UK 1
Topsoil 2 Report

A Report in to 2020 – 2021 UK1 Topsoil findings

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1. Introduction

The original Topsoil UK1 1.0 had 2 objectives:

• Technical: Explore the connectivity of surface water and groundwater to improve understanding of groundwater and surface water interactions in the Wear catchment in the context of climate change.

• Engagement: Communicate an understanding of groundwater and surface water interactions and the implications of these for catchment management to wider stakeholders.

A range of themes were investigated, including agricultural soil management. This theme, which is generally accepted as *the* key to the management of water quality, flood risk, carbon capture and sequestration and biodiversity was further developed into the Topsoil capitalisation project: Topsoil 2.0.

In common with other Topsoil partner projects UK1 concentrated on understanding the movement of water, and therefore soluble nitrates, through the soil profile into groundwaters under different tillage conditions.

Nitrogen pollution within drinking water causes methemoglobinemia (blue baby syndrome), which reduces the blood's ability to carry oxygen. Symptoms include shortness of breath and blueness of the skin. Infants below six months who drink water with high levels of nitrate can become seriously ill and die. Excessive nitrogen in surface water results in nutrient enrichment of water bodies, creating algal blooms which deoxygenate the water and suffocate aquatic life.

The UK 1 Topsoil investigations were carried out at three farms across County Durham with four trial sites. These sites have been chosen due to the different cultivation practices they implement; these consist of traditional ploughing, a combination of traditional ploughing and intensive surface cultivation, a transition from traditional ploughing to zero tillage, and long term zero tillage. The combination of these sites gives a clear ability to compare different tillage regimes and the effect that they have on the topsoil.

1.1 Background

1.1.1 Houghall Farm (Farm 1)

Houghall Agricultural College incorporates a secondary education farm, consisting of a mixed livestock and arable practices, located 2 miles south of Durham city. The livestock reared at the college are cattle, sheep and pigs. These enterprises run alongside their arable rotation, maximising the use of on-farm products. The arable rotation consists of wheat, barley, beans, fodder beet and rye. This rotation has been developed to provide usable feedstocks for the arable units, as well as improving soil health on the farm through diversity.

1.1.1.1 Tillage and Crop history

Houghall College has traditionally used conventional cultivation to prepare fields with ploughing, followed by using a power harrow combination drill to seed the next year's crop. However, they have recently transitioned to direct drilling; cultivation has still been required on a small scale to level the field when necessary, but this has been kept to a minimum. The recent crop of 2020 was the first year of direct drilling into the field; this was achieved with the use of Roundup to clear the field before drilling.

Table 1 - Houghall College Rotation

Year	Crop	Establishment Method
2020 Autumn	Winter Wheat	No Till
2019 Spring	Beans	Plough
Oct 2018-Jan 2019	Fattening lambs	
	Stubble turnips	
2018 Autumn	Winter Barley	Plough
2017 Autumn	Winter Wheat	Plough
2016 Spring	Beans	Plough

1.1.2 High Sharpley (Farm 2)

High Sharpley Farm is a minimal till agricultural farm typical of the north-east, located South of Sunderland. This farm prioritises producing high yielding arable crops, with a high input model ensuring good soil health and microbial activity. To accomplish this, they have a diverse rotation that allows a good soil health and maximises crop yield.

1.1.2.1 Tillage and Crop history

Farm 2 uses multiple cultivation tools to maximise their profit on the farm; they also use cultivation to extend the growing season, allowing for water management. This is important to the farmer due to the typically shorter planting windows in the north-east, as well as their priority on high-value cash crops such as winter wheat and winter barley.

Table 2 - High Sharpley Rotation

Year	Crop	Method	Reason to Plough
2021 Summer	OSR	Min Till	
2020 Autumn	Winter Barley	Plough	Kill volunteers
2019 Autumn	2nd Winter Wheat	Plough	Surface too wet
2018 Autumn	1st Winter Wheat	Min Till	
2017 Autumn	Oil Seed Rape	Min Till	
2016 Autumn	Winter Barley	Plough	Kill volunteers

1.1.3 Wallish Walls (Farm 3 BASE plots)

Wallish Walls farm is a large mixed farm with mainly arable and a small herd of belted Galloway Cattle, located within the Derwent (Tyne) River Catchment. The farm has been regenerative for over 20 years and uses a combination rotation and cover crops to maintain soil health. There are two Topsoil plots on this farm; one that is direct drilled in common with the rest of the farm, and one in a five-year plough trial.

1.1.3.1 Tillage and Crop History

Farm 3 covers a large area and does not use any deep cultivation techniques other than on the BASE plot. To manage the farm a combination of different drills are used depending on the requirements for planting. This allows the tillage to be varied to get optimal performance from the crops they grow. Farm 3 also tried inputting organic matter into the soil by introducing the livestock into their arable rotation; this is important for their degraded land which had low organic matter content.

Table 3 - Wallish Walls

Year	Base Crop	BASE Plough plot	BASE Direct Drill plot
2020-1	Spring OSR	Deep Cult.	A
2019-20	Winter barley	Deep Cult.	Direct Drill
2018 -19	Winter Wheat	Deep Cult.	Direct Drill
2017-18	Beans	Deep Cult.	Direct Drill
2016-15	Winter Wheat	Deep Cult.	Direct Drill

1.2 Aims

To collect soil and water data to understand how water moves through the soil, influencing soil health, crop growth and development, and informing surface/subsurface water availability and quality.

1.3 Objectives

- Compare and contrast soil structure and characteristics, biology, moisture capacity, infiltration and retention under different tillage regimes:
    - Traditional ploughing
    - Combination of traditional ploughing and intensive surface cultivation, both underpinned by heavy organic matter inputs
    - Transition from traditional ploughing to zero tillage
    - Long term zero tillage.
- Begin the creation of a multiple year database collecting data from local soils under local climatic conditions and different land management approaches and tillage systems.
- Create a forum through which the costs and benefits of integrated land and surface/groundwater management can be discussed from a combined sustainable farm business and environmental perspective, including the future potential of Paid Ecosystem Services.
- Communicate results to the wider farmer audience through a series of on-farm events in a "Demonstrator Farm" format, utilising Frontier Agriculture and Tyne RT farmer facilitation group networks and through the Catchment Based Approach via the Wear and Tyne Catchment Partnerships. WRT has promoted Topsoil insights through other agricultural engagement projects, particularly in the Browney and Gaunless catchments.

2. Investigation methods

2.1 Farm selection

The three farms were chosen due to the different tillage regimes but similar approach to management. Farm selection was based on the availability of people willing to take part in the project and allow access to the field for regular soil sampling and analysis.

