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Runoff and subsurface drain response from mole and gravel mole drainage across episodic rainfall events

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ABSTRACT

Shallow drainage techniques such as mole and gravel mole drainage are used in low permeability soils to siphon off infiltrating rainwater and mitigate the associated rise in watertable. Their purpose is to improve trafficability and agricultural production. In Ireland, long-term climate predictions envisage an increased level of short-term extreme rainfall events. Therefore, a key question is how these drainage techniques perform during episodic, high intensity rainfall events, specifically in terms of discharge hydrographs and associated parameters (principally flow start time, flow peak time, lag time, peak flow rate and flashiness index). We examined 12 rainfall events over a 1 year period on a clay-loam dominated grassland site of 1.4% slope in the south of Ireland. Four drainage treatments, namely; (A) an un-drained control, (B) Mole drainage installed in January 2011 (sub-optimal installation conditions), (C) Mole drainage installed in July 2011 (optimal installation conditions) and (D) Gravel mole drainage installed in July 2011 were examined. Results showed that gravel mole drainage exhibited shorter response times to rainfall events and ultimately drained greater volumes. Drain flow from mole drainage treatments B and C produced longer start, peak and lag times and lower peak and total flows relative to the other flow discharges. Variations in discharges from all treatments were closely correlated to soil moisture status, 30 days antecedent rainfall and rainfall event intensity. Drain flow response in all treatments was seen to deteriorate in time with the strongest responses evident in early events. Flow hydrographs showed strong variation in flow characteristics, within and across treatments and across events. If the predicted increase in short-term extreme rainfall events materialises then such systems will have to operate in increasingly adverse conditions. This will require changes in system design to improve the effectiveness of mole and gravel mole drainage.

1. Introduction

The production of milk from grazed grass is a key feature of agricultural production in temperate regions, such as Ireland. On poorly drained grassland farms, problems associated with slow recovery time and an inability to traffic and graze the land in adverse weather (Keane, 1992; Fitzgerald et al., 2008) negatively impact profit margins (Shalloo et al., 2004). Proposed production gains in Irish agriculture (Department of Agriculture, Fisheries and Food, 2010; Läpple and Hennessy, 2012) will rely heavily on increased output from existing farm systems and land resources (Patton et al., 2012). As much of this land is classed as "marginal" (49% of total land area; Gardiner and Radford, 1980) due to natural limitations related to its soil, topography, relief and climate or "significantly wet with impeded drainage" (60%; Collins and Cummins, 1996), the role of effective land drainage systems in meeting output targets is clear.

Many farms in north-western Europe suffer from the dual handicap of poorly drained soils and high precipitation levels. In Ireland precipitation ranges from approximately 750–3000 mm year^{-1} while evapotranspiration ranges from 390 to 570 mm (Mills, 2000). Updated 30-year rainfall averages show a clear trend towards increased precipitation in recent years (Walsh, 2012a, 2012b). Under climate change predictions the total annual rainfall will not vary substantially but significant changes in seasonal patterns will be evident with a likelihood for drier summers and wetter winters and a substantial increase in the number of short period extreme rainfall events (Nolan et al., 2013). These events are particularly

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important due to their link with surface waterlogging and flooding on poorly drained soils. If such predictions transpire, drainage systems will have to operate in increasingly adverse conditions and persistently cater for extremes of flow that are heretofore rare.

Mole drainage (€125–300 ha^{-1}, Crosson et al., 2013) is a shallow drainage technique comprising a series of closely spaced (1.0–2.5 m apart) unlined channels at approximately 0.4–0.6 m depth in cohesive soils (ideally a soil having >45% clay and <20% sand; Burke, 1978; Cavelaars et al., 1994). They increase the infiltration capacity of the soil by cracking, fracturing and loosening the heavy structureless layers close to the soil surface (Goss et al., 1983; Hallard and Armstrong, 1992). This allows excess water to be drained more quickly from the upper layers of the soil after rainfall events.

Mole drains are formed with a tractor mounted mole plough consisting of a chisel nosed torpedo-like cylindrical foot, attached to a narrow leg, and drawing a slightly larger cylindrical expander behind. Gravel mole drainage provides an alternative to mole drainage in those soils which cannot sustain a stable mole channel (Mulqueen, 1985). It was developed to overcome the limitations associated with less cohesive soils and offers a more robust system with a much longer lifespan than traditional mole drainage, but at a much higher cost (€1500–2800 ha^{-1}, Crosson et al., 2013). Generally both systems are installed perpendicular to a network of open or sub-surface field drains that act as an outlet for the water collected by the mole drains (Castle et al., 1992; Mulqueen, 1998).

