Animal & Grassland
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Moorepark Dairy Levy Research Update

Teagasc Heavy Soils Programme – Lessons Learned

A guide to the key findings of the Teagasc Heavy Soils Programme to-date

Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork.

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Teagasc heavy soils programme – lessons learned

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1. Background and initial objectives

The initial development of the Heavy Soils Programme was encouraged by a number of factors, namely; a number of years of extreme summer rainfall, particularly 2009 and 2012; an appetite for more detailed research with regard to the management of heavy soils and land drainage and the impending removal of quota restrictions which would incentivise the need for optimal use of all resources, including land. A large proportion of farms nationwide are located on land which due to natural limitations related to soil type, topography, relief and climate remain poorly drained. Of the 3.18 million Ha of managed grassland nationally, it is estimated that 0.96 million Ha (30%) are imperfectly or poorly drained. Poorly drained soils, by their nature, typically remain wet for prolonged periods each year and reach saturation during rain events. Farms on such soils are subject to shorter grazing seasons, due to a need to limit damage to soils/swards, and lower productivity, profitability and resource efficiency than those on free draining soils. The level of volatility associated with such soils will depend on the proportion of such soils on a given farm and weather in a given year. Generally profitability on such soils is closely related to weather and as such can be extremely volatile.

It was decided to establish a programme to develop a network of farms on poorly drained soils to act as a test bed for strategies and management practices that could be implemented to improve the efficiency and performance of farms dominated by such soils. The selection of participant farms was initially focused in Munster and was supported by Kerry Agribusiness, Dairygold and Tipperary Co-operatives. A shortlist of potential candidates, drawn up by Teagasc Advisory staff and Co-op representatives, were visited in 2011 and 2012 before the initial seven participant farms were selected. These were:

- John Leahy, Athea, Co. Limerick;
- John O' Sullivan, Castleisland, Co. Kerry;
- Donal Keane, Lisselton, Co. Kerry;
- Sean O' Riordan, Kishkeam, Co. Cork;
- Con Lehane, Ballinagree, Co. Cork;
- Danny Bermingham, Doonbeg, Co. Clare;
- TJ Ryan, Rossmore, Co. Tipperary.

This initial group was joined by three more farms in the 2014 – 2016 period, again selected from a shortlist within their respective areas. These were:

- Alan Wood, Crossmolina, Co. Mayo;
- David Brady, Stradone, Co. Cavan;
- James McMahon, Swans Cross, Co. Monaghan;

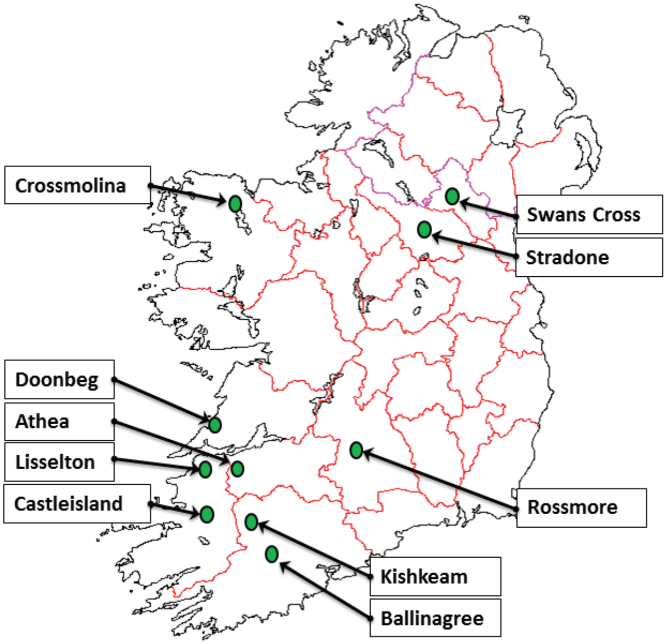


Figure 1. *Farm location map*

A key requirement was that each farmer would be willing to monitor, record and share information with regard to farm inputs, management practices, outputs and financial performance as well as hosting on-farm events and visiting groups. This commitment has served the programme very well by facilitating detailed analysis of the farm systems over time and the development of solutions to common restrictions to efficiency and productivity on poorly drained soils. The openness of each farmer has been crucial to the sharing of information and lessons learned with visitors and the wider public.

The initial objective was to demonstrate methods to sustainably improve grassland productivity and utilization, decrease volatility in these parameters and sustain viable farm enterprises on poorly-drained soils. Initially the major focus areas were land drainage design and implementation and grassland management. Over time this has evolved with soil fertility, fodder reserves, and farmyard & grazing infrastructure requiring greater consideration as the project developed. Like any group of farms, there are specific issues that are more or less topical depending on which farm is considered.

We would like to acknowledge the continued support of the programme farmers and their families in participating in the programme and facilitating much insight into their farming systems and huge interaction with the wider farming community. The support of each of the Co-operatives involved (Kerry Agribusiness, Dairygold, Tipperary, Lakeland Dairies and Aurivo) is also acknowledged.

All heavy soils programme information, regular programme updates and links to other resources is available from the dedicated website www.teagasc.ie/heavysoils

2. Farm performance and development

Information related to the development of the farms is presented in Table 1.

Table 1. Average herd details						
Year	Herd size	Stocking rate (Cows/Ha)		Herd EBI (€)		Six week calving rate (%)
		Farm	Milking platform	Total	Fertility	
2011	78	1.70	2.12	84	47	72
2012	85	1.71	2.27	112	73	68
2013	84	1.69	2.24	134	79	76
2014	88	1.85	2.30	150	87	74
2015	95	1.81	2.45	161	89	74
2016	100	1.85	2.56	82	35	69
2017	104	2.00	2.80	89	39	75
2018	107	2.00	2.90	119	45	74
2019	106	2.00	2.80	134	53	83
2020	103	2.00	2.82	139	61	83

Since the beginning of the programme, herd size has increased by approximately 32% from the 2011 level, with a corresponding increase in milking platform stocking rate from 2.12 to 2.82 cows/Ha. Herd EBI has increased from €84 in 2011 to €139 in 2020 (EBI figures from 2016 to 2020 reflect the August 2016 EBI base change of -€71 applied universally). The 6 week calving rate has averaged approximately 75% with 2019 and 2020 being the only years where a rate of over 80% was achieved.

Average farm output and financial performance is presented in Table 2.

Table 2. Average farm output and financial performance							
Year	Milk solids (kg/Ha)	Gross output		Total cost		Net margin	
		(€/Ha)	(c/Litre)	(€/Ha)	(c/Litre)	(€/Ha)	(c/Litre)
2011	850	3236	35.6	1838	20.3	1398	15.3
2012	869	3092	35.4	2143	24.7	948	10.7
2013	940	3689	40.0	2332	25.4	1357	14.6
2014	935	3725	39.3	2134	22.4	1591	16.9
2015	1091	3245	32.0	2145	21.2	1100	10.8
2016	1068	2865	28.3	1911	19.7	954	8.6
2017	1289	4508	38.4	2355	20.1	2153	18.4
2018	1404	4530	35.9	2961	23.3	1571	12.6
2019	1338	4250	35.7	2676	22.4	1574	13.3
2020	1405	4406	36.2	2591	21.1	1815	15.0

Output in terms of milk solids/Ha has increased from 850 kg/Ha in 2011 to 1,405 kg/Ha in 2020, an increase of 65%. Gross output ranged from €2,935/Ha in 2016, when milk price was at its lowest to €4,530/Ha in 2018. High cost years, 2012, 2013 and 2018 relate to weather, typically excessive rainfall, or as in 2018 extremes from a very wet spring to a very dry summer, and associated curtailed production and prolonged housing and meal feeding.

Grass production is measured by regular farm walks and recorded and managed using Pasturebase (Pasturebase.teagasc.ie). Grass production for 2020 is presented in Table 3.

Table 3. 2020 grass production

Farm	Annual tonnage (DM/Ha)	Pre-grazing yield (kg/Ha)	Average number of grazings per paddock	Number of walks	Seasonal production (kg/Ha)		
					Spring	Summer	Autumn
Castleisland	13.8	1288	8.6	34	1438	8551	3028
Lisselton	12.5	1768	5.9	25	666	9275	2556
Ballinagree	12.4	1322	8.1	36	1326	6959	2327
Doonbeg	11.7	1515	6.6	40	1474	7971	2190
Athea	13.2	1619	6.9	51	2680	8207	2288
Rossmore	13.4	1483	8.1	31	1673	9265	2482
Kishkeam	11.3	1380	7.0	31	1251	7697	1808
Stradone	12.7	1628	5.8	39	1033	8636	2735
Swans Cross	11.7	1617	6.3	26	1088	6123	1651
Crossmolina	10.4	1403	5.3	18	667	5944	1770
Average	**12.3**	**1502.3**	**6.9**	**33.1**	**1330**	**7863**	**2284**

Annual grass production has shown a steady increase over the period of the programme (Table 4). This level of production will need to be maintained to ensure sustainability and profitability of these farms. An on-going review of poorly performing paddocks allows for investment to be planned with regards to land drainage, soil fertility, reseeding and grazing infrastructure.

Table 4. Average annual grass production

Year	Grass production (Tonnes DM/Ha)
2011	10.6
2012	7.8
2013	10.3
2014	11.0
2015	11.3
2016	11.3
2017	11.9
2018	11.7
2019	13.5
2020	12.3

HSP productivity and financial performance has been built on investment in land drainage, soil fertility, farm infrastructure and reseeding, amongst other strategies. These strategies developed through on farm research have facilitated increases in efficiency and scale. These gains have shown that management strategies can be applied which overcome limitations associated with challenging soils. This is achieved through utilizing large quantities of grass and efficiently converting this to milk, combined with stringent cost control.

3. Climate

Variation in climate formed part of the selection process for farms involved in the programme. The impact of weather is generally most associated with rainfall and soil temperature at these locations, these and a number of related measurements are continuously monitored at each HSP site by on-site weather stations. These measurements include rainfall, wind speed and direction, air temperature, soil temperature, evapotranspiration and solar radiation. Generally, rainfall is lowest at the East coast and highest at the West, altitude will also play a major roll (Figure 2).Otherwise, local factors such as aspect, topography and proximity to weather breaks will dictate local weather patterns.

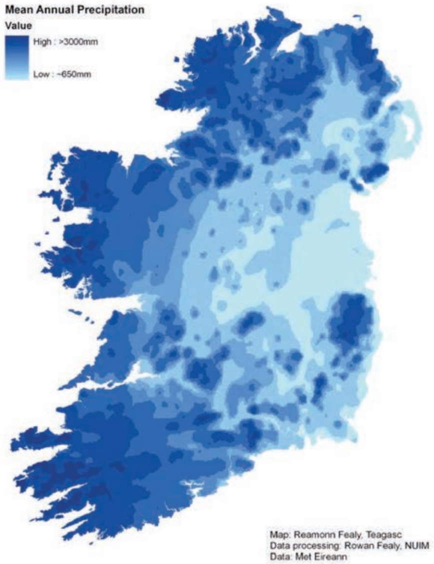


Figure 2. *Mean annual precipitation in Ireland. Note increasing rainfall towards the West and with higher altitude. High rainfall areas on the East coast are related to the Wicklow and Mourne Mountains*

The long-term annual rainfall values (met.ie) in the vicinity of HSP sites ranges from 982 mm (Rossmore, Tipperary) to 1,757 mm (Ballinagree, Cork), (Table 5). Typically, however, the Kishkeam, Co. Cork farm receives the highest rainfall level, since on-farm measurement began.

Table 5. Annual rainfall and farm locations

	Long term average (met.ie) (mm)	Range, 2015-2020 period (mm)	Northing	Westing	Elevation above sea level (m)
Ballinagree	1756.7	1,391 - 1,795	51°59'	08°56'	231
Kishkeam	1621.5	1,404 - 1,960	52°12'	09°08'	233
Athea	1320.2	1,183 - 1,662	52°27'	09°19'	139
Castleisland	1297.6	1,244 - 1,631	52°13'	09°28'	36
Doonbeg	1185.1	1,034 - 1,398	52°44'	09°30'	9
Crossmolina	1161.5	1,117 - 1,771	54°06'	09°17'	15
Lisselton	1095.3	1,005 - 1,351	52°28'	09°33'	8
Stradone	1093.3	1,049 - 1,207	53°57'	07°11'	180
Swans Cross	1078.5	981 - 1,151	54°09'	07°02'	115
Rossmore	981.8	1,036 - 1,269	52°36'	08°01'	105

The rainfall figures indicate the effect of site location and altitude on rainfall rate.

