

EXECUTIVE SUMMARY

BACKGROUND AND MOTIVATION

One of the requirements for improved management of irrigation systems is the knowledge of the amount of irrigation water that can be applied before runoff takes place. This amount, which determines the volume of water that can be efficiently applied, is determined mainly by the application rate and the infiltration capacity of the soil. If the infiltration characteristics of a soil are known beforehand, the hydraulic and mechanical attributes of irrigation systems can mostly be modified accordingly during the system design phase. It is, therefore, important to gain a better understanding of the factors which control soil infiltration characteristics. The infiltration capacity of soil is largely determined by the combined effects of temporal soil surface conditions, i.e. the degree of sealing and compaction, and permanent soil characteristics such as texture and clay mineralogy.

Soil surface characteristics are very dynamic. It is normal for a surface seal or crust to form as a result of a combination of mechanical and/or chemical factors under the impact of water drops. The nature of this crust is modified by characteristics of the water and/or soil.

Variations in water quality (as measured by the electric conductivity and sodium adsorption ratio), and the water application rate and drop size, in combination with varying soil characteristics, thus give rise to a large range of infiltration capacities. While much is already known about the effect these factors have on crust formation on recently cultivated (unsealed) soils, much less is known about the effect cyclic irrigation has on soils which have already been sealed by previous irrigations - as is evident in practice.

This project was motivated by the need to identify the effect which the interaction between soil and water characteristics has on soil surface sealing during cyclic irrigation conditions and to quantify the effect, if possible.

AIM

The aims of the project proposal to the WRC were as follows:

- i. Determine whether surface seals which form on soils varying in exchangeable sodium percentage (ESP) and/or clay mineralogy, remain stable or break down during successive irrigation cycles.
- ii. Since most of the previous studies regarding soil sealing were conducted on unsealed soils, this project aimed to determine the degree to which the findings of these earlier studies would be transferable to soils which have already been sealed.
- iii. Formulate recommendations regarding the modification of existing irrigation systems and the design of new ones by considering soil infiltration capacity, thereby improving water use efficiency.
- iv. Determine the effect that a variation in irrigation water quality has on seal and crust formation under cyclic irrigation.
- v. Determine whether or not different irrigation application rates affect the infiltration rate of soils with existing crusts.

MATERIALS AND METHODOLOGY

Soils of similar texture, covering a range of clay mineral composition, were selected and subjected to simulated irrigation applications at different rates. A range of ESP's was induced on the selected soils and it was determined what the effect this and different water qualities had on the infiltration rate. Cumulative infiltration (CUMINF), after a given time period, was used as a measure of crust formation.

Soils properties

- Eight different soils were selected to cover a range of clay mineral composition within a narrow texture range. The symbols used to distinguish soils and their clay mineral properties are as follows:

- LK4: Kaolinite is the dominant clay mineral with illite and talc as subordinate clay minerals.
- LK5: Pirofillite is the dominant clay mineral with kaolinite and illite as subordinate minerals.
- LK6: Kaolinite is the dominant clay mineral, with illite and smectite as subdominant minerals.
- TB: Kaolinite is the dominant clay mineral, with abundant illite and some smectite.
- TD: Smectite is the dominant clay mineral, with kaolinite subdominant and some illite.
- FR: Illite is the dominant clay mineral, with subdominant kaolinite and some smectite and interstratified clay minerals.
- VK: Illite is the dominant clay mineral with subdominant kaolinite and smectite.
- WG: Kaolinite is the dominant clay mineral with abundant illite and manganese oxides.

- The texture of the soils used in the study varied between sandy clay loam and sandy loam with a clay content of between 16 and 26 percent.
- The ESP of the soils was adjusted to values of 1, 2, 5, 10 and 15, by leaching with an aqueous solution having a sodium adsorption ratio (SAR) equivalent to the desired ESP.

Water quality

The electrical conductivity (EC) of the water used to simulate irrigation water in the experiments was as follows:

- water adjusted to a desired SAR: 15 mS m⁻¹,
- rain water: 7 mS m⁻¹,
- municipal water: 69 mS m⁻¹,

Irrigation simulation

A mobile field irrigation simulator was used in the initial stages of the investigation. Practical problems which were experienced, such as damage to field plots between irrigation events, necessitated that a laboratory type rain simulator be used for the remainder of the investigation. The laboratory irrigation simulator was previously used with great success in studies to determine crust formation on unsealed soils.

