European Innovation Partnership (EIP) Wales

Using 'Internet of Things' (IoT) technology to improve slurry management on farms

Year 2 Report

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Contents

1. Background

The aim of this EIP project is to use 'Internet of Things' (IoT) technology to improve slurry management on farms. Three dairy farms with LoRaWAN gateways have leased and installed a range of compatible field based IoT sensors that record and monitor soil and weather-related conditions. The real-time information gathered by the sensors could help farmers make better decisions on when to and when not to apply slurry on their fields to minimise the risk of run-off losses and make the best use of a nutrient rich resource on their farms.

The project is a step-by-step process of trialling the technology, developing the application, and monitoring the attitude of the users to create learning outcomes. If successful, this process could then be used as a template for trialling other forms of technology within the farming industry.

The Smart Slurry EIP has been run on three farms in North Wales with the aim of assessing the capabilities of a range of LoRaWAN sensors. The sensors were placed in marked fields and in the slurry tanks on each farm. The data recorded by the sensors was fed into a data visualisation tool which advises the farmer whether field conditions are suitable for applying slurry.

Each farm has had a LoRaWAN gateway installed on them, which made this project possible. Details on each farm and their location can be found below. This information has been gathered from the Farming Connect website which details activity on Demonstration Farms (Farming Connect, 2023).

1

Glynllifon Farm
Glynllifon agricultural college, including the woodland, extends to 300 hectares. It is the first Digital Playground in North Wales, which offers opportunities to experiment with the IoT in a rural setting.

2

Erw Fawr Farm
Erw Fawr is a Farming Connect Demonstration Farm. It is a 192-hectare holding farmed by Ceredig and Sara Evans in partnership with Ceredig's parents, Ifan, and Ann. The family produces milk from a high yielding pedigree Holstein herd, run on an all-year round calving system. The Branwen herd was established in 1980 when the farm converted from beef and sheep to dairy.

3

Hen Dŷ Farm
Hen Dŷ near Caernarfon is farmed by Aled, an eighth-generation dairy farmer, and his son Osian. They run a herd of 340 Holstein cows and sell their milk to Tomlinson's Dairies in Wrexham. Aled is always striving to improve standards for farm management whilst taking care of the environment.

Map showing farm locations. Farms are numbered above on the map.

The project is the first example of a multi-sensor IoT system used by farmers in Wales. The project has brought together farmers, regulatory authorities, digital software engineers and soil scientists to establish, trial and refine the system over a 2-year period. They have also been involved in the project's focus group that assess progress four times during the work to provide a feedback loop to ensure the technology is used to its best capacity and refined to meet the farmers' needs.

The following five different sensor types were installed on each of the three farms:

- Soil Moisture sensor
- Soil Temperature sensor
- Air Temperature sensor

- Rain gauge sensor
- Tank Depth Sensor

IoT technology can provide farmers with logged evidence to show the data that were used when making slurry application decisions on farm, as part of a self-auditing system.

This information could prove to be particularly useful considering the new regulatory measures to protect water quality from agricultural pollution currently being implemented from 2021 to 2024.

The project design was split into four separate phases over two years. The phases are as follow:

PHASE 1 – Farm assessment, Soil Survey and Planning Sensor Positioning

- Each farm was surveyed to identify the best positions to deploy a LoRaWAN gateway.
- Desktop assessment was conducted as accurately as possible to identify site specific challenges and minimise time delays during installation.
- Using 'RF Cloud' – a LoRaWAN planning tool software – the project commissioned a software engineer to generate an individual topographical plan of the signal coverage for each farm and the surrounding area.
- Develop a detailed understanding of the soil characteristics of the fields that were used for the project.
- Each farm to offer two or three fields as possibilities.
- Commission a soil survey on fields from all three participant farms using the latest soil scanning technology.
- Demonstrate soil scanning technology used and considered in September 2019 at Henfaes Research Centre that is part of Bangor University. With this data, a soil scientist, such as Professor Davey Jones of Bangor University, advised the OG on where the best areas are for locating the sensors in each field.
- OG to organise the lease of the LoRaWAN gateway and the sensors needed for the work. Installed project specific gateway at Hen Dŷ and check existing gateways for maintenance and compatibility.
- Open call for interested individuals and organisations to sit on the focus group that was used throughout the project.

PHASE 2 – Hardware integration and configuration

- Integrated, configured, and decoded the sensors to the gateways.
- The OG purchased and assessed varied brands/models of each type of sensor at Glynllifon, with the support of specialists, to de-risk the project.

PHASE 3– Midway Analysis & Review

- Reviewed learning points from the first two phases and adapted the plan, before deploying sensors on the other two project farms.

- The focus group to review the project so far.
- Analysis of the OG and focus group attitude to the technology.
- Sensors leased and deployed at Hen Dŷ and Erw Fawr ready for next phase.

PHASE 4 – Project roll-out and trial

- Autumn 2020 sensors deployed and ready at Hen Dŷ and Erw Fawr.
- Data collection during the winter months when slurry storage pressures are at their highest. The sensors were monitored for a full 12 months.
- The farmers took readings from the sensors into consideration and kept a weekly log of whether they agree or not with the system's output on land suitability for slurry application. They noted down the reason if they did not agree.
- The OG collaborated with specialists to integrate a predictive element to the management model by tracking 48 hours weather forecasts.
- Four and eight months into phase 4 the focus group provided feedback on the 'Pethau' based visualisation tool and the project in general. A final focus group meeting occurred at the end of this phase.
- Feedback from farmers and college students involved in the trial was used to make improvements to the configuration and decoding. Once the feedback had been collated a solution was created and applied to allow the OG to view the changes over the visualisation interface. The project continued to be operational, and the OG assessed how effective the new improvements were.
- 3 months was allocated at end of project to provide contingency and time to evaluate and prepare final report.