Another consideration is the "excess", which is the amount of rainfall less the amount of evapotranspiration and is a measure of how much water is required to drain via overland flow or percolation through the soil. We can take the 2020 figures from the Kishkeam, Cork and Swans Cross, Monaghan farms (highest and lowest rainfall in that year) as an example. Total Rainfall was 1,697 mm and 1,151 mm respectively, while evapotranspiration was approximately 450 mm in both cases, leaving an excess in each case of 1,247 mm and 701 mm (Figure 3). Therefore, while rainfall is approx. 47% higher in Kishkeam, when evapotranspiration is accounted for, the amount of water to be drained in Kishkeam is actually 78% higher than at Swans Cross in 2020. This is important to bear in mind as evapotranspiration is reasonably uniform throughout the country, while rainfall is not. Every mm of rainfall above evapotranspiration equates to 10,000 Litres per Ha to drain. The drainage capacity of the soil and the local catchment will dictate what effect this will have on farm management.

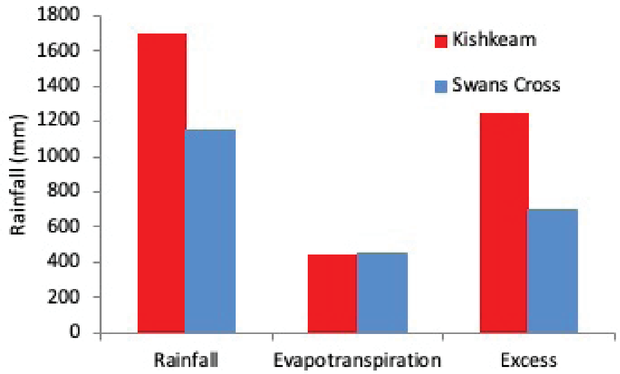


Figure 3. *2020 rainfall, evapotranspiration and excess at Kishkeam, Co. Cork and Swans Cross, Co. Monaghan farms*

The total rainfall for each farm in 2020 is shown below (Figure 4).

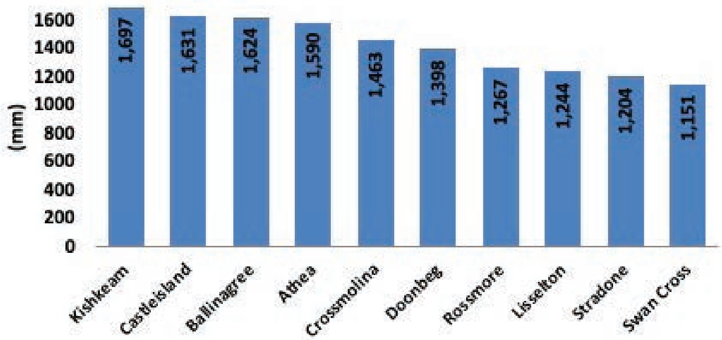


Figure 4. *2020 rainfall at all HSP farms*

The wettest month in recent years was December 2015 which averaged 319 mm across farms, while April 2017 was recorded as the driest month (25.5 mm). We have seen a number of sustained wet and dry periods in the last number of years which have caused difficulties in terms of management, most notably in 2018 when persistent rain in Spring and early Summer give way to drought by mid-Summer. Generally rainfall doesn't tend to vary much from long-term average values in any given year but monthly variations can be significant during particularly wet and dry periods. As such annual average rainfall can mask the effects of seasonal variation (Figure 5).

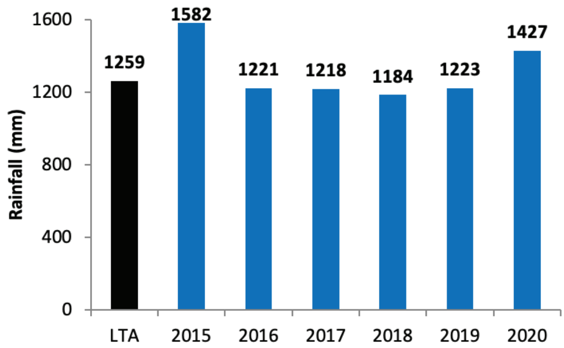


Figure 5. *Long term average (LTA) annual rainfall across HSP sites compared with recent totals. Generally annual values do not vary hugely, with the exception of 2015. Seasonal variation gives a better indication of impact of rainfall on management*

The impact of extreme weather was highlighted in 2018. Soil moisture deficit (SMD) is the amount of rain needed to bring the soil moisture content back to field capacity, which is a scenario where soil moisture is neither excessive nor lacking. A negative SMD indicates saturation while positive values represent a deficit. A look at SMD in 2018 indicates the variability in soil moisture observed. On average soils remained saturated for the first 119 days of the year (to April 29th), within 37 days (by June 5th) a deficit of 30+ mm had been reached, beyond which growth is restricted, and SMD peaked at 80.3 mm by Mid-July with severely restricted growth throughout this period. While such extremes and particularly drought conditions are very rarely a concern on such soils, the restrictions are clearly observed in grass growth records (Figure 6).

In 2018, growth on the HSP farms was slow to start in the spring due to persistent rain and saturated soils. It then peaks in late May/Early June in line with PBI average performance. Growth began to be restricted at this time and a sharp drop is observed during the summer before rainfall in late July results in a second peak in growth. As would be expected for these soils, drought conditions did not affect growth as severely or for as long as on other farms.

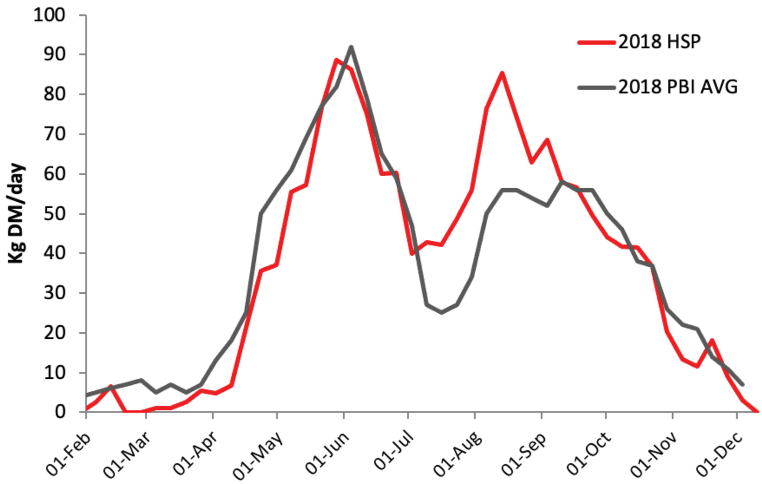


Figure 6. *2018 grass production on HSP farms compared with PBI (Pasturebase average)*

Soil temperature is related to soil moisture levels as the rate or warming will be slowed where soils are saturated. A soil temperature of 6˚C is required for grass growth and this level is achieved on average for 307 days/year on HSP farms and ranges from 285 days in Kishkeam, Cork, due to altitude and rainfall, to 327 days/year at Castleisland and Lisselton, both Kerry.

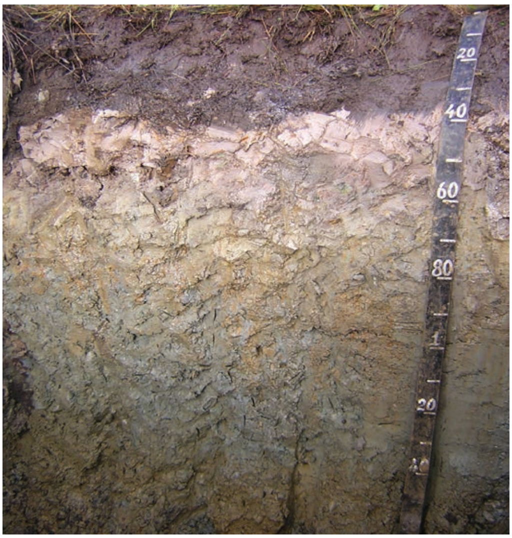
4. Soil classification

The natural variability of soils is apparent between different regions of the country, and indeed within farm boundaries. A campaign to classify, sample, measure and map soil type and characteristics at a paddock scale across the programme farms was undertaken as part of the Heavy Soils Programme. In order for the Programme to develop coherent and credible management techniques and strategies for all soil types and variations thereof, in-depth knowledge of the individual soils was required. The capture of high resolution and spatially explicit soil data enables an understanding of the agronomic and environmental aspects that need to be considered in the development of each farm. The deliverables from this exercise included: high resolution soil maps, detailed soil classifications, measurement and interpretation of soil hydrological and chemical characteristics and a bank of soil samples from each farm. The soil type, soil series and drainage class of the dominant soil in each paddock was outlined. Some example soil profiles are shown in Figure 7.

Stagnic Brown Earth: 14.0Ha in Stradone

Surface Water Gley: 12.4Ha in Rossmore

Gleyic Brown Earth: 12.4Ha in Crossmolina



Humic Alluvial Gley: 5.3 Ha in Kishkeam

Figure 7. *Example soil profiles from four HSP farms and their extent at each location.*

Mapping of the location and extent of each soil type on a given farm was established through an auger and test pit survey. Initially an auger survey was carried out on each farm, involving an auger bore on average every hectare to investigate the soil physical features. Their resulting distribution was an even coverage across each farm (Figure 8). The Dutch auger was driven into the soil to a depth of 1 m. The soil features were described and recorded. Horizon type, depth, texture, colour, mottling, structure, roots and stones were recorded along with many more physical attributes detailed in the Irish Soil information system soil profile handbook. Soil type and drainage class were assigned.

Figure 8. *Extent of auger survey at Castleisland, Co. Kerry*

Thereafter a number (3-4) of representative soil profile pits were excavated using the auger survey as a guide to represent the dominant soils on each farm. These pits were 1-2 m in depth and allowed for detailed description of soils. In total 34 soil profiles were excavated across the 10 programme farms This survey produced high resolution soils maps and detailed soil classifications of every soil subgroup on each farm (Figure 9).

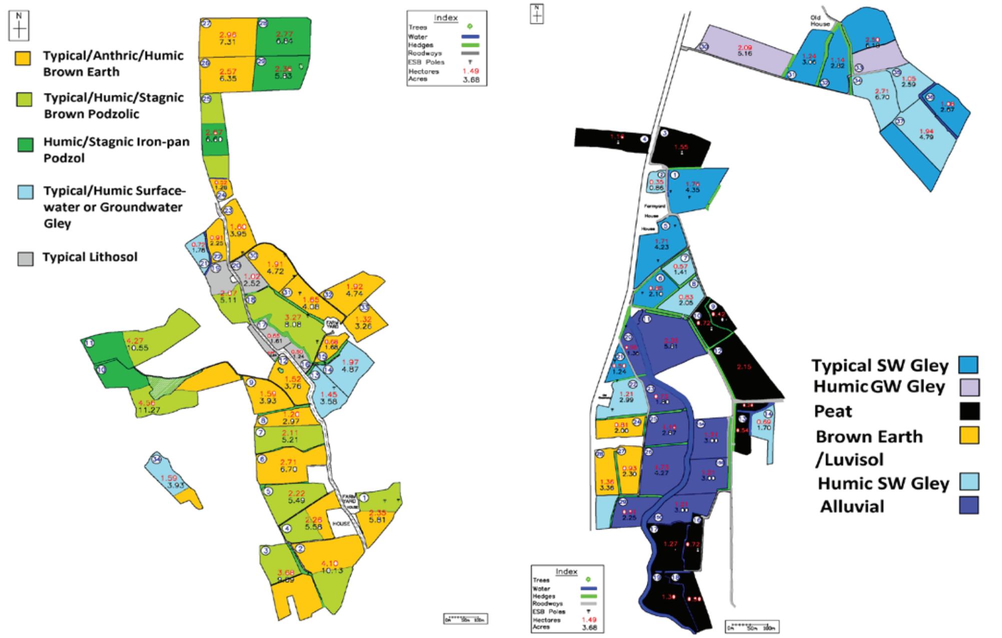


Figure 9. *Soil classification maps for HSP sites at Ballinagree, Co. Cork and Doonbeg, Co. Clare*

5. Land drainage

Land drainage design summary

The following points list the key considerations when planning and implementing a drainage system.

