The waterfootprint of crop production in Belgium

Anne Gobin[1*]

Abstract: *The water footprint concept (Mekonnen and Hoekstra, 2010) has created great awareness of sustainable water use and water consumption. In Belgium 75% of the total water footprint of consumption is associated with plant and animal products, while only 23% of the total water footprint of national production is attributed to crop production. The objectives of this study are to quantify the green water footprint and its variability for the major arable crops in Belgium against the wider concepts of the water footprint of national production. A regional dynamic crop model geared towards climate impact on biomass production, REGCROP (Gobin, 2010), was run to calculate the crop water use for six major arable crops during the period 1988-2012. The water footprint of national crop production in Belgium is subject to a large variability owing to variability in both crop water use and yield between soils and between years. The green water footprint of seed and grain crops is larger than tuber and root crops, and depends on the proportion of marketable produce to biomass produced per surface area. The total annual actual water use of arable crop production averages at 379 litres.day*$^{-1}$*.caput*$^{-1}$ *for the period 1988-2012, representing 50.5% of the total green water footprint of production in Belgium. Water use and water availability should become more integrated when evaluating cropping systems for their sustainable water use.*
Keywords: *water footprint, Belgium, arable crops.*

Riassunto: *Il concetto di impronta idrica ha creato grande consapevolezza sull'uso sostenibile ed il consumo dell'acqua. In Belgio il 75% dell'impronta idrica totale del consumo è associato alle produzioni vegetali e animali, tuttavia solo il 23% dell'impronta idrica totale della produzione nazionale è attribuita all'agricoltura. Gli obiettivi di questo studio sono di quantificare l'impronta idrica verde e la sua variabilità per le principali colture seminative in Belgio contro la concezione più ampia di impronta idrica della produzione nazionale. Un modello colturale regionale dinamico, pensato per valutare l'impatto climatico sulla produzione di biomassa, REGCROP (Gobin, 2010), è stato applicato per il calcolo del consumo idrico delle sei principali colture, nel periodo 1988-2012. L'impronta idrica della produzione agricola nazionale del Belgio è soggetta a una forte variabilità a causa della variabilità sia del consumo idrico delle colture che della resa, tra suoli differenti e negli anni. L'impronta idrica verde delle colture da seme e dei cereali è maggiore rispetto a quella dei tuberi e delle radici e dipende dal rapporto della produzione commerciabile con la biomassa prodotta per unità di superficie. Il consumo totale annuo effettivo di acqua delle colture seminative è stato in media di 379 litri/giorno/pro capite per il periodo 1988-2012, pari al 50,5% dell'impronta idrica verde totale della produzione del Belgio. L'uso dell'acqua e la sua disponibilità dovrebbero essere maggiormente integrate nel momento in cui vengono valutati i sistemi colturali in termini di uso sostenibile dell'acqua.*
Parole chiave: *impronta idrica, Belgio, seminativi.*

INTRODUCTION

Belgium is a small but densely populated country. Its strongly globalized economy and transport infrastructure at the heart of a highly industrialised region in Europe helped make it the world's 15th largest trading nation in 2007. Amongst Belgium's main imports are raw materials, chemicals, pharmaceuticals, machinery, foodstuffs and oil products. The Western lifestyle, and in particular a high-meat diet, result in a very large average water footprint of national consumption of around 1888 $m^3.yr^{-1}$ per capita (Mekonnen and Hoekstra, 2010), of which a small fraction is supplied through own resources. Belgium has a higher footprint than its surrounding countries, with the exception of Luxemburg (Fig. 1). Belgium's total waterfootprint amounts to nearly 19.6 billion m^3, which represents 5171 litres per person per day. The figures by Vincent *et al.*, (2011) are slightly higher but for reasons of international comparison the data provided by Mekonnen and Hoekstra (2010) are used here. Though Belgium has a temperate maritime climate, fresh water resources are limited in availability due to a combination of high demand and limited supply. Large impermeable surfaces hinder water infiltration and groundwater replenishment. In addition, a large proportion of surface and subterranean water are polluted. The water consumption exceeds own resources, and is therefore dependent on the water resources of other countries. Supply chains can be clearly traced, and the external impacts can be related to the producing countries.

