Analysis of Soil and Weather Data

Study of data gathered from LoRaWAN Instruments on three farms across North Wales

Analysis and Report by:
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Changelog

v1.0 2022-09-20 Initial Report
v1.1 2022-09-28 Data re-analysed with alternative Forecast Dataset
v1.2 2022-10-30 Draft issued for review

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1 Introduction

Background

This report draws on data that has been gathered from a previous project which was to deploy sensors relating to environment and field conditions around 3 farms in North Wales.

The project was exploratory and aimed to introduce wireless sensors and associated technologies into dairy farms to gather data on air temperature, rainfall, soil temperature and soil moisture.

The original scope was to perform technology appraisal to see if it can help with farming decisions toward the application of slurry or other fertilisers with the aim of minimising water course pollution from surface run-off.

Each of three farms deployed an air temperature sensor, a rain gauge, and three combined soil temperature and moisture probes to be deployed in separate field zones.

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 inspect the historical data that was permanently stored.


(Left) Soil Sensor (Right) Air Temp and Rainfall Sensors

Figure 1: Typical Sensor Deployment

Figure 1 shows the typical deployments of the sensors.

Objectives

In this report we use the permanently stored data and derive some summary statistics and explore what the dataset tells us about the field and environment conditions.

The sensors were first deployed in April & May 2021 and in most circumstances (aside damage or battery expiration) 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:

- **Freezing Conditions.**
- **Low Soil Moisture.**
- **High Soil Moisture,Water logging & Saturation.**
- **Rainfall.**
- **Protracted Dry Periods: I.e. No Rainfall.**
- **T-Sum 200.** Seasonal temperature analysis.

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

2 Freezing Conditions

2.1 Low Soil and Air Temperature

In this section we identify the lowest temperatures recorded for fields and farms.

As shown in table 1, no sensor in ANY field recorded freezing soil temperatures over the study period.

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

Table 1: Lowest Soil Temperatures

Whilst the air temperature did drop below zero - (as shown in table 2) - these were not sustained periods and (as demonstrated above in table 1) neither cold nor sustained enough to permeate the soil.

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

Table 2: Lowest Air Temperatures

The air temperature profile at Erw Fawr shown in Figure 2 highlights only a few short spells of sub-zero air temperatures over the whole study period, highlighting what was probably quite a mild winter.

Notice in particular the very warm weather during that last week of 2021 into 2022 with the nightly minimum being above 10 degrees.

The other two farms show very similar temperature patterns, and it is noted they are all coastal sites.

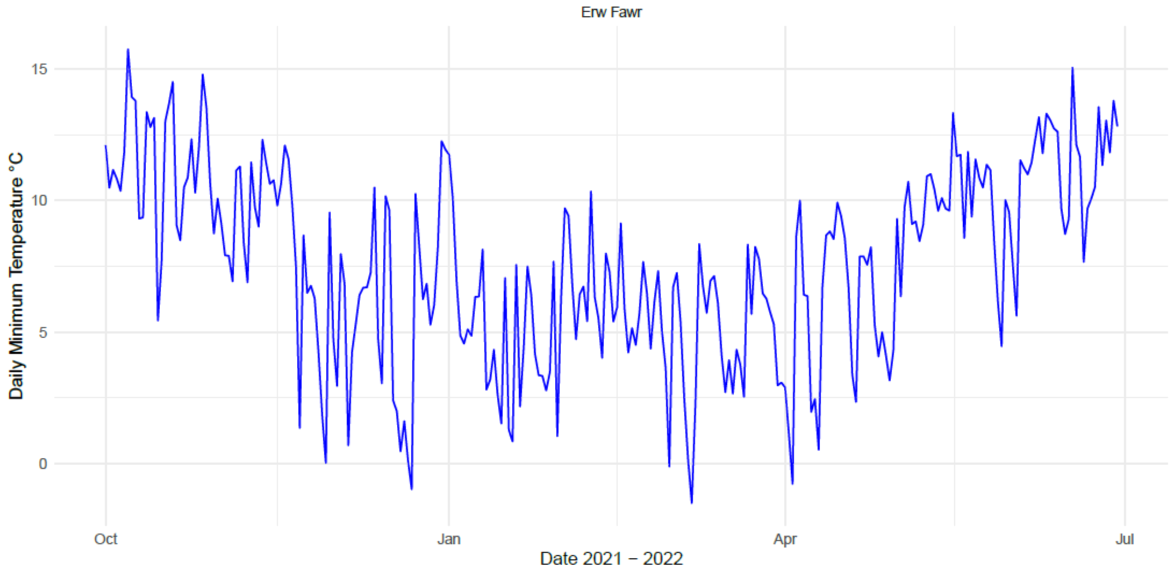

Figure 2: Daily minimum air temperature over the reporting period

2.2 Warming & T-Sum 200

The T-SUM 200 approach[1] is:

... a method to determine when to make the first application of nitrogen fertilizer in Spring

The method is simply described as "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 3. Figure 4 shows the variation in the last 10 years, based on historical data from a weather internet dataset. [2]

1 https://farmwest.com/climate/calculator-information/t-sum-200/
2 https://home.openweathermap.org/marketplace

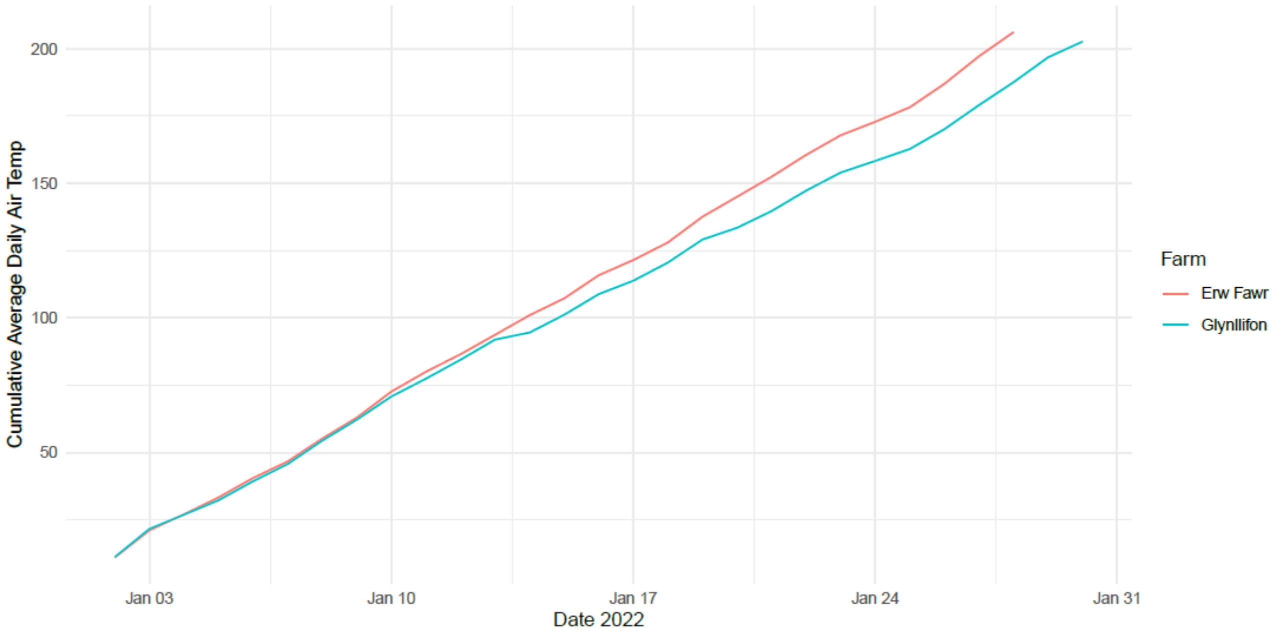

Figure 3: T-SUM 200 for 2022

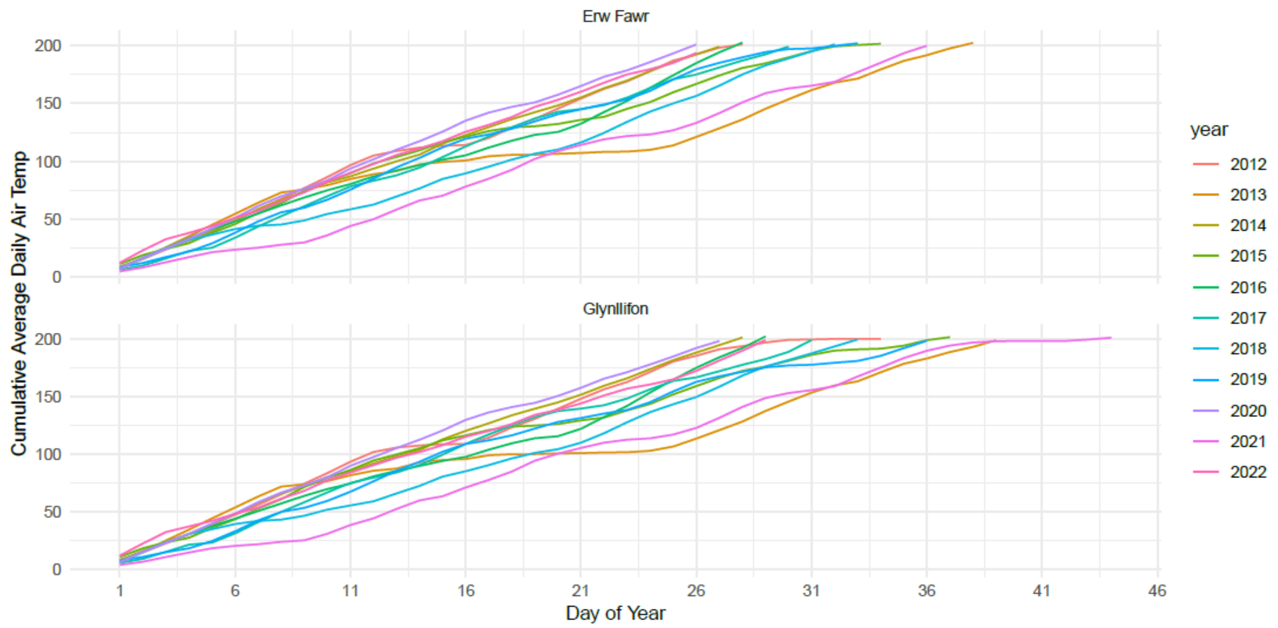

Figure 4: T-SUM 200 2012 to 2022

3 Soil Temperature

Figures 5 & 6 shows the relationship between air temperature and soil temperatures over two time periods.

Figures 5 shows the temperature profile over the whole reporting period and Figure 6 shows a “zoomed in” section over just March and April 2022.

Typically the changes in the soil temperatures *(observed at50mmunder the surface)* closely follow the air temperature. Things appear to change around the start of April where grass growth has an effect in seemingly locking-in warmth.

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 very similar soil temperature seasonal profile. They are all however situated in quite similar settings: coastal, low altitude.