- No drainage work should be carried out before the drainage characteristics of the soil are established by a site and soil test pit investigation.
- Drainage of poorly drained mineral soils has positive effects on greenhouse gas emissions by reducing losses of nitrous oxide, while drainage is linked to carbon loss on carbon-rich soils, such as peats. The cessation of drainage works on such soils and the re-wetting of some organic soils is proposed.
- Two types of drainage system exist: a groundwater drainage system and a shallow drainage system. The design of the system depends entirely on the drainage characteristics of the soil.
- Distinguishing between the two types of drainage systems essentially comes down to whether or not a permeable layer is present (at a workable depth) that will allow the flow of water with relative ease. If such a layer is evident a piped drain system at this depth, is likely to be effective. If no such layer is found during soil test pit investigations, it will be necessary to improve the drainage capacity of the soil. This involves a disruption technique such as mole drainage, gravel mole drainage or sub-soiling in tandem with field drains.
- Drains are not effective unless they are placed in a permeable soil layer or complimentary measures (mole drainage, sub-soiling etc.) are used to improve soil drainage capacity. If water isn't moving through the soil in one or other of these two ways, the watertable will not be lowered.
- Outfall level must not dictate the drainage system depth. If a permeable layer is present, it must be utilised.
- Drain pipes should always be used for drains longer than 30 m. If these get blocked it is a drainage stone and not a drainage pipe issue.
- Drainage stone should not be filled to the top of the field trench except for very limited conditions (the bottom of an obvious hollow). Otherwise it is an extremely expensive way of collecting little water.
- Most of the stone being used for land drainage today is too big. Clean aggregate in the 10–40 mm (0.4 to 1.5 inch approx.) range should be used, with further benefits evident for smaller (10-20 mm) material.
- Sub-soiling is not effective unless a shallow impermeable layer is being broken or field drains have been installed prior to the operation. Otherwise it will not have any long-term effect and may do more harm than good.
- Most land drainage systems are poorly maintained. Open drains should be clean and as deep as possible and field drains feeding into them should be regularly rodded or jetted.
- If cleaning an open drain, it is vital that weeds/debris should be removed from the drain bed and one bank only. The other bank should be left undisturbed throughout that season. Sediment traps should be installed to prevent sediment losses and excessive erosion.

Approximately 49.5% (3.4 m ha) of the total land area of Ireland is classified as "marginal land" which is affected by natural limitations related to its soil, topography, relief and climate. The major limitation of this marginal land is its poor drainage status and much is in need of artificial drainage if its productivity is to be improved. In wet years, poorly drained soils may never dry out as persistent rainfall maintains high soil moisture content. Grass yields are limited due to the adverse effect of excess water and a lack of air at rooting depth, which limits plant respiration and growth. In cases of prolonged waterlogging, plants will eventually die due to a lack of oxygen in the root zone. Furthermore waterlogged soils are impassable to agricultural traffic (both machinery and livestock) for long periods, due to high soil moisture content and reduced soil strength. This reduces the number of grazing days and hinders silage harvesting, thus introducing higher costs related to imported feedstuffs.

The purpose of land drainage is to remove excess water from the soil as quickly as possible. How best to achieve this will vary with soil type. There is a need therefore for a better understanding of the underlying causes of drainage problems and of the design and implementation of appropriate drainage systems to resolve these problems. We must move away from the short-sighted approach that a broadly similar drainage system can be installed in every wet field regardless of soil and site conditions.

Causes of impeded drainage

The difficulties of drainage problems in Ireland are largely due to our complex geological and glacial history. Soil layers of varying texture and composition have the effect of irregularly distributing groundwater flow, with fine textured soils acting as a barrier to movement, impeding drainage, and lenses of gravels and sands promoting water flow, transmitting groundwater over large areas with resulting seepages and springs on lower ground. In poorly drained soils the rate of water infiltration at the soil surface is regularly exceeded by the rainfall rate due to:

- Low permeability in the subsoil (or a layer of the subsoil).
- High watertable due to low lying position and poor/poorly-maintained outfall.
- Upward movement of water from seepage and springs.

Objectives of land drainage

To achieve effective drainage the works will have to solve one or more of these problems. The objective of any form of land drainage is to lower the watertable providing suitable conditions for grass growth and utilization. A controlled watertable promotes deeper rooting which improves productivity and improves load-bearing capacity of the soil.

When planning any drainage programme, the potential of the land to be drained needs to be first assessed to determine if the costs incurred will result in an economic return through additional yield and/or utilisation. Some thought is needed in deciding the most appropriate part of the farm to drain. From a management point of view it is better to drain that land which is nearer to the farmyard and work outwards, however it may be more beneficial to target areas with high potential for improvement. This ensures a better return on the investment.

Drainage investigations

What exactly is the problem? Collect all the information at hand, over an extended period to establish where and what the root causes are. Where does the water gather or pond? Where does overland flow if any occur? Where are the worst underfoot conditions? Where are the poorest areas of grass growth? Are there weeded areas? How good is the existing drainage network (if any)? Is the whole profile made up of poor soils or is the problem caused by specific layers? Is there water movement at any depth? This information will help in deciding where best to invest in drainage works.

Knowledge of previous drainage schemes in the area, and their effectiveness will often provide a key insight. A number (approx. 1 per ha) of test pits (at least 2.5 m deep) should be excavated within the area to be drained to investigate. These are dug in areas that are representative of the area as a whole; consider digging in wet and dry areas for comparison sake. Soil test pits are very dangerous and prone to collapse. You should not enter soil test pits but instead observe from a safe distance. Inspect different soil layers as they come up in the excavator bucket. As the test pits are dug, the faces of the pits are observed, soil type should be established and the rate and depth of water seepage into the test pit (if any) recorded. Visible cracking, areas of looser soil and rooting depth should be noted as these can convey important information regarding the drainage status of the different layers. The depth and type of the drain to be installed will depend on the interpretation of the characteristics revealed by the test pits.

Two principle types of drainage system are distinguished:

- **Groundwater drainage system:** A network of piped drains exploiting permeable layers.
- **Shallow drainage system:** Where movement of water is impeded at all depths.

Groundwater drainage system

Strong inflow of groundwater or seepage from the faces of test pit walls, indicate that layers of high permeability are present. Under these circumstances the use of a piped drainage system (at the depth of inflow) is advised to capture and remove this water, thereby controlling the watertable. Deep piped drains are usually installed at a depth of 1.5-2.5 m and at spacings of 15–50 m, depending on the slope of the land and the permeability and thickness of the drainage layer. Piped drains should always be installed across the slope to intercept as much groundwater as possible, with open drains and main piped drains running in the direction of maximum slope. Where groundwater seepage and springs are identified, deep drains, 2 to 4 m deep can be used to intercept flow. Pipe drains are most effective in the layer transmitting groundwater flow, characterised by high water breakthrough. This issue is very site specific.

Clean aggregate, in the 10 – 40 mm grading band, should to be used to surround the drain pipe. The gravel should be filled to a minimum depth of 300 mm from the bottom of the drain to cover the pipe. The stone should provide connectivity to a layer of high permeability and should not be filled to the ground surface. The purpose of a drain pipe is to facilitate a path of least resistance for water flow. In long drain lengths (greater than 30m) a drain pipe is vital to allow a high a flow-rate as possible from the drain, stone backfill alone is unlikely to have sufficient flow capacity to cater for the water volume collected.

Figure 10. *Test pit excavation*

Figure 11. *Drainage trench excavation*

Shallow drainage systems

Where a test pit shows no inflow of groundwater at any depth a shallow drainage system is required. These soils with very low permeability throughout are more difficult to drain. Shallow drainage systems aim to improve the capacity of the soil to transmit water by fracturing and cracking the soil. They rely on soil disruption techniques, namely; mole and gravel mole drainage and sub-soiling.

Mole drainage is suited to stone-free soils with a high clay content which form stable channels. Mole drains are formed with a mole plough comprised of a torpedo-like cylindrical foot attached to a narrow leg, followed by a slightly larger diameter cylindrical expander. The foot and trailing expander form the mole channel while the leg creates a narrow slot that extends from the soil surface to the mole channel depth. The mole plough creates both a zone of increased permeability adjacent to the mole leg (shallower depths) and a channel for water flow at moling depth. The effectiveness of mole drainage will depend on the extent soil cracking during installation. As such the ideal time for carrying out mole drainage is during dry summer conditions, to allow for maximum cracking in the upper soil layers and adequate traction to prevent wheel-spin on the surface.

Figure 12. *Mole plough showing cylindrical foot and expander*

Gravel filled moles employ the same principles as ordinary mole drains but are required in soils which will not sustain an unlined channel. The gravel mole channel is filled with gravel from an attached hopper which supports the channel walls. Gravel moles require a very specific size range of gravel aggregate to ensure that they function properly. Washed aggregate within a 10-20 mm size range should be used. Sub-soiling is used effectively where an iron pan or cemented layer impedes drainage. The effect is to break the layer and crack the soil. A stable channel will not be formed.

Figure 13. *Gravel mole plough showing hopper*

Figure 14. *Single leg winged sub-soiler*

Collector drains, which are installed across the slope at 0.8 – 1.0 m deep, are required for all shallow drainage systems. Depending on the topography and slope, the collector drains will be at a spacing of 10–40 m. A larger spacing reduces costs but results in a much higher chance of failure. The disruption channels themselves are drawn at right angles to the collectors (up-slope) at spacings of 1.0-1.5 m and a depth of approximately 0.4-0.5 m. Stone backfill for collectors should be filled to within 250 mm of the surface to ensure interconnection with the disruption channels when installed afterwards.

Outfalls/maintenance

Every drainage scheme is only as good as its outfall. Maintenance vastly improves the capacity and the lifespan of the drainage system, but also helps with water storage, sediment trapping and remediation of nutrient losses. Drainage systems are poorly maintained in most cases. A maintenance plan should be adopted for both in-field and open drains, focusing on areas susceptible to blockages. This provides a cheap and effective means of improving drainage by maximising the effectiveness of existing drainage infrastructure.

Fine soil particles are many times smaller than the aggregate (e.g. stone) around a pipe or the slits in the actual drainage pipe. This means they can get washed from the soil and ultimately settle in field drains and impede flow. Iron (ochre) can also block drains where it accumulates after being washed out of the soil. Plants and their roots can thrive in open channels, at the pipe outlet and deep within the pipe system causing blockages. Collapse/sedimentation of open drains, due to flow conditions, undercutting of banks or livestock damage can also cause impediments.

- Drainage systems will deteriorate at a fairly steady rate until blockages become established and "self-cleaning" is inhibited.
- If flow is slowed or stopped entirely then large volumes of sediment in the system will be deposited. Relatively minor blockages can quickly undermine the whole system.
- Regular inspection, cleaning and maintenance is required.
- During wet years, excessive soil damage by machinery and livestock can reduce the natural drainage capacity of the soil, handicapping the drainage system.

Open drains, culverts and outfalls must be cleaned regularly to remove any obstructions while they should be established to as great a depth as possible to aid flows. Exclude livestock access to open drains. Field drain pipes and outlets should be jetted/flushed or rodded regularly to maintain flow, and their outlets should be well marked and protected during the cleaning of open drains.

To protect fish eggs and small salmonids, drainage works and the maintenance of drainage systems in areas likely to contain these species should be carried out between mid-May and mid-September. If cleaning an open drain, it is vital that weeds/debris should be removed from the drain bed and one bank only. The other bank should be left undisturbed throughout that season. Sediment traps should be installed to prevent sediment losses and excessive erosion.

When a drainage scheme has been completed, the layout should be drawn and noted on a farm map. This map can then be used as a guide when maintaining the works, as well as a record of the works. Land drain outlets should be regularly cleaned and maintained especially if open drains are cleaned/upgraded as this will result in blockages at the drain outlets. The use of a concrete or un-perforated plastic pipe over the end of the drain pipe, minimum 1 m in length, will protect the outlet from damage and will make locating and maintaining it easier.

Land drainage case studies

Land Drainage Case Study 1: Con Lehane, Ballinagree, Cork

As a first step soil test pits were dug to examine the soil profile. The profile uncovered (pictured below) contained evidence of slow water infiltration (drainage) and movement. Strong seepage of groundwater into the pit was noted from approximately 1.5 m depth. Given the position of the site in the landscape (mid-slope on steep high ground) it was concluded that groundwater, moving downslope, was maintaining a shallow watertable and inhibiting surface water infiltration. Drainage on this site would have to remove this excess water to control the watertable depth and allow increased surface water infiltration. The design required is classed as a groundwater drainage system, comprising field drains located in the layer where groundwater can move (from approx. 1.5 m depth in this case). Soil test pits also uncovered a number of large stones and boulders (0.1 – 0.8 m approximately in size). Such stones would make excavation of field drains and removal of soil more problematical.