* Corresponding author's e-mail: anne.gobin@vito.be
1 Flemish Institute for Technological Research (VITO), Boeretang 280, 2400 Mol, Belgium.

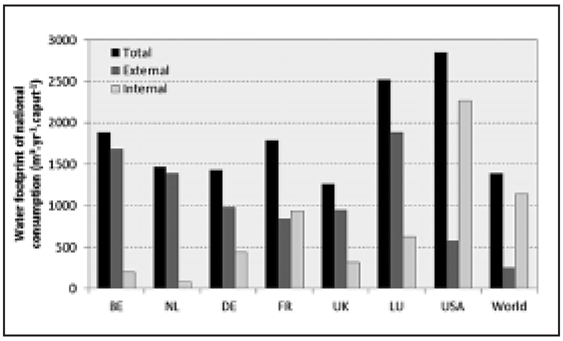

Fig. 1 - The water footprint of national consumption (total, internal and external) for several countries (in $m^3.yr^{-1}.caput^{-1}$) (data source: Mekonnen and Hoekstra, 2010).
Fig. 1 - Water footprint del consumo nazionale (totale, interno ed esterno) per diversi paesi (m^3/anno pro-capite) (fonte: Mekonnen e Hoekstra, 2010).

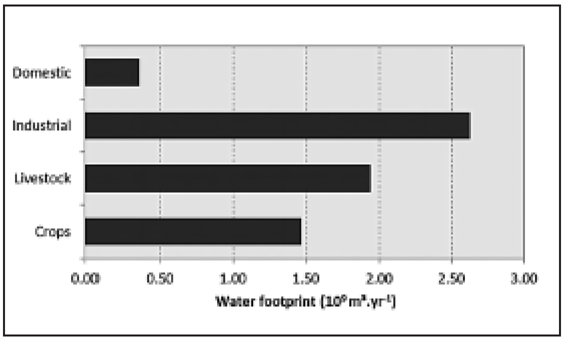

Fig. 3 - Breakdown of the water footprint in Belgium attributed to national production (in 10^9 $m^3.yr^{-1}$) (data source: Mekonnen and Hoekstra, 2010).
Fig. 3 - Suddivisione del water fooptint del consumo in Belgio attribuito alla produzione nazionale (10^9 m^3/anno) (fonte: Mekonnen e Hoekstra, 2010)

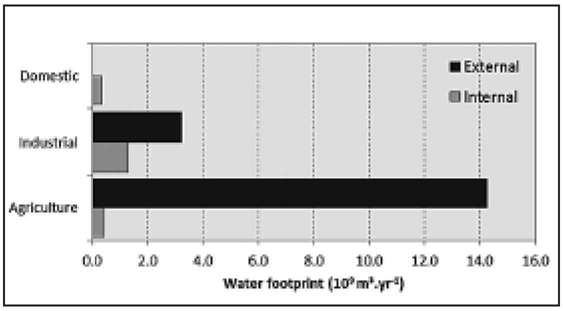

Fig. 2 - Breakdown of the water footprint for consumption in Belgium (in 10^9 $m^3.yr^{-1}$) (data source: Mekonnen and Hoekstra, 2010).
Fig. 2 - Suddivisione del water fooptint del consumo in Belgio (10^9 m^3/anno) (fonte: Mekonnen e Hoekstra, 2010).

The majority of the total water footprint is associated with the consumption of plant and animal products (75% or 3879 litres), while consumption of industrial products accounts for 1199 litres per person per day and domestic use for 93 litres per person per day. The water footprint for consumption is largely connected with imported agricultural products (73%), followed by industrial production (Fig. 2). The figures for agriculture are made of crops and livestock; the latter includes grass, drinking water, and water used for service purposes (such as the cleaning out of stables). Since many crops are used as animal feed, the real impact of raising livestock is underestimated. The crops that contribute to half of the external crop water footprint are mainly wheat, cotton, soya and coffee. The crops that contribute mostly to the internal water footprint are wheat, sugarbeet, barley, potato and maize. The largest water footprint related to livestock is associated with milk production; more than half of the livestock products are imported. Wheat is the import that contributes most to the external water footprint with France as main supplier, followed by Germany and Canada. The second largest contributor, cotton comes mainly from India. Soya and coffee are mainly imported from Brazil.

