Predicting freshwater demand on Irish dairy farms using farm data

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Abstract

Freshwater use in agriculture is a matter of discussion due to rising concerns over water scarcity, availability and pollution. To make robust predictions of freshwater demand, a large dataset of agricultural data is needed to discern the relationships between production parameters and water demand. The objective of this research was to predict freshwater demand (L yr^{-1}) on Irish dairy farms based on a minimal set of farm data. A detailed water footprint (WF) was calculated for 20 dairy farms for 2014 and 2015, and the relationships between the WF and agricultural inputs explored via a mixed modelling procedure, to develop a minimal footprinting solution. The WF comprised of the consumption of soil moisture due to evapotranspiration (green water, GW) and ground and surface water (blue water, BW). The performance of the models was validated using an independent data set of five dairy farms. The GW model was applied to 221 dairy farms to establish the relationship between the GWF of milk and economic performance. The average total volumetric WF of the 20 farms was 778 L/kg fat and protein corrected milk (L/kg FPCM) (range 415 – 1,338 L/kg FPCM). Freshwater for pasture production made up 93% of the GW footprint. Grass grown, imported forages and concentrates fed were all significant predictors of GW. The relative prediction error (RPE) of the GW model was 11.3%. Metered on-farm water and concentrates were both significant predictors of BW. The RPE of the BW model was 3.4%. When applied to 221 dairy farms ranked by net margin per hectare, there was a trend ($P<0.05$) towards higher profitability as the GWF decreased, indicating that the GWF of dairy farms can be improved by implementing good management practices aligned with improving profitability.

Key words: freshwater use prediction, milk production, mixed models, profitability

1. Introduction

Sustainable production of animal source food is at the forefront of political agendas for two main reasons. First, demand is increasing due to population growth and changes in dietary patterns (FAO, 2009; Steinfeld, 2006; Wirsenius et al., 2010). Second, there is an increasing interest in sustainable animal production (Aiking, 2014; Steinfeld et al., 2013; Thornton, 2010). Of the resources used for the production of animal source food, freshwater could become a limiting factor (Galli et al., 2012; Postel, 2000). As pressures on water resources intensify globally, there is growing interest in evaluating the complex ways in which human activities affect the world's water resources (UNEP, 2007; WEF, 2015). Volumetric water footprints (WF), defined as the sum of the volumetric water use along the entire supply chain of a product, have emerged as an important sustainability indicator in the agricultural and food sectors, contributing towards the efficient use of freshwater. Hoekstra et al. (2011) described a volumetric WF as the sum of consumption of soil moisture due to evapotranspiration (green water), the consumption of ground and surface water (blue water), and the degree of freshwater pollution due to wastewater discharges (grey water). Grey water represents an emission and is better represented in other impact categories through life cycle assessments (Milà i Canals et al., 2009; Pfister et al., 2009) and was omitted from this analysis. Volumetric WFs are useful in highlighting the role of freshwater use in production systems, but do not inform on the environmental impact of freshwater use (Ridoutt et al., 2009). The water stress index (WSI), a mid-point indicator, can be used to assess the impact associated with blue water consumption in relation to global freshwater scarcity (Pfister et al., 2009). Each source of blue water use is multiplied by the WSI value of the location of water use and summed across the supply chain of the system to account for the environmental impact of blue water use.

Although most of the global concerns about water scarcity relate to blue water, it is imperative to consider water use in the context of green and blue water because increasing green water use efficiency in agriculture can help reducing the burden on blue water sources (Hoff et al., 2010; Rost et al., 2008; Vidal, 2010). Furthermore, both blue and green water sources can have alternative uses (e.g., food crop production, eco-system services). Insight into green water use can contribute to optimizing resource allocation. Irish agricultural systems do not currently suffer water shortages or droughts due to Ireland's temperate maritime climate (Kottek et al., 2006). More intensive production in some dairy centric catchments, however, may lead to localised water shortages in the future. This has already become a serious threat to dairy production in some countries, especially in years with below average rainfall (Ejaz Qureshi et al., 2013; Gleick and Ajami, 2014). Hence, there is a requirement for balance between water abstraction and recharge rates. Water footprinting is one tool that can be used to assess water abstractions per unit of dairy product produced (Murphy et al., 2017).