Three different application rates were evaluated, viz. 30, 60 and 90 mm h⁻¹.

RESULTS

Clay mineralogy

Kaolinite dominated soils which contain no smectite, were found to be chemically stable. A modest decrease in CUMINF which was observed from one irrigation application to the next, was ascribed to mechanical sealing caused by the impact of drops. From the first to the sixth irrigation cycle, CUMINF decreased between 16 and 25% respectively for soils with an ESP of 1 and 15. Where low concentrations of smectite were present in kaolinitic soils, it contributed to chemical sealing and, consequently, gave rise to a decrease in CUMINF. Where iron- and manganese oxides were present in kaolinitic soils, these were also associated with a decrease in CUMINF.

Illitic soils were found to be more dispersive than kaolinitic soils and also displayed a larger decrease in CUMINF with increases in ESP. This implies that the chemical breakdown of aggregates contributes to sealing. The decrease in CUMINF from the first to the sixth cycle was 17% for an ESP of 1 compared to 36% for an ESP of 15. While the effect of the irrigation cycle was similar to that of kaolinitic soils for low soil ESP values, sealing increased markedly at higher ESP values compared to kaolinitic soils. Low concentrations of smectite in illitic soils did not contribute much to increased sealing. A possible explanation is that these soils formed small cracks during the drying out phase, which caused the seals to partially separate and lift from the soil below.

Smectite dominant soils displayed poor aggregate stability. This is mainly ascribed to the swelling potential which causes the aggregates to quench immediately after wetting. On the other hand, the shrinking characteristic of smectite rich soils caused the seal to partially break up during the drying out phase. As a result the decline in CUMINF is not as pronounced from one cycle to the next as is the case with illitic or

kaolinitic soil. At an ESP level of 1 the CUMINF declined by approximately 11% from the first to the sixth cycle, which is notably lower than the decrease found for kaolinitic and illitic soils. However, at an ESP of 15 the decline was 52%, which is much more than the corresponding decrease for the other two soils. This decrease can be ascribed to a much stronger dispersion effect at the higher ESP level, which strongly influences sealing in mainly the sub-surface layer.

Different to the other clay minerals, **pirofillite** dominated soils were found to display an increase in CUMINF with a small increase in ESP, e.g. from 1 to 5. However, further increases in ESP caused a decline of CUMINF, as found with other clay minerals. This anomalous behaviour can be ascribed to the relatively neutral electrical charge of pirofillite and the consequent low binding force which enables erosion of the crust as it is being formed. The sub-dominant illite which is present in the soil is suspected to contribute to the decrease in CUMINF at high ESP levels where illite is chemically less stable. The decrease of CUMINF for the individual ESP levels from the first to the sixth cycle was very similar, which can be explained by a very low or no chemical effect on sealing.

Water Quality (EC and SAR)