2.2 IMetos

2.2.1 Site location

The IMetos probes were positioned randomly in the field, within the constraints of ensuring that the locations were away from tramlines and in the high production area of the field. This meant machinery was not regularly travelling over the area and therefore compacting the soil which would have resulted in an inaccurate representation of the field.

2.2.2 Installation of probes

When installing the IMetos probes, WRT ensured that the probes were installed the same way in every field to get accurate and relevant data. All four probes arrived having already been calibrated to ensure that the data were comparable.

The Aqua check probes were installed into a tightfitting hole drilled with a soil auger. WRT ensured that there was good probe to soil contact and water could not get down the side and affect the results.

Watermark sensors were all installed horizontally at measured intervals of 300, 600 and 900 mm, with the wires left dangling below the sensors in order to prevent them acting as a pathway for water which would misconstrue our results. All sensors were marked with the appropriate depth to avoid inaccurate results being caused by incorrect placement. The depth was measured from the surface of the soil to maintain consistency across all the different installations and ensure that we can compare results. This installation process is in line with the manufacturer's guidance.

Data collection was set to hourly intervals for all the probes but was reduced to twice a day during the winter. This was due to the low light conditions which otherwise could have resulted in low battery problems such as data no longer being recorded.

2.3 Nmin sampling

2.3.1 Sampling locations and depth

N min sampling was carried out via random sampling at multiple locations across the field; however, transcendent sampling was used on one field due to the slope of the field as this would provide more informative data. The sampling sites consisted of a primary site (located at the same point as the probe), a control site (located in an undisturbed location e.g. a hedgeline on the field boundary), and multiple comparators sites (located in-field). The sample sites were recorded using National Grid References (NGR), ensuring consistent results. The soil sampling was carried out within a metre of each other to ensure the same location was sampled every time. Sample-specific codes were used to track locations and ensure the results were labelled correctly every time. The samples were taken every two months to allow the progression of nitrogen through the topsoil horizon to be tracked. The samples were all taken at 300, 600 and 900 mm to ensure that we were getting consistent and accurate results.

2.3.2 Sampling process

To ensure consistent results, a formal methodology was devised detailing the depths at which the samples would be taken and how they would be collected and managed, to ensure the results could be compared accurately.

Prior to excavation, all sample bags were labelled with the depth, location and time, to ensure there was no confusion of samples and that, once collected, the samples were ready to be sent to the laboratory. Samples were collected using a soil auger throughout the whole 300 mm of their depth. Once taken, the samples were placed into a clean bucket where they were mixed up and broken down to provide a consistent sample of each 300 mm profile. After mixing, they were placed into a sample bag and put into a cool box for transportation before being packaged ready to be delivered to the laboratory. Any excess soil was put to the side until all samples were collected down to 900 mm; the surplus was then placed back into the hole.

WRT ensured that the samples were sent to the lab immediately for analysis; samples would not be taken if they could not be posted as they would lose nitrogen if they were stored in the bags for a long period of time, reducing the accuracy of the results. All results were then gathered and presented in Excel form and a t-test analysis was conducted to test for any significant difference between trial farms. The data were also used to create graphs to visualise the effect of the nitrogen profile throughout the year, giving insight to farmers about how nitrogen works within the soil and how timing of nitrogen application is important.

2.4 Worm Counts

The Agriculture and Horticulture Development Board's tutorial on worm counts provided the methodology for the worm counts performed as part of this trial. The soil sampling and probe locations were used to provide the locations for the worm counts; these were also tracked with the NGR to ensure that all the sites could be located throughout the trial. The sampling times for all sites were within a week of each other to ensure consistency of results. Sampling was started at the same time of day to reduce any effect of daytime activity. Following the AHDB guidelines we carried out 10 20 x 20 x 20 pits together accurate representation of the field. The soil was removed, placed onto tarpaulin and visually went through it, removing worms and placing them into categorised boxes for counting.

All data collected was stored in an Excel file that allowed for evaluation of the results. These results will be compared to cultivation practices and data that we have collected from N min testing and the IMetos station.

2.5 VESS Assessments

WRT carried out Visual Evaluation of Soil Structure (VESS) assessment in line with Scotland's rural University College (SRUC), at the same time as worm counts due to the same pit size. The same locations were used as for soil sampling and in the same vicinity as probe locations. Soil was removed and placed into the Tarpaulin for visual assessment and was scored in accordance with the guidelines immediately prior to worm counts.

4. Results

4.1 IMetos Infiltration Data

Data from participating farms has been selected to demonstrate insights derived.

4.1.1 Water Infiltration: Farm 1 (Soil: Sandy Loam)

Error! Not a valid bookmark self-reference.: Farm 1 graph showing rainfall infiltration. The graph is of a nine-day duration. The right vertical axis measures rainfall per hour, represented by the yellow columns. A three-day rainfall event was recorded from 24th June, depositing 27mm.

The left vertical axis shows the AquaCheck volumetric water content. The orange, blue and red lines represent probe sensors at the three shallowest depths: (blue =100mm, orange = 200mm, grey =300mm). Other depths have been omitted for presentation clarity.

Graph analysis shows that the infiltration of the water to Sensor 1 (the blue line) at 100mm takes 7 hours, reaching Sensor 2 (the orange line) at 200mm a further 8 hours later. Infiltrated moisture does not reach Sensor 3 (the grey line) at 300mm at all, which continues its existing trajectory.

The soil type is sandy loam, which should in principle show effective infiltration through the soil horizon, but this is not the case here. This field was converted from traditional ploughing to zero tillage this year. The presence of a residual plough pan at 200-300mm below the surface is preventing infiltration. The response of the orange line (Sensor 2 at 200mm), rising above the 100mm depth blue line (Sensor 1), indicates a temporary volumetric water peak at that depth, as infiltration is restricted by the plough pan immediately below.