Current WF studies are based on large datasets, covering many different aspects of a production system. Gathering high resolution data, however, is not always possible due to limitations in cost or willingness of farmers to supply accurate data over a prolonged period. Extensive data requirements, therefore, limit WF assessments to a small population of farms and hinder application of water use assessment models to the general population. The objective of this study was to predict freshwater demand (in litres per year) on Irish dairy farms based on a minimal set of farm data. Furthermore, the water prediction models developed in this study were applied to a national farm data dataset of 221 dairy farms. This application of the models allowed for exploration of the relationship between the WF per unit of milk and farm economic performance.

2. Materials and methods

2.1 Water footprint system boundaries

Twenty-five commercial dairy farms were selected from the Teagasc advisory database. The study farms were in the south and south-west of Ireland. Selection criteria of the study farms included availability of herd and production data for 2014 and 2015 and willingness of the farmer to collect and maintain data accurately. Twenty farms were used for the development of predictive models and the five remaining farms were used for independent validation. The system boundary was cradle-to-farm gate. Freshwater use included water consumed for cultivation of crops for concentrate feed, imported forages and for on-farm cultivation of grass, and water required for animal husbandry and farm maintenance. Consumed water refers to loss of water when it is evaporated, incorporated into a product or returned to another catchment. Results were expressed per kg FPCM (fat and protein corrected milk) (CVB, 2000). Water use related to energy and fertilizer production was not included owing to its negligible contribution to the WF of milk in the study of De Boer et al. (2013)

2.2 Data collection

Water meters were installed on each farm to record direct water volumes (m^3) throughout the farm including water used to facilitate milk production processes and water consumed by livestock. Domestic water consumption was measured separately and subtracted from the total water supply to determine water supply to the farm enterprise only. Water volumes were recorded monthly via an online survey with the farmers reading each of the installed meters and inputting the data into the online system. Milk production data were sourced from the Irish Cattle Breeding Federation (ICBF) records. Additional information gathered included information on farm imports, such as concentrate feed and imported forages. Cow diet was supplemented with imported forage when grass growth was insufficient to meet herd feed requirements. The use of forage varied over the farms in type and volume. Forages imported were predominantly grass silage, hay and maize silage. Concentrate fed to dairy cows, feed ingredient composition and source information was taken from Upton et al. (2013) based on data from local feed mills. The percentage share of ingredients in concentrates and the economic allocations for each ingredient was taken from Murphy et al. (2017). Raw data from water meter recordings and surveys were exported to spreadsheets and subsequently used to compute the total WF per farm, and per unit of milk. Economic allocation was used to allocate water consumption between dairy and beef output as necessary. This approach has been used for similar livestock systems (De Vries and de Boer, 2010; O'Brien et al., 2014a).

2.3 Water footprint calculations

The green and blue WF for two consecutive years for each farm were calculated following the method described by Murphy et al. (2017) and based on consumptive water use.

To assess the freshwater requirement for growth for each crop input (concentrates, forages and grass), the evapotranspiration (ET) was computed based on climate data, soil type and actual yield data. First, AQUASTAT (Eliasson et al., 2003) was used to compute the reference ET (ET_o) for each crop location. Second, the potential ET (ET_p) over a crop's growing period, assuming maximum soil water availability was derived using the crop co-efficient (Kc [t]) and the reference ET_o on AQUASTAT using the Penman-Monteith equation (Allen et al., 1998). Third, results from AQUASTAT were used to derive the rainfed ET of the crop (ETrf). ETrf is an estimate for the volume of water evapotranspired (green water) of a crop over the growth period. Fourth, actual crop yields taken from the FAO (2014) were used to quantify the consumption of rainwater (green) and irrigation (blue) water in litres per kg of dry matter. The ET from actual yield of a crop (Eta, mm/ha) was derived from the relationship between water supply and crop yield, described by Doorenbos and Kassam (1979). Irrigation was assumed to be absent where ETa ≤ ETrf. When ETa ≥ ETrf, irrigation volumes were calculated by:

$$Irrigation\ volume = (ETa - ETrf) / Ireff \quad (1)$$

Ireff is the irrigation efficiency, with 0.7 assumed for all crops (Allen et al., 1998). All irrigation water was assumed to be consumptive, implying that losses in the irrigation system did not return to the same water shed, representing a worst-case scenario.

