatments including different grass and clover mixes, sulphur fertiliser rates, slurry, Smart Grass growth promoter, and biostimulant products.
- The effects of these treatments on forage biomass were measured using a rising plate meter, taking at least five measurements in each treatment strip. The treatments were replicated in two of the experiments (testing sulphur and slurry) which meant that the results could be statistically analysed. However, none of the results were statistically significant. The treatments were not replicated in the other three experiments, either because this was logistically difficult (e.g. drilling different variety mixes) or the fields were not large enough to have multiple test strips (e.g. to test Smart Grass and biostimulant products). These unreplicated trials gave useful clues about which treatments resulted in the most biomass. However, none of the treatments caused large effects on grass biomass that were consistent across several measurement dates, so it was often difficult to conclude with certainty which treatments may have been beneficial.
- These rising plate meter results illustrate very well the challenges that farmers growing forage crops have with testing the effect of new products which include: i) fields are often too small to replicate treatments to allow statistical analysis, ii) spatial variation within fields means that a large number of rising plate meter measurements must be taken, or treatment effects must be large, to be able to conclude with confidence that a treatment has had an effect, iii) taking sufficient rising plate meter measurements is laborious and expensive in time.
- A drone was used to collect multispectral images from each trial on a single date. The data was collected at a very high resolution with a measurement every few centimetres, giving over one million measurements per hectare. Satellite data was also acquired for each trial. This data had a resolution of 10-20m, giving 25-100 data points per hectare.
- The multispectral data was used to calculate several vegetation indices (VI), with the VI called WDRVI (Wide Dynamic Range Vegetation Index) correlating best with the ground-truthed rising plate meter measurements across all trials in both years. An increase in the WDRVI of 0.1 units corresponded with an increase in dry forage biomass of 2400 kg/ha. This relationship was used to equate differences in WDRVI caused by the agronomic treatments with differences in forage dry biomass.
- The drone and satellite data were analysed using the ADAS Agronomics approach. First a grid was created and mean VI assigned to each grid 3m x 3m square before being converted to a point data. Then the data were cleaned to remove headlands, treatment boundaries and locally extreme data points. A model of underlying variation was applied to the data to account for spatial variation within the field. The statistical analysis returned treatment effects with standard errors, allowing calculation of 95% confidence limits from which whether a treatment effect was statistically significant could be estimated.
- Analysis of the drone data revealed statistically significant differences in VI (which acts as a proxy measure of dry forage biomass) in four of the five trials.
    - Hardwick Farm 2020: red clover/ryegrass mix had 650 and 775 kg/ha more dry biomass than the white clover and ryegrass treatments respectively on 6th July
    - Hardwick Farm 2021: The ryegrass has 1100 kg/ha more dry biomass than the white clover and red clover/ryegrass on 30th May.

- Graig Olway Farm 2020: slurry increased dry biomass by 500 kg/ha on 6th July
- Graig Olway Farm 2021: Seaweed Organic 1 increased dry biomass by 340 kg/ha and Seaweed treatment 2 increased dry biomass by 140 kg/ha on 30th May. The Smart Grass had no effect.
- Trostrey Court Farm 2020: On 6th July, the full rate sulphur treatments had about 250 kg/ha more dry biomass than the zero and half-rate treatments, but these differences were not statistically significant.

- Analysis of the satellite data gave similar treatment effects to the drone data. Exceptions were that it did not detect a significant effect of Seaweed Organic 1 and it showed that the Smart Grass treatment significantly reduced biomass.
- The smallest significant difference detectable using drone data was commonly 100-200 kg/ha (dry biomass), but could be as much as 600 kg/ha.
- The standard error of the satellite data was typically two to three times greater than the drone data which indicates that smallest treatment differences detectable with satellite data will be two to three times greater than achievable by drone.
- It will be possible to detect smaller treatment differences using both drone and satellite data by including more replicate strips of each treatment.
- It is concluded that both drone and satellite data could be used by farmers to estimate grass biomass and to measure whether agronomic treatments increase grass biomass.
    - Drone data has the advantages of high precision and can be acquired in cloudy conditions, but it does require a high level of technical expertise for a farmer to operate and collect this data or a specialised contractor would need to be used.
    - Satellite data can be free, but does require expertise to acquire the data, it can only be captured in cloudless conditions which may not occur for several weeks sometimes and cannot detect treatment differences as small as can be detected using drone data.
    - Both drone and satellite data require specialist analytical skills to test whether an agronomic treatment has had a statistically significant effect on grass growth.
- Further work should:
    - Test the approaches for measuring the effect of agronomic treatments in a wider range of conditions including different farms, different grass and clover species and different agronomic treatments.
    - Develop approaches whereby groups of farmers can work together to test new agronomic treatments of common interest and share the costs of collecting and analysing the remote sensing data.
    - A farmer group could be facilitated to assess the pros and cons of using drone data compared with satellite data in terms of costs, time demands, requirement for external expertise and quality of results, to identify which is the best approach to use.

2 INTRODUCTION

Grass yield is laborious to measure because it either involves multiple measurements with a rising plate meter, or counting and weighing silage trailers, or manually weighing grass material from known lengths of swath. Some new forage harvester systems allow grass yield to be spatially mapped, but relatively few farmers have access to this technology. This situation contrasts with arable combinable crops for which most farmers have combine harvesters with yield monitors that can generate yield maps. The upshot of this is that arable combinable crop farmers can more easily test the effects 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 rate of productivity improvement.

Recently an Innovate UK feasibility study (Project Ref 132349) demonstrated that spectral reflectance of grass crops measured by satellite could be used to accurately measure grass yield (kg dry matter per hectare) up to a yield of 4500 kg/ha, with a 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 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.

Remote sensing of grassland presents a different challenge compared with arable crops because the crop reaches full ground cover more quickly during the season, after which differentiating grass growth between treatments becomes less accurate. Nonetheless, the previous UK Innovate feasibility study has shown that remote sensing using satellite imagery can accurately measure grass growth up to a grass yield of 4500 kg dry biomass per ha. Hence, the remote sensing approach should be applicable for measuring grass growth during the first several weeks of the growing season and during the first few weeks after a silage cut or grazing.

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 spatially referenced 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 had been published in a peer reviewed scientific journal (Field Crops Research); (https://www.sciencedirect.com/science/article/pii/S0378429017318312). This approach is now being used by about 200 arable farmers each year to test whether an agronomic treatment increases yield in various arable crops.

This approach of testing agronomic treatments has a number of benefits including being done on the farmers own fields, at a scale that is meaningful to the farmer, using commercial equipment to apply the treatments, and exploiting the abundance of spatially referenced yield data that farmers now collect. It should be possible to apply the same principles to grass yield data points, but this would need to be demonstrated.

