Agricultural Water Management 210 (2018) 96–107

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

The performance and behavior of land drainage systems and their impact on field scale hydrology in an increasingly volatile climate

P. Tuohy[a,*], J. O' Loughlin[a], D. Peyton[a], O. Fenton[b]

[a] Animal and Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co., Cork, Ireland
[b] Environment Research Centre, Teagasc, Johnstown Castle, Wexford, Co., Wexford, Ireland

ARTICLE INFO

Keywords:
Flow response
Drain discharge
Hydrograph
Groundwater
Climate change

ABSTRACT

Escalations in rainfall intensity, both in terms of volume and frequency are increasing the volatility associated with grassland agriculture on poorly drained soils. The principal mechanism of reducing this volatility is by means of land drainage; however the efficacy of drainage systems is widely variable and has not been fully quantified. The excavation of soil test pits and a corresponding examination of the soil profile enables bespoke land drainage system design. Across heterogeneous soil-scapes this leads to variations to both groundwater and shallow drainage designs. In the present study we examine the performances of 9 site-specific drainage systems (5 groundwater and 4 shallow drainage designs), during a high rainfall period (01/10/2015–31/05/2016) in terms of response times (start, peak and lag times), discharge characteristics (peak flow rate, total discharge, flashiness index, discharge hydrographs) and water table control capacity. Response times were not affected by drainage system or drainage design type, showing similar responses despite variation in soil types where appropriate drainage systems are installed. Total discharge (1098.4 vs. 189.6 m^3/ha) and peak flow rate (51.0 vs. 16.8 m^3/ha/h) were significantly higher in groundwater designs relative to shallow alternatives. Groundwater drainage designs generally maintained a deeper mean water table depth (0.82 m) than shallow designs (0.53 m) during the study period. The functional capacity of each land drainage system was inherently different. The comparison of such systems highlights contrasting behaviors 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 (groundwater versus perched water). All systems reduced the overall period of waterlogging and improved the conditions for both the production and utilization of the grasslands they drain, although temporal variations in agronomic parameters are likely to be more pronounced in shallow designs.

1. Introduction

In poorly drained grassland soils, both production and potential for grazing (utilization) are restricted due to surface water logging, reduced yields and low soil bearing capacity (Bell et al., 2011; Patton et al., 2012; Kandel et al., 2013). Generally, grassland productivity is positively correlated with annual precipitation (Smit et al., 2008) but in the case of poorly drained soils in temperate regions, excess rainfall can result in a saturated root-zone which inhibits production (Fitzgerald et al., 2008). Furthermore, these soils become impassable to both machinery and livestock traffic for extended periods (Keane, 1992). This introduces significant costs to the farm system as normal farming practices are curtailed (Brereton and Hope-Cawdery, 1988; Shalloo et al., 2004).

Clearly observable escalations in rainfall intensity, both in terms of volume and frequency are increasing the volatility associated with grassland agriculture on poorly drained soils. The impacts of climate change in Ireland (Kiely, 1999) are being felt most keenly by those farms where trafficability is marginal during periods of high rainfall. Increasing likelihood of adverse weather, principally high rainfall, is forcing landowners to invest significantly in mechanisms to increase the resilience of their grazing systems by reducing the impact of excessive rainfall.

Effective land drainage systems provide relief of excess water and control the water table thereby improving yields and grazing conditions and reducing the volatility associated with periods of adverse weather (Armstrong, 1985; Nijland et al., 2005; Ibrahim et al., 2013). The design of land drainage entails the specification and installation of drains in the soil at such a depth and spacing to control the water table at a predetermined depth below ground level under a particular intensity of

* Corresponding author.
E-mail address: patrick.tuohy@teagasc.ie (P. Tuohy).

https://doi.org/10.1016/j.agwat.2018.07.033
Received 14 December 2017; Received in revised form 20 July 2018; Accepted 29 July 2018

rainfall (Mulqueen, 1998). Effective design requires that soil physical properties are fully characterized with regard to their drainage capacity, and that the drainage system is tailored to optimize discharge levels from a particular soil (Galvin, 1986; Schultz et al., 2007; Skaggs et al., 2012). A number of drainage systems and techniques have been developed to suit different soil types and conditions with associated drainage characteristics, with this end in mind (Smedema et al., 2004; Tuohy et al., 2016b). These range from groundwater drainage designs, (1.0–2.0 m deep) which interact directly with groundwater by virtue of their position in a high permeability soil layer (Smedema and Rycroft, 1983; Teagasc, 2013) to shallow drainage designs, comprised of shallow (< 1.0 m) tile drains supplemented by mole drainage, gravel mole drainage or sub-soiling at spacings of 1–2 m, (Spoor, 1982; Mulqueen, 1985; Robinson et al., 1987; Tuohy et al., 2016a,b).

Consistent increases in rainfall levels in the south-west, and indeed nationally, are creating a renewed enthusiasm for land drainage works, particularly where grazing potential is impacted consistently in the main grazing season (March–November). Significant investments in land drainage systems are being undertaken at farm scale with little guidance on the performance capacity and potential returns achievable in a wide range of drainage design/soil type dynamics. The return on such investments is dependent on an increase in grass production and utilization (number of grazings/silage harvests) and these are both factors of the hydrologic changes brought about by the installation of the drainage systems. Therefore to understand the agronomic and economic impacts of site-specific drainage systems in a wetter climate, we must examine the hydrologic impact and responses of such systems during periods of high rainfall.

