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Application efficiencies and furrow infiltration functions of irrigations in sugar cane in the Ord River Irrigation Area of North Western Australia and the scope for improvement

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ABSTRACT

The introduction of irrigation in the Ord River Irrigation Area (ORIA) in the North West of Western Australia resulted in rising water tables in many parts of the ORIA. Commercial sugar cane production commenced in 1995 in the area, which exacerbated the problem caused by the longer growing and irrigation season and the large irrigation applications. Rising water tables are associated with deep drainage from paddocks and irrigation infrastructure. Improving the irrigation application efficiency (IAE) was identified as a manageable objective for sugar cane growers that is expected to reduce deep drainage. Existing irrigation practices were monitored and a surface irrigation model (SIRMOD) was used to simulate these irrigations. The lack of accurate infiltration parameters normally limits the extrapolation of SIRMOD simulation results to different irrigation scenarios. It was found that the infiltration into the Vertisols of the ORIA could be properly described by simple infiltration functions which were dependent on the soil moisture deficit (SMD) at irrigation as well as the shape of the irrigation furrow. The function described as Instantaneous Crack Fill (ICF) was appropriate for furrows with broad-based 'U'-shaped furrows while a non-ICF described the infiltration behaviour of deeper 'V'-shaped furrows. Summary tables were generated to illustrate the relationship between SMD, inflow rate, furrow length and irrigation duration for 'U'-shape and 'V'-shape furrows of Vertosols in the ORIA. From the tables it was determined that gains of up to 20% can be achieved in the IAE compared to the current situation.

1. Introduction

The management of rising ground water levels in the Ord River Irrigation Area (ORIA) in the North West of Western Australia is essential to ensure the sustainability of the irrigated agriculture in the region. McGowan (1987) concluded that the hydrological conditions in the certain parts of the ORIA had changed in response to irrigation that had taken place since 1964. Laws (1991) found that water levels were rising at between 20 and 50 cm/year over most of the ORIA with groundwater at less than 3 m from the surface in one localised area. Laws (1991) also concluded that the groundwater levels had not stabilised and that serious land degradation through waterlogging and salinity would occur if they continued to rise unchecked. The issue became more pressing with the changes in land-use in the ORIA with the introduction of sugar cane as a long season crop following the construction of a sugar mill in 1995 (Wood et al., 1998). Prior to that period short season

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horticultural crops were the dominant crops even though sugar cane was grown in the area for only a brief period in the early 1960s.

Rising water tables are caused by deep drainage losses in irrigated fields and/or the irrigation infrastructure. Various workers, Rose et al. (1979), Gordon and Gardner (1997), Kinhill (1999) and Banyard (1983) calculated a range of deep drainage fluxes varying from a negative flux (Rose et al., 1979) to 119 mm/year (Kinhill, 1999) under irrigated sugar cane and in the deep drains and supply channels of the irrigation infrastructure of 19–33 mm/year (Banyard, 1993).

The deep drainage losses are influenced by many factors. Some, such as restricting the irrigation opportunity time and the tail drain outflow would probably reduce the deep drainage losses in the field and the tail drain, respectively. Such factors can be fine tuned by improving the irrigation application efficiency (IAE), which is defined as the ratio of the water taken up by the crop and water applied to the field (Fairweather et al., 2003). In this context it is assumed that maximising the IAE would reduce deep drainage losses.

Beside the threat of rising water tables, issues regarding the total water consumption have gained prominence in the ORIA due to changes in the pricing structure of irrigation water as well as the restrictions on irrigation water allocations. Improvements in the IAE usually lead to a reduction in volume of water used hence improving the economic returns.

Bos (1979) reported a range of IAE of 60–90% for surface irrigation on clay soils. Wood et al. (1998) documented a range of IAE of 60–75% based on a survey conducted amongst sugar cane growers of the ORIA in 1996 and 1997. This would suggest some scope to improve the IAE. The survey highlighted the need to quantify the IAE on farm because growers estimated the IAE based on a metered inflow into the irrigation paddocks, an estimated duration of outflow with little knowledge of the moisture stored in the soil.