3 AIMS AND OBJECTIVES

The objective of the study was to develop a novel way of rapidly measuring the effects of agronomic treatments on grass yield using images from satellite and drone. This was achieved by combining new knowledge from two Innovate UK funded feasibility studies, to develop a method for rapidly testing the effect of agronomic treatments on grass yield. The project explored whether spectral reflectance information acquired by satellite or drone could be used to rapidly test the effect of agronomic treatments applied to grass in tramline trials. The aim of this project was not to test whether remote sensing can be used to simply measure grass growth, as this has been proven already (†Berry *et al.,* 2018). This project is about enabling farmers to test the effect of new agronomic practices cheaply and reliably.

†Berry, P.M., Blacker, C. and Leese, S. (2018). GRASS improvement using Satellite TECHnologies: GRASSS-TECH. Innovate UK Project No 132349.

4 METHODS

Three highly progressive grassland farmers came together to investigate this over a three-year period (data gathering over a 2-year financial period).

David Jones
Hardwick Farm, Old Raglan Road, Abergavenny, NP7 9BT

David Morgan
Trostrey Court Farm, Usk, Monmouthshire, NP15 1HT

Russell Morgan
Graig Olway Farm, Usk, Monmouthshire, NP15 1NB

4.1 Treatments

In 2020 and 2021 the following trials were set up on each farm (Table 1). In each trial, agronomic treatments were allocated to neighbouring strips across the field.

- Variety trial at Hardwick Farm
- 2020 only: sulphur fertiliser trial at Trostrey Court Farm
- Slurry trial in 2020 and biostimulant trial in 2021 at Graig Olway Farm

Rising plate meter measurements were taken weekly from early June through to the third cut. Drones were then flown over the grass fields by Environment Systems on one date in each year, and following the drone flight forage samples were collected on the same day.

Table 1 Summary of field trials set up on each farm

Farm	Tramline Width	2020		2021	
		Treatment type	No. of treatments	Treatment type	No. of treatments
Hardwick	24m	Variety	3	Variety	3
Trostrey	24m	Sulphur	4	No trial	-
Graig Olway	36m	Slurry	2	Smart Grass & 2 seaweed extracts	4

4.1.1 Hardwick Farm

2020 and 2021

David Jones reseeded the field using three variety mixes. Each treatment received the same management throughout the season. In 2020, the first cut of silage was taken on 24th April, the second cut on 1st June and the third cut on 6th July. In 2021, the first cut of silage was taken on 29th April and the second cut on 10th June.

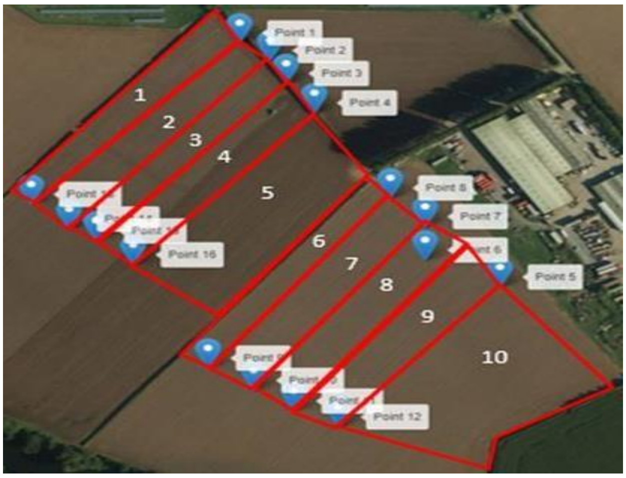
Tramline 1	Spitfire (Italian/Hybrid/Perennial Ryegrass)
Tramline 2	Spitfire (Italian/Hybrid/Perennial Ryegrass)
Tramline 3	White clover mix
Tramline 4	White clover mix
Tramline 5	Spitfire Pro-Nitro (Italian/Hybrid/Perennial Ryegrass/Red Clover)
Tramline 6	Spitfire Pro-Nitro (Italian/Hybrid/Perennial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

4.1.2 Trostrey

2020

David Morgan investigated the effects of applying different rates of sulphur fertiliser. Each tramline received the same amount of non-sulphur fertiliser and management throughout the season. Sulphur fertiliser (liquid elemental product) was applied on 22nd May and 22nd June. The first cut of silage was taken on 2nd May (before differential treatment applications), the second cut on 1st June, the third cut on 11th July and the 4th cut on 30th August.

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



4.1.3 Graig Olway

2020

Russell Morgan investigated impacts on yield and quality of grass of using slurry in his fertilising plan. Each tramline received the same amount of inorganic fertiliser and other management throughout the season. The slurry was applied on 26/06/2020 using a trailing shoe – shallow injection method. The first cut of silage was taken on 25th June and the second cut on 23rd July. Prior to the trial, the fields were grazed by sheep until the end of spring.

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

2021

In 2021, different treatments were tested including Smart Grass, Seaweed Organic Treatment 1 and Seaweed Treatment 2.

Map	Application	Rate
Tramline 1, 3, 5, 7 & 9	Farm standard	
Tramline 4,6	Smart Grass	20g/ha
Tramline 2	Seaweed organic treatment – 1	10L/ha
Tramline 8	Seaweed treatment – 2	10L/ha

4.2 Physical grass measurements

Grass growth was measured by ADAS at regular intervals 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.

4.3 Drone flights

Environment Systems flew each field on one date per year (6th July 2020 and 30th May 2021) and carried out the following tasks including;

- Tasked and acquired red green blue (RGB) and multispectral imagery from a drone
- Capture visible RGB data using a 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 Real Time Kinematic (RTK) technology onboard the drone
- 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.

Table 2 Reference data relating to the drone light wavelengths measured (nm)

Band	Name	Min	Max	Central
Band 1	Green	530	570	550
Band 2	Red	640	680	660
Band 3	Red Edge	730	740	735
Band 4	NIR	770	810	790

4.4 Satellite images

Environment Systems Data Services also acquired satellite images from the Sentinel-2 satellite at the closest possible date to the drone 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
- 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.

Table 3 Reference data relating to Sentinel-2 10 m band light wavelengths measured (nm)

Band	Name	Min	Max	Central
Band 2	Blue	438	532	492.1
Band 3	Green	536	582	559
Band 4	Red	646	685	665
Band 8	NIR	774	907	833

4.5 Data analysis

4.5.1 Vegetation index calculation

Eleven vegetation indices (combination of two or more wavelengths designed to highlight particular properties of vegetation) were calculated from the data (Table 4) for statistical analysis. The vegetation indices were averaged using a 3x3m grid for drone imagery and 10x10m grid for satellite.