The efficiency of a drainage system is a measure of its ability to respond to rainfall events and discharge appropriate volumes of water. In a changing climate, a trend towards more rainfall and/or a greater number of high intensity rainfall events (Kiely, 1999; Walsh, 2012a,b; Nolan et al., 2013) is putting increasing pressure on land drainage systems (Sloan et al., 2016) and altering the dynamics with relation to efficiency. The performance of drainage systems installed is hugely variable and for the most part, poorly understood. A review of the performance of a range of recently installed land drainage systems in terms of their response to rainfall events, water table control and flow discharge behavior in a high rainfall period would add to the understanding of the capabilities and limitations of such systems and generate new knowledge with respect to the efficiency of various drainage designs, and their potential usefulness in improving the agronomic value of poorly drained soils in an increasingly wet climate.

The objectives of this study were to a) quantify the general performance and effectiveness of 9 site-specific drainage systems over a number of rainfall events of varying magnitude during an extended high rainfall period, b) compare system responses and performance across drainage systems and drainage design types during rainfall events of like magnitude, c) quantify behavior characteristics of drainage systems and drainage design types and d) determine the principal factors which dictate their behavior. Performance was measured in terms of water table control, response and discharge parameters (namely flow start, peak and lag times, peak flow rate, flashiness index and total discharge) and discharge hydrographs.

2. Materials and methods

2.1. Site details

The study involved 9 drainage systems across 7 farms in southwest Ireland (Table 1; Fig. 1). The farms are all participants in the Teagasc 'Heavy Soils Program', which aims to demonstrate methods to improve grassland productivity and utilization, decrease volatility and sustain viable farm enterprises on poorly drained soils. They were selected from within regions where poor soil drainage coupled with climate (principally precipitation less evapotranspiration) inhibits potential for

Table 1
Site Details.

Site	Location			Average annual precipitation (1981-2010)[a]		
	Northing	Westing	Elevation ASL	Precipitation	Station distance from site	Slope
	(degree)	(degree)	(m)	(mm)	(km)	(%)
1	52°36'	08°01'	105	982	6.5	1–2%
2	52°28'	09°33'	8	1095	1.0	1–2%
3	51°59'	08°56'	231	1757	5.5	7–9%
4	51°12'	09°08'	233	1622	7.8	6–7%
5	52°44'	09°30'	9	1185	2.0	< 1%
6	52°27'	09°19'	139	1320	4.3	4–6%
7	52°13'	09°28'	36	1298	2.5	4–6%

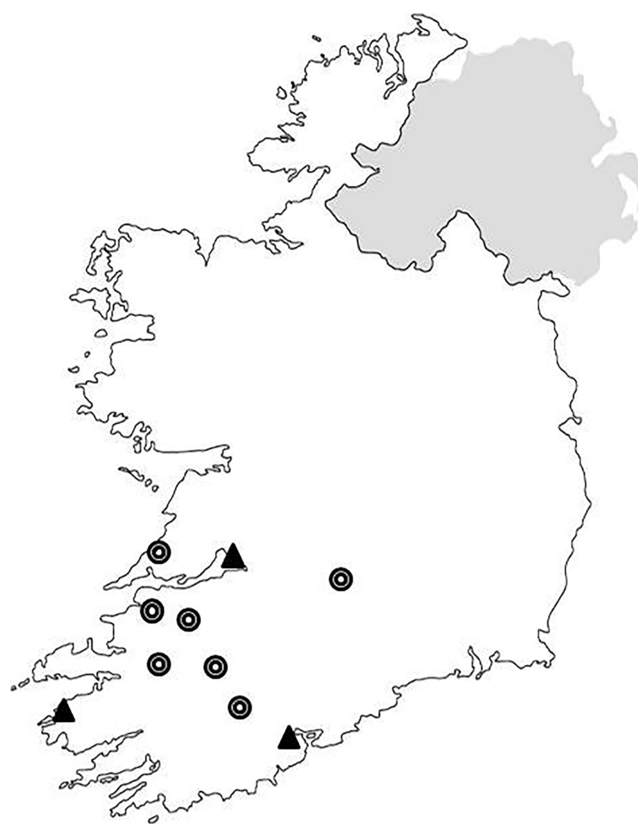

Fig. 1. Location of drainage sites (◎) and meteorological stations (▲) in the south-west of Ireland.

production and on-farm profitability. In conjunction with each farmer an area of the farm with a history of impeded drainage was selected and a new drainage system was installed (Table 2). The drainage systems were designed to optimize system performance using the methods outlined in Tuohy et al. (2016b) by tailoring design to the intrinsic soil properties. In the case of both site 1 and site 7, adjustments to the site-specific designs led to the installation of alternative drainage systems on equivalent areas, as a result a total of 9 distinct drainage systems were installed (Table 2).

Drainage systems 1.1, 1.2, 2, 3 and 4 are classified as groundwater drainage designs (GW), which interact directly with groundwater by virtue of their position in a high permeability soil layer, where percolation to the water table is uninhibited (Smedema and Rycroft, 1983; Teagasc, 2013), while drainage systems 5, 6, 7.1 and 7.2 are shallow drainage designs (SH), installed where all layers in a soil profile are fine, heavy and poorly permeable and efforts are focused on improving