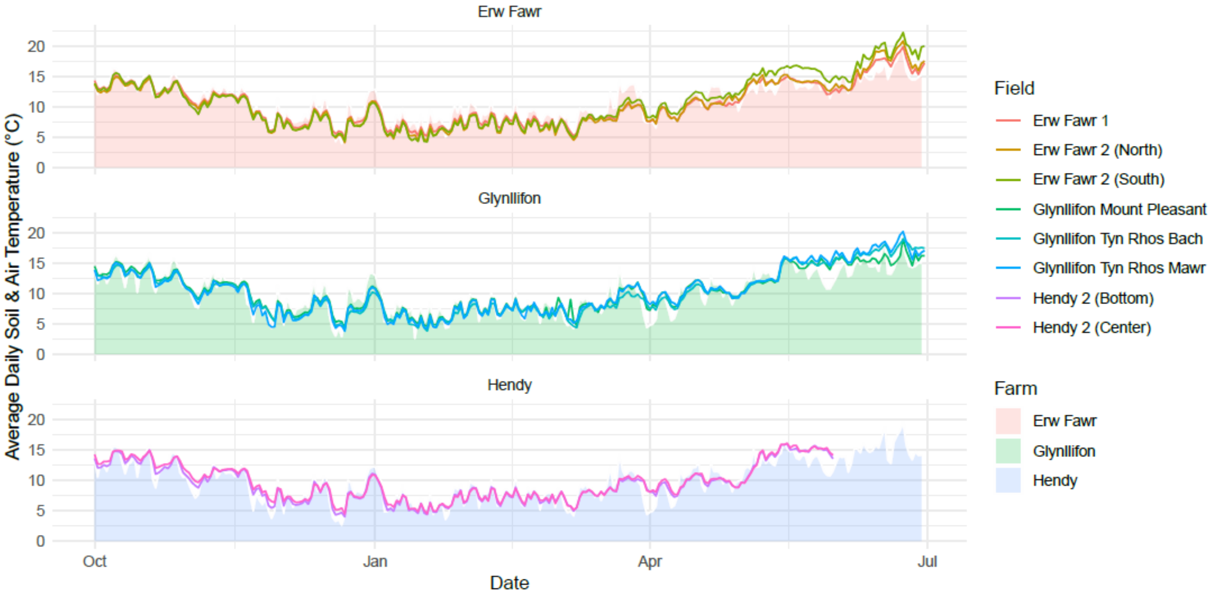

Figure 5: Field soil temperature (line) with Farm air temperature (shaded) over the reporting period

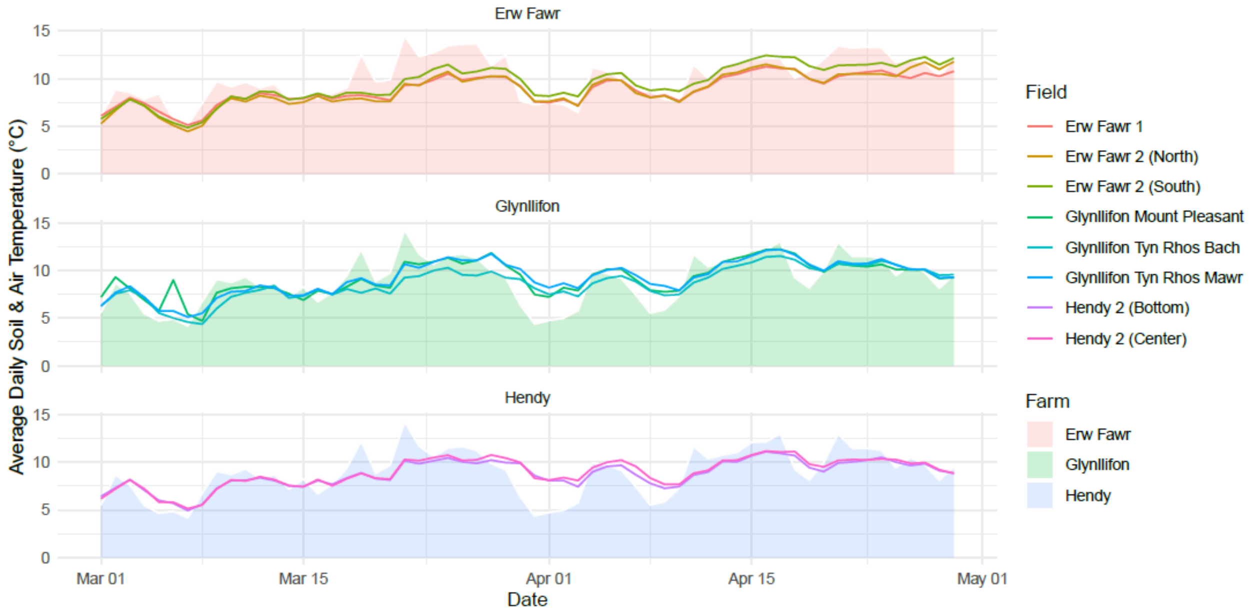

Figure 6: Field soil temperature (line) with Farm air temperature (shaded) over March and April

The highlighted time period displayed in Figure 6 better illustrates the relationship between air and soil temperature. Soil temperature has a lag which is slower to both warm and cooldown than the air temperature which influences it.

4 Soil Moisture

Soil moisture sensors detect the amount of water in the soil as a percentage. Almost every soil type will be completely saturated by50%with some soil types (E.g. sandy) being able to retain much less water than others and so saturate at a lower percentage. See the footnote[3] for one resource which offers more explanation of this concept.

This percentage can be though of as the fraction of the weight of the water in the wet soil[4], and thus if we were to take a 1Kg soil sample that was recording, say 30% moisture, and hypothetically split apart the water and dry soil into seperate containers, the water would 300grams and the dry soil 700grams[5].

Soil moisture levels vary with rainfall, soil type and numerous local conditions (drainage, evaporation, plant uptake, etc).