The final phase of the site investigation involved measurement and mapping of the site. This allowed for field levels and layout to be established and most importantly outfall conditions to be assessed. On this site, field slope and outfall conditions were never in doubt but in most cases a level survey is required to optimise the location of field drains and ensure adequate falls.

Figure 15. *Typical soil profile at Ballinagree, Cork site*

Teagasc
Agriculture and Food Development Authority

Detailed Drainage Specifications

Land Owner
Con Lehane

Paddocks/Area
12

Date: 20/06/20xx

Paddock	OUTLINE DESIGN	Detail
	Open Drains	
	• Existing open drain at northern site boundary must be deepened to 1.7 m	Total length:95 m
	• Existing open drains at eastern site boundary must be deepened to 2.0 m	Total length:226 m
	• Bank slope must not be steeper than 2:1 (vertical:horizontal)	
	• Spoil may be removed or where good quality spread, large stones/boulders will need to be buried over drainage aggregate backfill (see note below)	
	Field Drains	
	• 10 x field drains across slope at 20 m spacing (as per specification map)	Total length:900 m
	• To a minimum graded depth of 1.7 m	
	• Use 80 mm corrugated pipe with 1-2m sewer or concrete shore at all outlets	
	• Add 400 mm depth porous fill being 10-40 mm washed stone	
	• Backfilled thereafter with soil, spoil to be spread	
	• Where large stones/boulders raised during drain excavations are present these can be used to backfill field drain trenches also (after placement of porous fill)	
	Miscellaneous	
	• Existing waste ground (rock-pile) will need to be reduced in size to allow for field drain installation	

Figure 16. *Drainage design specification*

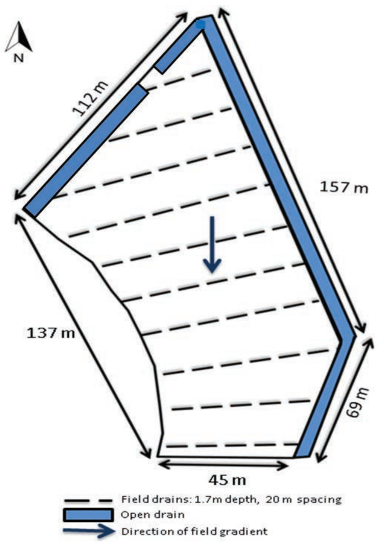


Figure 17. *Drainage design map*

Notes on drainage design and installation

The information gathered from the opening of on-site soil test pits indicated that the site was underlain by a consistent layer of highly permeable soil, first encountered at an approximate depth of 1.5 m below the surface. The high stone and gravel content as well as the proliferation of roots and structural cracks to substantial depths within the profile indicated that there was sufficient capacity for infiltration (drainage) of water through the profile to a groundwater drainage system. The purpose of the drainage system designed for the site was to target this highly permeable layer at 1.7 m and exploit the water carrying capacity it has.

It was decided to install groundwater drains to a minimum depth of 1.7 m and a 20 m spacing (see map) spanning the width of the site and running across the main field gradient. The existing open drain at the eastern side of the site was cleaned and deepened to a depth of 2 m to act as an outfall for the new field drains. The existing gullet at the field outlet point was lowered to allow for this. The existing open drain at the northern end of the site was also deepened to 1.7 m, to intercept as much groundwater and surface water (coming from the adjacent forestry) as possible before it could enter the site. Field drains were installed in two stages in order to avoid difficulties related to subsidence and collapse of the field drain trench during installation. Initially a 1.0 m deep trench was excavated using a wide moulding bucket, after this a narrower tile drainage excavator bucket (pictured below) was used to complete the drain to its final depth (1.7 m). Each drain was installed and backfilled immediately. The groundwater drains consisted of an 80 mm corrugated perforated PVC pipe with a gravel aggregate envelope (10 - 40 mm grade) backfilled to within 1.3 m of the soil surface (to ensure maximum connection to the high permeability soil layer) and thereafter backfilled with soil (and larger stones/boulders raised during drain excavation).

Figure 18. *(a) Trapezoidal moulding bucket and (b) narrow drainage bucket*

Table 6. Costs of drainage works at Ballinagree, Co. Cork	
Item	€/ha
Drain installation @ €45/hr. (73 hrs.)	€3,285
Drainage pipe @ €0.89/m (592 m)	€525
Drainage stone @ €13.87/t (118 t)	€1,640
Total Cost	€5,450

Land Drainage Case Study 2: Sean O' Riordan, Kishkeam, Cork

As a first step soil test pits were dug to examine the soil profile. The profile uncovered (pictured below) contained a tightly consolidated and high clay content subsoil. There was increased stone content with depth and bedrock (shale) at depths of 2.5 to 3.0 m. There was some inflow of groundwater at depths of 1.0 – 1.2 m but this was not consistent in all soil test pits. This water movement indicated that a groundwater drainage system at this depth could be beneficial. However, as it was not consistent throughout the site, other means of drainage would need to be employed to ensure a successful outcome. The layer at 0.3 – 1.0 m depth is a heavy clay with no apparent structure (natural cracking). It was classed as poorly permeable and would require the intensity of drainage provided by a disruption technique (mole or gravel mole drains or sub-soiling) being supplemented by a network of collector drains. Mole drainage was not feasible on this site due to the large amount of stones present. Given the high cost associated with gravel mole drainage and the level of groundwater discharge naturally facilitated by suitably deep collector drains, it was decided that sub-soiling the site would be an adequate method of subsoil disruption.

The final phase of the site investigation involved measurement and mapping of the site. This would allow for field levels and geometry to be established and outfall conditions to be assessed. A laser-level survey was used to assess falls and provide guidance on the most appropriate positions of field drains.

Figure 19. *Typical soil profile at Kishkeam, Cork site*

Teagasc – Agriculture and Food Development Authority

Detailed Drainage Specifications

Land Owner
Sean O' Riordan

Paddocks/Area
23

Date: 04/07/20xx

Paddock	OUTLINE DESIGN	Detail
	Open Drains	
	• Existing open drains at eastern site boundary must be deepened to 1.5 m	Total length:100 m
	• Bank slope must not be steeper than 2:1 (vertical:horizontal)	
	• Spoil may be removed or where good quality spread	
	Field Drains	
	• 6 x field drains across slope at 15 m spacing (as per specification map)	Total length:900 m
	• To a minimum graded depth of 1.1 m	
	• Use 80 mm corrugated pipe with 1-2m sewer or concrete shore at all outlets	
	• Add 800 mm depth porous fill being 10-40 mm washed stone	
	• Backfilled thereafter with soil, spoil to be spread	
	Subsoiling	
	• Subsoiling to be carried out at 0.6 m depth and 1.5 m spacing using single-leg winged subsoiler	
	• Subsoiler will be pulled uphill from lower end of site and cross field drains at right angle	

Figure 20. *Drainage Design Specification*

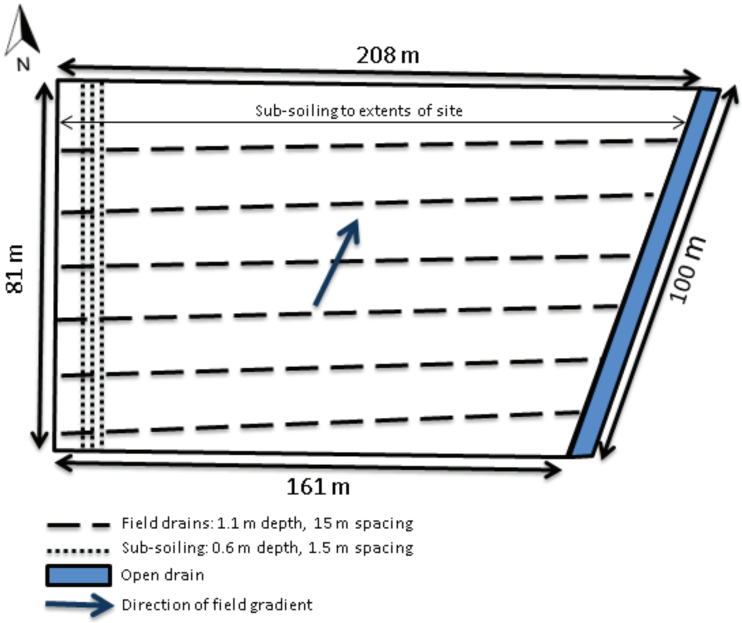


Figure 21. *Drainage Design Map*

Notes on Drainage Design and Installation

The information gathered from opening of on-site soil test pits indicated that the soil profile was consistently heavy and dense with abundant stones. In some areas there were lenses or zones of higher permeability with the potential for significant groundwater movement (at depths of 1.0-1.2 m). Drainage design in this case would have to provide an outlet for this groundwater while also improving the infiltration capacity of the heavy and dense subsoil commonly found.

It was decided to install a series of collector drains across the main field gradient at a spacing of 15 m (see map). While the drains act predominantly as conduits for surface water being collected, the in-flow of groundwater at 1.0 – 1.2 m depth in certain areas of the site allows for groundwater drawdown. For this reason all collector drains were installed to a minimum depth of 1.1 m. The existing open drain at the eastern side of the site was cleaned and deepened to a depth of 1.5 m to act as an outfall for the new field drains. The drains consisted of an 80 mm corrugated perforated PVC, with a gravel aggregate envelope (10 - 40 mm grade) backfilled to within 0.3 m of the soil surface (to ensure maximum connection to the disturbed (sub-soiled) soil and topsoil) and thereafter backfilled with soil.

Sub-soiling was carried out with a single leg winged sub-soiler (below) to improve permeability of the upper layers and increase the level of infiltration of surface water into the soil profile and ultimately into the collector drains. Sub-soiling was carried out at a depth of 0.6 m and a spacing of 1.5 m when good weather ensured dry soil conditions and allowed for the maximum level of soil disturbance. The depth of sub-soiling was set to ensure maximum fracturing and disturbance of the soil. The spacing was determined as the closest spacing allowable given the width of the tractor used for drawing the sub-soiler and the need to avoid tracking over the newly formed disruption channels.

Figure 22. *Drainage Work at Kishkeam, Co. Cork*

Table 7. Costs of drainage works at Kishkeam, Co. Cork	
Item	€/ha
Drain installation @ €45/hr. (36 hrs.)	€1,625
Drainage pipe @ €1.03/m (566 m)	€585
Drainage stone @ €10.78/t (101 t)	€1,085
Sub-soiling	€125
Total Cost	€3,420

Land Drainage Case Study 3: Alan Wood, Crossmolina, Mayo

As a first step soil test pits were dug to examine the soil profile. The profile uncovered (pictured below) contained evidence of slow water infiltration (drainage) and movement. A thin topsoil was underlain by a uniform silt with some mottling (discolouration) becoming more permeable from 1.4 m depth. Strong seepage of groundwater into the pit was noted from approximately 1.4 m depth consistently across the site. The most appropriate drainage system for this site would be a groundwater drainage system which would remove excess groundwater and allow surface water to infiltrate through the profile. In this case the drains would be located in the layer where groundwater can move, at approximately 1.4 to 1.7 m.

The final phase of the site investigation involved measurement and mapping of the site. This would allow for field levels and geometry to be established and outfall conditions to be assessed. A laser-level survey was used to assess falls and provide guidance on the most appropriate positions of field drains.

