Abstract Improving irrigation efficiency is of primary importance in arid and semi-arid regions of the world as a consequence of increasing incidences of soil and water salinisation. In the cotton-growing regions of Australia salinisation is generally a result of inefficient irrigation practices, which lead to excessive deep drainage (DD). There is therefore the need to apply a relatively inexpensive approach to assessing where inefficiencies occur and make prediction of suitability of existing and new water storage sites. However, physical methods of measuring DD, such as flux meters and lysimeters, are time-consuming and site-specific. In this paper we apply a rapid method for determining the spatial distribution of soil in an irrigated cotton field in the lower Gwydir valley. First, ECa data (using EM38 and EM31) were used to determine a soil-sampling scheme for determining soil information such as clay content and exchangeable cations to a depth of 1.2 m. The soil data and water quality information were input into the SaLF (salt and leaching fraction) model to estimate DD rate (mm/year). In developing the relationship between ECa and estimated DD, three exponential models (two-, three- and four-parameter) were compared and evaluated using the Aikakie information criteria (AIC). The three-parameter exponential model was found to be best and was used for further analysis. Using the geostatistical approach of multiple indicator kriging (MIK), maps of conditional probability of DD exceeding a critical cut-off value (i.e. 50, 75, 100 mm) were produced for various rates of irrigation \( I = 300, 600, 1,200 \) and \( 1,500 \) mm/year. The areas of highest risk were consistent with where water-use efficiency was problematic and thus leading to the creation of perched water tables. The advantage of this approach is that it is quick and is applicable to situations where efficient use of water is required. The results can be used for irrigation planning, particularly in the location of large irrigation infrastructure such as water reservoirs.

Introduction

The arid and semi-arid regions of the world are being called upon to meet the increase in demand for agricultural products. This is being facilitated by dependence on irrigation. However, irrigation practices are often inefficient, leading to water loss through deep drainage (DD). Consequently, problems with perched water tables are often the result. In the irrigated cotton-growing regions of southeastern Queensland and northwestern New South Wales, irrigation efficiency is increasingly becoming an important natural resource management issue. This is because of the number of instances where shallow perched water tables, caused by excessive DD, are creating problems leading to waterlogging and, in isolated cases, are causing soil salinisation (Willis et al. 1997; Triantafilis et al. 2002).

Several techniques exist which are used for measuring DD. These include direct physical methods such as soil water flux meters (Cary 1970; Dirksen 1974; Kawanishi 1983), lysimetry (Gee et al. 1994; Young et al. 1996) and environmental tracers (Cook and Herczeg 1998). Despite their relative accuracy, the major disadvantages of these methods are that they are time-consuming (Gee and Hillel 1988) and site-specific. Therefore they do not account for the spatial variability of soil hydraulic properties, and hence DD. As reported by Rice et al. (1986) and Johnston (1987), the rate of DD can change considerably within a few metres in an irrigated field due to the spatial and temporal variation of soil properties, non-uniform water application and variable quality of applied water.
What is required is a relatively cheap and efficient technique for delineating the spatial variability of soil properties that directly influence the hydraulic characteristics, and hence DD, of a field soil. One method of rapidly measuring soil attributes, is non-contacting electromagnetic (EM) induction instrumentation. The instruments measure the bulk soil electrical conductivity ($EC_a$) – a function of clay content and mineralogy, volumetric soil water content, salinity, porosity and soil temperature (McNeill 1980). As a result, EM instruments have been used in mapping the spatial distribution of soil attributes such as clay content (Triantafilis et al. 2001a), depth to clay (Doolittle et al. 1994), moisture (Kachanoski et al. 1988) and salinity (Lesch et al. 1992, 1995; Triantafilis et al. 2000, 2001b). EM instruments have also been used to determine the rates of leaching from chloride mass balance models (Slavich and Yang 1990), where field variations in $EC_a$, as measured by a Geonics EM38 meter, was found to be strongly correlated to changes in DD.

In this paper we establish a relationship between soil $EC_a$ (EM38) and estimates of DD calculated using the so-called salt and leaching fraction model or SaLF (Carlin and Brebber 1993). A 3-parameter exponential model was fitted to the data and was subsequently used to estimate DD at each of 27,464 $EC_a$ measurement sites across “Auscott Midkin” Field 11. Multiple indicator kriging (MIK; Cattle et al. 2002) was used to determine risk areas and hence where improvements in irrigation efficiency could be made.

Materials and methods

Site description

The Gwydir valley is located in northern New South Wales of Australia. Moree (located 500 km north-northwest of Sydney), is the largest township in the valley (Fig. 1). The field selected for detailed study, is Field 11 on “Auscott Midkin”. It is located approximately 25 km north-northwest of Moree. It was selected due to the history of problems associated with a perched water table that causes waterlogged soil conditions. This is particularly the case in the southern parts of the field, where sandy soil types, associated with a prior stream formation, are predominant (Fig. 2a). Geodetically, the area is located at approximately 29°18′N and 149°45′E, which is equivalent to the Australian map grid (AMG) reference of 6755660 N and 767020 E.

Stannard and Kelly (1968) identified three distinct surface depositional systems in the lower Gwydir valley: (1) clay floodplains, (2) prior stream formations, and (3) levee deposits of present-day watercourses. The most widespread of these are the clay floodplains, which occupy approximately 85% of the lower Gwydir valley landscape. Prior stream formations, together with the levee deposits of present-day streams, occupy only a relatively small percentage (15%) of the lower Gwydir soil landscape (Needham 1991). These are slightly elevated in relation to the surrounding clay floodplains and are gently undulating in surface topography. The soil types of the prior stream formations are variable and change rapidly over short distances. They include deep sands (Entisols), shallow transitional red-brown earths (Inceptisols), and brown soils with marked textural boundaries (Inceptisols). The latter, which are dominant, consist of light-textured surface horizons that overlay medium to heavy clays. The subsoil of the prior streams may be a remnant of medium to heavy textured material or may grade into sandy material at depth (Stannard and Kelly 1968). Figure 3 shows a schematic representation of a terminal branch of a prior stream channel, as described by Stannard and Kelly (1977) in the lower Namoi valley.