Table 4 Vegetation Indices (VIs) were calculated from the data

Vegetation Index	Description	Formula	Wavebands	Created for
Canopy Chlorophyll Content Index (CCCI)	The CCCI measures crop nitrogen status.	$CCCI = \frac{\frac{NIR - rededge}{NIR + rededge}}{\frac{NIR - Red}{NIR + Red}}$	Red Red edge NIR	Drone only
Chlorophyll Index Red-Edge (CIRE)	This VI estimates canopy chlorophyll or N content.	$CIRE = \frac{NIR}{red\ edge} - 1$	Red edge NIR	Drone only
Normalised Difference Red Edge index (NDRE)	Assesses the health of vegetation.	$NDRE = \frac{NIR - red\ edge}{NIR + red\ edge}$	Red edge NIR	Drone only
Normalised Difference Vegetation Index, NDVI	NDVI is an index of plant greenness or photosynthetic activity.	$NDVI = \frac{NIR - Red}{NIR + Red}$	Red NIR	Drone and Satellite
Normalised Green-Red Difference Index, NGRDI	NGRDI measures surface greenness and is 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	Drone and Satellite
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	Drone and Satellite
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	Drone and Satellite
OSAVI		$OSAVI = (1 + 0.16)\frac{(NIR - Red)}{(NIR + Red + 0.16)}$	Red NIR	Drone and Satellite

Green leaf index, GLI		$GLI = \frac{(2Green - Red - Blue)}{(2Green + Red + Blue)}$	Blue Green Red	Drone (RGB) and Satellite
NGRDI		$NGRDI = \frac{(Green - Red)}{(Green + Red)}$	Green Red	Drone (RGB) and Satellite
Visible Atmospherically Resistant Index, VARI		$VARI = \frac{(Green - Red)}{(Green + Red - Blue)}$	Blue Green Red	Drone (RGB) and Satellite
Triangular greenness index, TGI		$TGI = -0.5[(670 - 480)(Red - Green) - (670 - 550)(Red - Blue)]$	Blue Green Red	Drone (RGB) and Satellite

4.5.2 Regression of vegetation indices against rising plate meter data

The spectral reflectance values that corresponded with the location of each field rising plate meter measurement were then identified and collated. We focused our analysis on vegetation index WDRVI because it was shown to have the strongest relationship with grass biomass, as measured using a rising plate meter at each site (Table 5). However, other vegetation indices had similar correlation coefficients (e.g. NDVI), so other vegetation indices could have been used. The relationship across all sites (Figure 1) indicates that increasing WDRVI by 0.1 units corresponds to an increase in grass biomass of 1847 kg/ha and helps to equate changes in WDRVI to a practical output.

Table 5 Correlation coefficients summarising how well each spectral reflectance index correlated with grass biomass measured using a rising plate meter (kg/ha) in 2020. Values above 0.5 represent a good correlation.

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

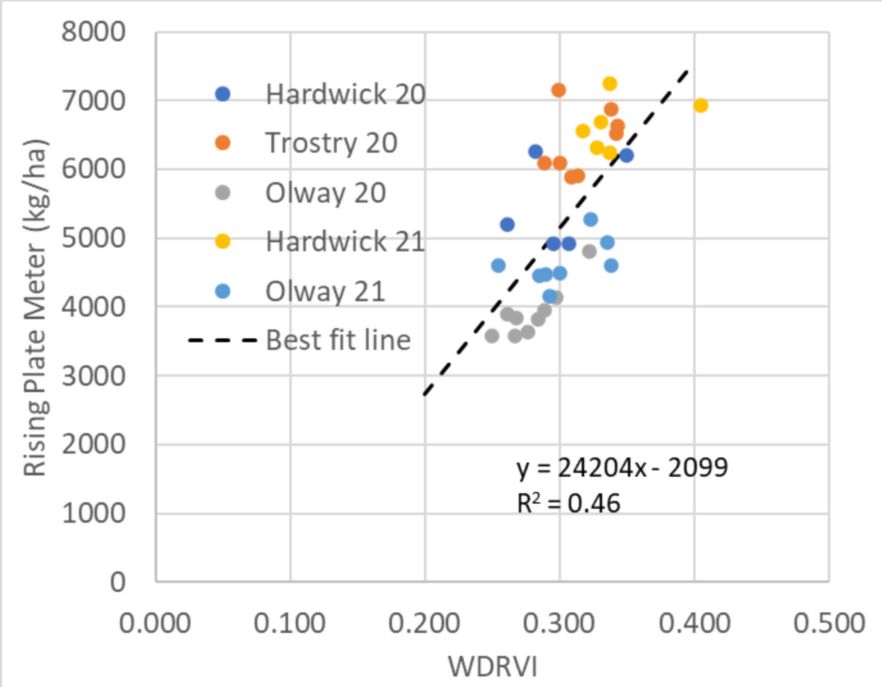


Figure 1 Relationship between spectral reflectance index WDRVI and grass biomass measured using a rising plate meter across all the trials in 2020 and 2021. Each point represents the average value of a tramline. Best fit line: y=24204x-2099, R^2=0.46, P<0.05.

4.5.3 Analysis of drone and satellite data

The satellite and drone data were analysed using the ADAS Agronomics approach. Grids were set up, aligned with the direction of the treatment boundaries. Data was summarised to a 3 x 3 m grid for the drone data and 10 x 10 m grid for the satellite data. First, the data were cleaned to remove headlands and locally extreme data points. Rows were removed on either side of a treatment boundary to ensure there was no overlap of treatments. Then a model of underlying variation was applied to the data to account for spatial variation across rows and along rows, and the effect of the treatment. The statistical analysis returned treatment effects with standard errors, allowing calculation of 95% confidence limits.

5 RESULTS

5.1 Hardwick

5.1.1 2020

Physical measurements of the treatment strips using a rising plate meter produced the data summarised in Table 6 below. It is not possible to statistically analyse this data because the treatment strips were not replicated. The measurements taken closest to the time of the drone flight on 6th July 2020 show that the biomass values were lowest for the white clover treatment. It is not possible to test whether these differences were statistically significant because the treatment strips were not randomised due to the practicalities of drilling different varieties.

Table 6 Grass biomass estimated from rising plate meter measurements (kg/ha)

	Ryegrass	White clover	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**

The WDRVI data from the drone was processed and analysed using the ADAS Agronomics technique. The data analysed is illustrated in Figure 2 which shows the remaining data after data cleaning. Analysis of the WDRVI data collected from the drone and satellite in 2020 showed consistent results, with the ryegrass / red clover treatment having a significantly greater WDRVI treatment than the ryegrass and white clover treatments (Table 7). The effect was for the ryegrass / red clover to have a WDRVI value that was 0.027 units greater than the white clover mix, which equates to a greater dry biomass yield value of about 650 kg/ha, and 0.032 WDRVI units greater than the ryegrass – which equates to a greater dry biomass yield of about 775 kg/ha. The satellite imagery showed the same ranking of yield between the treatments with treatment differences that were also statistically significant. Additionally, the satellite data showed that the ryegrass treatment had a significantly smaller WDRVI value than the white clover treatment. It is not possible to equate this to a dry biomass value because ground truth measurements were not taken at the same time as the satellite image was captured.