Figure 23. *Typical soil profile at Crossmolina, Co. Mayo site*

teagasc Agriculture and Food Development Authority	**Detailed Drainage Specifications**	
	Land Owner Alan Wood	
	Paddocks/Area 26,27	
		Date: 16/07/20xx

Paddock	OUTLINE DESIGN	Detail
	Outlet	
	• No suitable outlet exists,substantial works are required to provide an outlet at the required depth.	
	• Culvert under public road needs to be upgraded (to 12' pipe) and deepened.	
	• Approximately 250 m of open drain needs to be upgraded and deepened below this culvert to provide a suitable outlet (to back swamp of lough)	Total length: 250 m
	Open Drains	
	• Existing open drain at southern site boundary must be deepened to 2.0 m	Total length:170 m
	• Existing open drains at eastern site boundary must be deepened to 1.8 m	Total length:160 m
	• Bank slope must not be steeper than 2:1 (vertical:horizontal)	
	• Spoil may be removed or where good quality spread	
	Field Drains	
	• 5 x field drains across contours (as per specification map)	Total length: 1100 m
	• To a minimum graded depth of 1.7 m	
	• Use 80 mm corrugated pipe with 1-2m sewer or concrete shore at all outlets	
	• Add 500 mm depth porous fill being 10-40 mm washed stone	
	• Backfilled thereafter with soil, spoil to be spread	
	Subsoiling	
	• Subsoiling to be carried out at 0.6 m depth and 1.5 m spacing using single-leg winged subsoiler	
	• Subsoiler will be pulled uphill from lower end of site and cross field drains at right angle	

Figure 24. *Drainage design specification*

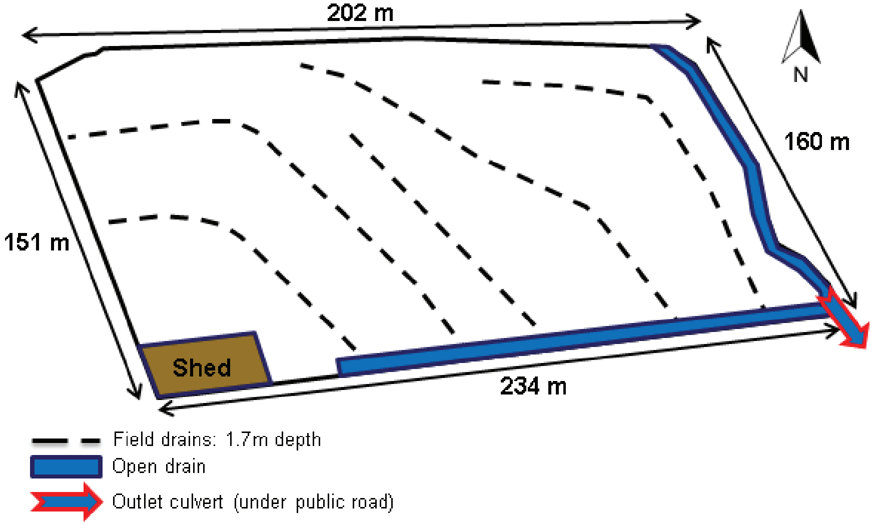


Figure 25. *Drainage design map*

Notes on Drainage Design and Installation

The information gathered from the opening of on-site soil test pits indicated that the site was underlain by a consistent layer of highly permeable soil, first encountered at an approximate depth of 1.4 m below the surface. The high silt content as well as the presence of roots and structural cracks to substantial depths within the profile indicated that there was sufficient capacity for infiltration (drainage) of water through the profile to a groundwater drainage system. The purpose of the drainage system designed for the site was to target the highly permeable layer (from 1.4 m depth) and exploit the water carrying capacity it has.

It was decided to install groundwater drains to a minimum depth of 1.7 m (see map) spanning the width of the site and running across the main field gradient. The placement of the drains did not follow any set pattern and was dictated by the field topography. Drains were positioned in natural depressions and along slope contours to ensure the natural flow of water was encouraged into drains. The existing open drain at the southern side of the site was cleaned and deepened to a depth of 2.0 m to act as an outfall for the new field drains. The existing culvert at the field outlet point was lowered to allow for this. This culvert was under a public road which had to be cut during the works and re-laid thereafter. Providing an outlet from the field was a major undertaking, an additional 250 m of open drain had to be excavated and the works required in the digging of this and removal of associated spoil added significantly to the overall cost. The existing open drain at the northern end of the site was also deepened to 1.8 m, to intercept as much water (coming from the adjacent areas) as possible before it could enter the site. Drains were installed in two stages in order to avoid difficulties related to subsidence and collapse of the field drain trench during installation. Initially a 1.0 m deep trench was excavated using a wide moulding bucket, after this a narrower tile drainage excavator bucket (as described earlier) was used to complete the drain to its final depth (1.7 m). Each drain was installed and backfilled immediately. Even using this strategy there was particular sections which collapsed and slowed the progress of installation. The groundwater drains consisted of an 80 mm corrugated perforated PVC pipe with a gravel aggregate envelope (10 - 40 mm grade) backfilled to within 1.2 m of the soil surface (to ensure maximum connection to the high permeability soil layer) and thereafter backfilled with soil.

Figure 26. *Drainage work at Crossmolina, Co. Mayo*

Table 8. Costs of drainage works at Crossmolina, Co. Mayo	
Item	€/ha
Open drain installation @ €35/hr (76 hrs)	€2670
Field drain installation @ €35/hr (51 hrs)	€1790
Drainage pipe @ €1.13/m (338 m)	€380
Drainage stone @ €11.07/t (189 t)	€2100
Sub-soiling	€125
Total Cost	€7,065

Land drainage system performance

The drainage systems installed across HSP sites represent a range of drainage system types (in terms of depth, spacing and supplementary measures) across a range of soil types and climactic conditions. After drainage systems were installed, a monitoring programme was established. Flow-meters are recording water flow rates, a number of in-field wells with water level sensors are recording water-table fluctuations, moisture sensors close to the surface monitor soil moisture content, while weather conditions are recorded by an on-site met station. Analysis of this data will be on-going for a number of years and allows an assessment of the effectiveness of the various drainage systems in terms of drainage discharge rates, response times and overall system performance over a range of seasons and weather conditions. While systems costs and their effect on production and utilization are measurable in the short term, a long term analysis of performance and lifespan is required before we can draw conclusions with regard to their economic benefit.

Performance analysis of drainage systems installed on Heavy Soils Programme farms is highlighting how drainage system type, soil type and seasonal variations in soil moisture affect drainage system performance. All systems reduce the overall period of waterlogging and improve the conditions for both the production and utilization of the grasslands they drain. Those deeper systems with direct connectivity to groundwater were seen to discharge greater volumes of water and maintain a deeper water table relative to shallow drainage designs. The comparison of such systems highlights contrasting behaviours of individual drainage systems and drainage design types, which is dictated largely by the hydraulic capacity of the soil within their catchment and their connectivity to different water bodies. This work is allowing a more complete understanding of the capacity and limitations of individual drainage systems, and further informing on appropriate drainage design practices for poorly drained soils.

The functional capacity of each specific land drainage system was inherently different. Groundwater drainage designs exploit natural conditions to discharge large volumes of water and can control water table directly by means of their interaction with layers and zones of high permeability. Shallow drainage designs are combatting the natural state of their host soils by relying on shallow disruption techniques which are ultimately destined to revert to their original state, particularly in the case of mole drainage and sub-soiling techniques. They have a smaller zone of influence, no direct connectivity to the water table and displace lower volumes of water which is collected directly from the surface.

The response of each system to rainfall is quite clear. Examples are presented in Figure 27 In each drainage system, rainfall events show corresponding increases in drain discharge.

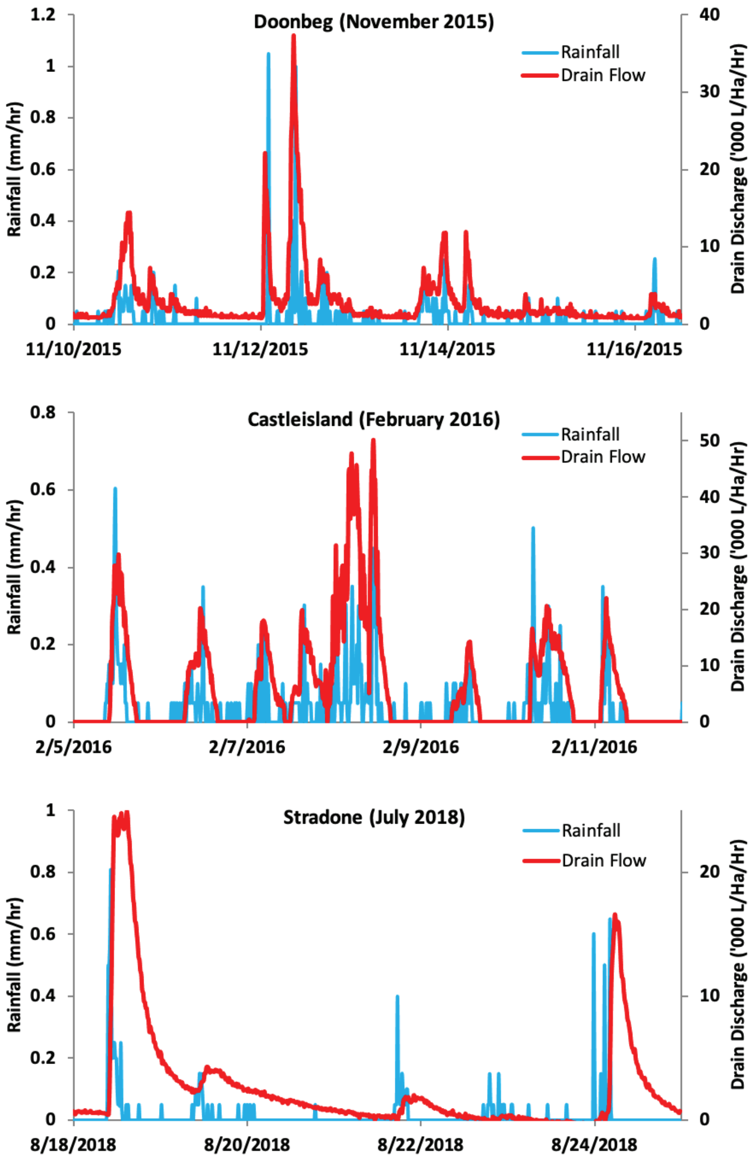


Figure 27. *Drain discharge vs. rainfall at 3 drained sites*

Comparative costs (€/ha) of land drainage works on all programme farms

The mean cost of the drainage systems installed was €5960/ha. The cost of the drainage systems was dependent on a number of factors. These included;

- The suitability of existing open drains as outfalls for the proposed field drains.
- The type of drainage system, particularly if a shallow drainage system was required.
- The intensity of field drainage required.
- The cost of and time taken by the contractor.
- The cost of materials, particularly stone aggregate.

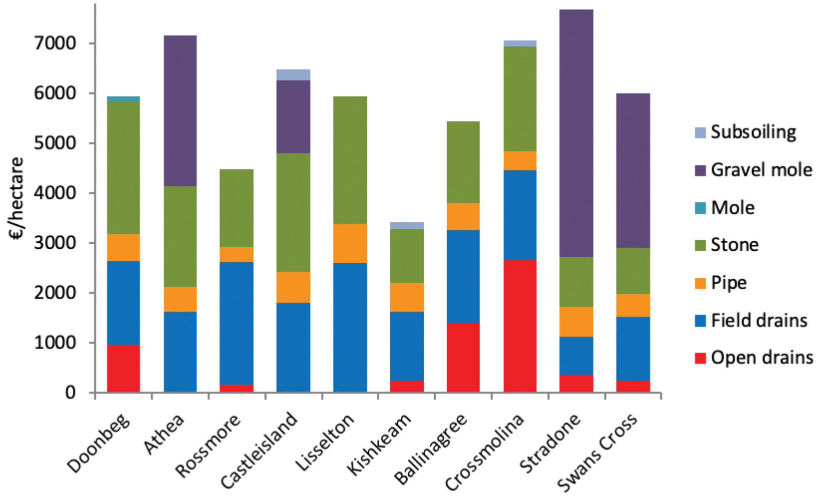


Figure 28. *Land Drainage works costs at each HSP site*

All systems were shown to reduce the overall period of waterlogging and thereby improve the conditions for both the production and utilization of the grasslands they drain. **Drained sites increased grass production by between 4 and 7 T DM/Ha/year with a payback on capital invested of approximately 5-6 years.**

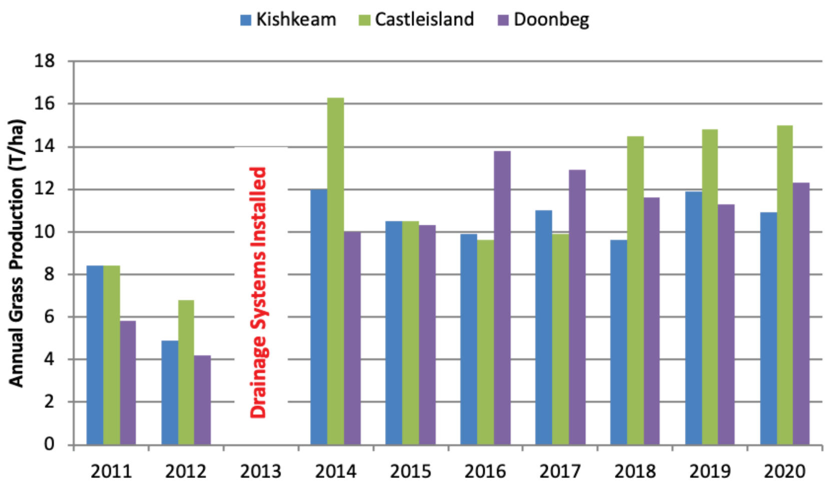


Figure 29. *Grass growth at some drained sites before and after drainage works*

Environmental impact

The implementation on land drainage works is known to affect the dynamics of water movement from drained sites and as such the potential impacts on water quality need to be recognised. Examinations of potential environmental impact of these systems showed that both phosphorus and nitrogen attenuation capacity are dependent on surface and subsurface soil chemistry and drainage design specification. The potential for nutrient loss is related to soil type, chemistry and the level of interaction that drained water has with attenuating layers or elements of the soil body. Shallow drainage systems, for example are more likely to promote high intensity flows which have little interaction with the soil body relative to groundwater systems which promote water movement through the soil. Furthermore, soils with high levels of organic matter are known to have poor nutrient retention capacity and as such are vulnerable to nutrient loss. Land drainage system design needs to account for such variability and implement works that identify and negate against impacts on water quality.