The challenge is to use sensors to improve slurry management. Rather than just switching on the sensors and seeing if they work, there is a step-by-step process of trialling the technology, developing the application, and monitoring the attitude of the users. The project has reviewed the sensors to see which is best, but simply taking a soil moisture reading, for example, would not provide a solution to the challenge. Therefore, the purpose of the project is to develop and application to improve slurry management and create learning outcomes from the approach used.

This second-year report has been commissioned by the operational group OG and had considered whether the project is keeping to the plan, is on track and make observations and recommendations based on this. Geraint Hughes, the appointed EIP broker, worked with the OG to submit an EIP application for financial support and additional specialist knowledge for this project. Updates and relevant outputs about the work were provided by Geraint Hughes for this report.

2. The research of the project

The sensors were first deployed in April & May 2021 and in most circumstances are still producing data. Nevertheless, for this study, we look at the 6-month period from 1st October 2021 through to 30th June 2022. In some items of analysis, where winter is in focus, we look at a slightly shorter period running to the end of April. The initial brief is to expose some of the environmental characteristics that dictate (or at least guide) the application of slurry, or other fertilisers, with the aim of minimising water course pollution from surface run-off. These characteristics are as follows:

• Temperature

• Soil Moisture.

• Rainfall.

• T-Sum 200. Seasonal temperature analysis.

We take these characteristics into consideration in the subsequent sections as we investigate each metric recorded in detail.

Temperature

- Typically, the changes in the soil temperatures (observed at 50mm under the surface) closely follow the air temperature. Things appear to change around the start of April where grass growth has an effect in locking-in warmth.

Farm	Field	Lowest Soil Temp (°C)
Erw Fawr	Field 1	3.7
Erw Fawr	Field 2 (North)	2.7
Erw Fawr	Field 2 (South)	2.7
Glynllfon	Mount Pleasant	3.1
Glynllfon	Tyn Rhos Bach	2.9
Glynllfon	Tyn Rhos Mawr	2.4
Hendy	Field 1	2.4
Hendy	Field 2 (Bottom)	2.7
Hendy	Field 2 (Center)	3.4

Figure 1: Lowest Soil Temperatures. Source - Rob Shepherd, Report: Study of data gathered from LoRaWAN Instruments on three farms across North Wales

- It is also evident that the 8–10-degree threshold is not crossed until mid-March. (Apart from an unseasonably warm spell as the year changed).
- It is apparent that the three sites have a remarkably similar soil temperature seasonal profile. They are all however situated in quite similar settings: coastal, low altitude.
- No sensor in ANY field recorded freezing soil temperatures over the study period. (Sheperd, 2022)

Farm	Lowest Air Temp (°C)
Erw Fawr	-1.51
Glynllfon	-1.72
Hendy	-2

Figure 2: Lowest Air Temperatures. Source - Rob Shepherd, Report: Study of data gathered from LoRaWAN Instruments on three farms across North Wales

- Whilst the air temperature did drop below zero (as shown in Figure 2) these were not sustained periods nor cold enough to permeate the soil (as demonstrated above in Figure 1)
- The three farms show similar temperature patterns, and it is noted they are all coastal sites (Sheperd, 2022).

Soil Moisture

- Erw Fawr 2, North and South - Despite being the same field, 350m apart, have different soil moisture properties. This was evident during sensor placement: South being very wet with more clay-like consistency and North being very sandy.
- In general terms, the soil moisture has less variability and remains consistently higher over the winter period in contrast to late autumn and spring where there is much more variability in soil moisture with a trending decline in moisture throughout springtime.
- By inspection of the charts, we can see that there are no periods of low soil moisture (<30%)
- It is rare to find a 48-hour period where soil moisture is less than e.g., 34% (Sheperd, 2022)

		Soil Moisture	
Farm	**Field**	**Min %**	**Max %**
Erw Fawr	Field 1	12.9	42.2
Erw Fawr	Field 2 (North)	12.5	43.2
Erw Fawr	Field 2 (South)	11.8	42.5
Glynllfon	Mount Pleasant	13.5	48
Glynllfon	Tyn Rhos Bach	16.6	45
Glynllfon	Tyn Rhos Mawr	13.3	46.9
Hendy	Field 2 (Bottom)	12.9	45.8
Hendy	Field 2 (Center)	13.3	43.2

Figure 3: Soil Moisture Ranges. Source - Rob Shepherd, Report: Study of data gathered from LoRaWAN Instruments on three farms across North Wales

Rainfall.

- The rain gauges at site provide a reasonably accurate observation of the quantity of moisture introduced to the soil.
- Glynllifon had the highest maximum daily/weekly & monthly amount of rainfall, but the lowest rainfall in total over the period.
- Lack of rain is an equally important characteristic. Table 5 shows the number of days in the 6-month (Oct-Apr) study period (a total of 212 days) - where no rain fell, on each farm. Interestingly for Glynllifon this is almost 50% (1 in 2). Farm Days with no rain. (Erw Fawr 95, Glynllifon 99, Hen Dŷ 85).
- A single rain free day (I.e., in between days with rain) is the most common, but periods of at least 3 days with no rain are common (Sheperd, 2022).

	Maximum Rainfall Volume (mm)			
Farm	**Daily**	**Weekly**	**Monthly**	**Total**
Erw Fawr	30.6	64.6	164.6	494.6
Glynllifon	46.2	90.8	222.6	341.2
Hendy	35	50	144.4	425.4

Figure 4: Maximum Rainfall Recorded. Source - Rob Shepherd, Report: Study of data gathered from LoRaWAN Instruments on three farms across North Wales

T-Sum 200

The T-SUM 200 is a method to determine when to make the first application of nitrogen fertilizer in spring. This is done by adding up the average daily air temperatures (discounting values below zero) since 1st Jan and waiting for the date at which this sum reaches a total of 200. Each of the farm's progressions towards the accumulation of 200 is shown in figure.