2.3.1 Grass growth data

Data on annual grass and silage production on each farm were collected from PastureBase Ireland (PBI) (Griffith et al., 2014). PBI allows the quantification of grass growth and DM production (total and seasonal) across different enterprises, grassland management systems, regions and soil types, using a common measurement protocol and methodology. The farmer inputs the grass growth data from their farm via an online portal. Grass growth was measured on each paddock from January to December on each study farm for each year by visual assessment (O'Donovan et al., 2002). Both grazing yield and silage yield estimated on harvest date were measured separately by the farmers and then combined to give total grass production (kg DM) and average yield per hectare (kg DM/ha) for all farms.

2.4 Impact assessment

In order to calculate the stress-weighted WF per farm, each source of blue water consumption was multiplied by the relevant regional WSI (Ireland = 0.022) (Pfister et al., 2009) and summed across the supply chain of the dairy system. To assess the global impact of freshwater use, the stress-weighted WF was normalised by dividing it by the global average WSI (0.602), giving a quantitative comparison of the pressure exerted from freshwater use through the production of a product (milk), relative to the impact of consuming 1 kg of water across the globe (Ridoutt and Pfister, 2010).

2.5 Statistical modelling

A mixed model procedure (Proc Mixed; SAS Institute Inc., 2015) was used to predict the effect of a number of farm variables on consumption of green water (GW) and blue water (BW) (in total volumetric litres per farm) over two consecutive years as follows:

$$GW = a + bA + cB + dC + eD + fE + gF + hG + iH \quad [1]$$

$$BW = a + bA + cB + dC + eD + fE + gF + hG + iH + jI \quad [2]$$

A is the farm area (Hectares), B is total milk produced on farm (Litres), C is the number of animals in the dairy herd, *D* is litres of milk produced per cow (L/Cow), E is the total concentrates fed (kg DM), F is total grass grown on farm (kg DM), *G* is grass yield per hectare (kg DM/ha), *H* is imported forages (kg DM) and *I* is metered on-farm blue water (m^3). Lower case *a* represents the intercept and *b* until *j* represents the coefficients of the equations. Farm area, milk produced, herd size, milk per cow, concentrates, grass grown, grass yield per hectare and imported forages and metered water were defined as fixed effects. Farm was defined as a repeated variable with a first-order autoregressive covariance structure. Non-significant effects (P > 0.05) were removed from the model by backward elimination.

2.6 Model validation

In this study, the GW and BW models developed with data from 2014 and 2015 were validated on five dairy farms. All data were exported to spread sheets on Microsoft Excel and subsequently used to validate the predicted WF of the individual farms. The predictions of the validation set were compared with the actual water volumes calculated for GW and BW and then the overall accuracy of the models was evaluated using relative prediction error.

The relative prediction error (RPE; (Rook et al., 1990)) was calculated as follows:

$$RPE = \left(\frac{RMSE}{Am}\right) x100 \qquad [3]$$

Where Am is the mean value of the actual data. The RMSE is derived from:

$$RMSE = \frac{\sqrt{\sum (P-M)^2}}{n} \qquad [4]$$

where M is the measured water volume demand, P is the predicted value and n is the total number of observations. RMSE informs on the performance of the correlations by comparing term by term the actual deviation between predicted and measured values.