Artificial drainage of poorly drained mineral soils has positive effects on greenhouse gas (GHG) emissions by reducing losses of nitrous oxide (N_2O), while drainage is linked to carbon loss on carbon-rich soils such as peats. The cessation of drainage works and the re-wetting of some organic soils is proposed. Mean carbon storage in HSP soils is 346.0 T/Ha, with carbon-rich organic and humic soils accounting for 8.3% and 20.8% of land area, respectively. Management of these soils will dictate the amount of carbon that is stored in the long term. Carbon takes long periods to build up, and when held in soils for a relatively long period as part of the terrestrial carbon cycle is said to be sequestered by the soil. The amount of carbon stored by soils provides an important sink to counterbalance and negate against the effects of increasing levels of carbon dioxide (CO_2) in the atmosphere. The maintenance of this carbon stock depends on its stability and it can be negatively (e.g. soil organic matter (SOM) degradation) or positively (e.g. organic amendment) affected by land management practices. Strategies related to land management will need to be informed by the relative amounts of carbon stored in different soil types and indeed their capacity to build carbon. Precision management will be required for each soil type and for each farm system to ensure improved water quality and carbon storage can be prioritized within profitable production systems.

Detailed guidance is available in the Teagasc Manual on Drainage – and soil management

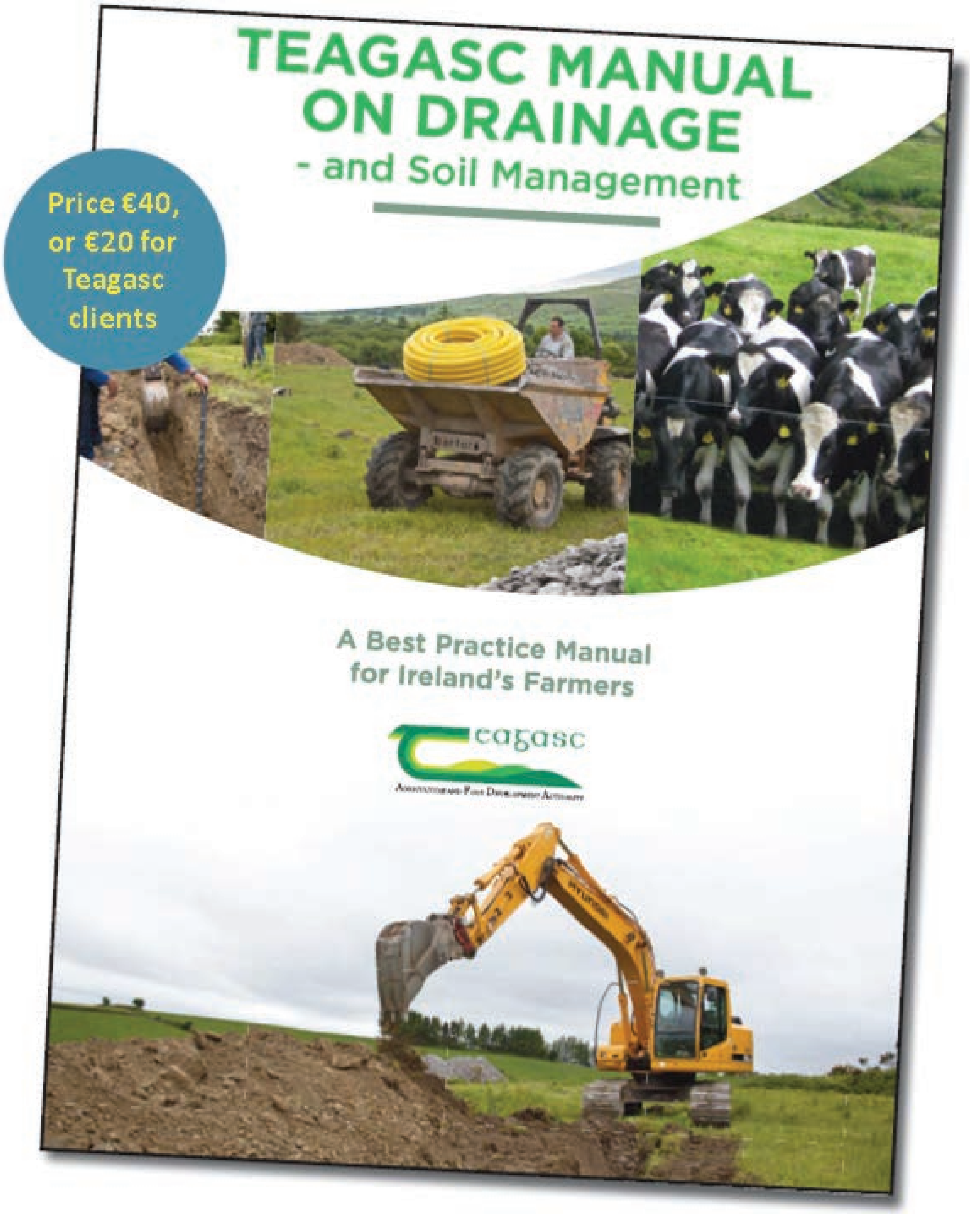


Figure 30. *The Teagasc manual on drainage – and soil management*

6. Soil fertility

As part of the programme, a soil sampling campaign has been undertaken to monitor soil fertility status. Every paddock is sampled on each farm, every year. Soil sampling has shown that most programme farms are below optimal soil fertility levels. The sampling interval and intensity has allowed for soil fertility to be addressed on a paddock by paddock basis. Lime and fertilizer application strategies have been developed with a focus on the underperforming sections of each farm. Increasing soil fertility on these soils brings particular challenges in terms of nutrient response rates. An intense regime of data collection at a paddock scale in terms of nutrient inputs (chemical/organic fertiliser, concentrates) and off-takes allows for an in-depth understanding of changes in soil nutrient levels when compared with annual soil tests over an extended period. Targeted nutrient improvement measures across the HSP farms has seen them move from a position where in 2013 only 2% of paddocks were optimum for pH, P and K (relative to 11 % nationally) to the current position where 15% of paddocks achieve this status (relative to 21% nationally).

Table 9. Soil pH status at HSP sites

Location	2013	2014	2015	2016	2017	2018	2019	2020
Castleisland	5.5	5.7	5.9	6.0	6.2	6.3	6.3	6.5
Doonbeg	5.8	5.8	5.7	6.1	6.1	5.8	6.1	6.1
Athea	5.5	5.8	6.2	6.5	6.6	6.6	6.5	6.5
Kishkeam	5.8	5.8	6.2	6.4	6.3	6.2	6.4	6.3
Listowel	5.7	5.5	5.9	6.0	6.0	6.0	5.8	5.9
Rossmore	5.8	5.8	6.2	6.2	6.2	6.4	6.2	6.3
Ballinagree	5.8	5.9	6.5	6.5	6.3	6.3	6.3	6.2
Crossmolina	5.4	5.6	5.7	6.1	5.9	5.8	6.0	5.8
Swanscross	--	--	6.4	6.5	6.4	6.3	6.4	6.3
Stradone	--	--	6.2	6.5	6.6	6.7	6.5	6.5
Average	**5.7**	**5.7**	**6.1**	**6.3**	**6.3**	**6.2**	**6.3**	**6.3**
Target	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2

Table 10. Soil phosphorus (P) (mg/l) at HSP sites

Location	2013	2014	2015	2016	2017	2018	2019	2020
Castleisland	4.7	6.4	4.2	5.3	5.2	7.1	6.8	5.9
Doonbeg	4.9	5.6	5.5	4.1	5.2	6.1	4.5	4.8
Athea	3.1	4.9	3.7	3.9	4.2	8.0	4.1	4.8
Kishkeam	1.9	4.4	2.8	3.1	3.4	6.2	4.0	4.1
Listowel	5.4	9.8	6.5	5.5	5.9	7.0	5.3	4.9
Rossmore	8.5	11.0	10.7	10.1	8.2	7.0	6.5	5.2
Ballinagree	5.6	6.5	5.1	6.2	5.5	5.8	4.8	4.7
Crossmolina	7.6	3.4	4.4	5.8	6.2	6.6	4.9	4.9
Swanscross	--	--	6.2	5.8	5.9	5.2	4.9	4.9
Stradone	--	--	3.1	5.1	4.1	6.5	7.7	7.4
Average	**4.9**	**6.5**	**5.2**	**5.5**	**5.4**	**6.6**	**5.4**	**5.2**
Target	5.1 - 8.0	5.1 - 8.0	5.1 - 8.0	5.1 - 8.0	5.1 - 8.0	5.1 - 8.0	5.1 - 8.0	5.1 - 8.0

Table 11. Soil potassium (K) (mg/l) at HSP sites								
Location	2013	2014	2015	2016	2017	2018	2019	2020
Castleisland	94	110	87	103	109	147	133	82
Doonbeg	74	96	91	64	84	122	81	59
Athea	134	125	104	106	98	154	123	89
Kishkeam	82	112	88	86	99	142	115	96
Listowel	89	140	105	74	91	98	89	73
Rossmore	97	95	106	111	108	99	70	57
Ballinagree	144	155	115	154	145	156	130	141
Crossmolina	105	112	73	92	107	142	83	93
Swanscross	--	--	170	150	165	156	131	139
Stradone	--	--	142	153	152	145	113	98
Average	**102**	**118**	**108**	**109**	**116**	**136**	**107**	**93**
Target	*101 - 150*	*101 - 150*	*101 - 150*	*101 - 150*	*101 - 150*	*101 - 150*	*101 - 150*	*101 - 150*

A major issue with building soil fertility status on such soils is a disparity in responsiveness to applied nutrients or lime and high levels of nutrient fixing elements, principally iron and aluminium, at some sites which leave phosphorus unavailable for plant uptake. There are however large variations in response to phosphorus application between farms and soils within farms (Figure 31).

