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Water use on nonirrigated pasture-based dairy farms: Combining detailed monitoring and modeling to set benchmarks

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ABSTRACT

Water use in intensively managed, confinement dairy systems has been widely studied, but few reports exist regarding water use on pasture-based dairy farms. The objective of this study was to quantify the seasonal pattern of water use to develop a prediction model of water use for pasture-based dairy farms. Stock drinking, milking parlor, and total water use was measured on 35 pasture-based, seasonal calving dairy farms in New Zealand over 2 yr. Average stock drinking water was 60 L/cow per day, with peak use in summer. We estimated that, on average, 26% of stock drinking water was lost through leakage from water-distribution systems. Average corrected stock drinking water (equivalent to voluntary water intake) was 36 L/cow per day, and peak water consumption was 72 L/cow per day in summer. Milking parlor water use increased sharply at the start of lactation (July) and plateaued (August) until summer (February), after which it decreased with decreasing milk production. Average milking parlor water use was 58 L/cow per day (between September and February). Water requirements were affected by parlor type, with rotary milking parlor water use greater than herringbone parlor water use. Regression models were developed to predict stock drinking and milking parlor water use. The models included a range of climate, farm, and milk production variables. The main drivers of stock drinking water use were maximum daily temperature, potential evapotranspiration, radiation, and yield of milk and milk components. The main drivers for milking parlor water use were average per cow milk production and milking frequency. These models of water use are similar to those used in confinement dairy systems, where milk yield is commonly used as a variable. The models presented fit the measured data more accurately than other published models and are easier to use on pasture-based dairy farms, as they do not include feed and variables that are difficult to measure on pasture-based farms.
Key words: water use, water efficiency, leakage, milking parlor, pasture systems

INTRODUCTION

Agriculture is the most significant water user in the world, accounting for an estimated 70% of global water withdrawals (World Water Assessment Programme, 2009); most of this water is used for irrigation. Agricultural demand for water is expected to grow to meet the 70% increase in global food production required to feed 9.7 billion people by 2050 (Food and Agriculture Organization, 2009; United Nations, 2015). As a consequence, where freshwater is scarce there will be an increased focus on improving the efficiency of water use (International Water Management Institute, 2007; Wani et al., 2009) and greater regulation of water use on environmental flows and water quality (Scarsbrook and Melland, 2015). Water footprinting methodologies are already being developed to enable water use comparisons between regions to increase the efficiency of water use (Ridoutt and Pfister, 2010; Zonderland-Thomassen and Ledgard, 2012).

Total water (**TW**) use on dairy farms is typically divided into 3 key areas: stock drinking water use (**SDW**), milking parlor water use (**MPW**), and irrigation water use. Cow water requirements [voluntary water intake (**VWI**)] have been benchmarked for confinement systems (Murphy et al., 1983; Meyer et al., 2004; Cardot et al., 2008), but limited information exists on SDW (Jago et al., 2005), MPW (Callinan, 2009; Murphy et al., 2014) and TW in pasture-based systems. Although many models can predict VWI (Castle and Thomas, 1975; Dahlborn et al., 1998; Appuhamy et al., 2014), most have been developed in confinement systems, which are markedly different to seasonal pasture-based systems (Roche et al., 2013). For example, confinement dairy systems have a more consistent quality of feed and DMI, which is easier to monitor and use in the predictive models. In comparison, DM of fresh pasture

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can vary from <12 to >30% (DairyNZ, 2012) and DMI of pasture is difficult to measure accurately. Consequently, many of these models are not practical for use on pasture-based dairy farms. Furthermore, we could not find any published prediction models for MPW or TW from pasture-based dairy farms, or estimation of water loss from SDW distribution systems on pasture-based farms.