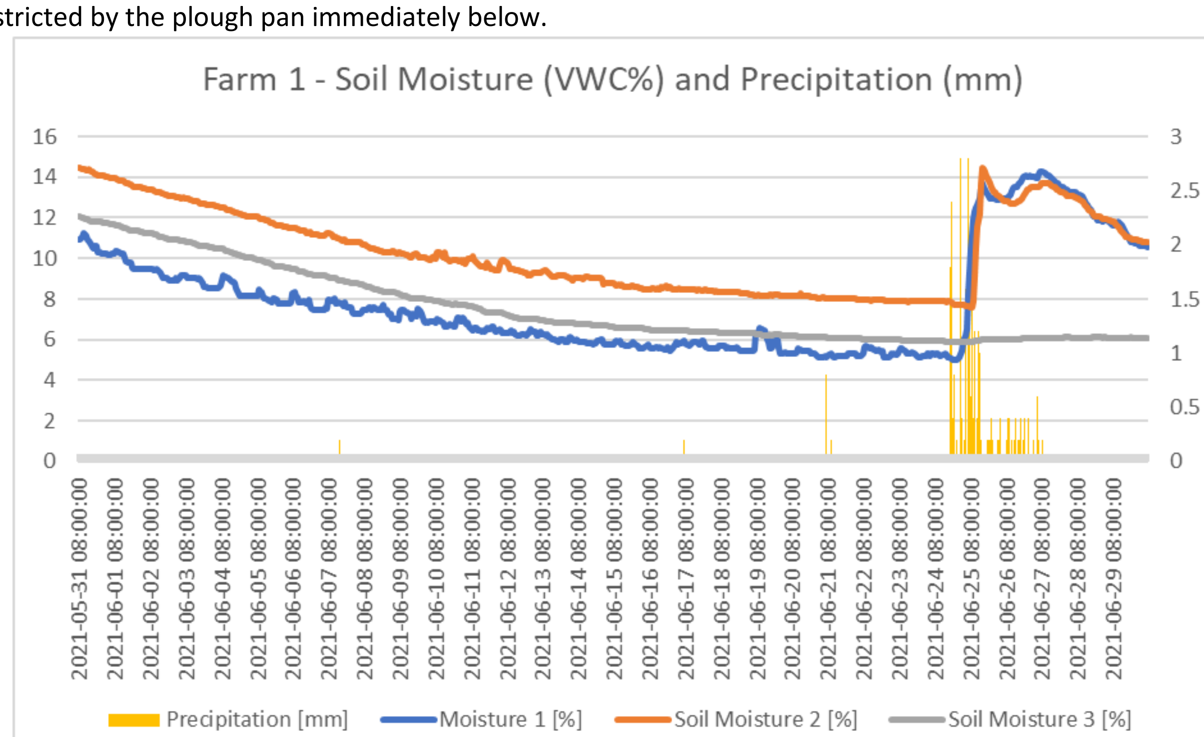

Figure 1 Graph displaying moisture content (VWC%) and precipitation (MM)

4.1.2 Soil Infiltration: Farm 2 (Soil: Clay Loam)

Figure 2: Farm 2 is like Figure 1with the left and right vertical axes measuring volumetric water content (VMC) and rainfall respectively. The grey columns indicate there was 30mm of rain over a similar period to that shown in Figure 1. Five volumetric moisture sensors are shown, from the dark blue line (Sensor 1; 100mm depth, lowest curve showing zero to 3% VMC) to the light blue line (Sensor 5; 500mm depth, highest curve showing 32% to 23% VMC).

Interpretation of the graph shows that the top 100mm of soil hit 0% VMC over the extended dry period, but moisture was retained in the lower depths, slowly declining over time. When it did rain, 14 hours elapsed before increased moisture was registered on Sensor 1 at 100mm depth, with moisture not being retained at the surface but infiltrating to the lower soil horizons, arresting the slow decline of moisture content and flattening the curves representing Sensors 2 to 5.

The tillage regime at this farm concentrates on improving soil structure and incorporating large volumes of organic matter. The very light sandy soil at Farm 1 should infiltrate moisture more effectively than the heavier land at Farm 2. The soil at Farm 2 should and does hold moisture better than at Farm 1. However, it is clear that Farm 1 is more susceptible to drought, not only due to naturally less effective water retention due to soil type, but the lower soil horizons are not recharged when there is rainfall, due to past cultivations. Action needs to be taken to break up the plough pan at 200 – 300 mm depth.

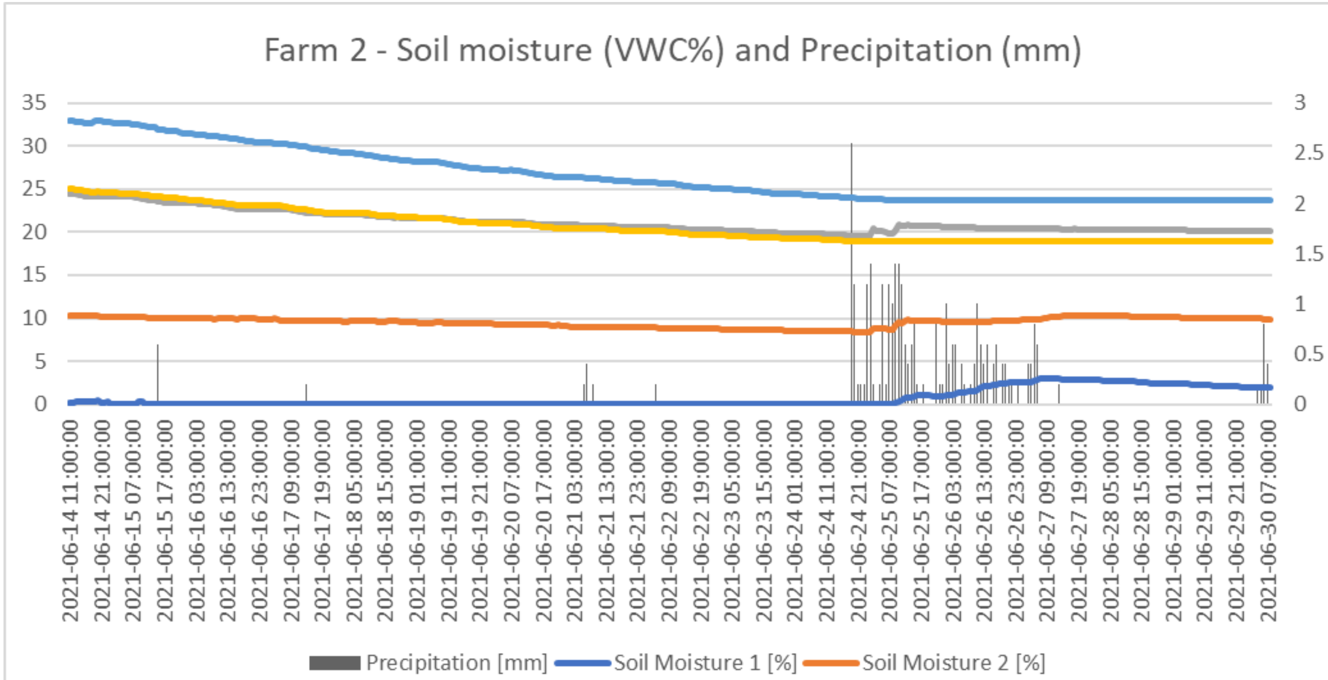

Figure 2 Soil moisture (VWC %) and Precipitation (MM)

4.2 IMetos Moisture Availability Farm 1

Further data from the Watermark sensors reinforces this point. **Error! Reference source not found.**: Farm 1, which covers the same date range as plate 3 although this has not been shown again for clarity of presentation, displays rainfall in millimetres on the right vertical axis as grey columns and soil pore water tension in kilopascals (KPa) on the left vertical axis. Soil pore water tension is shown at 4 depths: Sensor 1 at 200mm (yellow); Sensor 2 at 400mm (light brown); Sensor 3 at 600mm (light blue); and Sensor 4 at 800mm (dark blue).