The water footprint of national production is heavily influenced by industrial production representing 693 litres per day per person representing 41% of the total national footprint. The water footprint of livestock production is 511 litres per day or 30% of the total water footprint, while it amounts to 387 litres per day for crop production or 23% of the total water footprint. Domestic water supply only accounts for a small proportion in comparison (93 litres per person per day or 6%). The breakdown of the water footprint into green, blue and grey shows that the green water footprint is largest for crop production (77%) and livestock production (grazing; 89%), while for industrial production and for domestic water supply the shares of the grey water footprint are the largest with 88% and 79% respectively. Overall this results in a slightly larger share of the grey water (46%) than the green water (44%) to the total water footprint.

The agricultural sector is part of a much broader agro-business complex that includes food processing, bio-energy and bio-based chemistry. With 26.3% or slightly more than 800 km² of the country in 2012, arable cropping constitutes an important element in the Belgian rural landscape; grassland covers another 600 km². The major crops in terms of area are winter wheat, potato, grain maize, sugar beet, winter barley and winter oilseed

Texture	% Sand	% Clay	K_{sat} (mm h^{-1})	Bulk density (g cm^{-3})	Moisture content (vol %) at: Wilting point	Field capacity	Saturation
Loamy sand	82	6	91.3	1.44	5.7	12.1	45.7
Silty loam	8	13	13.9	1.35	10.0	33.0	48.9
Loam	30	25	9.7	1.40	16.4	31.9	47.2

Tab. 1 - Soil variables for the most common soils for arable cropping in Belgium (Saxton and Rawls, 2006). Textures are based on USDA classifications.
Tab. 1 - Variabili del suolo per i principali suoli per le colture seminative coltivate in Belgio (Saxton e Rawels, 2006). Le tessiture sono basate sulla classificazione USDA.

rape. Arable crops in Belgium are predominantly rainfed. The objectives of this study are to quantify the green water footprint and its variability for the major arable crops in Belgium against the wider concepts of the water footprint of national production.

MATERIALS AND METHODS

The green water footprint (WFP_{green}) was calculated for the six major agricultural crops in Belgium using meteorological and yield data series for the 1988-2012 period. The green water footprint is the green component of the water footprint (Mekonnen and Hoekstra, 2010), and reflects the water use per harvested crop.

$$WFP_{green} = \frac{10.\sum_{d=1}^{lgp} ET_d}{Y}$$

Where ET_d is the daily evapotranspiration in mm.day^{-1}, accumulated over the length of the growing period (*lgp*, in days). The factor 10 converts water depths in millimetres into water volumes per land surface. The nominator reflects crop water use in m^3.ha^{-1}, whereas the denominator (Y) is crop yield in tonnes.ha^{-1} as available from the statistics office for the different agricultural zones in Belgium during the 1988-2012 period.

For the most dominant soils per crop (Tab. 1) a regional dynamic crop model geared towards climate impact on biomass production, REGCROP (Gobin, 2010; Gobin, 2012), was run to calculate the daily crop evapotranspiration. Crop growth is simulated from planting dates until the accumulated thermal units equal the required potential thermal units (*PTU* in Tab. 2). The amount of solar radiation intercepted depends on the seasonal distribution of ambient temperature and moisture supply in both soil and atmosphere. Phenological development is confined to crop specific threshold temperatures which form the boundaries of phenological activity. The potential evapotranspiration was calculated according to the

Crop	Surface Area (km²)	Average (t/ha)	PTU (°C)	PET (mm)	soil (Tab.1)
Winter Wheat (WW)	1939 ± 118	8.0 ± 0.9	1700	592 ± 41	SiL & L
Sugar beet (SB)	893 ± 155	66.7 ± 8.6	1800	610 ± 43	SiL & L
Potato (POT)	613 ± 105	44.7 ± 4.7	1350	556 ± 38	LS
Winter Barley (WB)	503 ± 193	7.4 ± 0.8	1450	521 ± 34	SiL & L
Grain Maize (GM)	371 ± 208	10.0 ± 1.7	1300	525 ± 42	LS
Oilseed rape (OS)	66 ± 28	3.6 ± 0.4	1500	639 ± 43	SiL & L

Average area and yield are calculated at national level. PTU is potential thermal units. PET is potential evapotranspiration.