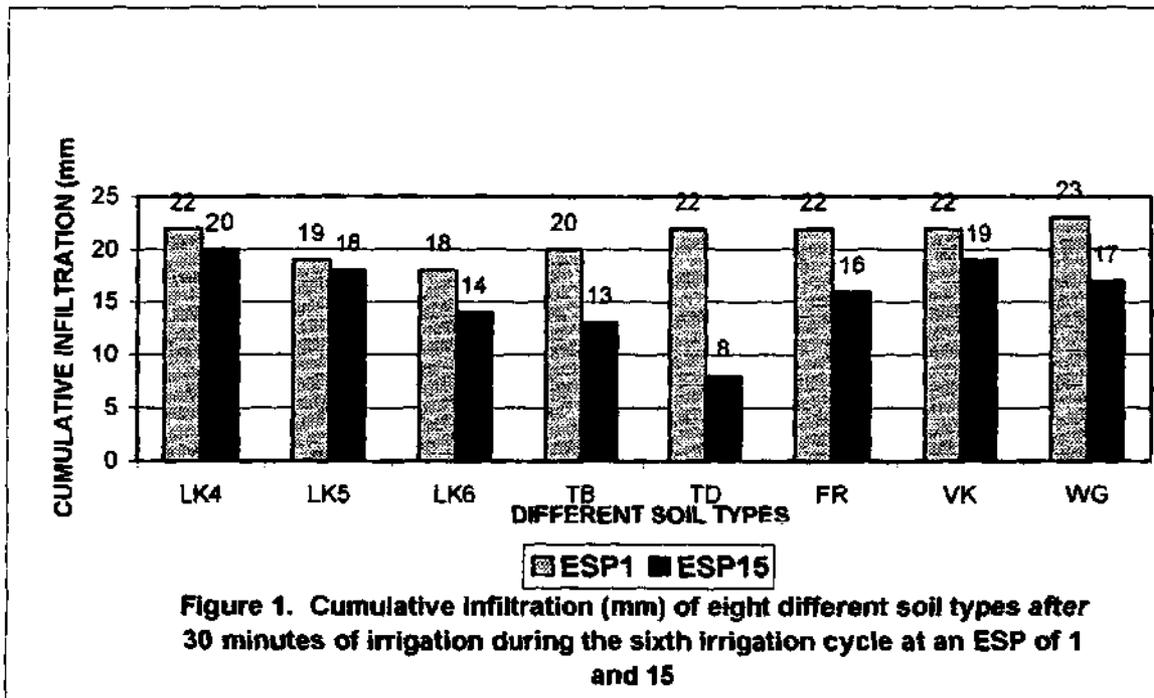
Kaolinite dominated soils were found to be responsive to low ECs. Low ECs gave rise to a reduction in flocculation, which in turn, gave rise to increased sealing and a reduction in CUMINF. As EC increased, the CUMINF improved due to the increase in flocculation. The trend was the same with smectite present in a kaolinite dominated soil. In this case, the relative decrease in CUMINF from the first to the sixth cycle was, however, more pronounced.

Smectite dominated soils were found to be sensitive to the SAR of irrigation water, while the electrolyte concentration played a lesser role in the stabilisation of the aggregates. It appears that the ESP level of these soils have a stronger influence than electrolyte concentration. It is deemed possible that a combination of a very low EC water in combination with a high soil ESP would display such strong dispersive characteristics that the soil will easily erode. Under these conditions the soil will be continuously eroded as it is formed, giving rise to improved CUMINF.

Illitic soils reacted similarly to kaolinitic soils to the effects of EC and sodium up to an ESP threshold of approximately 10. Above an ESP of 10 CUMINF decreased drastically, which was not the case for kaolinitic soils.

The CUMINF of the eight soils at ESP values of 1 and 15 after a 30 minute application, during the sixth irrigation cycle, is presented in Figure 1. It is evident that the kaolinitic soils (LK4, LK6 and WG) were not very prone to increasing ESP. The smectitic soil (TD) was more prone to increases in ESP and formed a stable seal. The response of the illitic soils (FR and VK) were intermediate between those of kaolinite and smectite. The pirofillitic soil (LK5) was not sensitive to ESP increases and the CUMINF was practically the same for both low and high ESP values.

In summary, kaolinitic soils were found not to be very sensitive to any change in water quality; smectitic soils were more sensitive to increases in SAR-values than to low EC values; and illitic soils reacted very similar to kaolinitic soils, except at ESP levels above 10, where there was a sharp decline in the CUMINF.



Application Rate

Figure 2 shows the percentage decrease in CUMINF between the first and sixth irrigation cycle at three application rates for three soils (LK4 is kaolinitic, TD is smectitic and FR is illitic) with an ESP of 15. At 30 and 90 mm h⁻¹, the decrease is highest for the illitic soil, while the decrease at 60mm h⁻¹ is most for the smectitic soil.