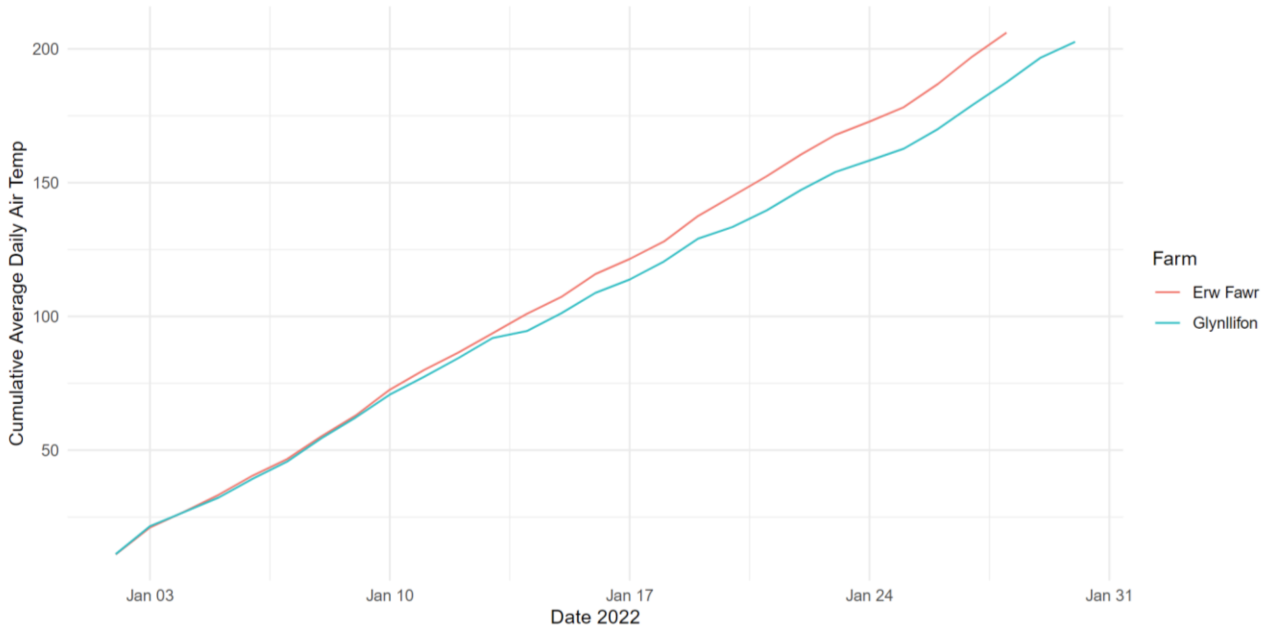

Figure 5: T-Sum 200 for 2022. Source - Rob Shepherd, Report: Study of data gathered from LoRaWAN Instruments on three farms across North Wales

3. Sensor Specific Information

There were three brands of gateways that were considered for use in this project - MultiTech, RAK Wireless and Lorix One.

MultiTech is the most widely trusted amongst industry consultants and experts due to its durability and reliability. It is a carrier industry grade product and was chosen by Microsoft as the gateway to be installed at M-Sparc Science Park in Gaerwen earlier in 2019.

Figure 6: A 'MultiTech' gateway installed on the roof of the M-SParc Science Park near Gaerwen on Ynys Môn.

Each of the three farms deployed the following sensors:

- 1x Rain Gauge
- 1x Air Temperature & Humidity Gauge
- 3x Soil Temperature & Moisture Probes
- 1x Ultrasonic Distance Sensor

All the sensors transmit via LoRaWAN wireless messaging, a low-power long-range wireless network technology suitable for remote monitoring with high battery endurance. The farms were equipped with a web-based data dashboard to review real-time data as it was relayed from the site and can inspect the historical data that is permanently stored.

A wide range of sensors were evaluated for this project. This evaluation included the following criteria:

- Product Availability
- Build quality.
- Suitability for deployment in an agricultural setting
- Product cost

- Value for money

DataCymru's findings of the sensor analysis are found in the table below,

Image	Type and Cost	Comments
	Soil	
	SensoTerra	**Pros:** - Easy to setup with its own dashboard - Sealed and durable product
	£220	**Cons:** - Fixed 3-year lifespan on product – non-replaceable battery. - No temperature sensor - We could not conclude the same measurements as reported by the device on SensoTerra's dashboard.
	Meter 10HS Coupled with Elsys ELT	**Pros:** - Proven record in soil moisture metering. - Industry standard - Very high-quality output. Moisture results were accurate and repeatable.
	£150 + £100	**Cons:** - Needs transmitter - No temperature sensor
	Tinovi PM-10-5-SM	**Pros:** - Very cost effective - Combined moisture and temperature - Rechargeable battery

	£72 battery: £10	**Cons:** - Poor quality soil moisture readings that were not repeatable. - Uses a very specific battery that we had to source separately. - Reports of the probe corroding quickly.
	Tektelic Clover	**Pros:** - Cost effective - Combined soil moisture and temperature
	£120	**Cons:** - No decent information on how to convert the electrical readings to soil moisture. The manufacturer was not able to assist and suggested a calibration per-field, creates a barrier for future deployments.
	DecentLab DL-TRS11	**Pros:** - Very high-quality probe and transmitter - Combined soil moisture and temperature - Self calibrating.
	£645.00	**Cons:** - Expensive - Difficult to source
	Libelium Smart Agriculture Pro	**Pros:** - Combined soil and weather in one package - Solar panel powered for long endurance

	£937 + £250	**Cons:** - Poor quality wind & rain instruments did not last long. - Needed an extra £250 for an annual programming license - Not-trivial to setup and needed programming - Expensive
	Meter Teros 11 coupled with Elsys ELT and integration components.	**Pros:** - Very high-quality instrument that does not need calibrating - Combined temperature and soil moisture
	£180 + £100 + £15	**Cons:** - Slow to integrate the two parts together
	Rain	
	Pronamic Professional With Elsys ELT transmitter	**Pros:** - Comes with leaf grid and bird spikes to prevent debris gathering in the vessel. - Good mounting options. - Accurate - Easily deployed
	£150 + £100	Cons: - Does not record snow/hail, and the mechanism can freeze in cold weather.
	Pronamic Tower	**Pros:** - Low Cost