Tab. 2 - Variables related to determining the water footprint of crop production in Belgium. Average and standard deviation are for the period 1988 -2012 (25 years).
Tab. 2 - Variabili utilizzate per la determinazione del water footprint della produzione agricola del Belgio. Media e deviazione standard si riferiscono al periodo 1988-2012 (25 anni).

modified Penman-Monteith algorithm (Allen *et al.*, 1998) from radiation, temperature, wind speed and dew temperature, and varies within the crop growing season and with the year during the period 1988-2012. The crop rooting depth and water retention characteristics determine the maximum available water that can be stored by the soil and the crop determines the amount that is available to the plant.

RESULTS

The computations of crop evapotranspiration required for the estimation of the green and blue water footprint in crop production, were simulated with the REGCROP modelling approach. The dynamic water balance computes a daily soil water balance and simulates crop water requirements and actual crop water use. Since less than 5% of agricultural land in Belgium is irrigated, most of the internal crop water footprint is related to green water, which is the crop water use under rainfed conditions.

The seasonal sum of *PET* is highest for oilseed rape and sugar beet, and lowest for winter barley (*PET* in Tab. 2), and is explained by the growing season length and period of the year. The crop water use requires the modelling of crop daily evapotranspiration during the entire growing season. The maximum evapotranspiration rate is realised when the root zone is well watered and the soil surface is wet. The crop water satisfaction (crop coefficient) follows a growth curve from emergence to scenesence and depends on the crop type, its growth stage and canopy cover (Fig. 4). *Prima facie* winter grown crops such as cereals and rapeseed may have a comparatively larger crop water satisfaction but their growth characteristics such as the presence of dormancy are different from summer grown crops. The growth progress is expressed in percentage of the growing season (Fig. 4) and not in actual length so that shorter crop cycles require less water use. When water supply to the crop roots is insufficient, the actual evapotranspiration is reduced, and a water deficit develops in the crop, i.e. crop water stress, whereby the growth of the crop will be reduced proportionally. These dynamics enable the estimation of the consumptive use of water. The crop water use is largest for sugar beet followed by potato, and smallest for maize.

Yields vary between years and between agricultural regions in Belgium for the different arable crops (Fig. 5). Winter cereals are predominantly grown on loam and silty loam soils where wheat yields are on average 8.2 ± 0.9 ton/ha and winter barley 7.8 ± 0.9 ton/ha during the period 1988-2012, which is higher than the national average for the same period (Tab. 2). More than 60% of sugar beet and 70% of oilseed rape in Belgium is harvested on loam soils with sugar beet yields averaging at 68.3 ± 9.2 ton/ha an oilseed rape at 3.8 ± 0.5 ton/ha. Potatoes are cultivated on slightly sandier soils yielding 46 ± 5