The standard error values were small for the drone data indicating that this could detect small treatment differences equivalent to a dry biomass yield difference of as little as 120 kg/ha. The lower resolution satellite imagery had a detection limit that was about three times larger than the drone.

Table 7 Analysis of WDRVI data from drone and satellite

	Drone 06/07/20		Satellite 23/06/20	
Treatment	**Average WDRVI**	**Treatment effect compared with white clover, with 95% confidence limits**	**Average WDRVI**	**Treatment effect compared with white clover, with 95% confidence limits**
White clover	0.28		0.36	
Ryegrass		-0.005 ± 0.005		-0.025 ± 0.016
Ryegrass / red clover		+0.027 ± 0.005		+0.041 ± 0.016

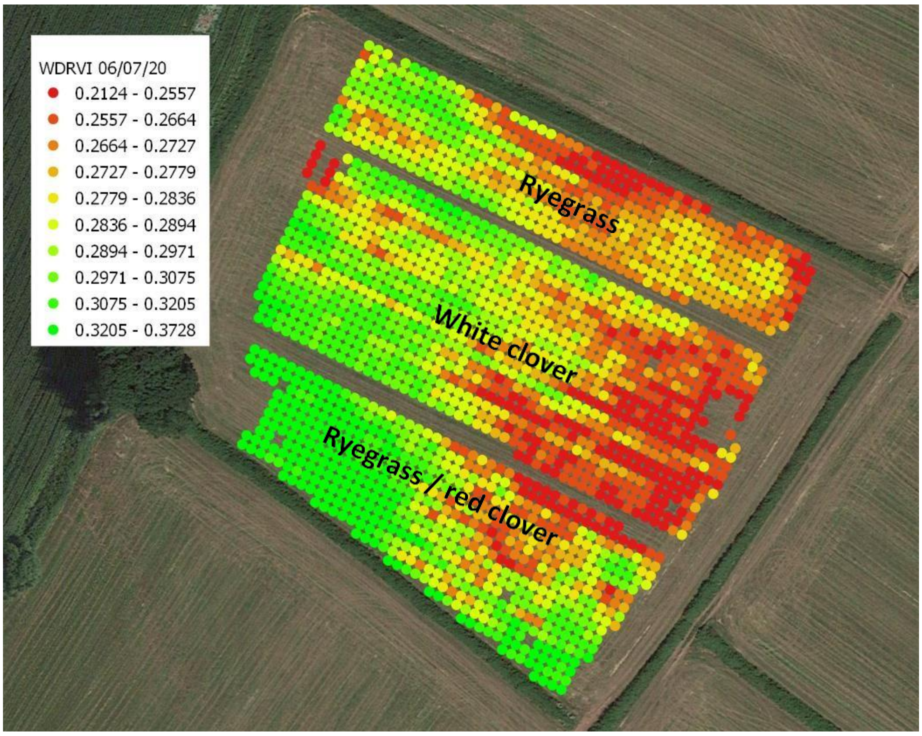


Figure 2 Hardwick 2020: drone WDRVI data (06/07/20) retained in the Agronomics statistical analysis after data cleaning

5.1.2 2021

Physical measurements of the treatment strips using a rising plate meter produced the data summarised in Table 8 below. The measurements taken closest to the time of the drone flight on 30th May 2021 show that the biomass values were lowest for the ryegrass/red clover treatment. It is not possible to test whether these differences were statistically significant because the treatment strips were not randomised due to the practicalities of drilling different varieties.

Table 8 Grass biomass estimated from rising plate meter measurements (kg/ha)

	Ryegrass	White clover	Ryegrass/ red clover
11th May	3501	3335	3391
19th May	4532	4336	4413
26th May	5771	5953	5316
30th May	6815	6790	6407
Average	**5155**	**5103**	**4882**

Analysis of the drone data (Table 9) showed that the ryegrass had a significantly greater WDRVI than the white clover by 0.046 units, which would equate to about 1100 kg/ha of dry biomass. There was no significant difference between the white clover and ryegrass/red clover mix. The data analysed is illustrated in Figure 3 which shows the remaining data after data cleaning. The satellite data analysis was consistent with the drone data analysis, in that the ryegrass treatment had a significantly greater WDRVI than the White clover.

The standard error values for the drone data indicate that this could detect treatment differences equivalent to a dry biomass yield difference of about 400 kg/ha. The lower resolution satellite imagery had a detection limit that was about 50% larger than the drone.

Table 9 Analysis of WDRVI data from drone and satellite

	Drone 30/05/21		Satellite 18/05/21	
Treatment	Average WDRVI	Treatment effect compared with white clover, with 95% confidence limits	Average WDRVI	Treatment effect compared with white clover, with 95% confidence limits
White clover	0.35		0.37	
Ryegrass		+0.046 ± 0.0017		+0.067 ± 0.022
Ryegrass / red clover		-0.004 ± 0.017		-0.015 ± 0.023

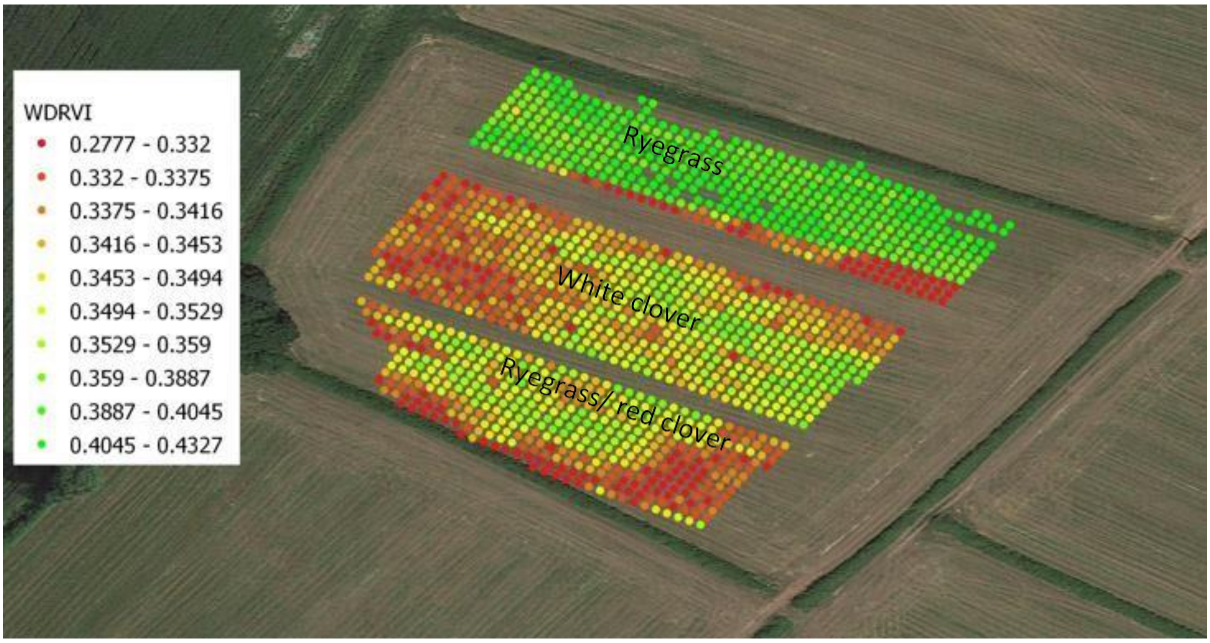


Figure 3 Hardwick 2021: drone WDRVI data (20/05/21) retained in the Agronomics statistical analysis after data cleaning