	With Netvox R718	
	£85 + £50	**Cons:** - Poor mounting options compared to the Pronamic Professional (above) - Susceptible to wintry weather effects. - R718 difficult to commission and not durable.
Air Temperature		
	Ursalink UC11-T1	**Pros:** - Durable - easy to configure
	£100	**Cons:** - Did not last 12 months before failing due to frost and/or UV damage - No longer on the market
	Synetica Senstick & Screen	**Pros:** - Low Cost - Good screen
	£120	**Cons:** - Poor build quality
	Milesight EM300-TH	**Pros:** - Good build quality - Low cost (This unit replaced the Ursalink UC11-T1 above when it failed)
	£70	**Cons:** - None
	Netvox R712	**Pros:** - Excellent screen - Durable mount.

		
	£90	**Cons:** - Not an outdoor grade sensor contained within. - Unlikely to operate in harsh outdoor conditions
Slurry Storage		
	Elsys ELT ultrasonic	**Pros** - Good build quality - Easy to configure - Reasonably accurate
	£250	**Cons** - Needs regular maintenance to ensure the sensor aperture is clear. - Can fail to work on surface crusts
	LMK382 from BD Sensors With Elsys ELT transmitter	**Pros:** - Submersible and very accurate - Designed for deployment in slurry. - Calibrated for slurry/effluent.
	£575	**Cons**: - Expensive - Needs extensive mounting apparatus.

Soil Sensors

The quality of the soil moisture readings is a high priority for criteria selection. All the products that were tested for durability and battery life were found to be suitable for an agricultural setting. From the analysis, the Metre Terror 11 probe coupled with the Elsys ELT transmitter were selected for the project due to having the highest accuracy on the tests and the probe also claims not to require calibration between different soil types. This would be a good benefit to the project as it would be a task that the farmers would not have to undertake. This unit and the battery proved a viable choice because it's widely available and it also has an external antenna which can help wireless communication in location with poor signa coverage.

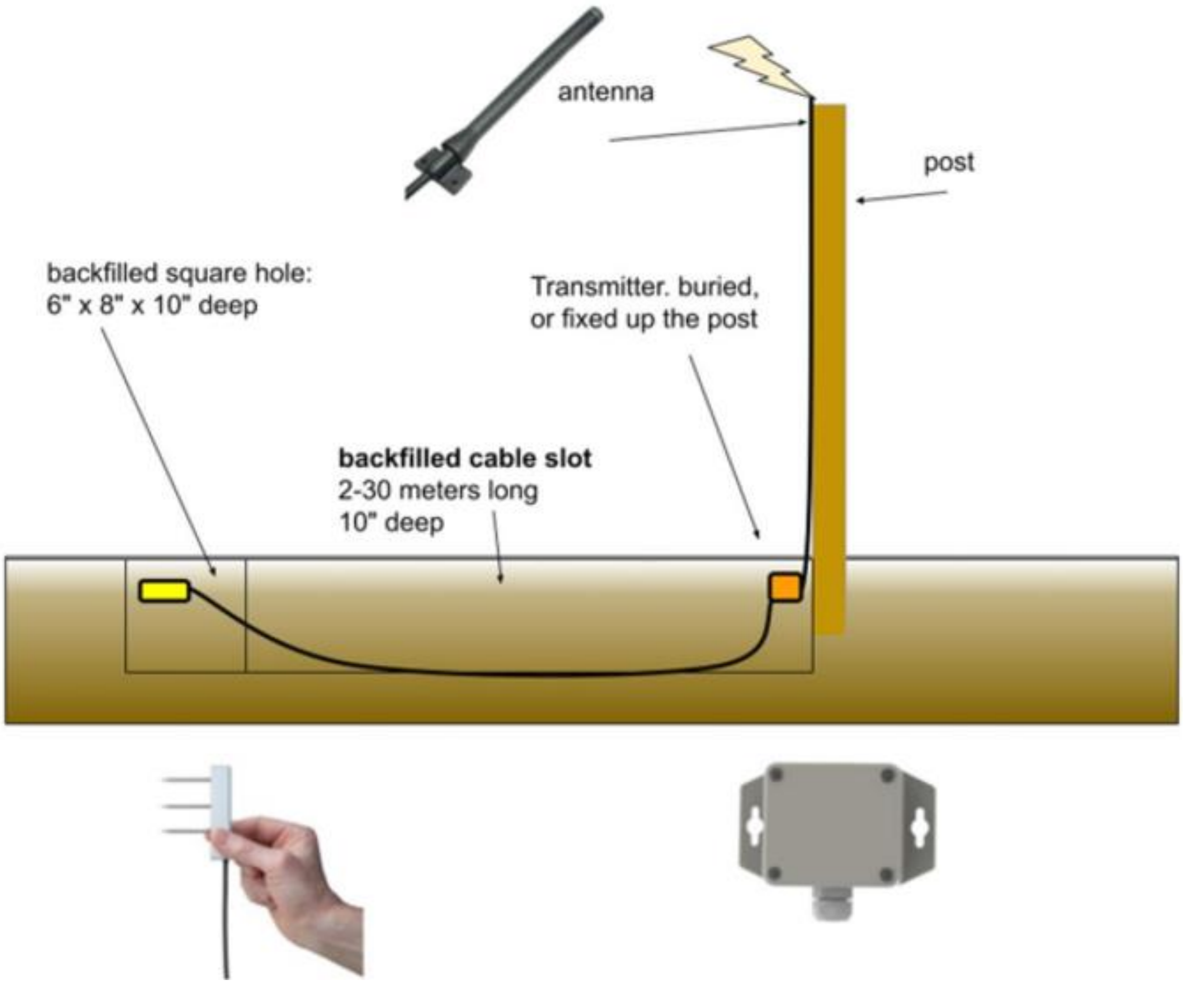

Figure 7: Diagram to show Soil Temperature & Moisture Probes set up.

