

Development of preferential flow below a soil moisture threshold

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Abstract

Application of 25 mm dye tracer to a 'dry' texture contrast soil (Sodosol) soil resulted in infiltration to a depth of between 85 cm and 114 cm via a combination of preferential flow processes. However when the same soil was 'wet' the dye tracer infiltrated uniformly to a depth of between 24 cm and 40 cm. Long term soil moisture monitoring demonstrated that a soil moisture threshold existed at approximately 300 mm total stored soil moisture (0-90 cm) which corresponded to approximately 30 % of plant available water content (PAWC). When rainfall occurred on soil with an antecedent soil moisture below the 300 mm threshold, infiltration was dominated by preferential flow processes, however when antecedent soil moisture was above the 300 mm threshold, infiltration resulted from equilibrium flow as predicted by the Richards equation. Knowledge that preferential flow occurs below a soil moisture threshold, enables agricultural managers to reduce loss of agrochemicals below the root zone by restricting application to times when soil moisture is above the threshold.

Key Words

Antecedent soil moisture, capacitance probe

Introduction

Preferential flow refers to processes in which infiltrating water by-passes the soil matrix, resulting in more rapid and deeper movement of water and solutes than would otherwise be expected (Simunek and van Genuchten, 2007). Numerous studies have demonstrated that preferential flow is both common and widespread (Flury *et al.*, 1994), resulting in the potential off-site movement of fertiliser and agrichemicals. The presence of preferential flow also invalidates assumptions of the Richards equation used in single porosity models to predict infiltration into variable saturated soils (Jarvis, 2007). Through dye tracer studies and long term soil moisture monitoring, the effect of antecedent soil moisture on preferential flow was investigated.

Methods

Dye staining

A 25 mm solution containing 4 g/litre Brilliant Blue FCF (C.I. Food Blue 42090) dye tracer was applied to a texture contrast soil (Sodosol) the soil via either a Morin rotating-disk rainfall simulator or hand held sprayer. Dye stained areas were excavated approximately 30 hours after dye application. Images of dye stained soil were captured using a Cannon 400D EOS digital camera, under a large white tent to exclude shadows. Images were corrected for radial and keystone distortion in Photoshop CS3 software. Dye stained regions were separated from unstained soil and converted to binary format in Image J software to enable analysis of the proportion of dye stained soil with depth.

Moisture treatments

Dye was applied to the soil surface in wet and dry conditions. The dry treatment was established by ambient drying under a rainout shelter during a prolonged period without rainfall. The wet treatment was established by applying 20 - 30 mm irrigation with pop-up sprinklers four times a week, for a period of 45 days.

Soil moisture measurement

Soil moisture was monitored using a continuously logging capacitance probe (EnviroSCAN Solo - Sentek Environmental Technologies, Kent Town, South Australia). The EnviroSCAN probe was mounted inside a 5.6mm diameter PVC plastic access tube which was rammed into the soil, ensuring a tight fit between the soil and the access tube. Soil moisture was monitored at 10 cm, 20 cm, 30 cm, 50 cm, 70 cm, 90 cm and 130 cm depths at 60 minute intervals between 19/9/07 and 30/5/08 and intervals between 1 and 10 minutes

between 26/6/08 and 10/7/09.

The effect of antecedent moisture on the occurrence of preferential and equilibrium flow was determined from changes in soil moisture following 44 rainfall events between 24/9/2007 and 16/8/2009. Soil moisture response to rainfall (>5 mm) was classified into five infiltration types.

- (i) PF-A: Preferential flow, evidenced by by-pass flow in which soil moisture response (>0.2 %) does not follow a logical sequence with depth.
- (ii) PF-B: Preferential flow, evidenced by infiltration rates in excess of 200 mm/hr.
- (iii) EQ: Equilibrium flow, in which infiltrating rainfall caused soil moisture sensors to respond in depth order and at infiltration rates <200 mm / hr.
- (iv) NR: No response, (>0.2 %) change in soil moisture following > 5 mm rainfall.
- (v) UR: Unknown response, in which soil moisture response to rainfall was unable to be classified as resulting from preferential or equilibrium flow.

Results

In the dry treatment, preferential flow processes resulted in dye infiltration to depths between 85 cm and 119 cm. Preferential flow included finger flow in the A1 horizon resulting from hydrophobicity, funnel flow in the A2 horizon and sand infills, ponding and spilling of thin rivulets down the side of the clay columns, and filling from the bottom up in shrinkage cracks and void spaces in the lower B horizons (Figure 1a-c). In the wet treatment, the dye tracer infiltrated to depths between 24 – 40 cm. Dye staining indicates that while the wetting front developed perturbations, true finger flow did not develop in the wet treatment (Hardie *et al.*, Submitted) (Figure 1d-f).