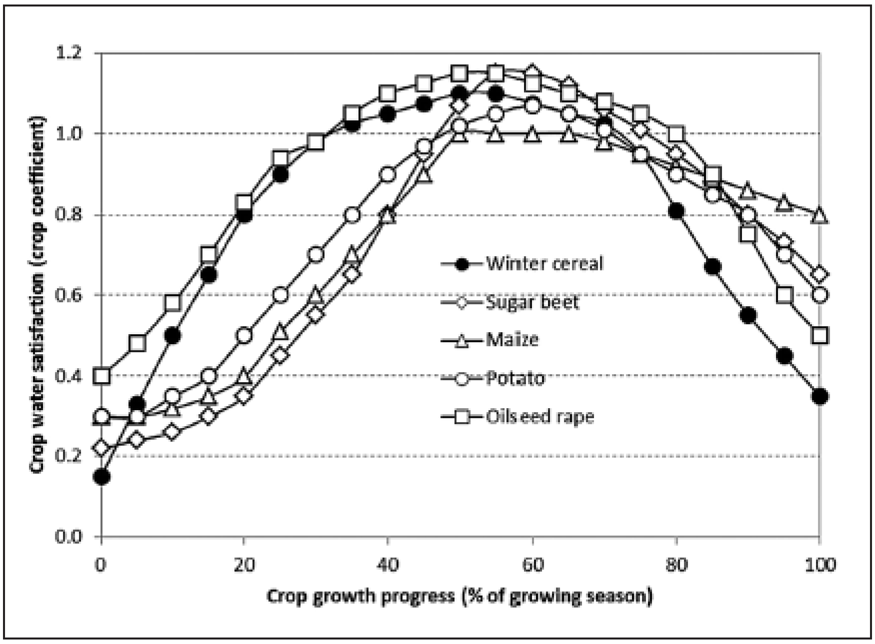

Fig. 4 - Crop water satisfaction (crop coefficient) during the crop growing season for major arable crops.
Fig. 4 - Coefficiente colturale durante la stagione di crescita per le maggiori colture seminative.

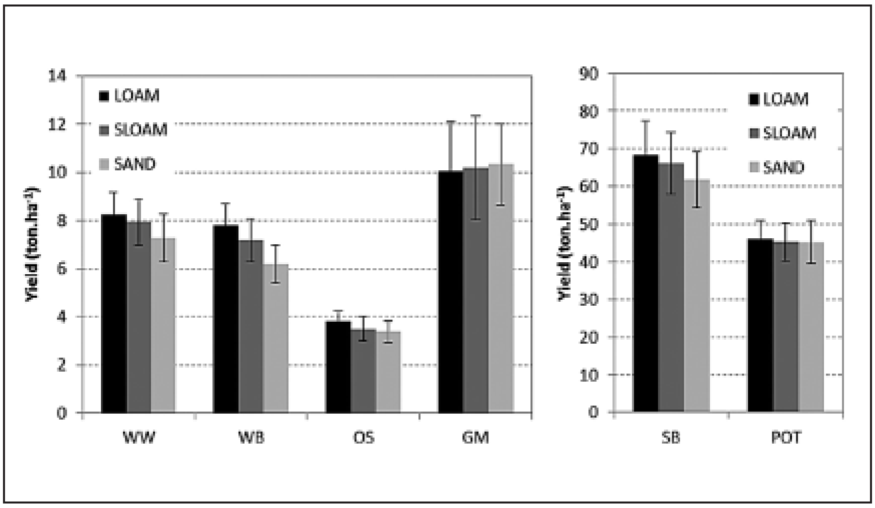

Fig. 5 - Yield variability of six major arable crops for three Belgian regions with contrasting soil textures (in ton.ha^{-1}) for the period 1988-2012. See Tab. 1 for soil characteristics and Tab. 2 for crop abbreviations.
Fig. 5 - Variabilità della resa delle 6 principali colture seminative in tre regioni del Belgio con contrastanti tessiture del suolo (ton/ha) per il periodo 1988-2012. Vedi Tab. 1 per le caratteristiche dei suoli e Tab. 2 per le abbreviazioni delle colture.

ton/ha or 3% higher than the national average. Most of the maize occurs on sandy soils reaching an average yield of 10.3 ± 2.2 ton/ha; the yield variability is largest for maize.
The green water footprint of the six major arable crops, calculated using Eq.1, shows that oilseed has a considerably larger green water footprint as compared to the cereal crops winter wheat and winter barley (Fig. 6). The root crops potato and sugarbeet have the lowest green water footprint owing to the relatively large tonnage of yield per season. The results are very similar to the data provided by Mekonnen and Hoekstra (2010), which is not so surprising since a similar method was used to calculate crop evapotranspiration. The nation wide annual actual water use for the period 1988-2012 is largest for wheat (638.6 ± 19.9 Mm^3.yr^{-1}), followed by sugar beet (341.3 ± 5.8 Mm^3.yr^{-1}) and potato (199.3 ± 7.1 Mm^3.yr^{-1}). The lowest annual actual water use is for oilseed rape (23.3 ± 1.1 Mm^3.yr^{-1}), maize (110.5 ± 14.7 Mm^3.yr^{-1}) and barley (124.7 ± 8.6 Mm^3.yr^{-1}) production in Belgium. The total annual actual water use of arable crop production amounts to 1438 ± 57.3 Mm^3.yr^{-1} or an equivalent 379 litres.day^{-1}.caput^{-1} for the period 1988-2012 representing 50.5% of the total green water footprint of production in Belgium.