5.2 Graig-Olway

5.2.1 2020

Physical measurements of the treatment strips using a rising plate meter produced the data summarised in Table 10 Grass biomass estimated from rising plate meter measurements (kg/ha) in 2020 below. Statistical analysis using ANOVA showed no statistically significant effects of the treatments in 2020. The drone image taken on 6th July is shown in Figure 4.

Table 10 Grass biomass estimated from rising plate meter measurements (kg/ha) in 2020

	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**

Figure 4 Drone image of Graig-Olway taken on 6/7/20

The three fields at Graig-Olway are in a different orientation and have treatment boundaries between the fields. Therefore the analysis was performed per field with a cross site analysis. The centre strip of each field did not receive any slurry.

Some data was removed from each field because it was either on a field boundary, outside the treatment area or unreliable data due to trees or underlying field variation. Field areas for which drone data was removed are illustrated in Figure 5 for all three fields. Data not included in the satellite analysis for the same reasons is illustrated in Figure 6.

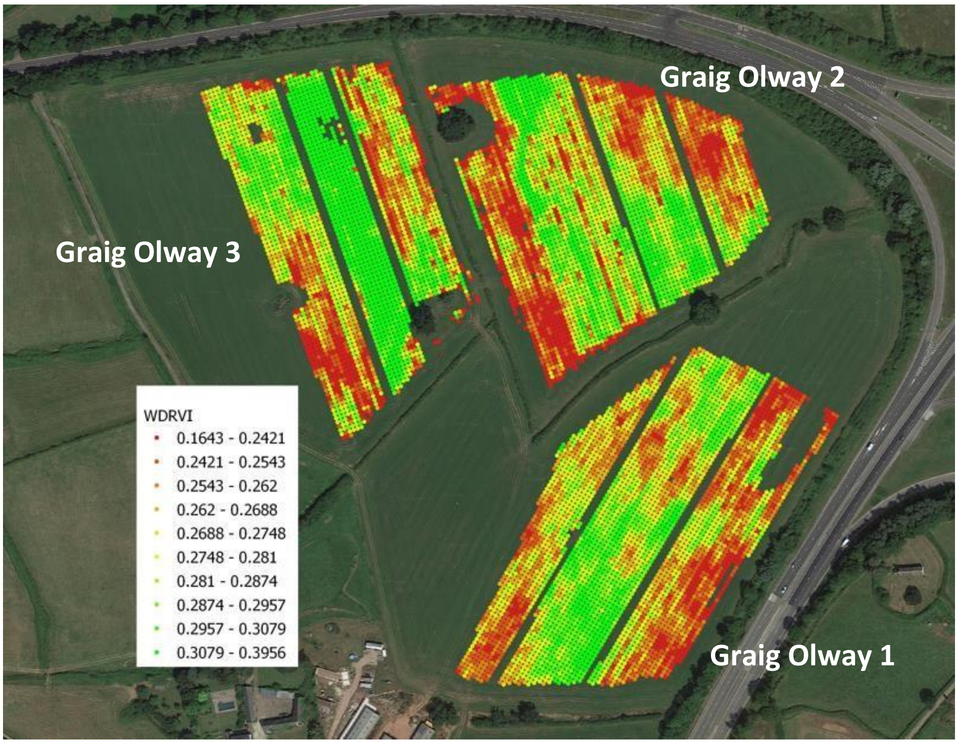


Figure 5 Graig Olway 2020: drone WDRVI data (06/07/20) retained in the Agronomics statistical analysis after data cleaning

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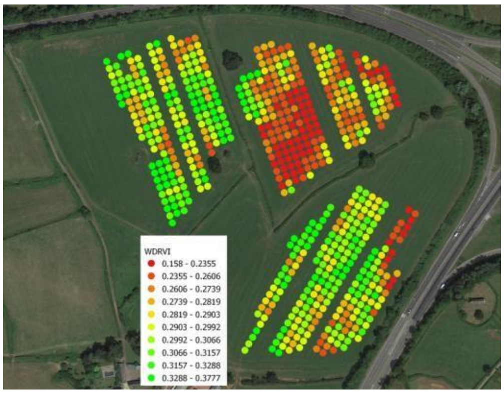
<tr><td>
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Figure 6 Graig Olway 2020: satellite WDRVI data retained in the Agronomics statistical analysis after data cleaning

The analysis shows that WDRVI was higher in tramlines with slurry application than in tramlines without slurry application (Table 9). Analysis of the drone data showed significant differences for each individual field and all three fields combined. Across all three fields, slurry increased WDRVI by 0.029 units which equate to an increase in dry biomass of about 500 kg/ha. The standard error values were small for the drone data indicating that this could detect small treatment differences equivalent to a dry biomass yield difference of as little as 120 to 340 kg/ha.

Analysis of the satellite data captured on 05/07/20 showed that the slurry treatment significantly increased WDRVI values in each field and across all three fields (Table 11). However, it is puzzling why the WDRVI values are lower than typically observed. While the survey fields are not covered by cloud, the full satellite image covering a wider area is heavily affected by cloud cover – it may therefore still be having an effect on the values created for this image. Data from the satellite image on 23/06/20 showed no statistically significant effects of the slurry treatment. The standard error values were two to five times larger for the satellite data (captured on 23/06/20) compared with the drone data, which explains why it was not possible to detect statistically significant differences using the satellite data captured on this date.