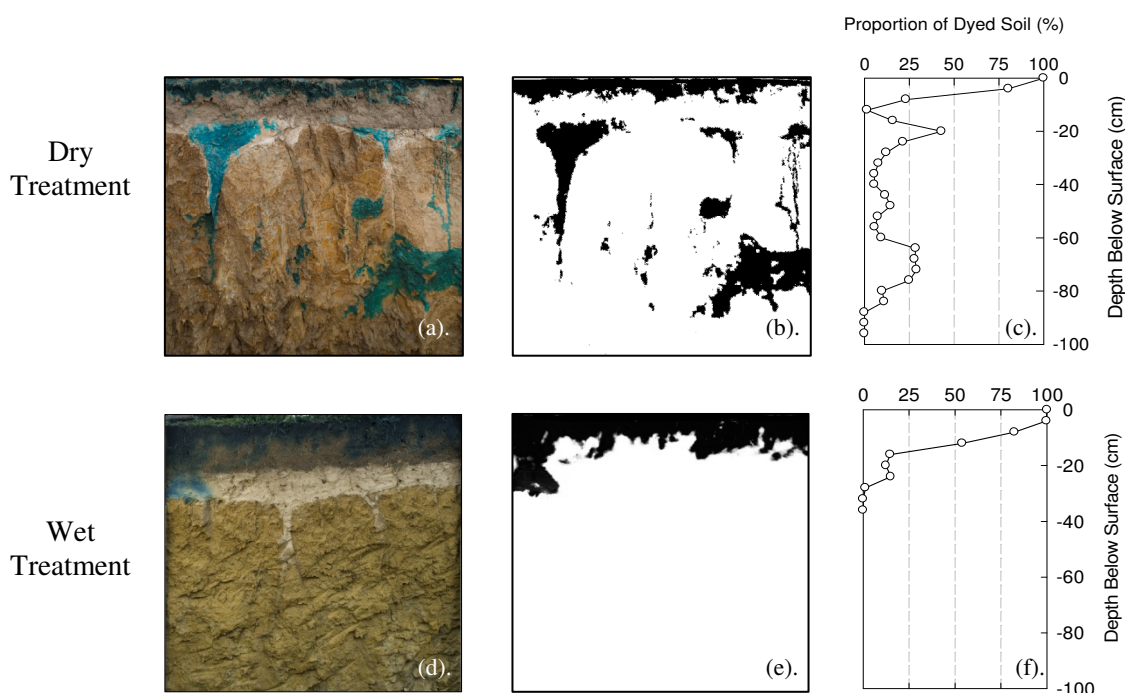


Figure 1. Example of the effect of antecedent soil moisture on dye tracer infiltration –dry treatment (a) image, (b) binary image (c) proportion of dye stained soil with depth. Wet treatment (d) image, (e) binary image (f) proportion of dye stained soil with depth.

The mean antecedent soil moisture (0-90 cm) of the two preferential flow classes (PF-A, PF-B) was significantly ($P < 0.05$) lower than the antecedent soil moisture of the equilibrium (EQ) flow class (Figure 2b). Results presented in Figure 2 indicate that when total soil moisture (0-90 cm) was below approximately 300 mm, infiltration, occurred via preferential flow (figure 1a). However when antecedent soil moisture was above 300 mm, rainfall infiltrated as uniform flow, which was largely restricted to the A horizon (Figure 1d). Based on seasonal changes in soil moisture the 300 mm soil moisture threshold corresponded to approximately 30 % of plant available water capacity (PAWC).

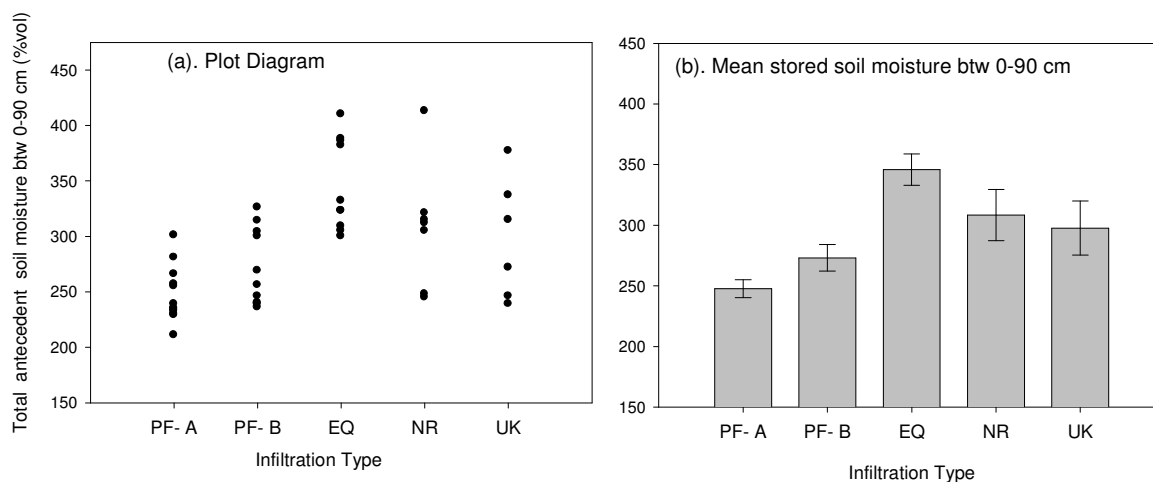


Figure 2. Effect of cumulative antecedent soil moisture between 0 cm and 90 cm on infiltration type (a) plot graph, (b) bar chart with – error bars represent ± 1 SE.

Discussion & Conclusion

Infiltration into the texture contrast soil at antecedent soil moisture contents below 300 mm total soil moisture (0 -90 cm) were dominated by preferential flow processes, which resulted in the rapid infiltration to approximately 1.0 meter depth. When the antecedent soil moisture was greater than 300 mm (0-90 cm), infiltration occurred as equilibrium flow. By restricting application of pesticides and fertiliser to times when soil moisture is above the 300 mm soil moisture threshold, agricultural managers can reduce the risk of shallow groundwater contamination via preferential flow. Results also imply that use of tipping bucket models or Richards equation based single porosity models which do not account for preferential flow are likely to be invalid when applied to soils below the threshold soil moisture content.

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