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# Prediction of drinking water intake by dairy cows

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## ABSTRACT

Mathematical models that predict water intake by drinking, also known as free water intake (FWI), are useful in understanding water supply needed by animals on dairy farms. The majority of extant mathematical models for predicting FWI of dairy cows have been developed with data sets representing similar experimental conditions, not evaluated with modern cows, and often require dry matter intake (DMI) data, which may not be routinely available. The objectives of the study were to (1) develop a set of new empirical models for predicting FWI of lactating and dry cows with and without DMI using literature data, and (2) evaluate the new and the extant models using an independent set of FWI measurements made on modern cows. Random effect meta-regression analyses were conducted using 72 and 188 FWI treatment means with and without dietary electrolyte and daily mean ambient temperature (TMP) records, respectively, for lactating cows, and 19 FWI treatment means for dry cows. Milk yield, DMI, body weight, days in milk, dietary macro-nutrient contents, an aggregate milliequivalent concentrations of dietary sodium and potassium (NaK) and TMP were used as potential covariates to the models. A model having positive relationships of DMI, dietary dry matter (DM%), and CP (CP%) contents, NaK, and TMP explained 76% of variability in FWI treatment means of lactating cows. When challenged on an independent data set (n = 261), the model more accurately predicted FWI [root mean square prediction error as a percentage of average observed value (RMSPE%) = 14.4%] compared with a model developed without NaK and TMP (RMSPE% = 17.3%), and all extant models (RMSPE% ≥ 15.7%). A model without DMI included positive relationships of milk yield, DM%, NaK, TMP, and days in milk, and explained 63% of variability in the FWI treatment means and performed well (RMSPE% = 17.9%), when challenged on the independent data. New models for dry cows included positive relationships of DM% and TMP along with DMI or body weight. The new models with and without DMI explained 75 and 54% of the variability in FWI treatment means of dry cows and had RMSPE% of 12.8 and 15.2%, respectively, when evaluated with the literature data. The study offers a set of empirical models that can assist in determining drinking water needs of dairy farms.
**Key words:** dairy cow, empirical model, water intake, sodium, potassium

## INTRODUCTION

The World Economic Forum lists water crisis among the top 10 likely global risks. Currently, agriculture accounts for approximately 70% of the world's total water consumption and this use is likely to increase to meet the growing demand for food (Schulte et al., 2014). It has been estimated that dairy cattle account for approximately 19% of the total global water footprint related to animal production, and of the total amount of water used to produce all animal food products, 98% is used to produce feed, whereas 1% is used for drinking (Hoekstra, 2012). Despite accounting for only a small proportion of the total amount of water needed to produce milk, water acquired through drinking is vital for production. This is illustrated by the fact that restriction of water has been shown to result in rapid, but usually reversible, reductions in feed intake and milk yield (Steiger Burgos et al., 2001). Lactating dairy cows have the highest free water intake (**FWI**) and also experience the largest flux of water of any domesticated ruminant (Woodford et al., 1984). Interestingly, the nutritional requirements for water vary by as much as a factor of 10 (Lassiter and Edwards, 1982), whereas the daily body water flux of a lactating dairy cow may be as high as 30% of its total body water (Beede, 2012).

Accurately quantifying FWI may be needed for a variety of purposes including understanding water intake requirements of animals in dairy farms. Estimates of FWI may also be useful when attempting to match available resources to newly constructed facilities. To do so, several mathematical models have been published

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and may be used to predict FWI in dairy cattle (e.g., Castle and Thomas, 1975; Little and Shaw, 1978; Murphy et al., 1983; Stockdale and King, 1983; Holter and Urban, 1992; Dahlborn et al., 1998; Meyer et al., 2004; Cardot et al., 2008; Khelil-Arfa et al., 2012; Appuhamy et al., 2014b). The majority of extant models require DMI of individual cows as an input, which may not be routinely available in commercial dairy farms. A few extant models (Castle and Thomas, 1975; Dahlborn et al., 1998; Khelil-Arfa et al., 2012) allow for predicting FWI without using DMI. Nonetheless, the performance of some of these equations has not been evaluated using independent FWI measurements, particularly from modern cows under current management. Additionally, the majority of the extant equations have been developed using data from feeding studies sharing similar experimental contexts and facilities. Therefore, successful extrapolation of these models to diverse commercial dairy herds might be limited. On the other hand, meta-analytic approaches can be applied to derive new equations presumably with greater extrapolation capacity using literature data covering different experimental contexts, diets, and animal characteristics. Particularly, the random-effect meta-analytic approaches support extrapolation as they assume data used for model development to be a random sample of the total population (Viechtbauer, 2010). The objectives of the present study were to (1) explore factors significantly associated with FWI and develop a set of empirical models for predicting FWI of lactating and dry cows using random-effect meta-analyses of literature data, and (2) evaluate extrapolation capacity of the new and extant models using an independent data set including FWI measurements made on modern cows.