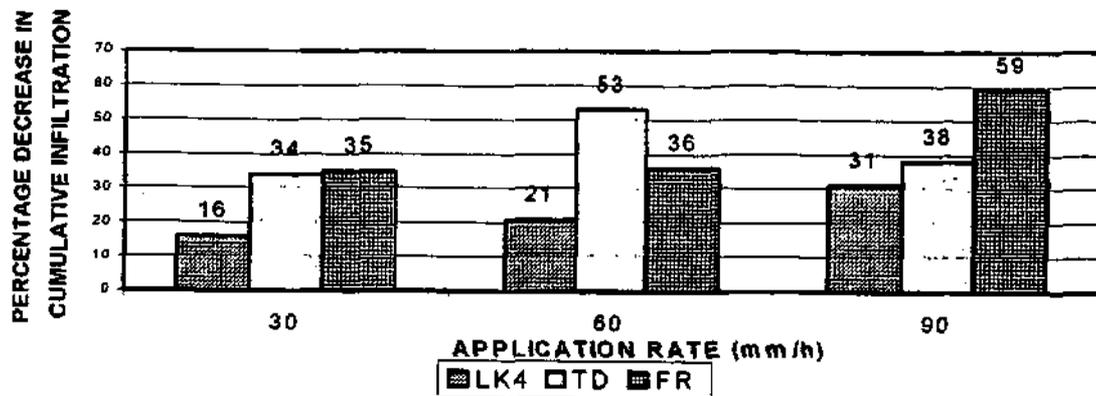


Figure 2. Percentage decrease in cumulative infiltration of three soil types from the first to the sixth irrigation cycle at different application rates at an ESP of 15. (LK 4 is kaolinitic, TD is smectitic and FR is illitic)

Exchangeable Sodium Percentage (ESP)

Regression equations were derived which relate CUMINF (after 30 min) after six irrigation cycles to the ESP of soils representative of the four clay mineral types (LK4 is kaolinitic, LK5 is pirofillitic, FR is illitic and TD is smectitic).

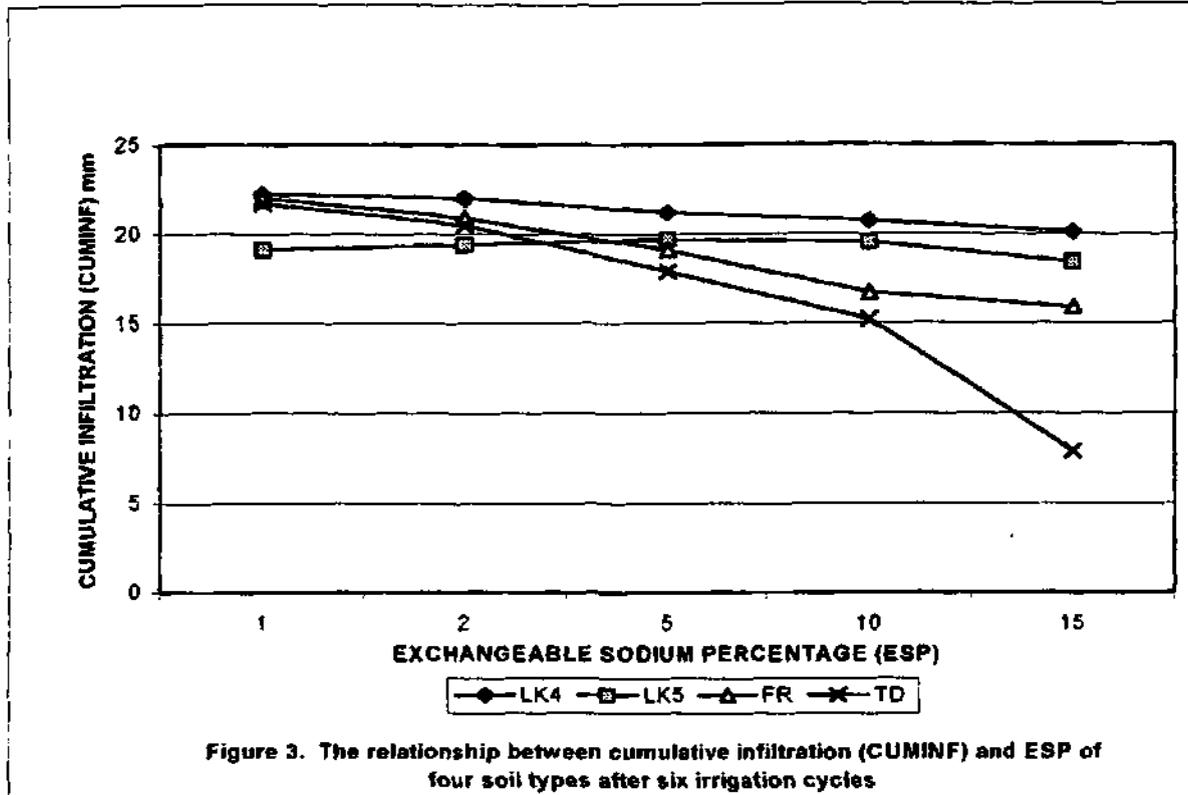
$$\text{CUMINF (LK4)} = 22.4 - 0.243 \text{ ESP} - 0.006 \text{ ESP}^2$$