Figure 8: Image of the soil sensor (left) and air and rainfall sensors (right)

Figure 8 shows the probe in-situ about to be pushed into sidewall of pit and the transmitter in an elevated position with protective pipe leading to pit 5-10 meters away.

Rain Gauges

DataCymru had previously worked with the Pronamic range of rain gauges and found the Professional model to be good quality and worked well with transmitters such as the Elsys ELT. Therefore, this set up was chosen for the project. The Pronamic Tower module was tested with a low-cost transmitter but these were lacking in quality and durability with limited mounting options which led them is being ruled out for this project. The rain gauge as part of the Smart Agricultural Pro unit from Libelium was also considered but the quality of the parts were poor which did not provide a cost effective option given the high cost of the Libelium SAP set up.

The main issue with most of the rain gauge sensors is that they are susceptible to cold weather. For example, the tipping bucket can become frozen, or accumulates with snow. There are more expensive heated vessels available for use with high grade meteorological sites but the cost of these are well above justifying it in an agricultural setting.

Air Sensors

The Ursalink UC11-T1 and the Senstick from Synetica were chosen as the best option for this project, partially due to the limited availability of other outdoor grade temperature sensors. Unfortunately, this model failed over winter at Hen Dŷ due to frost damage and/or UV degradation. This unit was then replaced with an M300-TH from Milesite. The Senstick survived two winters at Glynllifon working well for the duration.

Slurry Storage Sensors

The LMK382 and the ultrasonic unit from Elsys were tested at Glynllifon. The LM382 was accurate but difficult to mount. The Elsys unit worked well once mounted on a wooden bracket. Due to mounting challenges, the slurry storage sensors were not mounted at the other farms.

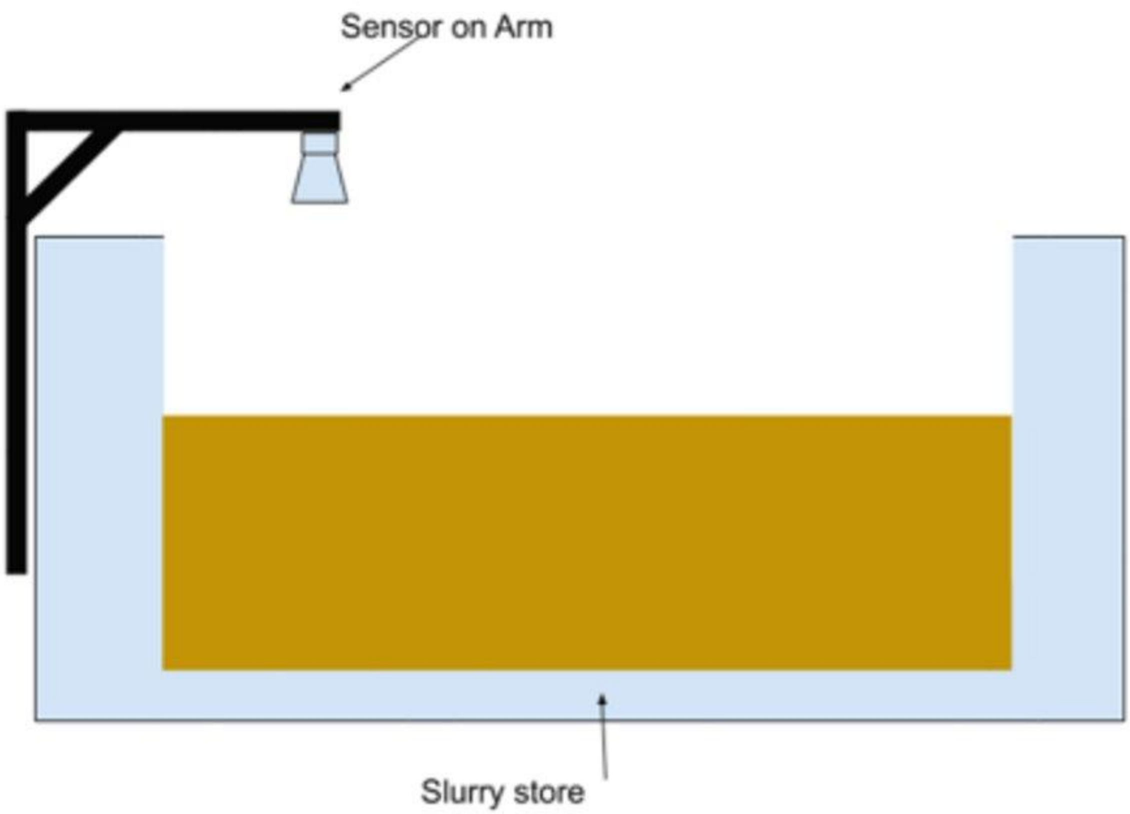

Figure 9: Ultrasonic Distance Sensor on slurry store diagram

4. Strategic relevance

The project aims to further build on the cooperation between the farming community and technology experts to solve common problems and bring about a smarter way of working.

This trial is already helping the farming community learn more about the capabilities of LoRaWAN technology, and if it is successful as a slurry management tool, it will help with decision making to reduce the risk of water pollution. Additionally, linking this technology with agriculture and legislation enforcement has the potential to help both stakeholders successfully work together for the benefit of their local communities. With the current legislation on nutrient management and further legislation due to come in, this work is truly relevant, and this tech could play a significant role now and in the future.

The door has been opened for other farmers and family members to diversify by incorporating more technology on farms. The knowledge that is gathered from this project will be shared with the farming community in Wales and will develop a skills base in agriculture that is fit for purpose for the future world. This could increase the number of jobs available within agricultural technology sectors encouraging those with an entrepreneurial flair to venture into this market to create further solutions for current agricultural challenges.