2.7 Economic performance and WF

The GW prediction equation (Equation 5) was used to predict the green WF of 221 dairy farms from the Teagasc national farm survey (NFS) dataset for the year 2012 (Hennessy et al., 2013) using data on concentrates, grass grown and imported forages. The BW prediction equation (Equation 6) was not used to predict the blue WF of the 221 farms as metered blue water volumes were not available for those farms. Grass growth data was calculated by using the difference between the net energy in units of feed for lactation (UFL) provided by concentrates and forages and the net energy demands of farm stock for maintenance, milk production and pregnancy as described by (Jarrige, 1989) and (O'Brien et al., 2014b). The economic performance of the 221 dairy farms was calculated from farm gross output, variable costs and fixed overhead costs from the NFS (Hennessy et al., 2013). Net profit (€) was calculated by subtracting variable and fixed costs from gross output. Net profit of the dairy farms was expressed per hectare of farm land. To compare profitability and WF in the least and most productive farms, the WF per unit of milk for the farms was ordered based on their economic performance (€/Ha) into the bottom, middle and top third of farms (~73 farms per group). Statistical differences in water footprints between the three groups were tested using general linear models in SAS using PROC GLM (SAS Institute, 2011). A Tukey post hoc test was used to compare the means between the groups and identify which groups were significantly different from each other.

3. Results

3.1 General farm characteristics

Table 1 shows the range of input and production details of the 20 study farms for 2014 and 2015 in terms of production. The average farm size (owned land + rented land) was 84 ha in 2014 and 88 ha in 2015. Milk production increased from 631,602 kg FPCM in 2014 to 761,152 kg FPCM in 2015. Average milk yield per cow increased from 5,052 kg FPCM per cow in 2014 to 6,129 kg FPCM per cow in 2015. Imported forages utilised by the farms fell from 33,524 kg DM in 2014 to 15,646 kg DM in 2015, while the quantity of concentrates increased from 61,132 kg DM in to 2014 to 67,323 kg DM in 2015.

3.2 Water footprint results

Table 2 presents a summary of the total green (GWF) and blue water footprints (BWF) as well as the stress weighted water footprint over the two years for the 20 farms used for the model calibration. WFs are categorised into on-farm WF (blue water only), concentrate WF, grass WF and imported forage WF. The sum of the GWF and BWF, as well as the total volumetric WF (i.e., both blue and green water) is also indicated.

In 2014, the total WF of the 20 study farms was on average 842 L/kg FPCM (range 497 – 1,338 L/kg FPCM) in 2014, and 714 L/kg FPCM (range 415 – 1,013 L/kg FPCM) in 2015.

The average WF over the two years was 778 L/ kg FPCM. The GWF made up 99% of the total WF with the BWF making up the remaining 1%. Freshwater consumed for grass growth accounted for 91% of the total volumetric WF.

3.3 Green water demand model

The mixed model solution for GW was:

$$GW = 826Cn + 419Gr + 498ImFr \quad [5]$$

Concentrates fed (*Cn,* in kg DM yr^{-1}), grass grown (*Gr*, in kg DM yr^{-1}) and imported forages (*ImFr*, in kg DM yr^{-1}) were all significant predictors of GW. All variables left in the model were significant at the P<0.05 level. The reported p values were; concentrates fed, 0.0012, grass grown, 0.0001, imported forages, 0.0017. The p values reported for the variables milk sales, number of cows, milk per cow, grass yield per hectare, and farm area, (P = 0.46, 0.2, 0.06, 0.051 and 0.03) did not reach statistical significance and therefore were excluded from the final model. The R^2 value of the final model was 0.91. The standardised coefficients for the remaining variables were; concentrates fed = 0.17, grass grown = 0.92 and imported forages = 0.12.

3.4 Blue water demand model

The mixed model solution for BW was:

$$BW = -20{,}392 + 8.1Cn + 0.92MW \quad [6]$$

The results indicate that ‘Concentrates Fed’ (*Cn*, in kg DM yr^{-1}) and ‘Metered Water’ (*MW*, in m^3 yr^{-1}) were the significant predictors of BW. Both variables left in the model are significant at the P<0.05 level, reporting p values <0.0001. The p values reported for the variables milk per cow, grass grown, grass yield per hectare, milk produced, imported forages, herd size and farm area, (P = 0.61, 0.60, 0.59, 0.49, 0.19, 0.18, 0.15) did not reach statistical significance and were therefore excluded from the final model. The R^2 value of the final model was 0.98 indicating that the model had a very strong explanatory power for farm level blue water demands. Metered water (on-farm BW only) was the most important variable as its standardised coefficient was largest (0.95). The standardised coefficient for concentrates was 0.15.

