Influence of porosity and permeate suspended clay concentration on clay entrainment within a Red Ferrosol

A.M. Awedat[1], S.R. Raine[2], J.McL. Bennett[3], R.K. Misra[4]

1 National Centre for Engineering in Agriculture (P5 Blk), The University of Southern Queensland, Toowoomba QLD 4350; Awedat.musbahawedat@usq.edu.au
2 Faculty of Engineering and Surveying (Z Blk), The University of Southern Queensland, Toowoomba QLD 4350; steven.raine@usq.edu.au
3 National Centre for Engineering in Agriculture (P5 Blk), The University of Southern Queensland, Toowoomba QLD 4350; john.bennett@usq.edu.au
4 Faculty of Engineering and Surveying (Z Blk), The University of Southern Queensland, Toowoomba QLD 4350; rabi.misra@usq.edu.au

Abstract
Soil pore size is an essential factor affecting pore blockage and subsequently saturated hydraulic conductivity (K sat). In this study we examined the effect of soil bulk density on suspend clay movement in a Red Ferrosol soil. Water with varying suspended clay concentrations (0, 5, 10 and 20 g L^{-1}) was allowed to infiltrate cylindrical soil cores of a Red Ferrosol packed at two bulk densities (1.0 and 1.2 g cm^{-3}). The Ksat was measured at both bulk densities and at all suspension concentrations. The outflow suspension concentration was measured as a function of pore volumes of drainage ~ 10 pore volumes. Following measurement, 2-cm long portions of undisturbed, drained soil cores were sampled from the top and bottom to measure water retention. Soil with low bulk density (1.0 g cm^{-3}) allowed easier passage of suspended clay than the soil at high bulk density (1.2 g cm^{-3}), even at a high suspension concentration (20 g L^{-1}) with little occurrence of pore blockage. At both bulk densities, significant increases in water retention occurred near soil surface (top of soil core) than subsurface (bottom of soil core). This suggests that accumulation of clay sediment may have lead to pore blockage in the soil surface segments. .

Introduction
Soil macropores affect soil infiltration and saturated hydraulic conductivity (K sat), whereby a minor increase in soil bulk density (decrease in soil macropores) causes a major decrease in K sat by several orders. For example, Kim et al. (2010) studied the effect of compaction on soil macropores and related parameters, explained that 8 % increase in soil bulk density decreases saturated hydraulic conductivity by 69 % due to decreasing the number of macropores by 70 %. Subsequently, it could be expected that entrainment of dispersed clay would be increased. . In general the main soil fraction colloids are associated in soil aggregates due to the cohesive nature of colloids, but are released following aggregate degradation (Oades, 1993). The main causes of soil aggregate degradation can be summarised as slaking, swelling and dispersion. The impact of clay swelling and dispersion on pore blockage and K sat is wildly documented; however, there are few studies explaining the impact of changes in porosity on the transport of the clay colloids and subsequent accumulation within soil layers.

This study examines the effect of soil bulk density on suspended clay transport, colloid accumulation and the consequent effect on K sat in soil cores, using water containing varying amount of suspended clay.

Methods
To obtain a contrasting clay suspension, a soil with high clay content (Black Vertosol) was dried and sieved with 2 mm sieve. 130 g of this soil was transferred to a 500 cm^3 beaker with 400 cm^3 of tap water. Ultrasonic energy was applied to the suspension for 15 min to disperse soil aggregates. The beaker containing the suspension was allowed to cool and settling of large soil particles before being transferred to a 20 L plastic container. This procedure was repeated several times until an 18 litre clay suspension was obtained. Four subsamples (each 100 cm^3) of the suspension were dried in an oven at 105 $^{\circ}$C for 24 h to determine the clay suspension concentration (90 ± 4 g L^{-1}). This bulk suspension was diluted to prepare sufficient quantity of suspension of three different concentrations (5 ± 1, 10 ± 2.1, and 20 ± 3.7 g L^{-1}). The sediment concentration of these suspensions was measured in the same way as for the initial bulk suspension.