Voluntary water intake models are available and include a range of variables. Commonly used variables used to predict VWI are DMI, DM, milk yield, and temperature (Little and Shaw, 1978; Stockdale and King; 1983, Kume et al., 2010). Other variables used include sodium content (Meyer et al., 2004), BW (Khelil-Arfa et al., 2012), sunshine hours (Cowan et al., 1978), rainfall (Cardot et al., 2008), and Julian day (Holter and Urban, 1992). Some of these variables are available on pasture-based farms or approximated with other measures, whereas others, such as sodium content and DMI, are difficult to measure. The objective of the current study was to quantify the seasonal pattern of water use to set benchmarks and develop prediction models of water use that are applicable to pasture-based dairy farms.

MATERIALS AND METHODS

Water use was measured on 35 dairy farms in the Waikato region of New Zealand (38°S, 175°E) between June 2013 and May 2015. Five farms were excluded from the data set due to insufficient or poor-quality data. Of the farm measurements, MPW, SDW, and TW were all recorded on 21 farms, and individual MPW, SDW, or TW was recorded on 10, 2, and 2 farms, respectively. The study sample size increased as water meters and telemetry were being installed and more farms began monitoring; the sample size grew until all 35 farms were supplying data, in total, 44.7 farm-years worth of data were collected. No specific average water-use values for any one day were calculated using data with a sample size less than 5 farms.

All SDW, MPW, TW, and farm total milk production data were converted to units per cow per day to allow comparisons across farms on a per-cow basis (L/cow per day, kg of milk fat plus protein, or milk yield/cow per day). Water use, milk fat plus protein yield, and milk volume were calculated from peak yearly cow numbers for the relevant season.

Farm Description

All farms were seasonal (spring)-calving dairy farms, and the main characteristics of the case study farms are summarized in Table 1. Farm herd size ranged from 160 to 1,150 cows per farm; 19 farms herringbone milking parlors and 16 had rotary parlors, with the number of bails (stalls) ranging from 16 to 52 and 30 to 60 bails, respectively. Average rainfall for the farms was 1,053 mm per year. Average yearly maximum and minimum temperatures were 18.8 and 8.6°C, respectively. Average Priestly-Taylor potential evapotranspiration and solar radiation were 2.49 mm/d and 14.6 MJ/m^2 per d, respectively. Average milk volume was 4,536 kg/cow per annum, and average milk fat plus protein yield was 394 kg/cow per annum.

Data Collection

Water use was collected continuously using water meters with a telemetry system. All water-use data were recorded at 15-min intervals, except 3 farms that supplied water-use data with hourly or daily volumes (2 farms measuring MPW; 1 farm measuring TW). The selected farms were categorized by production system type according to the amount of nonpasture feed purchased per cow per annum (Ramsbottom et al., 2015). A system 1 farm is the lowest input production system (pasture-based with no imported feed) and system 5 is the highest input system (25–40% imported feed).

Daily climate data were sourced for the entire study period. A total of 730 daily records on 24-h maximum temperature (°C), 24-h minimum temperature (°C), 24-h rainfall (mm), 24-h solar radiation (MJ/m^2), 24-h wind run (km), and 24-h potential evapotranspiration (mm) were obtained from the NIWA Virtual Climate Station Network (Cichota et al., 2008). The Virtual Climate Station Network uses data from weather stations and interpolates it over a 5 by 5 km grid across New Zealand.

Data Management and Calculations

Total water use is defined as MPW plus SDW and was measured at the source (abstraction point). Stock drinking water is defined here as the VWI of cows (water drank from a trough as opposed to water ingested in feed or metabolic water) and any water loss that occurs in water-distribution systems on farms (leakage incurred distributing water via pipes and troughs to cows in the paddock).

Water-use data were processed using Hilltop Software (Kmoch et al., 2015), a Microsoft (Redmond, WA) Windows-based database and reporting application suite for hydrology-related time series data. Visual quality checks were performed using the graphing functions of Hilltop Software. Invalid days (i.e., days that had missing data in the 15-min scale caused by recording errors) were removed. Data were excluded