3.5 Model validation

Table 3 summarises the results of the validation process, the table indicates the actual GW and BW in total litres compared to the predicted GW and BW demand for all five farms over 2014 and 2015, as well as the RPE for each farm. The RMSE for the GW model was 8,452,355 L. The average RPE for the GW model was 13% for 2014 (range 0.04 – 25.7%) and 9.7% for 2015 (range 4.1% – 18.3%). The overall average RPE over the two years was 11.3%. The RMSE for the BW model was 237,452 L. The average RPE for the blue water model in 2014 was 3.2% (range 0.5% – 5.7%) and for 2015 was 3.6% (range 0.2% – 4.8%) the overall average RPE over the two years was 3.4%.

3.6 Economic performance and WF of milk

The green WF of milk production for the bottom, middle and top third of NFS farms ordered in terms of net margin per hectare (€/Ha) are displayed in Table 4. The results from the PROC GLM procedure found all three groupings (~73 farms per group) of WF to be significantly different from each other with a significance of $P<0.05$. The WF of the top and middle third groups was 19% and 12% lower ($P<0.05$) than the bottom performing group, respectively.

4. Discussion

4.1 Model outcome

4.1.1 Green water prediction

For GW, the variables which reached significance were concentrates fed, grass grown and imported forages. The strength of the relationship between the dependent (WF) and independent variables was 0.91 indicating that the model is a strong predictor of the WF of a dairy farm. This level of accuracy is satisfactory for the intended use of this model as a way of estimating the WF of similar farms. A relative prediction error of between 10% and 20% suggests that the model described can be classified as providing acceptable prediction (Fuentes-Pila et al., 1996). The average RPE for the GW model in this study was 11.3%. However, some poor prediction accuracies were achieved for one farm for 2014, i.e. 26%. This level of error is due in part to changes in the quantity of imported forages used from one year to the next and suggests a degree of uncertainty in predicting the GW demand for the growth of imported forages. The overall level of model accuracy, however, is satisfactory for the intended use of this model as an indicator in a sustainability scheme.

4.1.2 *Blue water prediction*

For BW prediction, the strength of the relationship between the dependent (WF) and independent variables was 0.98 indicating that the model is a very strong predictor of the BW footprint of a dairy farm. This level of accuracy is more than satisfactory for the intended use of this model as a simplification method of relating farm inputs to water footprint outputs within similar populations. Relative prediction error values of between 0% and 10% suggest that the model described can be classified as providing good prediction accuracy (Fuentes-Pila et al., 1996). The average RPE for the BW model in this study was 3.4%. The application of the BW model can also be expanded to account for the impact of BW use through the water stress index, WSI (Pfister et al., 2009). Further data on crop origins and relevant irrigation water use would be needed to calculate the stress-weighted WF; this data is available and could be quantified by those applying the model through a sustainability scheme.

4.2 Model implications

Previously published WF literature has been constricted to using national production data or theoretical production data to represent heterogeneous systems (Ridoutt et al., 2012; Zonderland-Thomassen and Ledgard, 2012). This can be misleading when attempting to identify freshwater demands on a local scale. The approach taken in this study of utilising a population of farms at various levels of production and efficiency, combined with intensive data collection, has developed a clearer picture of the drivers of freshwater demands in Irish milk production at farm level, overcoming the limitations that previous WF literature have faced due to limited data availability.

This detailed approach, however, while useful for research studies, is not practical on a larger scale to represent the WF of a region or catchment. Therefore, the application of this high-resolution data to develop regression models which were evaluated in this study helps to reduce the need for intensive data collection over a long period of time while still capturing the variation of water demand between individual systems. This approach could be further applied to predict the freshwater demands of larger populations of milk production systems or of other livestock production systems, operating under similar production conditions provided region specific equations were calibrated through a detailed water footprinting method as described in this paper.

Fitzgerald et al. (2005) described how Irish dairy production systems are influenced differently due to climate variation in Ireland, affecting production parameters (e.g. crop and grass yields) and subsequently water use. Systems in the South East of Ireland, for example, experienced less grass availability in the summer months, due to soil water deficits and lack of sufficient precipitation. Systems in the North experienced later turnout in the spring time, as lower temperatures delayed the onset of grass growth. The South West was found to be the most productive region for dairy systems due to the mild temperatures and summer precipitation. As the farms used in this study were in the South and South West of Ireland the freshwater demand prediction models demonstrated in this research could be applied to farms in the same region.