Run-off can occur when soil moisture is over the field capacity, wherein the soil cannot hold any more water and saturates.

This field capacity value is a unique property, determined by the soil type.

Table 3 shows the maximum soil moisture (%) observation. This table (Table 3) also shows the minimum observed value, thereby illustrating the range of soil moisture that different fields may go through.

		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

Table 3: Soil Moisture Ranges

We can inspect soil moisture over time to gain some insight into the pattern of behaviour of soil moisture for each field,

Figure 7 shows the soil moisture seasonal profile for each field.

3 https://connectedcrops.ca/the-ultimate-guide-to-soil-moisture/
4 So called: *Gravimetric* Soil Moisture Measurement
5 This process is usually done by drying the sample to evaporate ALL the moisture to observe the resulting weight of dry soil

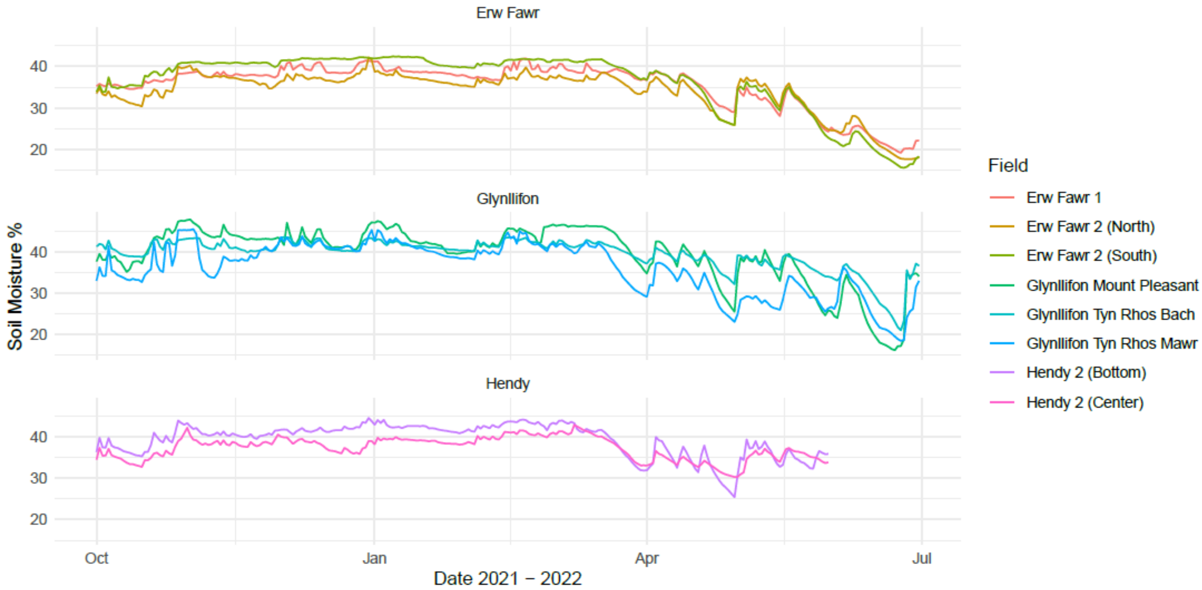

Figure 7: Field soil moisture over the reporting period

Some observations from this data on figure 7 are as follows:

- Erw Fawr 2, North and South - Despite being the same field, roughly 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.

4.1 Low Soil Moisture in Winter

By inspection of the charts we can see that there are no periods of low soil moisture (<30%) during the period Nov ’21 through Apr ’22.

4.2 Unsaturated Soil in Winter

Here we look at soil moisture over the wider winter period: 1st October 2021 through 30th April 2022 (212 days in total).

It would be desirable to determine when the soil moisture of a field is low enough so that water saturation - either current water logging, or imminent rainfall - does not present any risk of run-off of applied fertiliser or slurry.

