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Water balance of centre pivot irrigated pasture in northern Victoria, Australia

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ABSTRACT

The irrigated dairy industry in Australia depends on pasture as a low-cost source of fodder for milk production. The industry is under increasing pressure to use limited water resources more efficiently. Pasture is commonly irrigated using border-check but there is growing interest amongst dairy irrigators to explore the potential for overhead sprinklers to save water and/or increase productivity. This paper reports on a detailed water balance study that evaluated the effectiveness of centre pivot irrigation for pasture production. The study was conducted between 2004/2005 and 2005/2006 on a commercial dairy farm in the Shepparton Irrigation Region in northern Victoria. More than 90% of supplied water (irrigation plus rainfall) was utilized for pasture growth. Deep drainage of respectively 90 and 93 mm was recorded for the two observation seasons. During the 2004/2005 season, deep drainage resulted from large unseasonal summer rainfall events. Over the 2005/2006 season, deep drainage resulted from excess irrigation. The cumulative pasture dry matter (DM) production was 15.5 and 11.3 tonnes DM ha^{-1} for the two irrigation seasons, with an agronomic water use efficiency (WUE) of 16 and 12 kg DM ha^{-1} mm^{-1} respectively. The farmer's intuitive irrigation scheduling was found to be very effective; the pattern of irrigation application closely matched measured pasture water use, prevented water stress and resulted in high irrigation efficiency.

1. Introduction

The Australian irrigated dairy industry relies on perennial pasture as a fodder source for milk production (Armstrong et al., 2000). The irrigated dairy industry is a major user of water in the Murray-Darling Basin (Austin, 1998), using approximately 40% of total water diversions (Bethune and Wang, 2004) and border-check is the main irrigation method used (Australian Academy of Technological Sciences and Engineering, 1999).

The dairy industry in the Murray-Darling Basin is under pressure to improve water use efficiency (WUE) and to minimise the adverse environmental impacts of irrigation. There is an increasing interest of farmers in the potential for sprinkler irrigation (predominantly centre pivot) to improve the efficiency of irrigation and achieve higher levels of production. The centre pivot method enables improved control over water application with irrigation efficiency ranging between 75 and 95% (Clemmens, 2000), a greater ability to match irrigation applications with crop water

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demand (Burt et al., 1999), improved nutrient management through the use of fertigation, increased flexibility and reduced labour costs (Ayars et al., 1999; Foley and Raine, 2001; Al-Jamal et al., 2001).

A centre pivot irrigation system allows a higher frequency of irrigation than the border-check method. Potentially, this may reduce water stress towards the end of the irrigation cycle and improve ryegrass and clover pasture production (Blaikie et al., 1988; Dunbabin et al., 1997). Measurements under controlled experimental conditions highlighted the potential for increase in production and water use efficiency with sprinkler irrigation (Wood and Finger, 2006). However, there is limited information on the performance of the centre pivot irrigation system for pasture production under farm conditions.

Information is required on actual pasture water use and its relationship with reference evapotranspiration (ET) and dry matter (DM) production under grazed dairy farming conditions. Advection has been recognised as contributing to enhanced evapotranspiration in irrigation environments (Lang, 1973; Verma et al., 1978; Motha et al., 1979; Xuhui et al., 2004). ET under advective conditions is driven by a 3-D energy exchange. However, the current methods for estimating ET demand are based on the assumption of a 1-D energy exchange. The applicability of current methods for estimating pasture water use will depend on the degree to which advection impacts on ET.

The amount of plant production per unit of transpiration (transpiration efficiency) is a function of a species-specific constant (k_d) and the vapour pressure deficit (VPD) (Tanner and Sinclair, 1983). The species-specific constant k_d describes plant sink strength for assimilating carbon dioxide (CO_2) during photosynthesis, and its ability to convert photo-assimilate into plant biomass. Two photosynthetic categories of plants are typically present in pasture swards in the Murray-Darling Basin, C_3 plants (*Lolium perenne* and *Trifolium* spp.) and C_4 plants (*Paspalum dilatum*). C_4 species contain an enzyme that allows them to more efficiently absorb CO_2 during photosynthesis and consequently they are considered to have a greater sink strength and transpiration efficiency than C_3 species (Hatch and Slack, 1969). However, this enzyme only functions effectively when temperature exceeds 15 °C, thus C_4 growth is limited under cool conditions (Hatch and Slack, 1969). Seasonal changes in temperature and the amount of C_3 and C_4 species present in a pasture sward will impact on the water use efficiency. Understanding the trade-off between pasture species, water use and production will provide insight into opportunities for improving water use efficiency.

This study developed a detailed water balance of a centre pivot irrigated pasture on a commercial dairy farm in northern Victoria, Australia. Pasture water use was determined atmospherically using the Bowen ratio energy partitioning technique. Regular measurements of pasture dry matter production in combination with water use data were used to examine temporal patterns in water use efficiency.

2. Materials and methods

2.1. *Trial site*

The field trial was conducted on a commercial dairy farm near Nathalia, in northern Victoria (latitude of 36°01′17″S, longitude of 145°11′60″E, and elevation of 131 m). The monitored site consisted of a semi-circular area (31 ha), irrigated by a centre pivot with a 450 m radius. The climate at the site is semi-arid with seasonal variation in temperature and rainfall. The soil on the site is mainly Waaia loam (Skene and Poutsma, 1962) which is characterised by a shallow A horizon and by the presence of a restricting clay subsoil (Mehta and Wang, 2005). The basic properties of the soil are given in Table 1.

Irrigations over spring (September–November), summer (December–February) and autumn (March–May) were scheduled by the farmer according to his normal practice which is approximately based on a cumulative "pan evaporation minus rainfall" approach. To minimise pumping costs, irrigation was usually carried out during off-peak electricity tariff periods (weekends), with a further light irrigation in the middle of the week. The farmer used fertigation as part of his normal operation. Measurements were made during the 2004/2005 and 2005/2006 irrigation seasons. Irrigation season 1 (IS1) was defined as the period between 1st September 2004 and 15th May 2005. Irrigation season 2 (IS2) included the period between 1st September 2005 and 15th May 2006.

2.2. *Water measurements*

Irrigation (I), rainfall (P), actual evapotranspiration (ET_a) and soil water storage in the root zone (ΔS) were measured routinely during IS1 and IS2. Surface runoff was not monitored, but the farmer confirmed that there was no runoff leaving from the study site. In some instances there was capillary rise into the root zone which results in negative *D*. Consequently, *D* represents the net flux of drainage below the root zone and capillary rise. Deep drainage (*D*) below the root zone (0.4 m) was determined as the residual in the water balance:

$$D = I + P - ET_a - \Delta S \quad (1)$$

Rainfall was recorded hourly using a tipping bucket rain-gauge. Water applied each irrigation event was measured with

Table 1 – Basic soil properties of the Waaia loam soil type (after Mehta and Wang, 2005)

Soil horizon	Soil depth (mm)	Texture	K_s ($mm\ h^{-1}$)	FC, volumetric ($m^3\ m^{-3}$)	WP, volumetric ($m^3\ m^{-3}$)	BD ($Mg\ m^{-3}$)	OM (%)
A	0–150	Sandy loam	25.0	0.40	0.22	1.57	3.9
B	150–700	Heavy clay	1.6	0.44	0.29	1.60	2.6

Note: K_s, saturated hydraulic conductivity; FC, field capacity; WP, wilting point; BD, bulk density; and OM, organic matter.