This study has provided insight into the relative importance of each data stream used in the calculation of the WF of milk in Ireland. The standardised coefficients of the GW model were 0.92 for grass growth, 0.17 for concentrates and 0.12 for imported forages. In the BW model the standardised coefficients were 0.96 for metered water and 0.15 for concentrates. These results can be used to refine data collection strategies in the future, which would be useful when developing models to work within the scope of national sustainability programs such as Origin Green (BordBia, 2012).

4.3 Data required for prediction equations

For GW prediction, accurate grass growth records are necessary as grass production has the largest effect on GW demand. The use of grass growth recording programmes such as PastureBase Ireland (Griffith et al., 2014), which facilitates decision support of grassland management at farm level, is widely used by farmers to evaluate grass yields (Hanrahan et al., 2015). Grass growth recording has been shown to contribute to a farmer’s ability to extend the farm’s grazing season, improve grass yields and increase profitability (French et al., 2014; Läpple et al., 2012; O'Donovan and Kennedy, 2007), further highlighting the importance of recording grass growth. Data on annual concentrates fed and volume of imported forages can be collected easily directly from the farmer.

For the BW prediction, the volume of water used on farm has the largest effect on BW demand. This data is not easily collected and is dependent on the farmer having a water meter installed at the point of water abstraction. However, recording this water use is useful information as it can be used in the monitoring of leaks (Murphy et al., 2014).

The importance of GW consumption for grass growth indicated in the GW model, mirrors the results of Murphy et al. (2017) which indicated the large share of GW utilised for the production of milk on Irish dairy farms. Combining improved grass growth recording, as recommended in this research, increasing grass utilisation and reducing concentrate use can increase the share of GW use in pasture based systems. Reduced use of concentrate feed which implies a reduction in demand for blue water sources and reduced water stress will be an important measure of sustainability as consumers become more aware of the environmental impact of livestock production (Grunert et al., 2014).

4.4 Economic performance vs. GWF

We used the GW model developed in this research to assess the link between profitability and the GWF on 221 specialised Irish dairy farms. The relationship between the economic performance of dairy farms and the WF of milk produced has not been examined before. Previous studies linked dairy cow genetic merit (Ramsbottom et al., 2012) and carbon footprint (O'Brien et al., 2014b) to economic performance and showed that improvements in herd breeding index and carbon footprint increased the profitability on dairy farms. Figure 1 shows the relationship between the GWF and net margin per hectare for all 221 farms indicating a weak linear relationship with $R^2 = 0.27$, showing that as the GWF of milk decreased the economic performance was seen to improve. Grass yields (kg DM/ha) of the farms in the three performance bands (Table 4; bottom, middle and top) also increased as net margin per hectare increased indicating that as grass productivity improved so too did the profitability of the farms. This mirrors research studies which suggest pasture based farms can increase profitability through improved yields and utilization of grass which is a cheap source of feed and can be used to offset the need for concentrates (O'Donovan and Kennedy, 2007; O'Donovan et al., 2011; Shalloo et al., 2011). Milk production was highest, while the WF was the lowest in the most profitable group which facilitates the dilution of maintenance effects as described by (Capper, 2012), implying that the total resource cost per unit of milk is reduced. This suggests that improved farm management practices such as grass growth efficiency and increased milk production can provide a win-win for farmers to improve their economic performance while lessening their freshwater demands.

5 Conclusion

High resolution farm production data was collected and used to compute the WF of 20 Irish pasture based dairy farms. This high-resolution data was used to develop regional level water prediction equations negating the need for detailed data collection on every production unit within the same region. Farm variables such as Gr, (grass growth), Cn (concentrates fed) and ImFr (imported forages) were all significant predictors of GW demand. MW, (On-farm water use) and Cn (concentrate use) were predictors of BW demand. The application of the developed models to predict the green WF of 221 dairy farms further identified a trend towards a lower WF in farms which had the highest net profit per hectare. Profitable production can be achieved on rainfed pasture-based milk production systems while not adversely affecting the environmental performance from a water consumption point of view. This approach could be used to predict the freshwater demands of agricultural production systems of larger populations of dairy farms or other livestock production systems, operating under similar production conditions provided region specific equations were calibrated through a detailed water foot printing method as described in this paper.