The graph is divided into 3 sectors: Sector 1 (orange) where water availability is low and the crop is stressed; Sector 2 (green) where water availability is optimal; and Sector 3 (blue) where soil is at capacity and too wet for optimal growth. Interpretation of the graph supports the volumetric moisture analysis above in Section 4.1.1 Water Infiltration: Farm 1. Sensor 1 (yellow at 200mm) has very low water availability at the surface, following a period of low rainfall. The steps in the curve clearly show the crop pulling moisture during the day and less so at night. Sensor 2 (light brown at 400mm) shows a similar, but less defined pattern than Sensor 1, with Sensors 3 and 4 at 600 and 800mm depths showing slowly rising porewater tension measured as KPa, i.e. slowly declining potential water availability in the lower horizons.

The rainfall event of 24-26 June shows some benefits to water availability at Sensor 1 at 200mm as the KPa value falls. However, minimal change is shown below the plough pan, indicating minimal moisture percolation at Sensor 2 (400mm), and no effect on water availability at Sensors 3 and 4 at 600 and 800mm, as both continue the slowly drying trajectory established before the rainfall event within, and eventually moving out of, the optimal green zone. The presence of the plough pan, will reduce evapotranspiration, releasing moisture more slowly from the lower soil horizon, as the plough pan will severely restrict root access to that moisture.

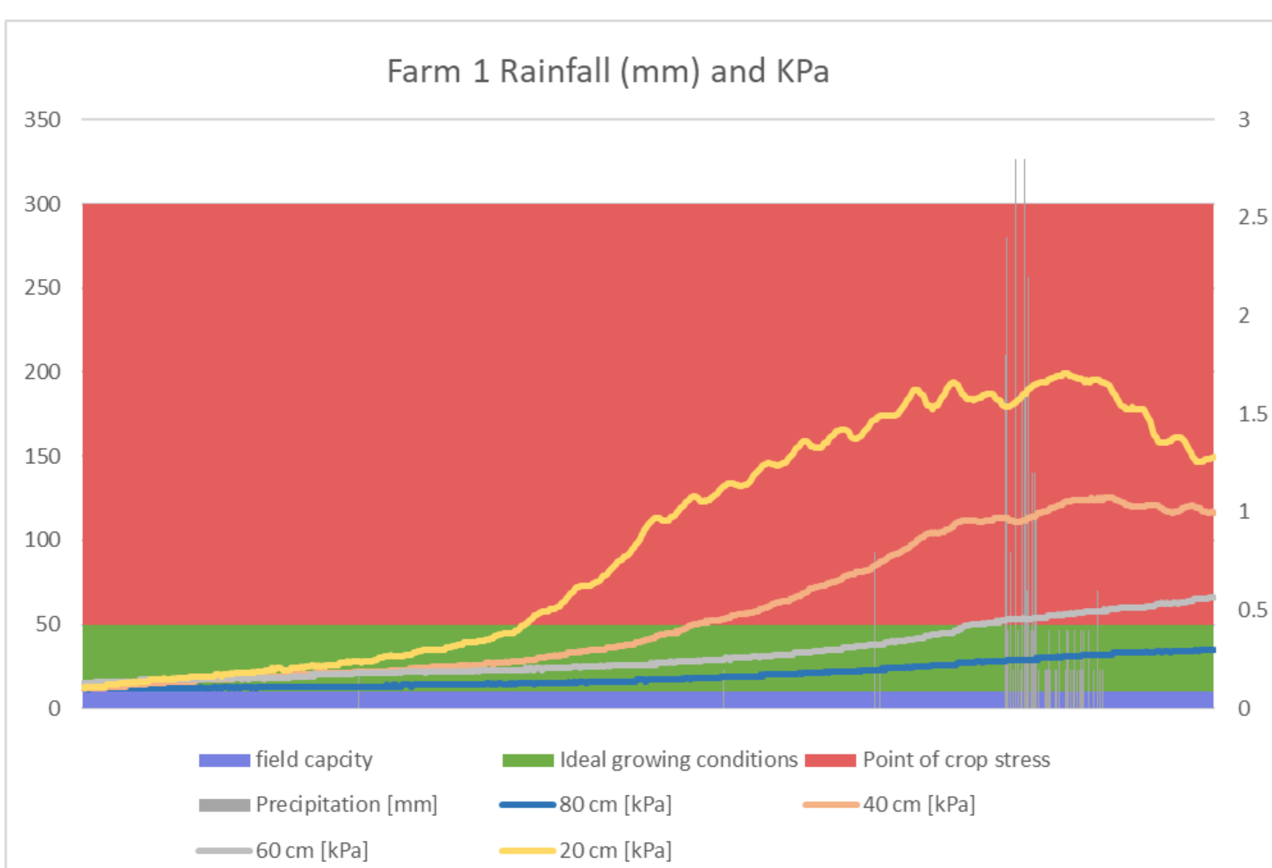

Figure 3 Rainfall (mm) and KPa

4.3 Nmin results

Nmin data was collected in line with the method statement. All graphs in this section are aggregated data from multiple sample points throughout the fields, giving an average representation of the nitrogen in each field throughout the growing season. WRT also carried out a t-test with two samples assuming unequal variance to see if there is any significant difference between trial plots. The data did not reveal a significant difference; however, this may be different had more data points been available.

4.3.1 Farm 3 Nitrate Retention: Plough

Figure 4 shows the nitrogen profile of the ploughed BASE plot on Farm 3 throughout the growing season. This field's oilseed rape crop was seeded in March. The fertiliser application on this farm was carried out in late March and consisted of 140 units of nitrogen; the sharp rise in soil nutrient nitrogen between these two sampling points can be seen in Figure 4. Higher nitrogen at deeper depths were not recorded, suggesting the plant is utilising all available fertiliser in the soil. As the crop reaches maturity in July-August it can be seen that there is a decrease in the amount of available nitrogen as the plant takes up the soil supplies.

