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How does crop management control soil hydraulic properties?

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Introduction

Arable cropping can have large impacts on soil properties, compared to pasture or forests, due to frequent soil disturbance, compaction, greater use of agrochemicals and higher off-takes of plant biomass (Sparling et al., 2000). Hence, mixed pasture-crop-pasture rotations (with both phases of two to five years duration) are common practice in New Zealand, as the pasture enables both soil structure-building and nutrient replenishment. It is generally accepted that such management practices modify the soil's structure and pore-size distribution (PSD). In particular, the saturated and near-saturated soil hydraulic properties are very sensitive to these management-induced changes.

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The length of time given over to either cropping or pasture within the above mentioned rotation varies and depends principally upon the current relative profitability of the two forms of farming and the need to maintain soil structure. In the last decade, the latter has gained increasing awareness in New Zealand (NZ) because NZ is now among the world's most intensive soil users, and must ensure a sustainable agri-culture. This has, among others, encouraged establishing an organic demonstration farm at Lincoln University in 1999. The aim of the conversion from intensive cropping to certified organic production was to rebuild soil structure and fertility. Conversion to pasture would be the ideal way to achieve this. However, the interesting feature of the established organic farm is that the crop / pasture rotation is since them on a two year cycle. With that management approach one tries to maintain economic crop production, whilst also trying to rejuvenate the soil's physical fertility.

Methods for quantifying the interactions between crop/ soil management practices, and soil structure/ PSD are needed to improve our capacity to assess the overall impacts of agricultural practices on soil 'physical fertility', and on the water balance. The objective of our study was to characterize these management-induced changes in soil structure, and therefore in the soil properties which control the fate of water and nutrients and the development of plant root systems as well as soil erodibility.

Sites and Methods

In our study, the change in soil hydraulic properties in response to crop/ pasture rotation was measured at the organic cropping farm of Lincoln University, on the Canterbury Plains of NZ's South Island. The soil is a well-drained sandy loam, formed in 50 – 100 cm of fine textured alluvium, classified as a Typic Dystrustept in the U.S. system and as a Pallic Soil, type Templeton sandy loam, in the NZ system. Such soils are used predominantly for grazed pasture, with some mixed cropping. The sample sites were in two adjacent fields on the same soil type. One site had been under grazed pasture for 2 years, after being cropped for 2 years. The adjacent site had been cropped for 2 years, after being in pasture for 2 years. Combined hood and disc infiltrometer measurements were conducted at pressure supply heads of 0, –2, –4, –8, and –12 cm. Following all infiltration experiments, we extracted 22 (eleven from each site) undisturbed soil cores, from beneath the positions where the infiltration had been measured. These cores were used to determine (desorption) water retention curves and bulk densities.

Once the $K(h_0)$ values were determined, the representative mean radius $r_{\Delta h0}$ [L] for two consecutive pressure heads, Δh_0, was determined as (Moret and Arrúe, 2007)

$$r_{\Delta h_0} = \frac{\sigma \Delta K}{\rho g \Delta M_O} \qquad [1]$$

where σ [MT^2] is the air-pore water interfacial surface tension, ρ [ML^{-3}] is the density of water, g [LT^{-2}] is the acceleration due to gravity, ΔK [LT^{-1}] is the difference in hydraulic conductivity between two applied pressure heads, and ΔM_O [L^2T^{-1}] is the difference in matrix flux potential between two applied pressure heads. The matrix flux potential is the area beneath the hydraulic conductivity function $K(h_0)$ within chosen limits (Gardner, 1958)

$$M_O = \int_{h_i}^{h_0} K(h)\, dh \qquad [2]$$

The representative mean radius, $r_{\Delta h0}$, defines a sort of pore index of "water conductiviness" that relates to the flow impedance for a pressure head range corresponding to a specific specific "pore size" (Moret and Arrúe, 2007). Calculation of $r(h_0)$ requires estimates of M_O. These were obtained as described in Reynolds et al. (1995).

Results

At each soil surface-applied suction, the hydraulic conductivity of the mixed cropping site was significantly greater than that of the grazed pasture site (Table 1). The variability of the data is larger under cropland than under pasture. For example, the coefficient of variation of the measured hydraulic conductivity ranged between 29 (at saturation) and 22% (at $|h_0|$ = 12cm) under pasture, and between 41 (at saturation) and 37% (at $|h_0|$ = 12cm) under cropland. The larger variability of conductivity at and near saturation indicates a larger small-scale variability of macropores (corresponding to pore radii which will be emptied when $|h_0| < 4$cm) compared to the variability of capillary pores.

Tab. 1: Mean values of hydraulic conductivity of the cropland and grasland sites.

	Hydraulic conductivity [mm s^{-1}] at supply pressure head [mm]				
Site	0	20	40	80	120
Cropland	0.0041	0.0062	0.0106	0.0156	0.0289
Grassland	0.0012	0.0016	0.0027	0.0039	0.0085

Using the results of the infiltrometer measurements, the effective water-conductive porosities were calculated (Figure 1). The water-conductive macroporosity was 0.044 vol.% for cropland and 0.010 vol.% for pasture. For the water-conductive meso-porosity, values of 0.073 (cropland) and 0.025 vol.% (pasture) were estimated. In contrast to the hydraulically active porosity, the total porosity relates to the water storage (Reynolds et al., 1995).

Based on the measured water retention curves, the total macro- and mesoporosities were calculated as the difference between the water content at 0 and 4 cm of pressure head, and at 4 and 12 cm pressure head. For cropland, the total macroporosity was 0.43 vol.%, the total mesoporosity 1.16 vol.%. The corresponding values for grasland were 0.21 and 0.50 vol.%.

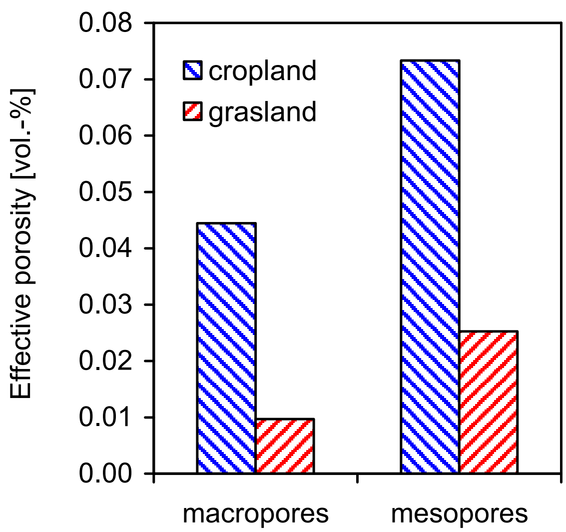

Figure 3: Effective porosity, calculated from the representative mean pore radius for two consecutive pressure heads of the Templeton sandy loam measured under different crop management. Macropores are defined as pores that drain at $|h_o| > 40$ mm, and mesopores as pores draining at $|h_o|$ between 40 and 120 mm.

Conclusions

Our study verifies that the crop and soil management practices have a large impact on soil hydraulic properties. The hydraulic conductivities as well as the amount of hydraulically active pores of the cropped topsoil were distinctly higher than those of the pasture topsoil. This may be mainly due to the loosening by tillage of the cropped soil some weeks before our measurements. Such soil operations are known to create a loose and fragmented, macropore-rich soil structure. The observed high infiltration rates under the cropped soil indicate that water flow took place between the aggregates rather than through the soil matrix. However, our measurements also show that this created soil structure is unstable. The observed decline in conductivity and effective porosity of the pasture soil compared to the cropped soil can be seen as a loss of aggregate stability due to cropping, resulting in collapse of inter-aggregate pores.

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