TABLES

Table 1. Summary of production parameters across 2014 and 2015 for 20 Irish dairy farms used in the model building dataset.

	Farm Area (Ha)[1]	Milk Sales (kg FPCM /year)[2]	Cow #	Milk / Cow (kg FPCM /year)	Concentrate (kg DM)[3]	Grass Yield (kg DM /Ha)	Grass Grown (kg DM)	Imported Forages (kg DM)	On-Farm Water Requirements (Litre)[4]
					2014				
Minimum	32	328,320	59	4,157	26,840	8,740	421,434	0	865,730
Average	84	631,602	126	5,052	61,132	12,895	1,021,052	33,524	3,034,337
Maximum	181	1,106,624	222	6,662	166,550	20,294	1,689,120	156,800	5,344,000
S.D	28	225,458	44	641	32,340	2,886	309,121	49,482	1,339,216
					2015				
Minimum	32	391,753	59	4,423	22,500	7,360	436,581	0	939,086
Average	88	761,152	126	6,129	67,323	13,080	1,078,986	15,646	3,861,419
Maximum	187	1,313,392	222	8,471	163,680	16,132	1,989,408	124,000	10,582,858
S.D	34	258,617	44	910	38,531	2,231	395,806	30,219	2,467,327
					2014 & 2015				
Average	86	696,377	126	5,590	64,228	12,987	1,050,019	24,585	3,447,878

[1] Ha = Hectares

[2] FPCM = fat and protein corrected milk

[3] DM = Dry matter

[4] On-farm water requirements = total volumes of water used by each farm for day to day milk production processes over the monitoring period.

Table 2. Summary of the volumetric blue water footprint (BWF), volumetric green water footprint (GWF), total water footprint and stress weighted WF of the 20 study farms in litres of water / kg FPCM of milk sold from cradle to farm gate for 2014 and 2015.

	On-Farm	Concentrates		Grass	Imported Forages		Total Water Footprint			Stress Weighted On-farm BWF	Stress Weighted Feed BWF	Total Stress weighted WF
	Blue	Green	Blue	Green	Green	Blue	Green	Blue	Total			
2014												
Minimum	1.6	8	0.3	455	0	0	493	2.2	497	0.1	0.3	0.4
Average	4.6	26	0.8	778	29	0	837	5.2	842	0.2	0.4	0.6
Maximum	8.1	60	1.5	1,180	118	0	1,332	9.1	1,338	0.2	0.6	0.8
S.D	1.9	12	0.3	211	41	0	208	2.0	208	0.0	0.1	0.2
2015												
Minimum	1.2	6	0.2	372	0	0	406	1.2	415	0.1	0.2	0.3
Average	4.2	25	0.8	670	11	0	709	5.5	714	0.2	0.4	0.6
Maximum	8.7	54	1.4	992	80	0	1,009	14.2	1,013	0.3	0.5	0.8
S.D	2.0	13	0.3	163	23	0	166	2.7	165	0.1	0.1	0.2
2014 & 2015												
Average	4.4	25.2	0.8	724	20.1	0.0	773	5.4	778	0.2	0.4	0.6

Table 3: Actual and predicted volume of green water and blue water (litres) and the associated RPE of each of the five farms in the validation dataset for 2014 and 2015.

