Criteria for adaptation of the design and management of centre-pivot irrigation systems to the infiltrability of soils

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Abstract

A selection of 45 topsoils from various localities throughout South Africa was subjected to laboratory-scale irrigation simulations at 4 droplet kinetic energy levels. For each soil, a maximum allowable kinetic energy was determined for design applications of 15,20 and 25 mm without causing ponding. After the soils were grouped as:

- chemically dispersive;
- chemically stable with minor presence of smectite; and
- chemically stable without any smectite,

the maximum allowable kinetic energy correlated reasonably well with the clay content of each group. Relationships between energy flux (design), design application (management) and clay content for the different groups were quantified. These relationships can be used to adapt design and management of irrigation systems, so that applications can be made without ponding or runoff.

Introduction

Due to the dramatic rise in energy costs and increasing competition for water resources by urban users it has become essential to ensure maximum water-use efficiency in irrigation systems. To accomplish this, irrigation systems should be designed and managed so that the application rate of water does not exceed the infiltrability of the soil. If this is not accomplished it will cause the following adverse effects:

- Excessive evaporation of ponded water
- Inefficient water use and sub-optimal crop production (Stern et al., 1992)
- Soil erosion
- Pollution of dams and rivers with agricultural chemicals.

The infiltrability of soils decreases with progressive infiltration due to a decrease in matric suction gradient (Hillel, 1980), but may also decrease due to the formation of a surface seal (Mclntyre, 1958). In cultivated soils the infiltrability is often controlled by the formation of a surface seal (Moore and Larson, 1979 ; Morin et al., 1989 ; Bloem, 1992).

Many studies have investigated the effect of soil surface-applied amendments on infiltration (Ben-Hur and Letey, 1989; Shainberg et al., 1990; Smith et al., 1990: Stern et al., 1992). However, the application of some of the ameliorants might not be cost-effective and when incorporated in the soil could cause plant nutrient imbalances. Even where the application of ameliorants is wise, there are nevertheless limits to the improvement in infiltration that can be achieved. The objective of this study was to determine how irrigation systems should be designed and managed within the constraints of limited soil infiltrability.

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Materials and methods

Samples collected from the upper layer (0 to 200 mm) of 45 soils throughout the Republic of South Africa were used in this study. The soil samples were air-dried and sieved through a 4-mm sieve. Some of the physical and chemical properties of these soils are given in Table 1. The clay mineralogical composition was determined by X-ray diffraction using a Co Kα radiation with a graphite monochromator.

A modified model of the drip-type laboratory-scale irrigation simulator described by Bubenzer and Jones (1971) was used in this study. Droplets were generated by 800 hypodermic needles which provided a known and constant drop diameter. The needles were arranged at a spacing of 40 x 40 mm on a 1.3 x 1.0 m closed water chamber which could be placed at variable height above the soil samples. A more detailed description of the simulator was given by Bloem et al. (1992).

In this study the average drop diameter was kept constant at 3.0 mm. It was calculated by measuring the average mass of a number of drops, that were assumed to be spherical in shape. Four levels of droplet kinetic energy (KE) (2.60; 8.07; 14.70 and 19.28 J-mnr'nr^2) were simulated by adjusting the falling heigts of the droplets to 0.3; 1.0; 2.0 and 3.0 m respectively. The impact velocities of the drops and the KE for different heights were calculated (Epema and Riezebos, 1983). The application rate was 60 mmh-^{1} and a total application of 90 mm was made. This application rate was chosen after an investigation by Liengme and Johnston (1991) found that the maximum application rate of centre-pivot irrigation systems varied between 17 and 84 mmh-'.

The sieved soil samples were packed (20 mm deep) into 50 mm deep, 272 x 221 mm soil trays over a 30 mm layer of coarse sand. The frame that supported 8 trays, was oscillated horizontally during the irrigation application to achieve an even distribution of droplets over the soil surface. The packed soil was saturated with water with an electrical conductivity (EC) of 70 mS-m-' from below. Following the saturation, the excess water was allowed to drain and then the trays were placed in the irrigation simulator at a 9% slope and irrigated with water with an EC of 70 mS-m-^{1}. Each measurement was replicated 3 times.