5. Collaborations

This trial is bringing people from a variety of backgrounds to collaboratively trial a solution which could help shape the way slurry and other farm processes are managed in the future. These stakeholders have been collaborating with each other during the project forging lasting relationships between agriculture, technology, and governance to solve common agricultural challenges beyond slurry management. This collaboration of knowledge and combined skills of the Operational Group benefits the project.

6. Attitude Analysis

The methodology for the attitudinal study comprises a longitudinal mixed methods approach. Data was collected through two primary sources namely four focus groups and a standardised questionnaire completed several times across the life of the project by the three farm managers.

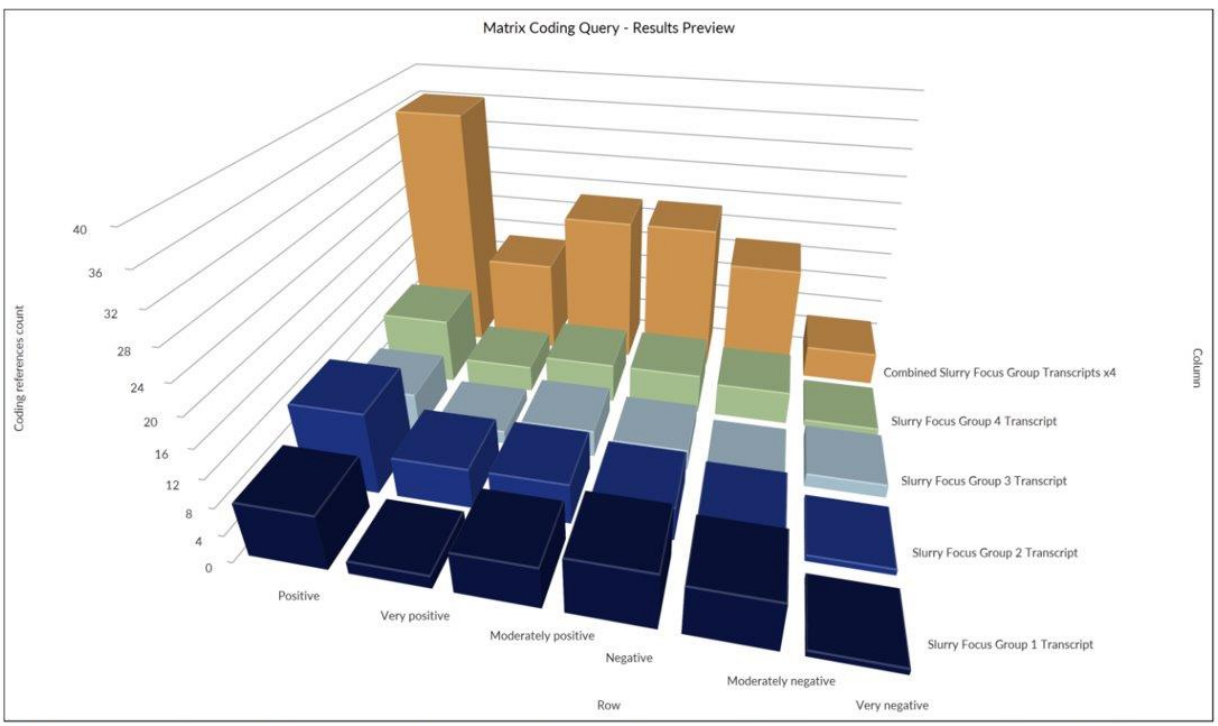

Figure 10: Graph plotting the four focus group transcripts combined and individually against sentiment/ attitude of the sentence content. Source: Wyn Owen, Report - Using IOT technology to improve slurry management on farms Monitoring Attitude

The main findings of the focus groups and questionnaire were as follows.

• According to analysis of the focus group transcripts, the farmer participants' attitude to the technology in this project increased from being neutral (equal positive and negative) to more positive than negative across the life of the project.

• The biggest change towards a more positive attitude occurred between the first and second focus groups

• Both the quantitative and qualitative data from the questionnaires supports the data from the focus groups

• Review of previous work in this field suggests that positive early attitudes as recorded here, are likely to encourage adoption of the technology (Chuang, 2020) as is early farmer involvement in the trialling of the equipment (Kaler, 2019)

• Even though the primary focus of this research was change in farmers' attitudes, the author observes that the involvement of and input from other participants (e.g., individuals from organisations with relevant technical expertise and from interested agencies) was extremely important and useful to the efficacy of the focus groups and the project overall (Owen, 2022).

7. Legislative backdrop

Since the start of this project, the Welsh Government have introduced a number of regulations. These include the following from April the 1st 2021.

Controlling the spreading of Nitrogen fertiliser (includes manufactured nitrogen fertiliser, slurry, and other organic manures)

- If you intend to spread nitrogen fertiliser you must first inspect the field to consider the risk of nitrogen getting into surface water.
- You must not spread nitrogen fertiliser on land if there is a significant risk of nitrogen getting into surface water, considering factors such as weather and slope. Mandatory buffer zones were established (as per existing cross compliance requirements).

Incorporation of manure

- Organic manure applied to bare soil must be incorporated within 24 hours in most circumstances. Exemptions may apply e.g., if precision spreading equipment is used.

Further regulations are also due to come in from the dates below.

<u>From 1 January 2023</u>

Risk maps

- If you intend to spread manure on the holding you must produce and maintain a risk map which highlights the areas on which spreading may cause pollution, including buffer zones and surface waters.
- Sites suitable for field heaps should be marked if manure is to be stored in field heaps.

Storage of organic manure

Other than slurry, any organic manure must be stored:

- In a vessel; in a covered building; on an impermeable surface; or in a free-standing temporary field heap.

Temporary field heaps

- Rules on the placement of manure field heaps will apply to minimise the risk of any leaching and run off reaching waterbodies.

Nutrient management planning

- A Nutrient Management Plan must be established for any nitrogen fertiliser application, which includes the soil nitrogen supply and the requirement of the crop.