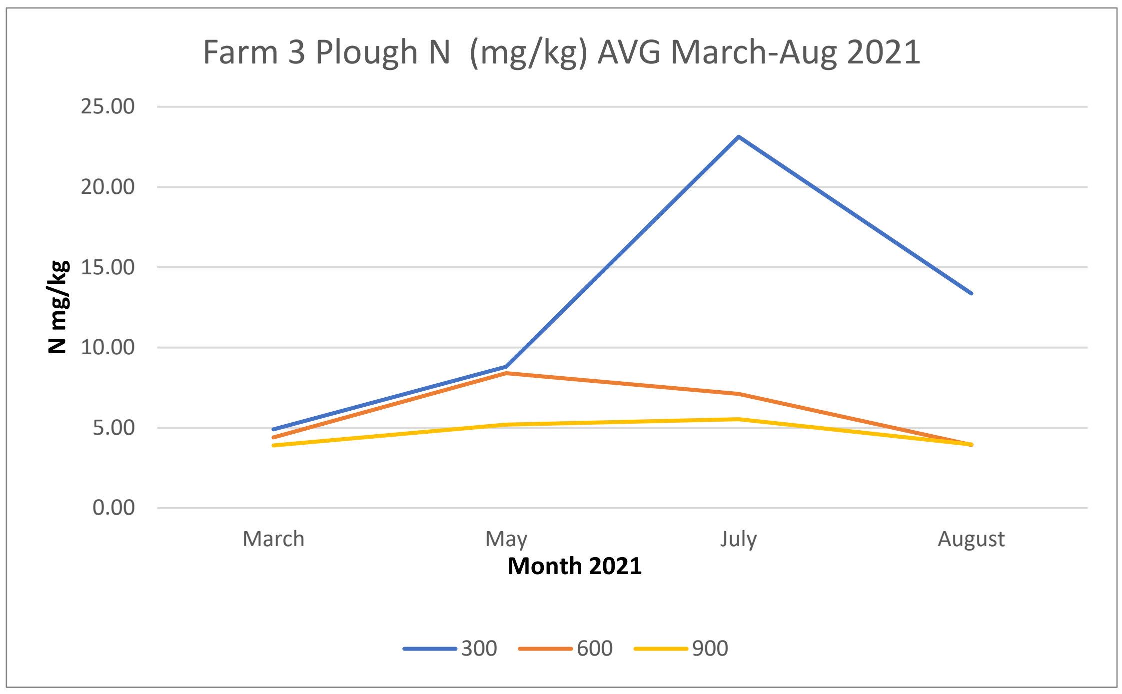

Figure 4 - CT Average March-Aug 2021

4.3.2 Farm 3 Nitrate Retention: Zero Till

Figure 5 shows the same crop from the Farm 3 ploughed site and has the same fertiliser application and timing however this oilseed rape is direct drilled. In comparison to Figure 4, this graph has an earlier and higher uptake of fertiliser with a higher overall peak in the initial application. The reason this could be the improved soil health allowing better absorption of the fertiliser. There is also a higher overall N min content in July which is five units higher than Figure 4. The effect of this will be better growth for the plant due to there being more availability of nitrogen, promoting stronger growth. However, there is infiltration of nitrogen down through the horizon which will probably reach the groundwater as plant roots are unlikely to take it up at this depth.

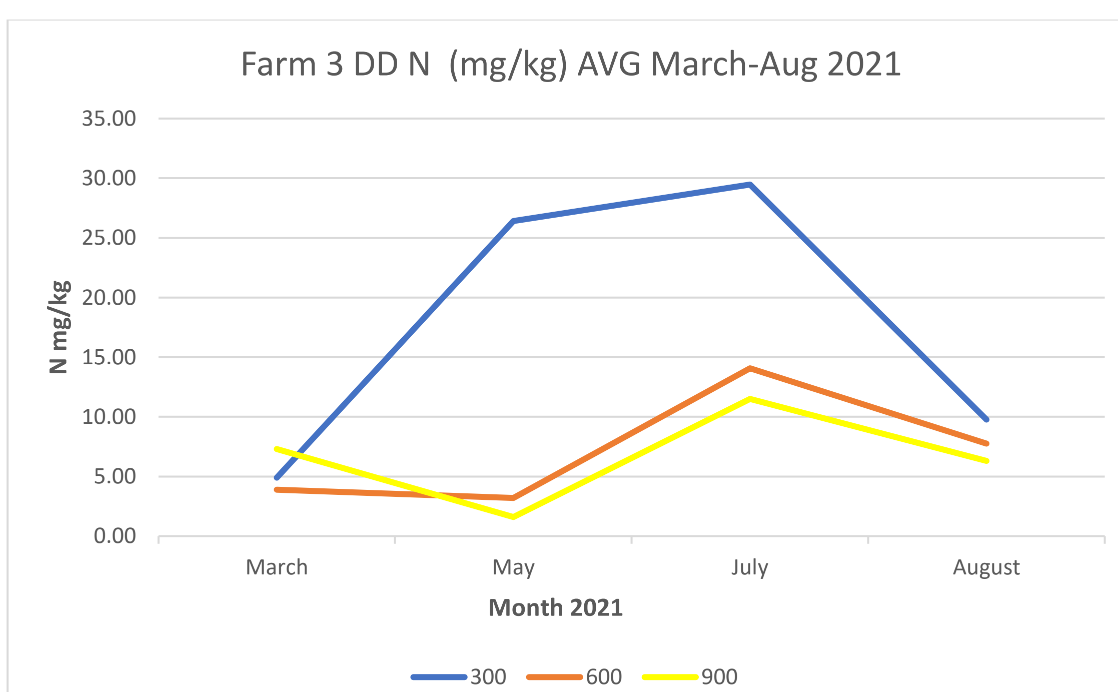

Figure 5 - DD N (mg/kg) AVG March-Aug 2021

4.3.3 Farm 2 Nitrate Retention: Hybrid Cultivation

Figure 6 is a representation of Farm 2's nitrogen profile with their hybrid cultivation model and organic inputs. From Figure 6 you can see that there is no clear data from this graph, only the brief peaks in nitrogen availability at higher depths. This suggests that there is ineffective application of nitrogen, and it is moving through the topsoil horizon potentially into the groundwater. We can also see that there is low availability of nitrogen at the surface for the plant to feed on; this could be due to the farm's use of organic manure slowly releasing nitrogen at suboptimal times for the plant, allowing leaching through the soil. This would mean nitrogen is being applied too early and that it is seeping through the topsoil when it is not needed by the plant, potentially causing pollution. An option to avoid this could be the later application of manure to suit the crop's development better.