Table 11 Analysis of WDRVI data from drone and satellite

	Drone 06/07/20		**Satellite 23/06/20**		**Satellite 05/07/20**	
Area	**Control average WDRVI**	**Slurry treatment effect, with 95% confidence limits**	**Control average WDRVI**	**Slurry treatment effect, with 95% confidence limits**	**Control average WDRVI**	**Slurry treatment effect, with 95% confidence limits**
Graig Olway 1	0.26	+0.021 ± 0.007	0.29	+0.011 ± 0.034	0.016	+0.047 ± 0.034
Graig Olway 2	0.27	+0.015 ± 0.014	0.26	+0.016 ± 0.023	0.006	+0.051 ± 0.039
Graig Olway 3	0.27	+0.049 ± 0.009	0.31	-0.006 ± 0.018	-0.031	+0.075 ± 0.070
Graig Olway cross site analysis	0.27	+0.029 ± 0.006	0.28	+0.003 ± 0.013	-0.004	+0.052 ± 0.024

5.2.2 2021

The rising plate meter measurements are summarised in Table 12. For the date when the drone images were taken (30th May), there were no clear benefits of any of the test treatments, and the Smart Grass had a lower average biomass than the control. It was not possible to statistically analyse this data because in each field either the test treatment or the control treatment were not replicated.

Table 12 Grass biomass estimated from rising plate meter measurements (kg/ha) in 2021

	11th May	19th May	26th May	30th May	average
A1 - Untreated	2278	2936	4028	4451	**3423**
A2 - Seaweed organic 1	2054	2894	3510	4470	**3232**
A3 - Untreated	2194	3006	4070	4596	**3467**
B4 - Smart Grass	1984	2432	3258	4162	**2959**
B5 - Untreated	2180	2460	3454	4490	**3146**
B6 - Smart Grass	2292	2656	3552	4322	**3206**
C7 - Untreated	2028	2698	3272	4596	**3149**
C8 - Seaweed treatment 2	2488	3062	4182	4944	**3669**
C9 - Untreated	2502	2768	3944	5268	**3621**

The drone and satellite data were analysed for each field separately to test each of the three biostimulant treatments. Some drone data was removed from each field because it was either on a field boundary, outside the treatment area or unreliable data due to trees or underlying field variation. Field areas for which drone data was removed are illustrated in Figure 7. Data not included in the satellite analysis for the same reasons is illustrated in Figure 8.

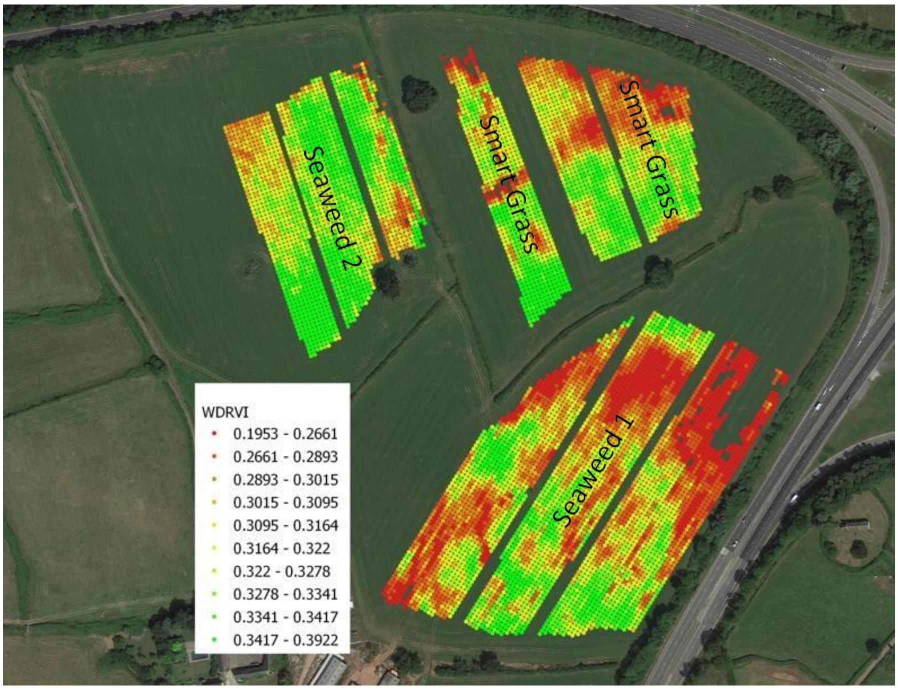

Figure 7 Graig Olway 2021: drone (30/05/2021) WDRVI data retained in the Agronomics statistical analysis after data cleaning

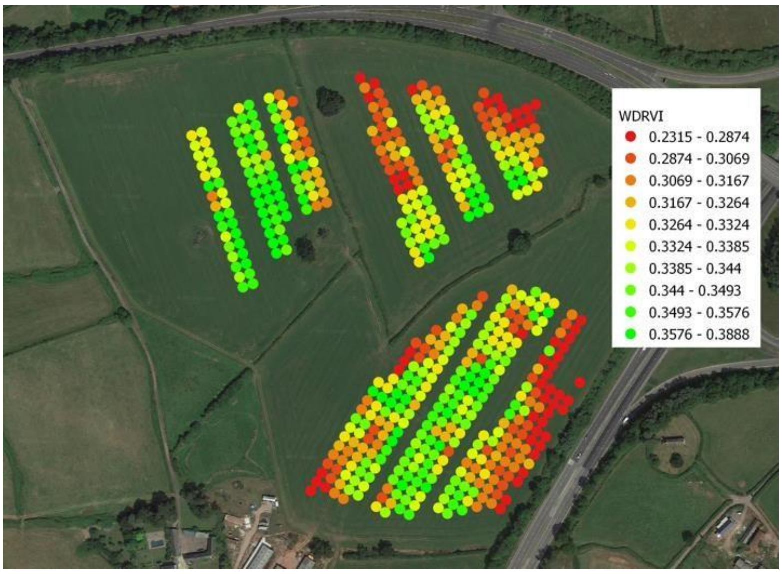

Figure 8 Graig Olway 2020: satellite (31/05/2021) WDRVI data retained in the Agronomics statistical analysis after data cleaning

Analysis of the drone data indicated that both the Seaweed Organic 1 and Seaweed product 2 treatments significantly increased the WDRVI, by 0.014 and 0.006 units respectively. These increases in WDRVI equate to increases in dry biomass of about 340 kg/ha and 140 kg/ha respectively. Smart Grass did not significantly affect WDRVI. The standard error values were small for the drone data indicating that this could detect small treatment differences equivalent to a dry biomass yield difference of as little as 120 kg/ha.

The satellite data showed effects consistent with the drone analysis, in that Seaweed Organic 1 significantly increased WDRVI. Seaweed product 2 increased biomass, but not by a statistically significant amount. Smart Grass significantly decreased the WDRVI. The standard error values were three to five times larger for the satellite data than for the drone data, which means satellite data did not allow detection of treatment differences as small as with drone data.

Table 13 Analysis of WDRVI data from drone and satellite

	Drone 30/05/21		Satellite 31/05/21	
Area	Control average WDRVI	Treatment effect	Control average WDRVI	Treatment effect
Seaweed Organic 1	0.30	+0.014 ± 0.005	0.31	+0.028 ± 0.030
Smart Grass	0.31	-0.002 ± 0.004	0.34	-0.020 ± 0.014
Seaweed product 2	0.33	+0.006 ± 0.005	0.34	+0.018 ± 0.019

5.3 Trostrey

Physical measurements of the treatment strips using a rising plate meter produced the data summarised in Table 14 below. Statistical analysis using ANOVA showed no statistically significant effects of the treatments in 2020.