Import/export of manure

- Any import/export of manure onto/off the holding must be recorded.

Nutrient applications

- Fertiliser applications must not exceed specified crop limits.
- Fertiliser must be applied as accurately as possible and spreading trajectory must be below 4 meters from the ground.

Records

- Records associated with Nutrient Management Plans and fertiliser applications must be kept.
- Exemptions from certain requirements will apply to extensive farms.

Holding limit

- The total amount of nitrogen in organic manure spread on any given hectare on the holding must not exceed 250kg for any 12-month rolling period.

17 February 2023

- Closing date of Welsh Government's consultation on an important proposed component of the Water Resources (Control of Agricultural Pollution) (Wales) Regulations (Welsh Government, 2022).

  Welsh Government Minister for Rural Affairs Lesley Griffiths announced (25th November 2022) the launch of a 12-week consultation on a licensing scheme for farming businesses to apply for a licence for a higher annual holding organic nitrogen limit of up to 250kg/ha, subject to crop need and other legal considerations.

From 1 April 2023

Holding limit - this was extended from 1 January 2023

- No more than 170kg of nitrogen from manure can be applied each year, averaged across the holding, either directly deposited by the animal or by spreading.

<u>From 1 August 2024</u>

Closed periods.

- The spreading of slurry will be prohibited during the following periods (certain exemptions will apply, see Welsh Government guidance):

Soil Type	**Grassland**	**Tillage land**
Sandy or shallow soil	1 September to 31 December	1 August to 31 December
All other soils	15 October to 15 January	1 October to 31 January

- Spreading after the closed period until the end of February will be limited to 30 cubic metres per hectare (8 tonnes per hectare of poultry manure) at any one time, and there must be at least three weeks between each spreading.

Slurry storage capacity

- 5 months (1 October – 1 March) of slurry storage will be required for any slurry produced by any livestock, other than pigs or poultry.
- For slurry produced by pigs and poultry, 6 months (1 October – 1 April) of slurry storage will be required.

Irrespective of the minimum storage requirement, you must ensure you have sufficient storage available to enable you to comply with the other requirements of the regulations (NFU, 2022).

8. Dissemination

The strong OG bought together for this application means that the outcomes were disseminated to many different stakeholders interested in improving farm management systems. Erw Fawr and Glynllifon are part of the Farming Connect Demonstration Farm Network which means that the project is very well positioned to benefit from the programme's various communication outlets.

For this reason, locating this project on an agricultural college and two current 'Farming Connect' demonstration farms opens the opportunity for demonstration and dissemination.

Open Signal coverage Plan

The project commissioned a software engineer to generate an individual topographical plan of the signal coverage for each farm and the surrounding area. The OG are happy to make the result of this survey public to give other businesses in the area a better idea if they could use the gateway to network their own IoT sensors.

Attitude Analysis

As at the start and end of the project, Farmers participating in the project events have also participated in the attitude analysis commissioned by the appointed project specialist.

Websites & social media

All OG members are active on social media either through professional or personal accounts. They have been posting regular content on these platforms throughout the project which will consistently raise awareness of the work being done.

Findings Dissemination

It is recommended that sufficient resources are allocated to share the learnings from this project. This includes creating videos whilst the sensors are in place on farms to show them being used and provide articles for access to information gathered by this project.

9. Summary

- This technology provides an audit trail which was especially important going forward regarding farm Nutrient Management Plans that has been set out in the legislation. This could be further bolstered by blockchain or enforcement authority having an independent network to function as verification.

- It is difficult to pin down the parameters for each of the sensor data to define the best conditions for applying nutrients. The legislation has been set without any guidelines on what these parameters should be to help farmers.

- The farmer participants' attitude to the technology in this project increased from being neutral to more positive than negative across the life of the project.

- The sensors have provided similar data as all three farms are coastal lowland dairy farms in the same county.

- This project supports better decision making beyond slurry application. For example, a soil temperature sensor could assist a farmer to decide when best to apply nitrogen fertiliser at the start of a new season when using the T-SUM 200 model.

- Technology is evolving rapidly and very few farm businesses have any capacity to conduct R&D work despite many being ready to invest time on it.

10. Conclusions

- There is scope for this project to evolve as it has uncovered many new avenues to be explored and is important it does not stop here. It has laid the foundations for LoRaWAN technology to provide better information when managing a nutrient rich source to improve farming and reduce water pollution.

- The technology trialled in this project does work for collecting data on farm conditions. Although the traffic light system was not developed during this project, the Pethau dashboard provides the data gathered by the sensors for the farmers to interpret and used to help decide on whether to apply slurry. Overall, we can conclude that this technology does improve farmers decision making.

- The approach and methodology have worked well overall. The phases of the methodology have enabled each stage of the trial to be assessed, giving success, and learning points from valuable failures. Each stage is important for the subsequent phase to have the best chance of success. The methodology has enabled lots of questions to be answered but also has raised some new questions for further developing this project.

- This technology will improve farms nutrient application using the T-SUM 200 method. The current T-SUM 200 guidelines cover vast areas including lowland and highland areas where the T-SUM 200 was reached at different times. Using farm specific data from the sensors will show when T-Sum 200 was reached accurately to help inform farmers to make better decisions based on this method. For example, a lowland farm is likely to reach T-SUM 200 earlier than an upland farm, therefore could apply slurry to the field earlier resulting in a better harvest.
- The three trial farms in this project are all coastal lowland dairy farms. This is a weakness of the project as they lack variety in terms of geographical location and type of farm. The sample of results could be improved with varied farm locations.

- Monitoring the attitude towards the use of the technology has proved to be a valuable approach in this project. Not only did participants attitudes change from neutral to more positive, but the biggest change to this happened early in the project. These early positive attitudes are likely to encourage the user's adoption of the technology going forward.