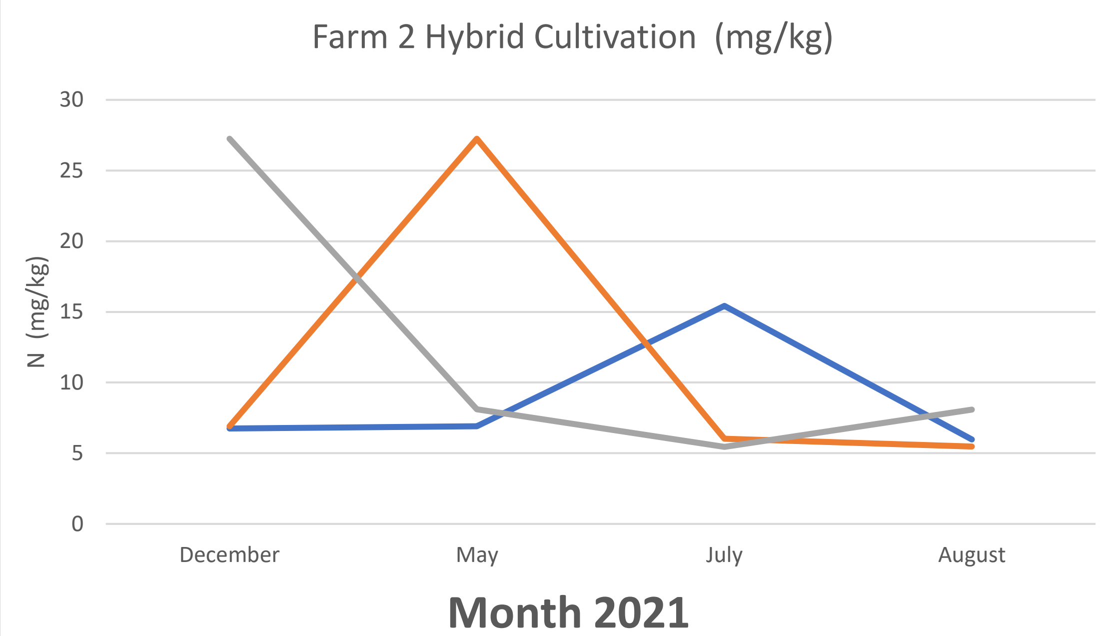

Figure 6- Hybrid Cultivation

4.3.4 Nitrogen retention: Farm 1

Figure 7 shows the availability of nitrogen for Farm 1's field. As can be seen in the graph, there are high readings in February, with a decline at 900 mm and an increase at 300 and 600 mm. Fertiliser was applied on this farm in March in the form of 200 units of nitrogen to provide for the crop's development. As can be seen in Figure 7, there was a small increase in nitrogen content after application, however this wasn't as significant a rise as at the other sites. This could be due to the lower soil health that was present in this farm due to the previous history of ploughing and low level of organic inputs. Furthermore, due to the tightly bound nature of the soil (Figure 1), the fertiliser may find it hard to penetrate the soil and be absorbed. However, the field did yield well which suggests that there was good timing of nitrogen application, i.e. when the plant needs it, allowing for effective uptake with minimal losses through the system. The higher reading in February may have been caused by early applications of autumn manure causing increased nitrogen levels.

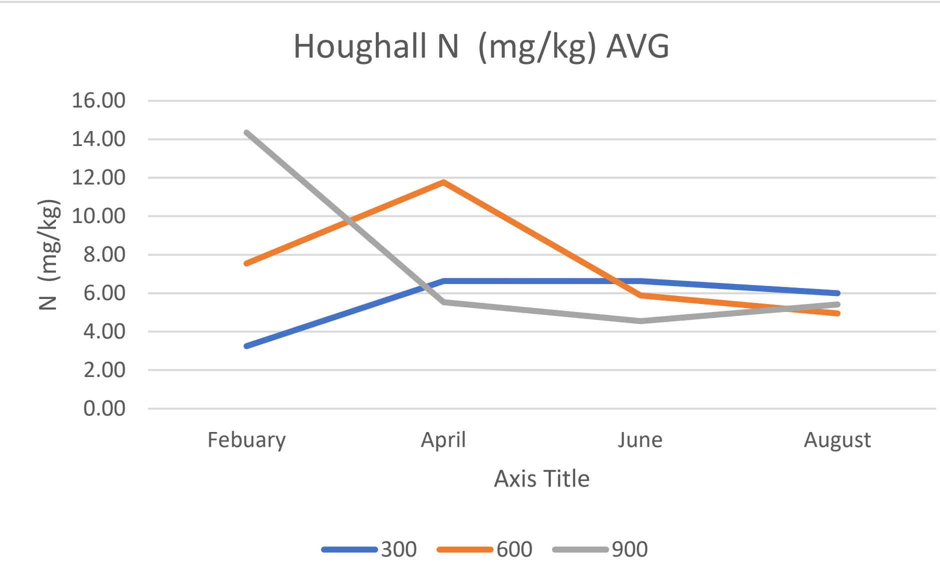

Figure 7 - Houghall N (mg/kg) AVG February - August

4.4 Worm Counts

4.4.1 Total Worm Counts

Worm count data has been taken from all three farms. Figure 8 reveals that there is a wide variety of worm count data with varying results depending on field. The first point is Farm 3 which had higher numbers of worms than the other farms; this is largely due to higher numbers of juvenile earth worms as adult earthworm numbers are not significantly different. Farm 1 had a smaller number of Aneic earthworms which are important for deep borrowing; this was surprising after the long history in direct drilling. Other factors which may be affecting this result are not currently known.

Another significant factor revealed in Figure 8, is that the number of earthworms at Farm 2 was significantly higher than at Farm 1. This could be due to the heavy inputs of organic matter at Farm 2 which are increasing the soil's health and providing food for the worms.