Different soil types have different water carrying capacities and so saturate at different soil moisture levels. Presently we do not have sufficient detail to determine exactly what the observed soil moisture level would read when a particular field is saturated. Nevertheless

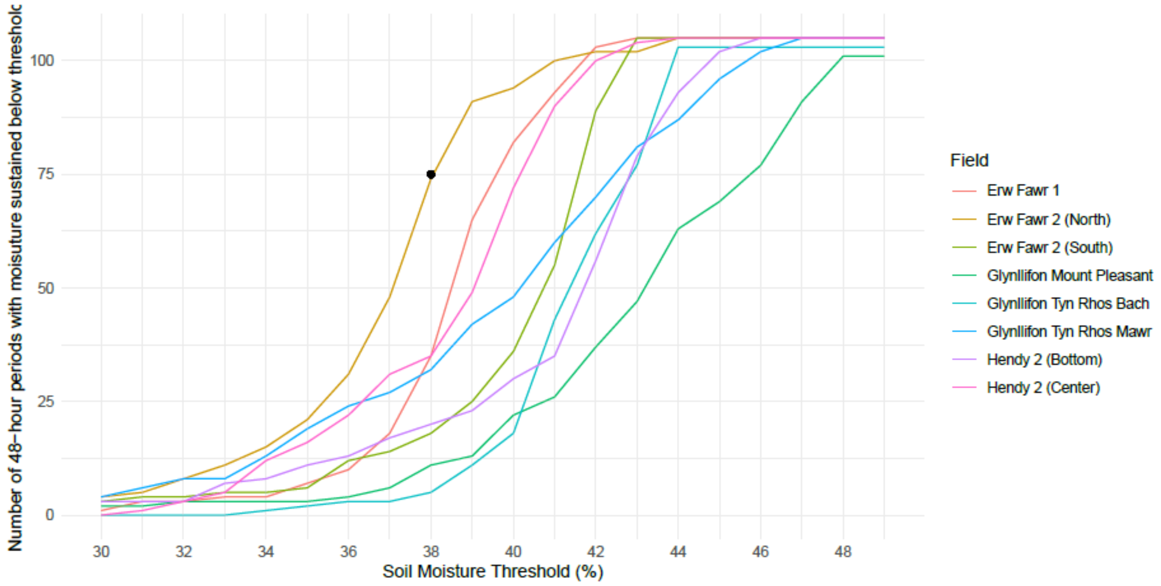

Figure 8: Availability of unsaturated ground for 48 hours at varying soil moisture thresholds

we can present a sliding scale of soil moisture levels and inspect the field performance data, using each level. Later, more expert, measured or anecdotal knowledge of specific soil types or fields can then make a more refined judgement about which level would be considered an approximation for unsaturated for each field.

Herein we shall term this level the **threshold**, which translates to *at or below* a specific soil moisture level. For example, with a threshold of 40% we are looking for field performance when the observed soil moisture level was *at or below* 40% for a sustained period.

We choose here an arbitrary window of 48 hours to represent a suitable period of time for planning using moisture values that are sufficiently sustained.

Figure 8 shows us, for varying soil moisture thresholds, how many times did a sustained 48 hour period occur, when the soil moisture was at or below the sliding scale of thresholds.

As an aide to interpreting this chart, please locate the point highlighted with a black dot. This point provides an example as follows:

Field-2, North at ErwFawr had 75 separate occurrences of sustained 48-hour periods with soil moisture at or below 38%.

More generallywe can see in figure 8 that by selecting a lower soil moisture threshold (looking for sustained drier soil) then there are fewer occurrences of such sustained 48-hour periods. It is rare to find a 48-hour period where soil moisture is less than E.g. 34%.

The fields shown by each line on figure 8 are self-organised by the data into the better draining fields towards the left, and with fields with higher water retention to the right. That is to say, For a better draining field (such as Erw Fawr/2/North), there are more occurrences of sustained 48-hour periods with lower soil moistures. Glynllifon/MtPleasant seems to be the field with the highest water retention as there are much fewer occurrences of 48-hour sustained periods at lower soil moisture thresholds.

Further interpretation notes for figure 8:

- Some of the 48-periods of sustained soil moisture at or below a threshold level may arise sequentially, totalling sustained periods much longer than 48 hours.

- The chart does not show *when* these 48-hour periods arise over the reporting period. The raw data shows us that the lower soil moisture thresholds tend to be clustered in late autumn or spring. We can see this by cross-referencing with figure 7.

5 Rainfall

The rain gauges at site provide a reasonably accurate observation of the quantity of moisture introduced to the soil.

Figure 10 on page 17 shows the rainfall over the period October to July across each farm in addition to the soil moisture profiles and the air temperature. Figure 10 highlights the influence of rainfall on soil moisture.