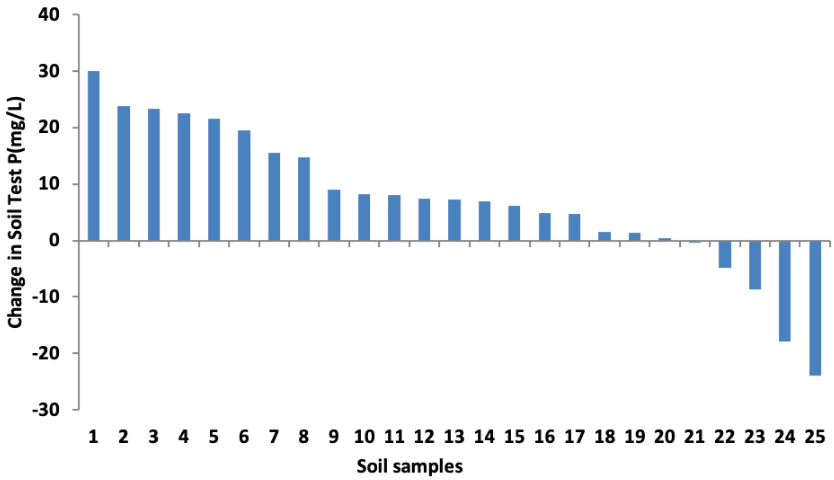


Figure 31. *Change in soil test phosphorus (measured using the Mehlich 3 method and not the standard Morgan's method so results are measured against a larger scale) following phosphorus application at 50 Kg/ha across 25 soil samples collected from heavy soils programme farms*

There remains a lot of room for improvement, which has led to detailed studies regarding individual response rates of soils through a series of intensive plot trials and incubated pot studies. This work has offered much insight into the responsiveness of individual soils across the Heavy Soils Programme farms. When grouped in 3 soil type categories; Loam (< 28% clay), Clay (>28% clay) and Organic (> 20% organic matter) there are clear differences in response to inputs. The "Loam" group shows a much stronger response to both lime (at a rate of 5 T/ha), (Figure 32) and phosphorus application (Figure 33) relative to the other categories.

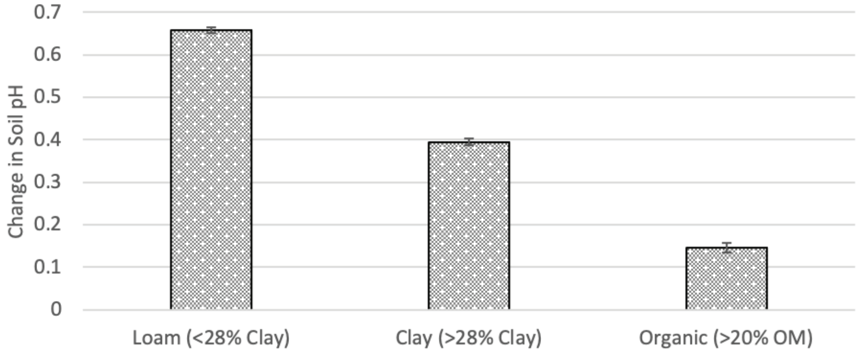


Figure 32. *Change in soil pH in 3 soil groups following lime application at a rate of 5 T/ha*

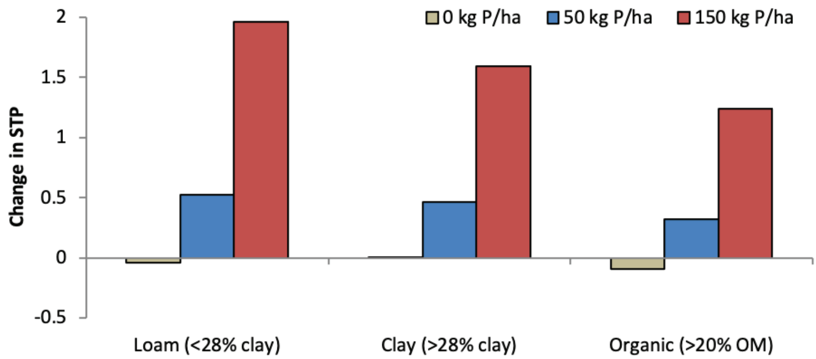


Figure 33. *Change in soil test phosphorus in 3 soil groups at 0, 50 and 150 kg P/ha*

Therefore, mineral soils (Loam and Clay) are shown to offer a much greater potential return for the phosphorus applied relative to organic soils with greater availability of plant available phosphorus and ultimately, greater production. Further analysis shows that phosphorus application to organic soils results in much higher levels of water soluble phosphorus relative to mineral soils. This is not plant available and is a measure of the risk of loss to surface and ground waters which is both an environmental and a financial loss as the nutrient applied is ultimately wasted.

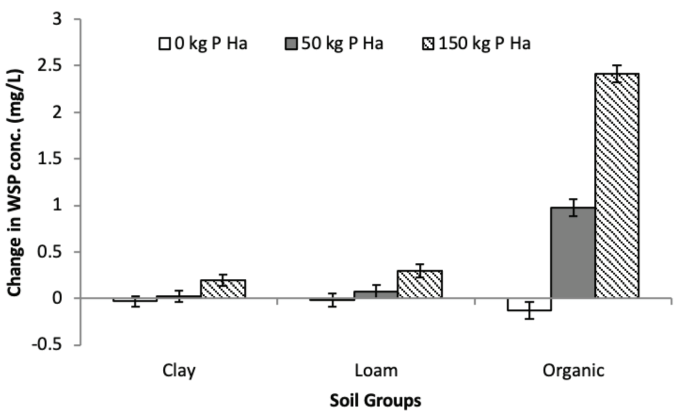


Figure 34. *Change in water soluble phosphorus in 3 soil groups at 0, 50 and 150 kg P/ha*

The benefits of attaining optimum soil fertility have been shown. On HSP farms, those soils with a pH above 6.0 will produce an extra 1.3 Tonnes DM/ha relative to those soils with a pH below 6.0 (Figure 35). In terms of soil test phosphorus, Index 3 soils are shown to yield an additional 0.8 Tonnes DM/ha relative to Index 1 soils (Figure 36).

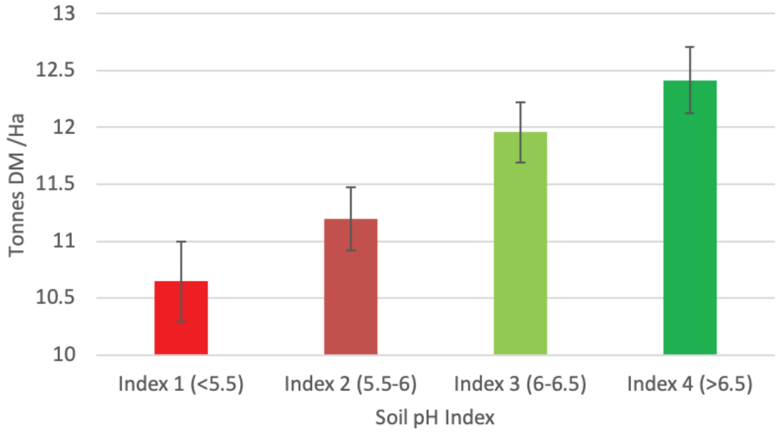


Figure 35. *Influence of soil pH on grass production*

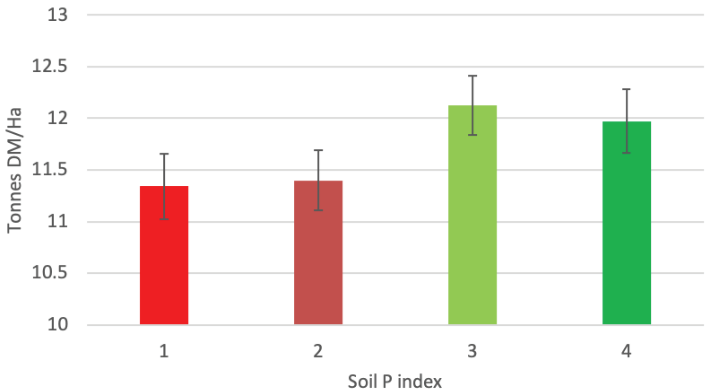


Figure 36. *Influence of soil test phosphorus on grass production*

While significant improvements to soil fertility have been made, there remains much further scope for improvement. To achieve optimum soil fertility a strategic approach that accounts for variation in response of different soils to nutrient input will be required, while ensuring that the risk of nutrient loss is reduced as far as is possible.

7. Grazing infrastructure and grassland management

Increasing grass utilisation on grassland farms is a key driver in increasing net profit. Improved grassland management relies upon robust grazing infrastructure; suitably sized and shaped paddocks with multiple access points serviced by roadways of sufficient quality and adequate drinking water. It is vital to consider the quality of your grazing infrastructure and acknowledge where deficits have arisen in recent years. Increases in herd sizes have placed pressures on existing infrastructure which has knock-on effects on grass utilisation, cow performance and health and labour input. Maximum grazing efficiency will not be achieved unless all grazing infrastructure is sufficient for the needs of the farm. Often, existing farm layouts, roadways and water systems have been largely untouched in many years and it can be easy to overlook the restrictions these place on farm management. On heavy soils farms, grazing infrastructure is particularly important to maximise grassland utilisation during periods of wet weather. Appropriate roadways, paddock access and water trough provision allows for a flexible approach in terms of grazing allocations and aggressive on/off grazing where required.

Farm grazing infrastructure on heavy soil programme farms

The initial focus of the Heavy Soils Programme, was primarily on the problems directly related to the soils themselves, namely land drainage design and installation and improving soil fertility status. However, following the extremely wet and difficult spring of 2018, a need for a renewed focus towards improving grazing infrastructure was highlighted. Throughout this year and since, we have worked with all programme farmers to establish if and where any deficits in grazing infrastructure exist, and put work plans in place over the coming years to resolve these issues. The first step in this process was an audit of infrastructure carried out on each HSP farm.

Grazing infrastructure audits

The audit on each farm was carried out by each farmer along with HSP staff and aimed to outline any issues around grazing infrastructure under a number of headings, namely; paddock size, shape and access points; extent, quality and condition of the farm roadway network and access to drinking water in paddocks. The audit involved a walk(s) of the farm and discussions regarding the above elements. A number of issues around grazing infrastructure were apparent on all farms. Many of these issues are relatively minor in their own right but combine to create difficulties in grassland management and utilisation, animal performance and labour input, particularly in periods of poor weather and difficult grazing conditions. A summary of the issues outlined at one farm are included herein. Once audits were completed a plan regarding priority areas of work was agreed and efforts were made to complete elements of this over the summer and in the following years. These improvements will be vital in our efforts to maximise grass production and utilisation, particularly in the shoulders of the grazing season. We would encourage all farmers to assess their own grazing infrastructure with regard to these elements and consider where priority investments need to be made in the coming years.

Case study farm example:

John O' Sullivan of Castleisland, Co Kerry went about improving grazing infrastructure in 2018 as he felt there were a number of deficiencies that needed to be addressed.

John farms 43 ha of heavy land, which required improvements in grazing infrastructure to facilitate better grass utilisation and prevent excessive poaching and soil damage. Rainfall in the area is approximately 1300 mm/year. In winter/spring 2017/18, 855 mm was recorded in a six month period. This resulted in extremely difficult grazing conditions on the farm and provided the incentive for upgrading grazing infrastructure. "As in most of the country, we had a really wet difficult spring and it showed up some of the shortcomings of our infrastructure and because we couldn't get cows to some paddocks without causing huge damage, we had them indoors for more than we wanted in February and March" recalls John. A review of grazing infrastructure on the farm was carried out in May 2018 to assess the status of all elements described earlier, including, paddock size and layout, farm roadways, fencing and water systems. The overall aim was to identify weaknesses in the existing infrastructure and put a plan in place for new infrastructure that would help achieve more grazings on the farm at the shoulders of the grazing season and at other times when conditions are borderline. The key finding of the review was that a number of areas were identified which were poorly serviced by roadways or access from roadways and which could offer additional grazing in poor weather conditions. On heavy soils it is desirable that all parts of the grazing platform are within 50 m of a farm roadway or spur road. This was the criteria applied when laying out new roadways/spur roads on John's farm.

The main grazing infrastructure improvements required were:

1. New roadway (4 m wide x 570 meters) servicing a 10.6 ha area.
   - » Reconfiguring of paddock boundaries in this area and additional water troughs.
2. Spur roads (2 m wide x 615 meters) to be laid to access seven ha of rented land
   - » Reconfiguring of paddock boundaries in this area and additional water troughs.
   - » These spur roads will also help access to two ha of owned ground in adjacent area.
   - » To facilitate more access points on rented land, gaps need to be made in hedgerows.
3. New Roadway (4 m wide x 550 meters) to service 14.0 ha of rented land.
   - » Reconfiguring of paddock boundaries in this area and additional water troughs.
4. Road surfaces and access gaps, particularly those on rented ground need attention.

It was decided that items 1 and 2, in the areas highlighted below, would be implemented in 2018 with other elements to follow thereafter.