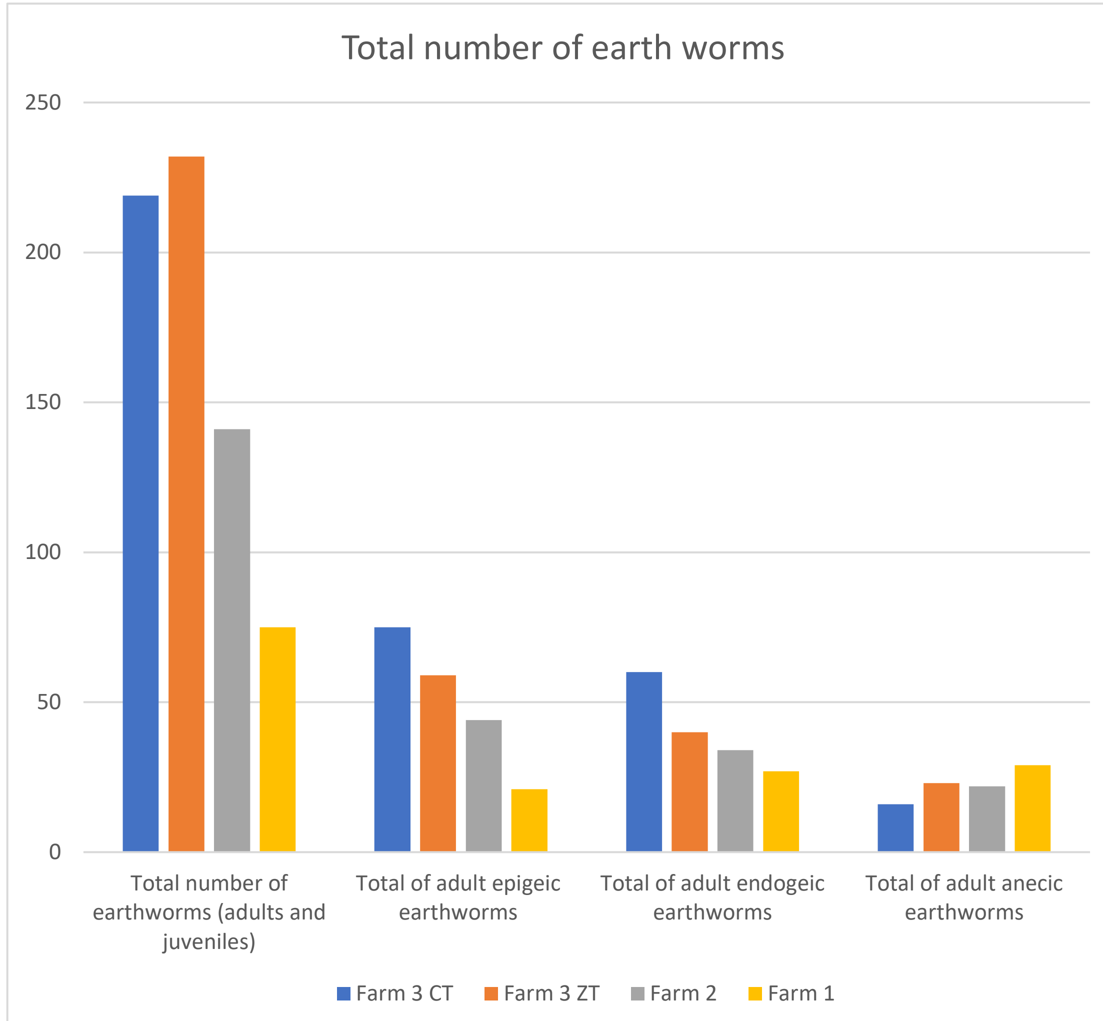

Figure 8 - Total Worm Counts

4.4.2 Worm counts Effect on Water Tension

To calculate the effect of worms on moisture retention or loss, the IMetos data for the watermark sensors was considered first. WRT compared data between the 1st and 24th of June and used the average water tension, the results of which are displayed in Figure 9. This revealed that there was a strong correlation of 0.99 between the number of earthworms and the water tension on the farm. To do this we used the 20 cm watermark sensor as this was the sensor with the most information, as well as being the most relevant for the plant absorbing water out of the soil. The graph clearly shows that as the number of worms increase, the water tension in the soil decreases. This information is beneficial for farmers making decisions about how to improve soil health and the benefits that will help with moisture availability.

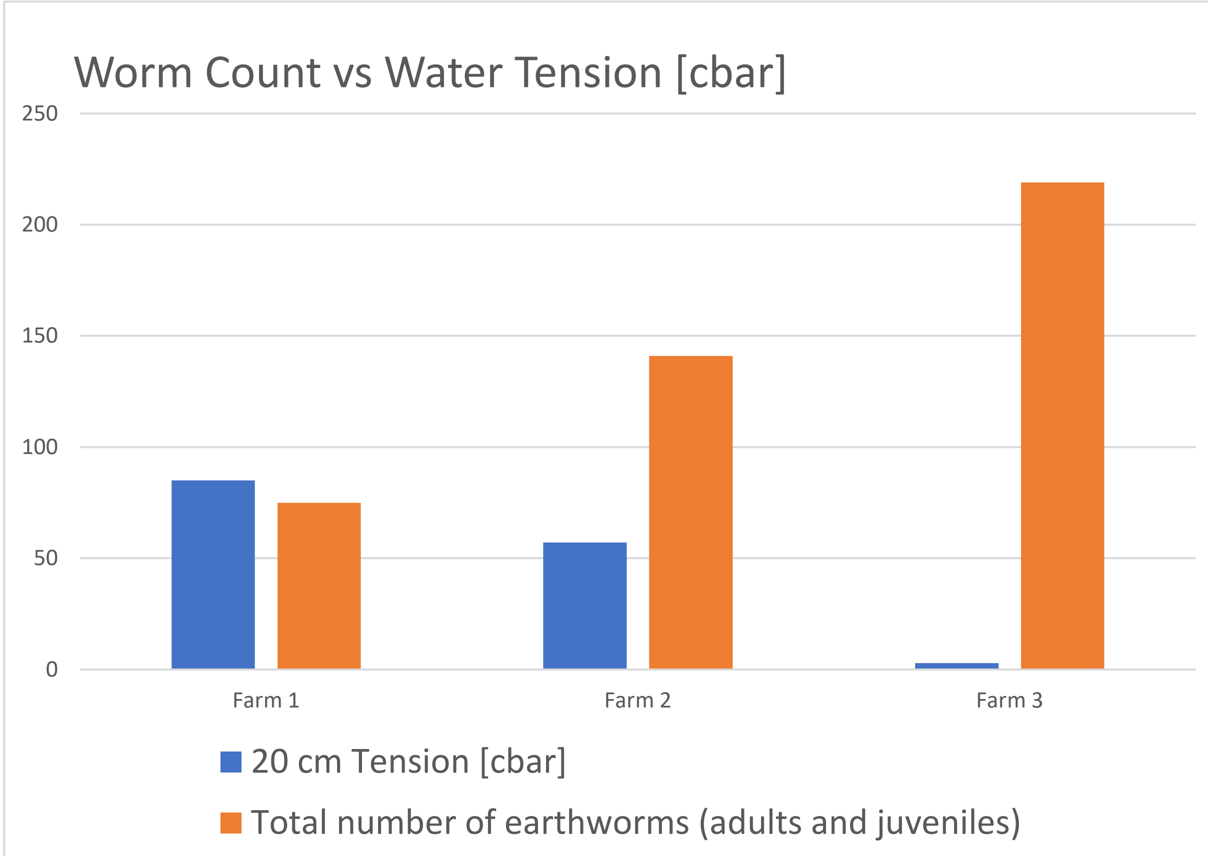

Figure 9 - Worm Count vs Water Tension (cbar)