Mole drains rely on a network of subsoil cracks and closely spaced channels to rapidly carry away excess soil water during rainfall events (Childs, 1943; Spoor, 1982; Hallard and Armstrong, 1992). However, the nature of such soil disturbance features dictates that the response to rainfall events will vary temporally due to a number of inter-related variables related mostly to antecedent soil and rainfall event conditions (Burke et al., 1974; Robinson et al., 1987). The understanding of the hydrological response of these drainage systems is largely unknown. The efficiency and resilience of mole drainage is largely dependent on soil type and installation conditions (specifically soil moisture content during installation). They are known to have a limited lifespan before re-installation is required (Galvin, 1983, 1986; Mulqueen, 1985; Cavelaars et al., 1994). It has also been found that seasonal differences are evident in flow responses due to the instigation/propagation of shrinkage cracks in prolonged dry periods and their subsequent degeneration in wet periods (Jarvis and Leeds-Harrison, 1987; Robinson et al., 1987). Therefore the capacity of these systems is hugely variable both in terms of initial conditions (soil type/installation) and subsequent weather patterns. The addition of gravel to the mole channel also alters its hydrologic capacity and affects flow response from the drained land (Mulqueen, 1985). This is another variable to be considered.

The objective of this study was to compare the effectiveness of mole and gravel mole drainage by investigating surface runoff and subsurface drain discharge over 12 intense episodic rainfall events during one year. Flows were investigated in terms of discharge hydrographs and response parameters (principally flow start time (relative to event start time), flow peak time (relative to event start time), lag time (peak flow time relative to peak rainfall time), peak flow rate and flashiness index) from the following treatments; (A) un-drained control, (B) Mole drainage installed in January 2011 (sub-optimal installation conditions), (C) Mole drainage installed in July 2011 (optimal installation conditions) and (D) Gravel mole drainage installed in July 2011.

2. Materials and methods

2.1. Site details

The study site (2.5 ha) was located at the Solohead Research Farm (52 ha) in the south of Ireland (52°30′N, 08°12′W) and slopes gently (1.4%) with a southerly aspect (Fig. 1). Average annual rainfall (10 years) on site is 1070 mm, with potential evapotranspiration of approximately 510 mm annually. The site suffered from waterlogging and poor trafficability in adverse weather conditions. High levels of runoff and long recovery times after rainfall events were a feature as high soil moisture contents and surface ponding were maintained in periods of persistent rainfall. General soil types in the area can be grouped together under the Elton soil association (Creamer et al., 2014) and have previously been classified as poorly drained gleys (90%) and grey brown podzolics (10%) (Gardiner and Radford, 1980). The subsoil is quaternary till with a shallow watertable (depth of 0 to 2.2 m below ground level, BGL) (Necpalova et al., 2012), which is indicative of its landscape position beside the River Pope (Fig. 1). Depth to the Devonian Sandstone bedrock on site varies from 5 to 10 m (Archer et al., 1996). The sandstone aquifer is a confined aquifer with saturated hydraulic conductivity (k_s) of 0.001 to 0.02 m day^{-1} (Jahangir et al., 2012).

Disturbed soil samples from soil test pits, representative of distinct soil horizons were bulked for each horizon and analysed for sand, silt and clay % laser diffraction method with correction for clay fraction underestimation (Konert and Vandenberghe, 1997). Indicative k_s was inferred for each sample using Saxton and Rawls (2006) assuming a soil organic matter content of 2.5% (by weight) (Table 1). These samples and previous analyses (Jahangir et al., 2013) show the soil profile to be poorly permeable with little potential for efficient drainage using conventional drain spacings (10–50 m). Therefore, the site required the closely spaced drainage channels and soil loosening effects provided by mole and gravel mole drainage. Soil type was not ideal with regard to the formation of a stable mole channel (Burke, 1978), but occupied a zone of uncertainty where it is unknown whether mole drainage or gravel mole drainage is most appropriate. Many more soils would fit into this category than those with the "ideal" soil type for mole drainage. A direct comparison of mole and gravel mole drainage on such a site therefore has much practical value. The site was an ideal staging ground for assessing and comparing such drainage treatments.

Table 1
Soil profile texture and estimated hydraulic conductivity.

Depth	>2 mm (%)	<2 mm			USDA textural class	k_s[a] (m day^{-1})
		Sand (%)	Silt (%)	Clay (%)		
0–25	11.5	41.3	23.4	35.3	Clay loam	0.047
25–80[b]	25.5	30.9	23.8	45.3	Clay	0.015
80–130	28.3	34.2	21.7	44.1	Clay	0.014
130–200	1.0	5.9	25.8	68.3	Clay	0.007

k_s = saturated hydraulic conductivity.
[a] Estimated using the hydraulic properties calculator of Saxton and Rawls (2006).
[b] Depth range over which the mole drains and gravel mole drains were installed.