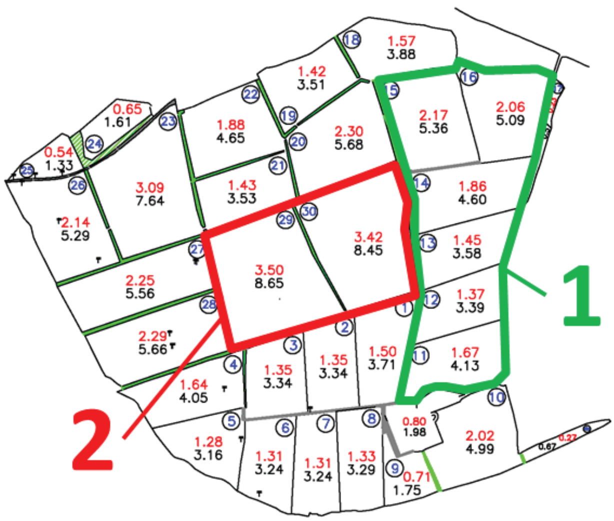


Figure 37. *Focus areas 1 and 2 in which new grazing infrastructure was installed in 2018*

Fortunately, the dry summer weather allowed these works to be completed in great conditions. The newly completed roadways are shown in the map below were completed in July/August of 2018.

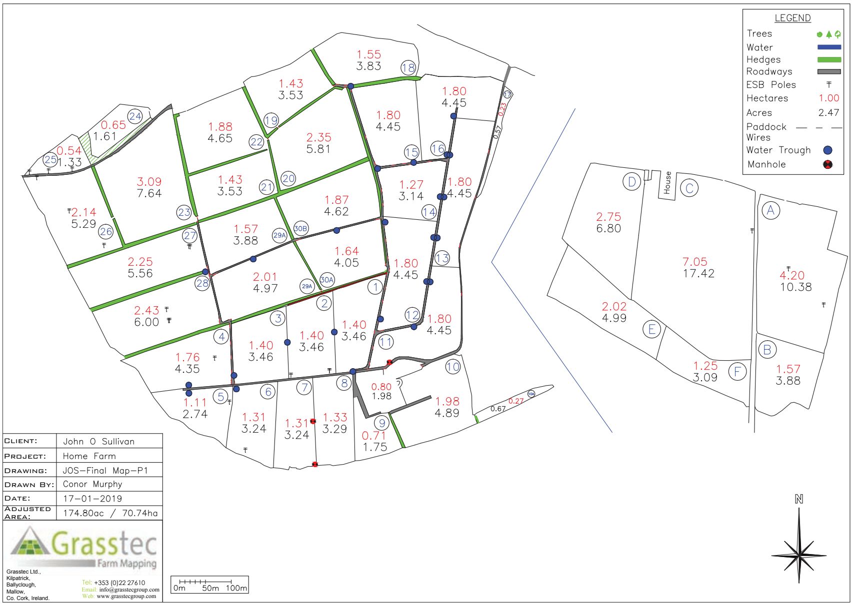


Figure 38. *Newly completed farm roadways and spur roads installed in the areas highlighted above*

Benefits to-date:

The cost of the works carried out in 2018 amounted to approximately €1,000/ha, including additional roadways, spur roads and, piping, troughs and fences. Grazing in 2019 began on February 12th and in total 30 grazings was achieved by the end of the month, which according to John would not have been possible without the new road infrastructure. With the exception of a short period in mid-march grazing continued generally uninterrupted despite relatively high rainfall (175 mm/7 inches in a 3 week-period). By April 1st 60% of the farm was grazed, a figure that would not have been achieved without the investment in grazing infrastructure. Research work has shown that each extra day grazing is worth €3/cow in spring and €2/cow in autumn. The benefits are seen in extra milk solids and greater labour efficiency, while silage stocks are maintained and slurry spreading costs are reduced.

At these rates, it doesn't require huge amounts of additional grazings to pay for high quality grazing infrastructure. The grazings, particularly in spring will also stimulate additional growth. The goal of the Teagasc Grass10 campaign – 10 grazings in the year on each paddock – is not possible if you don't get at least one grazing done by late march. It is also worth bearing in mind that the objective is not to get cows out regardless of weather or ground conditions, but rather that when conditions are improving, cows may be able to be put out if infrastructure is good. Even if that's only for three hours, grass utilisation is improved. "Upgrading your infrastructure is a really good investment," says John, "It generates a very healthy return of 10% to 15% p/annum. We're always looking for ways to make better use of use of grass and this helps enormously. Having good infrastructure is also better for people, because it reduces drudgery and makes the job easier and possibly more attractive for the next generation".

The lessons learned on this Kerry farm are relevant for farmers from all parts of the country, even farms in much drier areas will have parts of the farm that are wet at particular times of the year and good infrastructure is needed to access grazable areas, also flexibility and access are key to any grazing system and need to be provided by well-planned and well maintained infrastructure.

Further technical detail on grazing infrastructure specification is available in the Dairy Farm Infrastructure Handbook and Workbook; available from the Teagasc website at https://www.teagasc.ie/publications/2019/dairy-farm-infrastructure-workbook.php

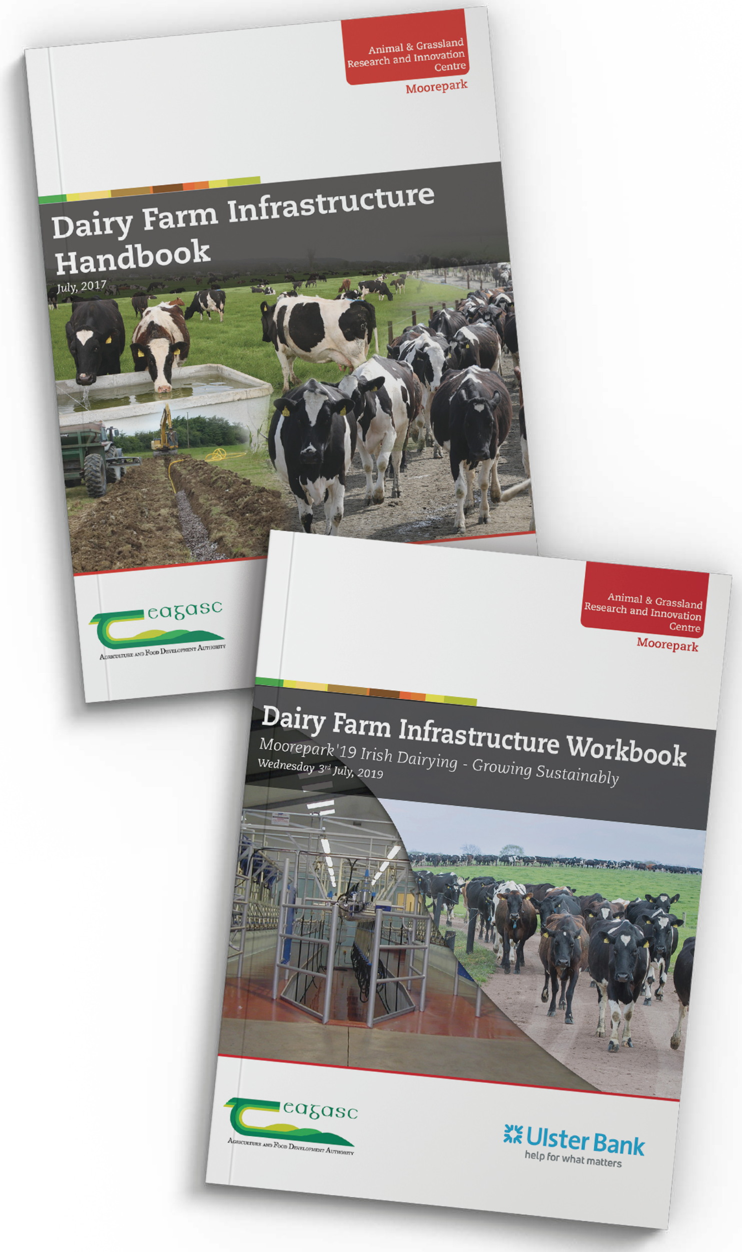


Figure 39. *Dairy farm infrastructure handbook and workbook*

8. Farmer feedback

The programme farmers answer some questions with regard to their involvement in the programme

What has been your main focus since you joined the Heavy Soils programme?

David Brady, Stradone, Co. Cavan;

"I joined the Heavy Soils Programme the same time I started measuring grass so my main focus is on growing and utilising more grass and to do that I needed a better understanding of my soil fertility, better grazing infrastructure and guidance on what form of drainage works for this farm."

John Leahy, Athea, Co. Limerick;

"The main focus of being in the programme has been to increase the profitability of the farm by growing and utilising more grass."

Danny Bermingham, Doonbeg, Co. Clare;

"Draining and reseeding 10% of the farm every year with soil fertility to the fore. Also improving farm infrastructure e.g roadways, cow paths and fencing etc."

What have you achieved as a result of being part of the programme?

David Brady, Stradone, Co. Cavan;

"I now have a vast amount of knowledge and expert advice on hand.I know that gravel mole drainage works very well. Although expensive it will pay for itself over a short number of years. We have made great strides in correcting our soil fertility issues on this farm and hopefully within the next couple of years it will be where we want it"

John Leahy, Athea, Co. Limerick;

"The whole farm is now producing 11to 12 Tons of grass on average up from 9 Tons at the start of the programme. Some paddocks have increased production by 8 Tons. This has allowed me to increase the number of cows from 80 to 110. This has been achieved through improved drainage, soil fertility, reseeding, and infrastructure which has allowed a longer grazing season".

Danny Bermingham, Doonbeg, Co. Clare;

"Soil fertility is improving year on year but it is a slow burn. I'm growing more grass and utilising it much better. I'm getting better utilisation of fertilisers relative to stocking rate as soil fertility improves. I'm getting top class advice from the team on the Heavy Soils Programme has been brilliant on achieving these gains. It is great to be networking with fellow Heavy Soils Programme farmers as it has been a huge benefit to the system here."

What messages would you given farmers on heavy soils or in areas of high rainfall that aspired to reaching similar levels of production as you?

David Brady, Stradone, Co. Cavan;

"Don't be afraid to ask other farmers and Teagasc advisors for help, they have a vast knowledge. Gravel mole drainage works on this farm but check your own farm out and do what is best for it."

John Leahy, Athea, Co. Limerick;

"My advice to anyone on heavy soils would be to firstly improve soil fertility and drainage before spending on concrete or facilities."

Danny Bermingham, Doonbeg, Co. Clare;

"Land drainage is expensive stuff. Knowing the proper drainage techniques relative to your soil profile is a must. All of the above especially reseeding is a waste of time without drainage or if soil fertility isn't up to scratch. Farm infrastructure has to be good in conjuction with all of the above. There is no point in growing 15 ton of grass if farm infrastructure does not allow utilisation of said tonnage."

Do you feel your investments in land drainage and soil fertility was worthwhile or is the other areas where you felt you got better returns on you investment (improving EBI, farm infrastructure or technology on the farm)?

David Brady, Stradone, Co. Cavan;

"Yes I believe land drainage and soil fertility investments are money well spent and they give the quickest return on investment."

John Leahy, Athea, Co. Limerick;

"Soil fertility and drainage have been the main drivers which have enabled me to increase cow numbers on the farm. I have drained 25 acres, it is now producing grass and is part of the milking platform. Farm infrastructure such as spur roads has also helped in utilising the grass."

Danny Bermingham, Doonbeg, Co. Clare;

"100% worthwhile. I would put farm infrastructure up there as well.We had a good herd re. EBI from the start and we are always ready to embrace technology."

If you were to take on another dairy unit on a heavy soils farm with poor soil fertility, drainage and infrastructure. Having been part of the Heavy Soils Programme and overseeing improvements on your home farm what approach would you follow?

David Brady, Stradone, Co. Cavan;

"The steps I'd suggest are:

Map the farm.

Soil test the whole farm.

Dig soil test holes to establish the best type of drainage.

Develop a fertiliser plan to correct pH and then P and K values.

Develop a drainage and infrastructure plan to be completed over a number of years with targets for each year and budget to complete."

John Leahy, Athea, Co. Limerick;

"Well the first step would be to keep looking until I found a dry farm!! Drainage first, soil fertility, reseed, and then infrastructure".

Danny Bermingham, Doonbeg, Co. Clare;

"It would be important to get soil fertility, drainage and infrastructure up to speed, and budget appropriately for each".

All heavy soils programme information, regular programme updates and links to other resources is available from the dedicated website www.teagasc.ie/heavysoils.

9. Notes

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