- The legislation set out by Welsh Government gives further importance to this project. Even if better farm managements solutions are not completely developed from this project, a better understanding of the technology and closer collaboration between farmers and IT technical expertise to further develop the emerging Agri-tech sector in Wales, is a big step forward. The OG should look to benefit from the government funding provided for tackling water pollution and nutrient management in the future.

- It is imperative to give as much time as possible to outdoor based trials of the technology. Due to the short timescale of the project, allowing as much time as possible for the cycle of gathering data, feeding back, and applying changes, will have a greater outcome and impact of any similar project using the same approach.

11. Recommendations

- Different soil types have different water carrying capabilities and so saturate at different soil moisture levels. Further work needs to be done to determine exactly what the observed soil moisture level would read when a particular soil type is saturated. This should be explored with Bangor Universities soil scanning technology outlined in phase 1. For example, the project results term this level as the threshold for applying slurry where the moisture level must be at or below the threshold for a 48-hour period. This threshold would vary four different soil types.

- There is room to improve helping with decision making. The aim was to develop a traffic light system as a straightforward way of aiding farmers with when to apply slurry would be valuable. However more work needs to be done on identifying the parameters that would be needed for interpreting the data into a traffic light interface.

- The approach could be improved by having a wider variety of samples. In this project the farm locations were all similar. If this project is rolled out to more farms there would and opportunity for more learning from a varied farm location and farm type. Trialling this project on upland farms as well as lowland should provide a varied set of results. A larger sample of farms would also provide more results for analysis and insight. Diverse types of livestock farming should also be considered as only dairy farming was trialled in this project and it would be beneficial to trial other types of livestock farming such as poultry.

- As an evolution of this system, it would be an improvement if the sensors could also include nutrient management for example measuring soil nutrient levels, current crop demand, future crop demand and slurry nutrient level. This has been considered in the project however the budget could not stretch far enough to include the additional technology and expertise needed for managing nutrient levels.

- Further work could be done on monitoring the phosphate and nitrogen levels in soil. This would help establish whether the soil needs further input from slurry and if so, how much. Gaining a better understanding of this would reduce the risk of phosphate and nitrogen pollution to waterways. Introducing a dissolved oxygen sensor and water nitrate sensor to this system would provide more data to improve decision making on nutrient management.

- To improve the analysis of the soil moisture readings, soil profiling would need to be done to determine exactly what the observed soil moisture level would read when a particular soil type is saturated.

- This EIP project has little artificial intelligence or machine learning elements. It currently relies on soil expertise to define when the soil is suitable for applying slurry. Introducing AI to this system would potentially improve it as a tool for farm management.

- Ongoing investigation into the cost of the technology after the project needs to be done. The technology must be viable going forward and this can be done by assessing whether it meets the farmer needs for this cost. Once the project has determined the functionality and usefulness of the IOT for slurry management, the ongoing cost would need to be analysed to see if it is outweighed by the benefits.

- This system could be commercialised and rolled out to the wider industry. The step-by-step approach of trialling the technology, developing the application, and monitoring the attitude of the users, makes sense and one that can be replicated for other technologies in farming benefiting the wider industry.

- If this project is developed further, it is recommended that monitoring users' attitude towards the technology is included as part of the methodology as this is a valuable part of the approach. Attitude analysis would provide learning outcomes that could help steer the project to improve the probability of technology adoption by users.

- Including brief information on current legislation in the path I dashboard would help nutrient management decisions. For example, if the window for applying slurry is closed, the dashboard could highlight this.

- This project could be further developed by rolling it out to a catchment area. For example, a catchment area for a river could be trialled and the water quality of the river could be tested regularly before, during and after the trial to see if this system improves water quality.

- There is an opportunity for this project to work with Tywydd Tywi for sharing views and defining the parameters for alerts, co-learning, and collaboration.

- The working relationship between farmers in western Scotland and Scottish Environment Protection Agency (SEPA) appears to be working in terms of farm compliance to the regulations (BBC, 2021). The system trialled in this project could enable self-monitoring which would requires less Natural Resources Wales (NRW) monitoring but with the aim of farm compliance and reduced pollution incidents. There could also be an opportunity for developing an approved status for farms adopting this technology which may also lead to these farms having more freedom over their nutrient management in the future.

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Attachments

Owen, W. (2022). *Using IOT technology to improve slurry management on farms Monitoring Attitude.* Organisational Development Consultants.

Sheperd, R. (2022). *Study of data gathered from LoRaWAN Instruments on three farms across North Wales.* DataCymru.

References

BBC. (2021, January 27). *New Wales farming pollution rules 'compel industry to change'*. Retrieved from BBC News: https://www.bbc.co.uk/news/uk-wales-55833335

Chuang, J. W. (2020). Farmers’ Knowledge, Attitude, and Adoption of Smart Agriculture Technology in Taiwan. *International Journal of Environmental Research and Public Health 17*, 1-8.

Farming Connect. (2023). *Demonstration Network Site Locations*. Retrieved from Business Wales: https://businesswales.gov.wales/farmingconnect/our-farms/projects

Kaler, J. &. (2019). Technology adoption on farms: Using Normalisation Process Theory to understand sheep farmers’ attitudes and behaviours in relation to using precision technology in flock management. *Preventative Veterinary Medicine, 170*, 1-8.

NFU. (2022, Dec 02). *Water quality regulations - dates you need to know*. Retrieved from NFU Cymru: https://www.nfu-cymru.org.uk/news-and-information/water-quality-regulations-dates-you-need-to-know/

Owen, W. (2022). *Using IOT technology to improve slurry management on farms Monitoring Attitude.* Organisational Development Consultants.

Sheperd, R. (2022). *Study of data gathered from LoRaWAN Instruments on three farms across North Wales.* DataCymru.

Welsh Government. (2022, November 25). *Consultation Document; Nutrient management – Managing the application*. Retrieved from Welsh Government services and information: https://www.gov.wales/sites/default/files/consultations/2022-11/nutrient-management-managing-application-livestock-manures-sustainably-consultation-document_1.pdf