## MATERIALS AND METHODS

### Data Sources

An extensive literature search was conducted for in vivo studies reporting measured FWI of lactating and dry dairy cows along with related information on DMI, dietary nutrient composition, milk yield, DIM, and BW. For lactating cows, 239 treatment means of FWI were retrieved originally from 69 research articles (Table 1). After excluding treatment means without corresponding measures of uncertainty (e.g., SD or SEM), sample size (N), treatment means of restricted water intake, and treatment means related to water treatments having significant effects on FWI, the final data set for lactating dairy cows included 188 FWI records published in 55 articles. Forty-three out of the 55 articles, or 78% of the studies, provided multiple FWI treatment means. Ninety-three percent of the FWI records were related to Holstein cows (81%) and their crosses (12%). Experiments conducted with dairy cows in North America (47%), Europe (25%), and Australia (8%) provided the majority of the records. Ten percent of the records were related to pasture-based diets, whereas the rest were from cows offered rations in the form of a TMR. Corn silage (13.0 to 74.5% of DM), grass or legume hay (4.0 to 81% of DM), alfalfa silage (7.7 to 83.8% of DM), and grass silage (17.4 to 63.5% of DM) were the major forage sources, whereas ground corn (2.6 to 46.3% of DM), barley grain (7.2 to 30.8% of DM), and soybean meal (1.0 to 24.0% of DM) were the major concentrate ingredients in TMR diets. Only 72 FWI measurements from 16 studies had information on both dietary Na and K, and ambient temperature (**TMP**). Dietary Na content (% of DM) in studies using salt blocks (e.g., Andersson et al., 1984; Bahman et al., 1993) included Na intake from salt blocks expressed relative to the DMI. A summary of the complete and subset data with dietary Na and K, and TMP records is given in Table 1. For dry cows, 19 treatment means of FWI and the other information were retrieved from 10 studies. A summary of dry cow data is given in Table 2.

### Model Development and Evaluation

***Lactating Cows.*** Three-level (cow → treatment group → study) random-effect model analyses were conducted first to quantify variability or heterogeneity of FWI across treatment groups within individual studies ($\boldsymbol{\tau_T^2}$) and among studies ($\boldsymbol{\tau_S^2}$). Summation of $\tau_T^2$ and $\tau_S^2$ gave the total heterogeneity of FWI measurements ($\boldsymbol{\tau^2}$). The 3-level random-effect model (Konstantopoulos, 2011) is given by

$$Y_{ij} = \mu + \eta(S)_j + \nu(T)_{ij} + \varepsilon_{ij},$$

where $Y_{ij}$ = mean FWI of the $i$th treatment group in the $j$th study, $\mu$ = overall mean, $\eta(S)_j$ = $j$th study-specific random deviation of FWI, which is assumed to be normally distributed with a mean 0 and variance of $\tau_S^2$, $\nu(T)_{ij}$ = random deviation of FWI specific to the $i$th treatment in the $j$th study, which is assumed to be normally distributed with a mean 0 and variance of $\tau_T^2$, and $\varepsilon_{ij}$ = sampling error or random variability of FWI among cows in the $i$th treatment of the $j$th study. Variance of $\varepsilon_{ij}$ is assumed to be known and calculated using standard deviation of the treatment means. When standard deviation was not reported, it was estimated with other uncertainty measures reported (e.g., SEM) and N as described in Alvarez-Fuentes et al. (2016).

The random-effect models were extended to mixed-effect models or meta-regression models including fixed