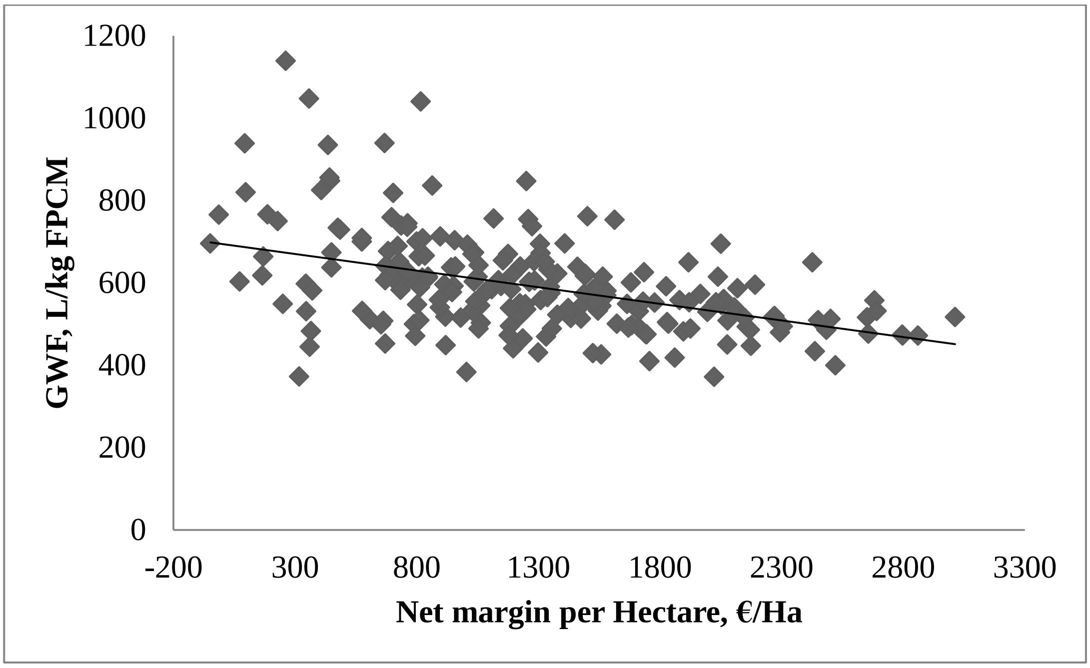
Actual Green	Predicted Green	RPE	Actual Blue	Predicted Blue	RPE
Litres	Litres	%	Litres	Litres	%
2014					
380,148,936	380,296,361	0.04	2,832,018	2,962,898	4.4
469,125,210	500,283,302	6.6	2,272,037	2,260,315	0.5
370,071,405	409,438,668	10.6	4,133,589	4,087,811	1.1
716,060,172	532,315,945	25.7	3,130,762	3,007,699	4.1
650,831,093	508,431,315	21.9	1,401,601	1,485,608	5.7
2015					
350,540,196	336,219,646	4.1	2,213,983	2,320,741	4.6
449,984,336	479,516,444	6.6	3,338,245	3,345,474	0.2
447,420,722	529,399,268	18.3	4,376,666	4,176,376	4.8
458,764,433	437,291,909	4.7	3,496,359	3,359,196	4.1
600,433,842	510,607,896	15.0	2,888,375	3,023,302	4.4
Average (14&15)		11.3	Average (14&15)		3.4

Table 4. Production characteristics and economic performance for the 221 National Farm Survey farms displaying the mean and standard deviation ranked into bottom, middle and top third of farms ranked by net profit margin per hectare.

Item	Mean	SD	Bottom	Middle	Top
Net Margin per Hectare, €/ha	1,200	705	833	1,474	2,798
FPCM, kg	363,136	207,725	258,829	398,368	1,100,550
Concentrates, kg DM	56,018	43,452	33,934	60,145	231,118
Grass Grown, kg DM	341,641	196,375	232,713	377,700	998,458
Forages, kg DM	25,348	13,108	50,337	21,693	44,029
Grass Yield, kg DM/Ha	9,119	3,029	7,597	10,075	17,790
Green Water, Litres	245,280,933	149,103,786	159,233,850	269,961,270	801,288,305
Green WF, L/kg FPCM	695	183	*774[a]	683[b]	630[c]

* Differing letter designations within rows were significantly different at the $P<0.05$ level. P value for the groups was $P <.0001$.

Figure 1. Scatter plot displaying the trend between net margin per hectare (€/ Ha) and the volumetric green water footprint (GWF) (L/ kg FPCM) of 221 dairy farms, R^2 = 0.27.



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