Sufficient quantity of a Red Ferrosol was collected from the top 15 cm depth from Agricultural Field Station Complex of the University of Southern Queensland, Toowoomba. This soil was air dried and sieved with a 2 mm sieve and mixed with tap water up to 1.2 times the plastic limit (Misra and Sivongxay, 2009) and was equilibrated overnight to reach stable water content. This moist soil was then packed into PVC tubes (8 cm height and 5 cm internal diameter) at 2 bulk densities (1.0 and 1.2 g cm^{-3}), using a method similar to that described by Misra and Li (1996). After packing, the lower ends of the cores were supported by cheesecloth and further 2 cm rings were attached to the top of the cores for water head application. Some essential properties of the soil are given in Table 1.

Table 1. Selected physical and chemical properties of the soil used.

Properties	Mean value ± SE
Clay %	44.1 ± 0.5
Silt %	25.5 ± 1
Sand %	30.4 ± 0.7
pH (soil-water ratio 1:5)	5.8 ± 0.05
EC (electrical conductivity, dS $^{m-}$1)	0.35 ± 0.001
Exchange sodium percentage (ESP; %)	3 ± 0.5
Cation Exchange Capacity (meq 100 g^{-1} soil)	26 ± 1

Saturated hydraulic conductivity measurement and leaching

K sat of the soil was measured using tap water (assumed sediment free) and varying clay suspension concentrations (5, 10 and 20 g L^{-1}) applied to the soil. Soil cores were packed at two different bulk densities of four replicates each; a total of 23 cores. The cores were supported and allowed to leach into plastic containers (400 cm^{-3}). Plastic bottles containing 1500 cm^3 of each suspension concentration were used for measuring the K sat of the soil at both bulk densities up to 10 pore volume of each core. A constant water head was maintained for each core at a pressure head of 1.5 ± 0.3 cm at the soil surface. The leachate was collected and weighed to determine K sat using Darcy's Equation, and was also measured for sediment outflow concentration. Clay concentrations were determined by taking 20 cm^3 of the out flow water of each pore volume measured and transferring this to heat resistant containers that were placed in the oven at 105 $^{\circ}$C for 24 h; weights were taken with an electronic balance (± 0.001 g). After drying, weights for each sample were used to calculate the sediment load.

Soil water retention and soil bulk density measurement

Undisturbed soil cores of bulk density 1 g cm^{-3} and 1.2 g cm^{-3} treated with tap water (0 g L^{-1}) and water with clay suspension concentrations. In this case 5 and 20 g L^{-1} were selected to determine clay suspension wffects on soil pores, due to blockage during K sat measurement. Known weight, aluminium, metal rings (3 cm height and 3 cm in diameter) were carefully inserted from the top and the base of selected cores, as shown in Fig. 1. The rings were then removed and supported with a piece of cheesecloth from below. The samples were saturated over a porous plate with tap water via capillary rise for 24 h. The weight of the ring before and after saturation was taken with an electronic balance (± 0.001). The samples were drained at -100, -200, -300 and -400 kpa water potential over 72 h. After the final water content was measured, the soil was removed from the rings and dried in the oven at 105 $^{\circ}$C for 24 h. The weight of dry soil and the volume of the metal rings were used to determine any changes in soil bulk density after treatment.