$$\text{CUMINF (LK5)} = 18.9 - 0.273 \text{ ESP} - 0.02 \text{ ESP}^2$$

$$\text{CUMINF (FR)} = 23.5 - 1.068 \text{ ESP} + 0.038 \text{ ESP}^2$$

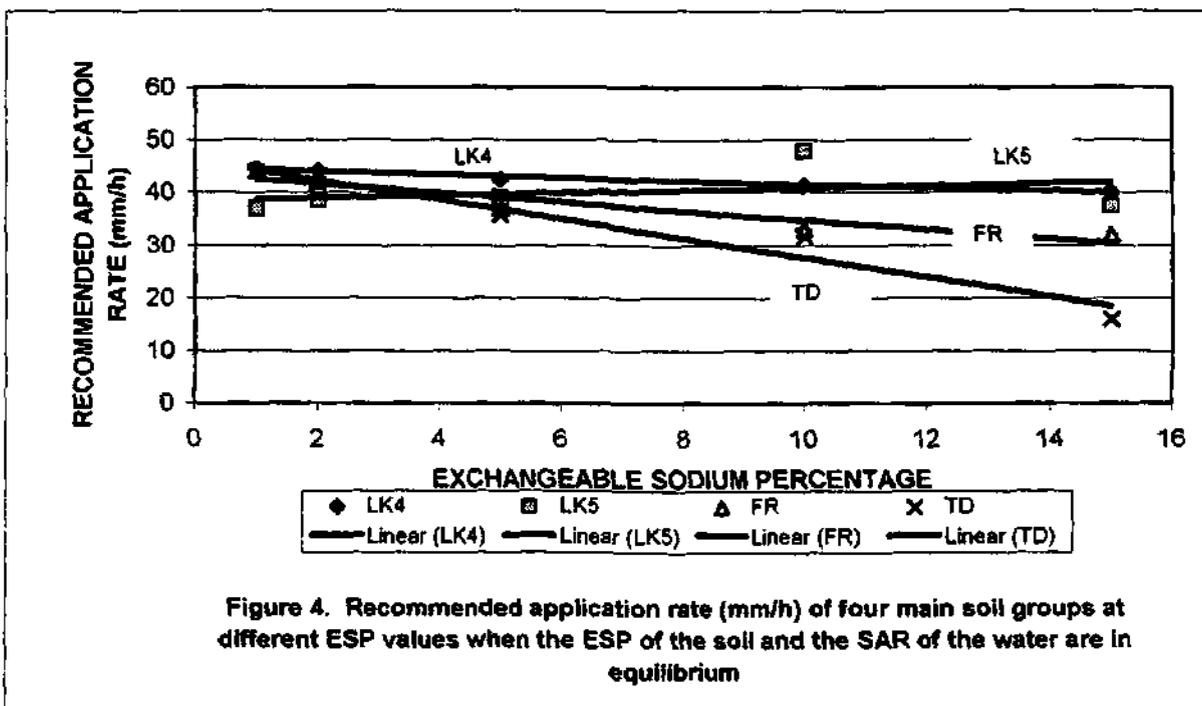
$$\text{CUMINF (TD)} = 21.6 - 0.397 \text{ ESP} - 0.033 \text{ ESP}^2$$

These relationships are also presented in Figure 3.



Recommended application rate

Figure 4 shows the recommended application rate for the four main soil groups at different ESP values when the ESP of the soil and the SAR of the water are in equilibrium. The linear regression relationships between acceptable infiltration rate (for a one hour application) and soil ESP, are proposed as guidelines for irrigators.



RECOMMENDATIONS FOR FURTHER RESEARCH

The laboratory type simulations should be verified in the field using real irrigation systems.

Smectitic soils with crust forming potential should be evaluated.

The infiltration characteristics of manganese rich soils should be further investigated.

The influence of certain soil chemical properties such as magnesium as the dominant cation, high phosphorus values, a variation in CEC and base status and lime rich soils should also be evaluated.

The infiltration characteristics of soils with a higher clay content should be evaluated.

An irrigation simulator with a variety of drop sizes similar to those of overhead systems should be developed and tested.

The number of irrigation cycles should be extended to 20 from the 6 or 8 which were used in this project.

A larger variety in slopes should also be evaluated to determine the interaction between slope and clay minerals on infiltration characteristics.