	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

Table 4: Soil Moisture Ranges

Table 4 shows the maximum recorded rainfall for each farm over various periods. This table highlights the different rainfall patterns amongst different sites; with Glynllifon having the highest maximum daily/weekly & monthly amount of rainfall, but the lowest rainfall in total over the period.

5.1 Rain Free Periods

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
Hendy	85

Table 5: Rain Free days per farm

The distribution of rain free days is also worth highlighting. Figure 9 shows how often rain free periods of different durations arose on each farm. A single rain free day (I.e. in between days with some rain) is the most common, but this chart also shows that periods of at least 3 days with no rain are not uncommon.

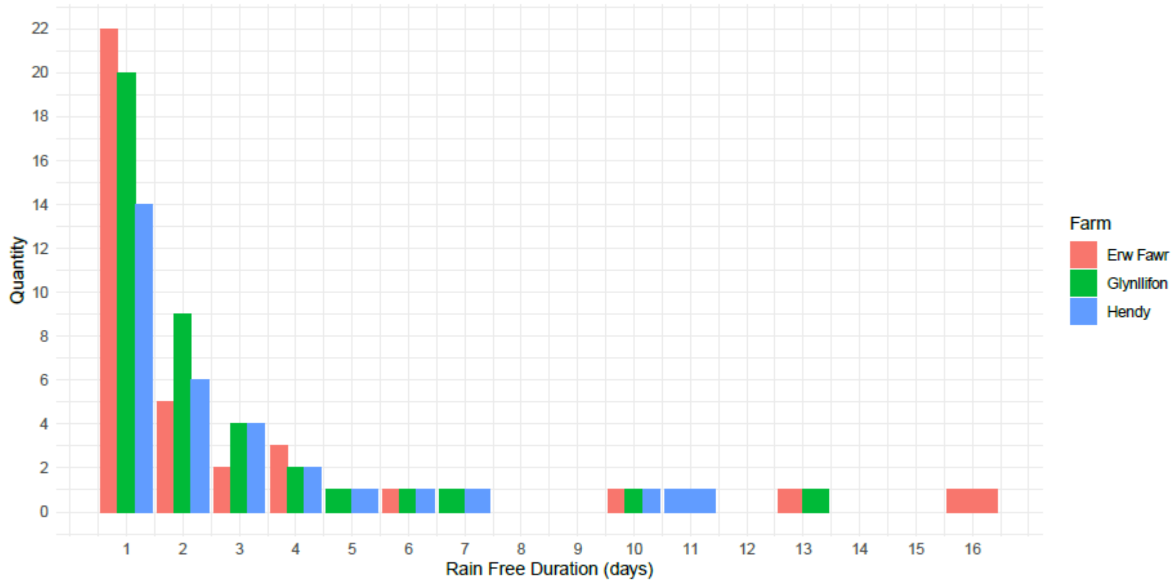

Figure 9: Number of rain free periods of different duration.

5.2 Rain Forecasts

We attempted to look into a hypothetical scenario consisting of a period of no rain, no frost, and unsaturated ground, in addition to there being no heavy rain forecasted. I.e. a reasonable appropriate situation to apply slurry whilst minimising risk of surface run-off.

Sadly, we were unable to find a historical forecast dataset with sufficient quality to make further analysis worthwhile. None of the accuracy measures we calculated (E.g. MAPE) were found to be close enough to be reliable, suggesting that despite being location specific datasets, the forecasts themselves are produced from a highly generalised weather model.