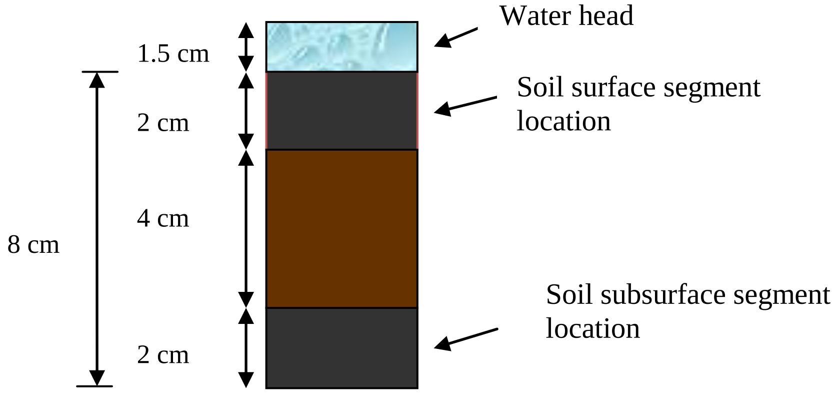

Fig. 1. A schematic diagram of soil cores showing the position of soil sampling rings used for soil water retention measurements.

Result and discussion

Hydraulic conductivity of the soil and sediment load in the out flow
Figure 2. Shows the variation in K sat for the soil cores packed at two bulk densities (1 and 1.2 g cm^{-3}) when Tap water and water with varying clay suspension concentrations (5, 10 and 20 g L^{-1}) are used.

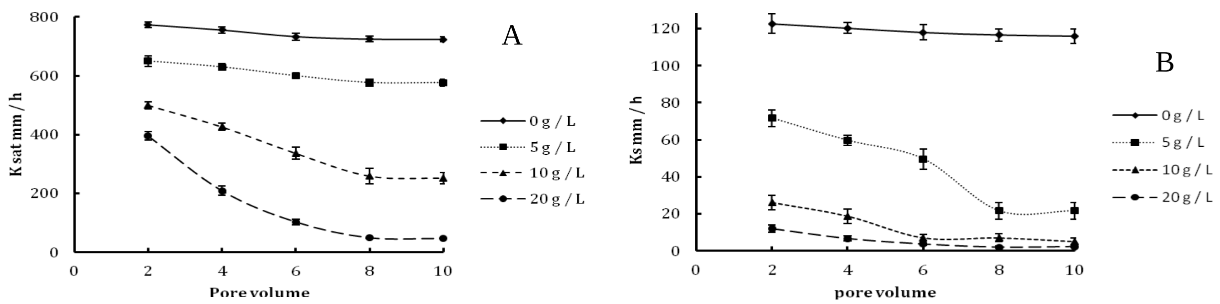

Fig. 2. Variation in K sat at + SE of three replicates with successive pore volumes of a Ferrosol packed at A) 1 and B) 1.2 g cm^{-3} when varying clay suspension concentrations were applied.

When tap water was used; the K sat of the soil packed at bulk density 1 g cm^{-3} (Fig. 2 A) reached steady state after 6 pore volume at a value of 700 mm h^{-1}, while this value decreased significantly, almost 7 times, when the same water was applied to the soil packed at 1.2 g cm^{-3} (Fig. 2B.). Also when a clay sediment concentration of 20 g L^{-1} was applied to the soil packed at lowest bulk density (1 g cm^{-3}), the K sat was approximately 46 mm h^{-1}, while this value was observed to approach 0 mm h^{-1} where bulk density was 1.2 g cm^{-3}. Temporal changes in sediment concentration in the drainage water were measured during K sat measurement to indicate if the out flow sediment load related to the sediment concentration in inflow water (Fig. 3.) There was a slight decreasing trend in