Table 14 Grass biomass estimated from rising plate meter measurements (kg/ha), in Trostrey sulphur trial 2020

	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

The drone image is illustrated in Figure 9. Some drone data was removed from each field because it was either on a field boundary, outside the treatment area or unreliable data due to trees or underlying field variation. Field areas for which drone data was removed are illustrated in Figure 10. Data not included in the satellite analysis for the same reasons is illustrated in Figure 11.

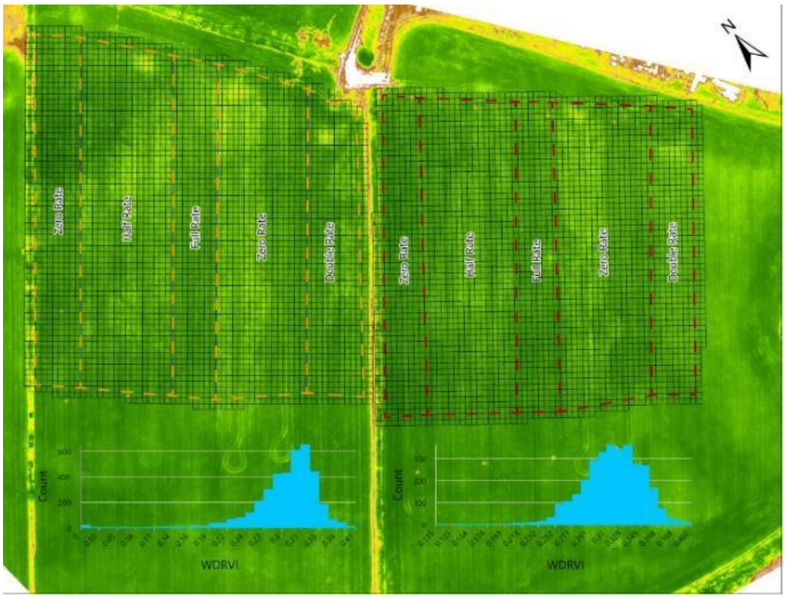

Figure 9 Drone image of the field taken on 6th July, together with the frequency distribution of WDRI values in each field

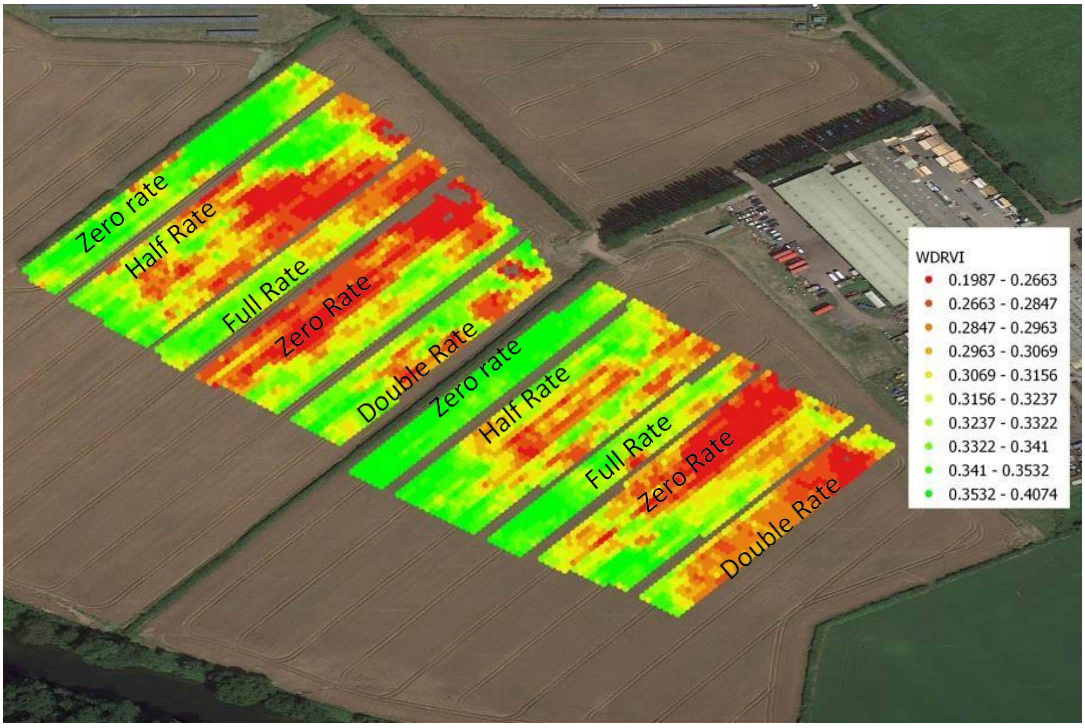

Figure 10 Trostrey 2020: drone (05/07/2020) WDRVI data retained in the Agronomics statistical analysis after data cleaning

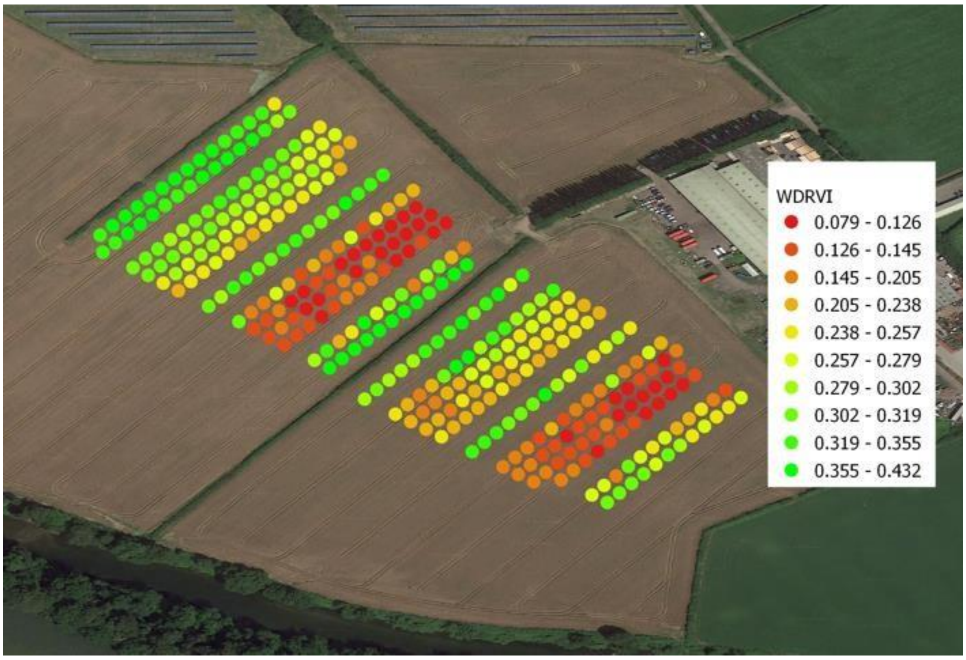

Figure 11 Trostrey 2020: satellite (23/06/2020) WDRVI data retained in the Agronomics statistical analysis after data cleaning

At Trostrey, a field boundary down the middle of the trial may have influenced the neighbouring treatments. Therefore, the trial was split into two fields and analysed separately, as well as one combined field to check if there was any impact of the boundary on the analysis. Furthermore, the trial was set up with zero rate as the control but there was concern that this treatment was on the field boundary in both fields which may have behaved differently to the main body of the field. Therefore, the trial was analysed in four different ways to check that these potential issues were not affecting the outcome of the analysis (as summarised below).