4.4.3 Worm counts effect on soil moisture

As well as considering the water availability in the soil in comparison to worms, WRT also wanted to analyse the effect of moisture and how the two are related to each other. To achieve this, data from the IMetos Aqua check probe and the 200 mm sensor were used. This revealed that there was a weaker correlation between the soil moisture and the number of worms; however, as the number of worms increases, the soil moisture reduces which contrasts with the water availability. This was not a strong correlation and the p value for this was not significant, suggesting that there is more research to be done in this area to see how the two interact. However, this is significant for farmers as it suggests that having healthy soils will improve the growing conditions for crops, as well as extending planting windows, and will not affect the ability to gain water in drier conditions.

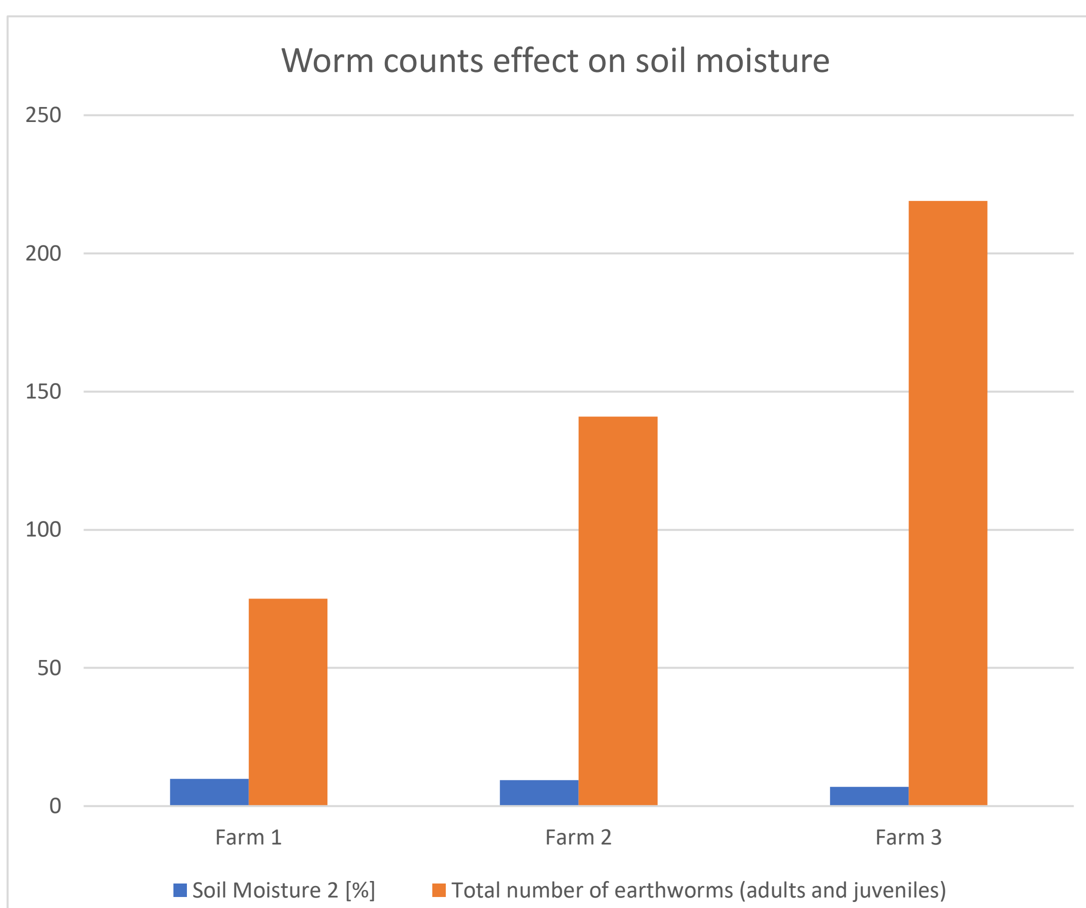

Figure 10 - Worm counts effect on soil moisture

5. Next steps

Subject to continued funding availability, continue to build the database on a year to year basis.

Analyse the statistical visibility of any variation in soil texture across each field and the degree to which the primary site is representative of the field.

The scale of sampling and analysis in subsequent years will be informed by the degree of soil variation observed, and experience gained in Year 1; the extent to which the primary site is seen as representative and observations from the primary site can be extrapolated.

Year 1 results at each farm will determine whether sampling and comparative analysis will continue at the control and primary sites only, or at any or all of the 9 in-field comparator sites.

Experience derived from Topsoil 2.0 is directly transferable to the analysis of grassland soils and implications for the management of livestock. A funding proposal is under development to progress grassland soil investigations, which will form a legacy project for Topsoil and for the Interreg North West Europe Carbon Connects project.

9. Insights Summary

The deployment of the IMETOS field climate stations bring considerable visibility into moisture, and therefore soluble nitrate, infiltration through the soil profile under different management conditions. When combined with other assessment methods: Nmin testing, VESS analysis and worm counts, valuable insights may be derived to better understand the relationship of soil health and water availability. Soil structure, water infiltration and retention are all influenced by tillage decisions and the incorporation of organic matter. Farm 1's results, when transitioning from traditional cultivation to direct drilling, have revealed that it takes time for traditionally cultivated land to recover, and that soil health and ecology will be affected for a period. The study results suggest that incorporating organic matter in particular, is a most significant factor in increasing soil health, ecology and productivity and can play a key role in any tillage regime.

Worm populations unsurprisingly benefit from the incorporation of organic matter. It is hard to overstate the importance of worms to soil structure and health. A large and diverse worm population operating through the soil profile improves the availability of water to plants and will reduce flood risk due to the soils' enhanced ability to infiltrate and retain water. This is a key area that should be explored further in more detail, as climate change drives more extreme weather patterns where regular rainfall cannot be relied on as much as in previous years. The implementation of holistic farm management practices is essential if farms are to eliminate pollution sources and pathways, remain commercially viable food producers, whilst protecting their Natural Capital and providing those Ecosystem Services essential to the environment and human well-being: carbon, flood risk and water quality management, biodiversity and amenity. The provision of Ecosystem Services will and must provide future income streams into farm businesses.