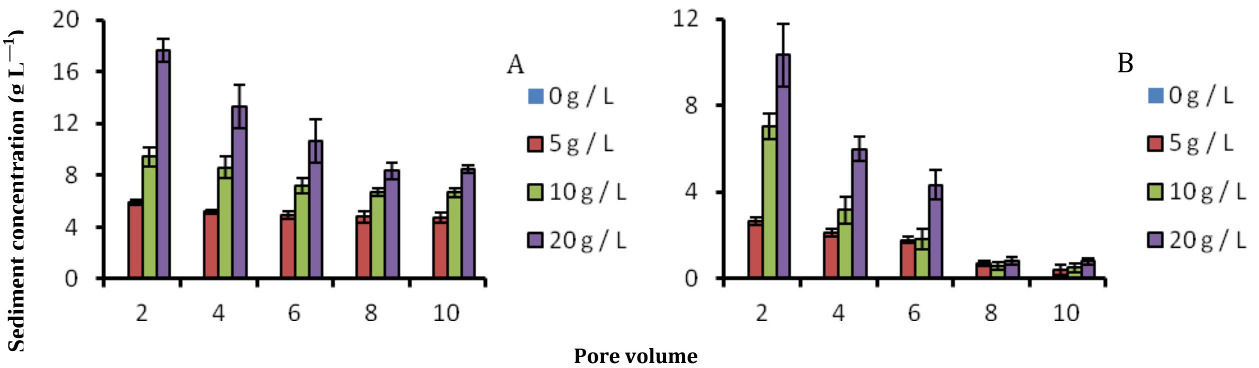

Fig. 3. Variation in sediment concentration in out flow of a Ferrosol packed at (1 and 1.2 g cm^{-3}) when clay suspension of varying concentrations were applied with successive pore volume.

sediment concentration with pore volume when clay suspension of 5 g L^{-1} was applied to the the low bulk density soil cores (Fig. 3A.). However, the changes in outflow sediment concentration were significant where 10 and 20 g L^{-1} clay suspensions were applied. The greatest change insediment load occurred in the 20 g L^{-1} clay suspension treatment, where a reduction from 17 g L^{-1} at pore volume 2 to 8 g L^{-1} at pore volume 10 was observed (Fig. 3A.). While some decrease was observed for all pore volumes, all clay suspensions appear to be approaching an asymptote for the low bulk density. However, by increasing bulk density to 1.2 g cm^{-3}, sediment was shown to become entrained within the soil cores, with all leachate clay suspension concentrations less than 1 g L^{-1}, irrespective of the permeate clay concentration.

Soil water retention
The soil surface segments of the 1.2 g cm^{-3} compacted soil (Fig. 4B1) retained more water than that of the low density soil (1 g cm^{-3}) at all potentials (Fig. 4A1), especially when the soil was treated with high concentration clay suspension. Increased water retention with increased bulk density could be expected due to increased clay content, a finer pore network, and increased matric potential. Fig. 4 A1 and B1 demonstrate that at the lower bulk density clay suspension concentration has more control over clay entrainment than at the higher bulk density. Hence, as poresity decreases, lower clay concentrations have an increased likelihood of becoming entrained. Interestingly, for both bulk densities the suspension concentration had no meaningful

effect on water retention in soil subsurface segments (1 and 1.2 g cm^{-3}) Fig. 4A2 and 4B2 respectively, which suggests that pore blockage occurs on the top surface.