1. Two separate fields with full rate as the control
2. Two separate fields with zero rate as the control
3. One field with full rate as the control
4. One field with zero rate as the control

The drone data analysis showed that the full rate sulphur treatments had greater average WDRVI values than the zero and half-rate treatments, but these differences were not statistically significant (Table 15). The Least Significant Difference (LSD) values were two to four times greater than in the other trials, which may have been caused by spatial variation within each field. The large LSD values explain why statistically significant differences were not detected. The only statistically significant effect was for the double sulphur rate to have a lower WDRVI value than the full sulphur or zero sulphur rates in the East field. This unexpected effect may have been caused by the double sulphur treatment causing the grass to lodge, resulting in a low WDRVI. The satellite data also revealed no statistically significant differences (Table 16). As well as combining the two separate fields into one field for the analysis, a cross site analysis was also performed which gave very similar results.

Table 15 Analysis of WDRVI data from drone

	Zero rate	Half rate	Full rate	Double rate
	Separate fields with full rate as control			
	Effect with 95% confidence limits	Effect with 95% confidence limits	Control mean	Effect with 95% confidence limits
East WDRVI	-0.013 ± 0.023	-0.013 ± 0.024	0.33	-0.037 ± 0.028
West WDRVI	-0.008 ± 0.026	-0.016 ± 0.027	0.31	0.000 ± 0.030
	Separate fields with zero rate as control			
	Control mean	Effect with 95% confidence limits	Effect with 95% confidence limits	Effect with 95% confidence limits
East WDRVI	0.32	-0.000 ± 0.018	+0.013 ± 0.023	-0.023 ± 0.022
West WDRVI	0.31	-0.007 ± 0.020	+0.008 ± 0.026	+0.009 ± 0.024
	One field with full rate as control			
	Effect with 95% confidence limits	Effect with 95% confidence limits	Control mean	Effect with 95% confidence limits
Both fields WDRVI	-0.010 ± 0.018	-0.016 ± 0.018	0.32	-0.020 ± 0.021
	One field with zero rate as control			
	Control mean	Effect with 95% confidence limits	Effect with 95% confidence limits	Effect with 95% confidence limits
Both Fields WDRVI	0.31	-0.006 ± 0.014	+0.010 ± 0.018	-0.009 ± 0.017

Table 16 Analysis of WDRVI data from satellite

	Zero rate	Half rate	Full rate	Double rate
	Separate fields with full rate as control			
	Effect with 95% confidence limits	Effect with 95% confidence limits	Control	Effect with 95% confidence limits
East WDRVI	-0.100 ± 0.137	-0.064 ± 0.142	0.30	-0.033 ± 0.167
West WDRVI	-0.093 ± 0.199	-0.069 ± 0.209	0.32	+0.004 ± 0.245
	Separate fields with zero rate as control			
	Control	Effect with 95% confidence limits	Effect with 95% confidence limits	Effect with 95% confidence limits
East WDRVI	0.18	+0.036 ± 0.110	+0.100 ± 0.137	+0.067 ± 0.126
West WDRVI	0.23	+0.024 ± 0.159	+0.093 ± 0.199	+0.097 ± 0.183

6 CONCLUSIONS & FURTHER WORK

- It is concluded that both drone and satellite data could be used by farmers to estimate grass biomass and to measure whether agronomic treatments increase grass biomass.
    - Drone data has the advantages of high precision and can be acquired in cloudy conditions, requires a high level of technical expertise for a farmer to collect the data, or a specialised contractor would need to be used.
    - Satellite data can be free but requires expertise to acquire the data, can only be captured in cloudless conditions which may not occur for several weeks, and cannot detect treatment differences as small as can be detected using drone data.
    - Both drone and satellite data require specialist analytical skills to test whether an agronomic treatment has had a statistically significant effect on grass growth.
    - In this project the cost of acquiring the drone data was approximately £850 per field. The consultant time cost of acquiring freely available satellite data from the Sentinel-2 satellite was approximately £200 per field. The consultant time cost of analysing the drone or satellite data to statistically test effects of agronomic treatments is estimated at £400 and £250 per field respectively. Possible additional costs include consultant time costs to help design the trial and position it fairly in the field to allow fair treatment comparison (£150) and to provide expert interpretation of the data with report (£150). These costs assume that the farmer is able to provide GPS coordinates of the trial and no consultant visits to the trial are required. All costs are ex-VAT.
- Analysis of the drone data revealed statistically significant differences in WDRVI (which acts as a proxy measure of dry forage biomass) in four of the five trials.
    - Hardwick Farm 2020: red clover/ryegrass mix had 650 and 775 kg/ha more dry biomass than the white clover and ryegrass treatments respectively on 6th July
    - Hardwick Farm 2021: The ryegrass has 1100 kg/ha more dry biomass than the white clover and Red clover/ryegrass on 30th May.
    - Graig Olway Farm 2020: slurry increased dry biomass by 500 kg/ha on 6th July
    - Graig Olway Farm 2021: Seaweed Organic 1 increased dry biomass by 340 kg/ha and Seaweed treatment 2 increased dry biomass by 140 kg/ha on 30th May. The Smart Grass had no effect.
    - Trostrey Court Farm 2020: On 6th July, the full rate sulphur treatments had about 250 kg/ha more dry biomass than the zero and half-rate treatments, but these differences were not statistically significant.
- Further work should:
    - Test the approaches for measuring the effect of agronomic treatments in a wider range of conditions including different farms, different grass and clover species and different agronomic treatments.
    - Develop approaches whereby groups of farmers can work together to test new agronomic treatments of common interest and share the costs of collecting and analysing the remote sensing data.
    - A farmer group could be facilitated to assess the pros and cons of using drone data compared with satellite data in terms of costs, time demands, requirement for external expertise and quality of results, to identify which is the best approach to use.
- Farmer feedback – what did they think, will they use this method in future