The magnitude of the IAE improvement can be assessed with computer simulations of irrigations using a surface irrigation model, SIRMOD (Walker, 1993). This model has been tested both overseas (Elliot and Walker, 1982; Walker and Skogerboe, 1987) and in Australia (Raine and Bakker, 1996; Esfandiari and Maheshwari, 2001) and Smith et al. (2005).

This paper firstly presents a range of IAE's of actual monitored irrigations. Information collected during those irrigations was used to develop furrow infiltration functions needed for the computer simulations of the monitored irrigations. Secondly, simulation results are presented using a general modelling approach assuming only a limited knowledge of the furrow infiltration functions. Thirdly, matrices of IAE developed with the simulations are presented for a range of inflow rates, furrow lengths and irrigation durations to assess the scope and the range of possible improvements in the IAE of irrigations in sugar cane.

2. Material and methods

2.1. *Area, climate and soils*

The ORIA is located in the North West of Western Australia near the township of Kununurra and Lake Argyle. The lake and a diversion dam in the Ord River ensures a regulated supply of water to the irrigation area which is delivered under gravity through a network of channels. Presently about 11,700 ha is under irrigation of which 3800 ha is dedicated to the growing of sugar cane, 1700 ha to pasture crops and the rest to the wide range of horticultural crops. An extension of the area under irrigation with another 44,000 ha is still being considered (Kinhill, 1999).

The area has a semi-arid tropical climate with a pronounced short hot wet season and a warm extended dry season. Annual evaporation exceeds rainfall, on average, by more than 2200 mm and commercial crop production is only possible with full irrigation (Muchow and Keating, 1998).

The two main soil types in the ORIA are: a brownish cracking clay soil with finely structured high pH top soils and a greyish cracking clay soil with relatively coarsely structured almost neutral pH top soils (Aldrick et al., 1990). Both would be classified as self-mulching Vertosols (Isbell, 1996). The infiltration behaviour of cracking clays is unique in a sense that when dry, the infiltration rate is initially very high but diminishes rapidly when becoming saturated to a point the infiltration rate has become negligible (Smedema, 1984; Mitchell and Van Genuchten, 1993; Austin and Perdergast, 1997; Gilfedder et al., 2000). The degree of cracking or crack volume depends on the moisture status of the soil while the crack geometry and patterns depend on the lateral distribution of the moisture extraction (Swartz, 1966; Mitchell and Van Genuchten, 1993).

2.2. *Flow measurements and field lay-out*

Water was applied to the upper end of the furrows (inflow) through syphons from a head ditch. Water leaving the furrow at the bottom end of the furrow (outflow) was discharged in a wide shallow tail drain, which in turn discharged in another drain as part of the drainage system of the ORIA. Inflow and outflow were gauged in a number of furrows simultaneously by means of paddle-wheel flow meters connected to a datalogger. The flow meters were housed in PVC pipes and installed in blocked furrows prior to irrigation. Each flow meter and pipe combination was individually calibrated.

The furrow spacing ranged from 1.6 to 1.8 m while the furrow lengths ranged from 200 to 1200 m. Furrow slope ranged from 0.066% to 0.11% while the shape of the furrows varied from a deep 'V'-shape to a shallow broad 'U'-shape.

2.3. *Soil moisture*

Changes in soil moisture content following an irrigation or the soil moisture deficit (SMD) were obtained from measurements with a neutron moisture meter probe (NP) (Greacen, 1981) at a depth of 20, 30, 40, 50 and 60 cm and then at 80, 100 and 120 cm. Prior to the NP measurements a standard count was obtained in a drum filled with water following the procedure according to Greacen (1981). The counts of the NP were divided by the standard count and the ratio related to a moisture content using calibration curves for these soils obtained from extensive soil sampling (Plunkett and Muchow, 2003). The surface soil (0–20 cm) of the beds was sampled manually before and after the irrigations to obtain the change in the