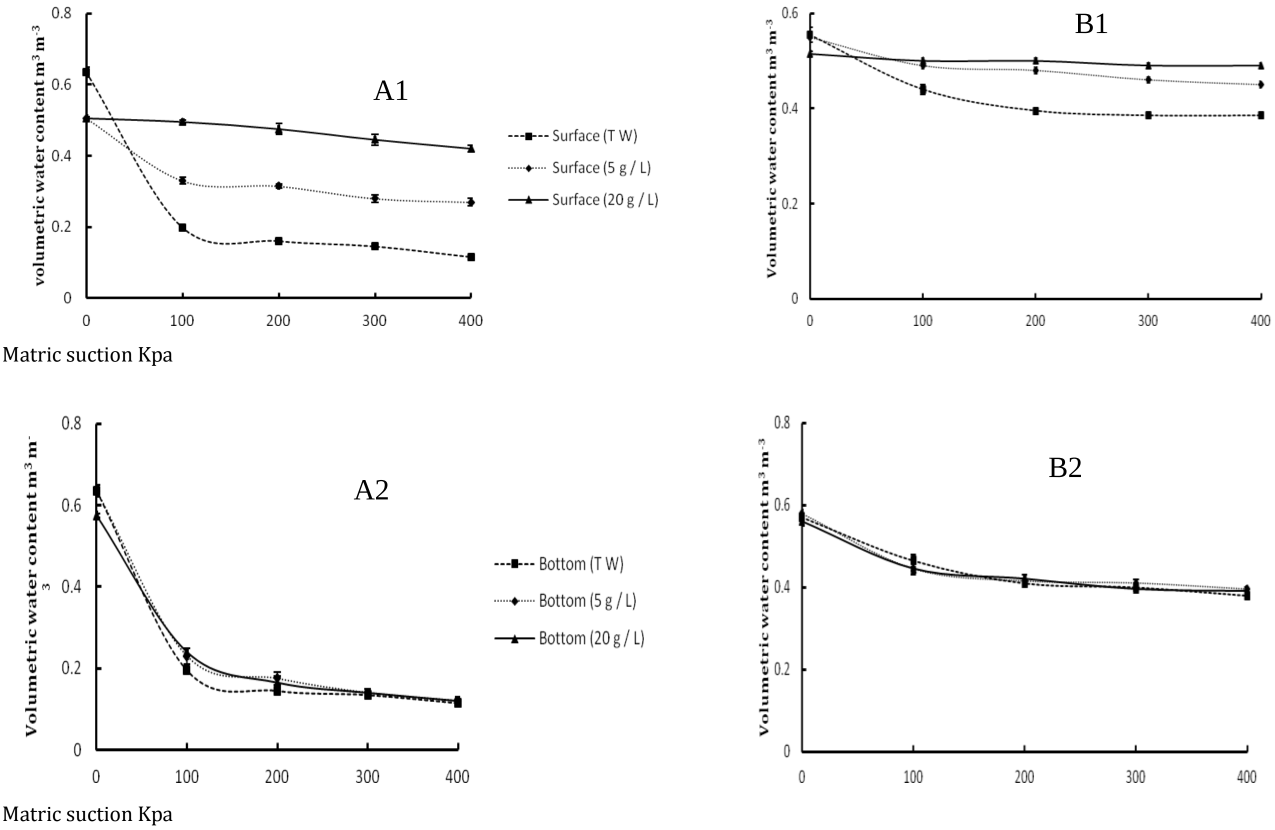

Fig. 4. Changes in volumetric water content + SE of the Ferrosol of 1 and 1.2 g cm^{-3} bulk density as a function of matric suction of surface and subsurface soil layers.

Conclusion

The result of our experiment on using clay suspension to irrigate soils with different porosity indicates that pore size has a considerable impact on dispersed clay movement within the soil. When the bulk density of the soil is decreased to provide large pores, the movement of the suspension through the soil cores was greater and the soil was able to percolate higher dispersed clay content. Increasing the bulk density of the soil crreates a finer soil pore network causing clay to become more readily entrained within soil layers. Importantly, soil water retention measurements show that the pore blockage takes place within close proximity to the soil surface, which identifies that dispersed clay is likely to become entrained in close proximity to its dispersal/infiltration point.

References

Kim HM, Anderson SH, Motavalli PP, Gantzer CJ (2010) Compaction effects on soil macropores geometry and related parameters for an arable field. *Geoderma* **160,** 244-251.

Misra RK, Sivongxay A (2009) Ruse of laundry grey water as affected by it interaction with saturated soil. *Journal of hydrology* **336,** 55-61.

Misra RK, Li FD (1996) The effect of radial soil confinement and probe diameter on penetrometers resistance. *Soil Tillage Research* **38**, 59-69

Oades JM (1993) The role of biology in the formation, stabilisation and degradation of soil structure. *Geoderma* **56,** 377-400.