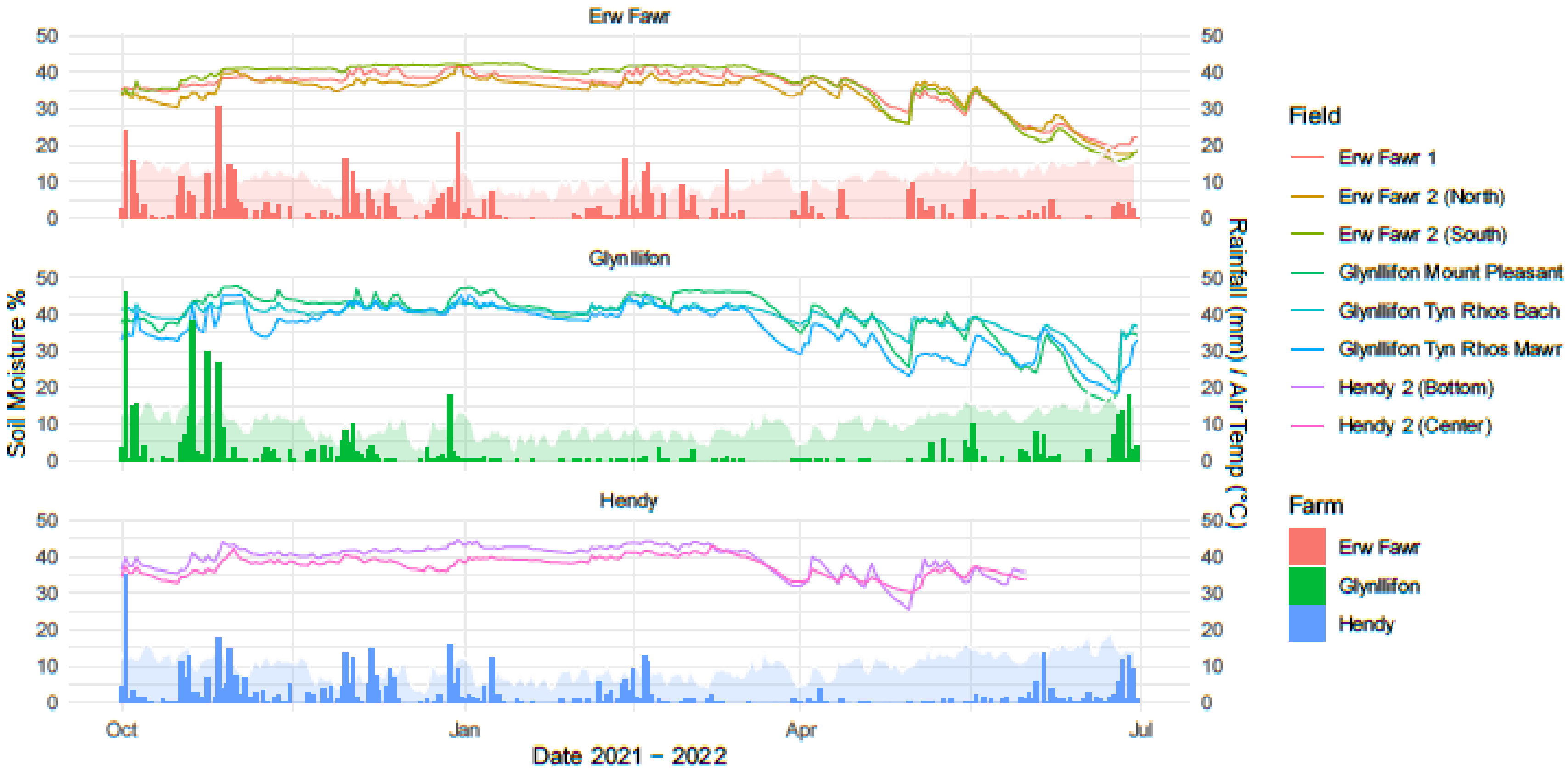

Figure 10: Field Soil Moisture Profiles with Rainfall (bars) and Average Air Temperature (shaded)

6 Notes

6.1 Caveats

It is worth mentioning the following points in relation to this analysis and discussion.

We describe “fields”however we only know the observations taken at the specific sensor location. There may be local factors which make the sensor location unrepresentative of the field as a whole.

6.2 Missing Data

From what would comprise a comprehensive dataset, some data are missing.

At Hendy one soil moisture sensor provided intermittent data. The gaps (throughout the study period)were enough to make overall analysis problematic and so has been discounted entirely. This sensor nevertheless has continued to work well.

The Air temperature sensor had an unseen malfunction and the data has some dropouts and a period of problematic data. These parts have been censored, but interpolated with historical data from an online weather source specific to this site; the combination of which is accurate enough to make analysis and observation satisfactory. Also at Hendy, in June ’22 two sensors were ploughed in-situ and the units were lost.

At Glynllifon a period of a flat battery on the air temperature sensor without replacement has meant a few weeks of missing air temperature data. This has been interpolated with historical data from an online weather source specific to this site.