DISCUSSION

The results show that there are considerable differences in crop water use, yield and the green water footprint of six different arable crops in Belgium for the period 1988-2012.
The period of the year during which the crop is

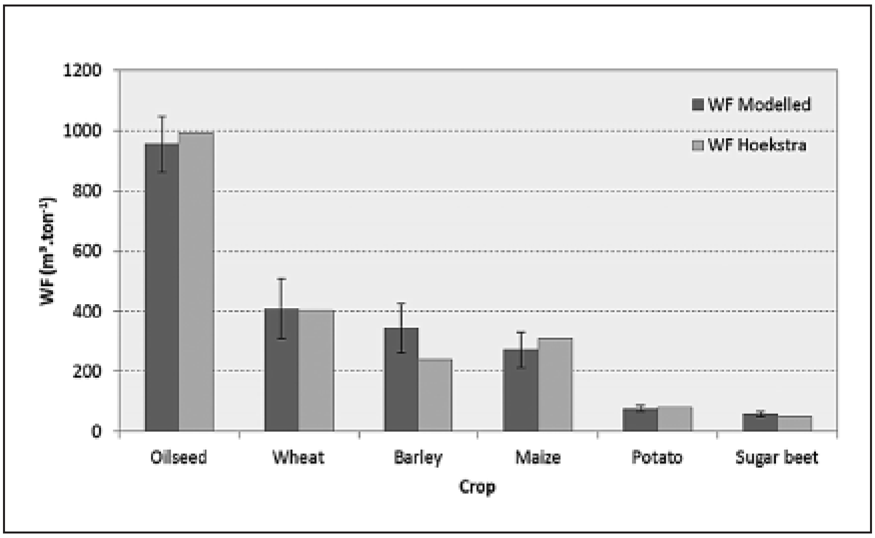

Fig. 6 - The green water footprint of the most important Belgian arable crops (in m^3.ton^{-1}) as modelled with REGCROP and as taken from Mekonnen and Hoekstra (2010).
The uncertainty bars reflect the standard deviation as an indication of variability between 1988-2012.
Fig. 6 - Water footprint verde delle principali colture seminative in Belgio (m^3/ton) simulata da REGCROP e riportata da Mekonnen e Hoekstra (2010). Le barre di incertezza riflettono la deviazione standard come un indicazione della variabilità tra 1988-2102.

grown has a considerable influence on its water use. Rapeseed and cereals are predominantly grown as winter crops and during their growing season temperatures are moderate and rainfall is more available. Sugar beet and potato are grown during the summer period and are in addition highly sensitive to water stress. These dynamics are captured by the crop water satisfaction (Fig.4) and the water balance.

The physical process behind crop water consumption is the process of actual evapotranspiration. The water use is around 200-300 g water transpired per g dry matter produced in C4 crops (maize) compared to usually more than 500 g in C3 crops (the five other crops). The relative difference in water use efficiency is reflected in a lower water footprint for grain maize as compared to other cereals, despite the fact that maize is cultivated during the summer which leads to a higher water consumption. With rising CO_2 concentrations water use efficiencies are reported to enhance in both C4 and C3 crops.

The harvested crop product and its proportion of the total biomass greatly influence the water footprint. Root and tuber crops therefore have a much lower water footprint as compared to grain and seed crops. When taking straw harvest into consideration, the water footprint of cereals is 40 to 45 % lower (own calculations). Harvesting green crops or harvesting a large share of the biomass produce reduces the water footprint further, but largely depends on the marketable product for the food, feed, fibre or fuel chain.

When the same crop is compared for different environments, not only the apparent differences in productivity (Fig. 5) but also the water consumption in the entire agro-ecosystem have important effects on the water footprint. Some crops are deep rooting and offer a better root network to water infiltrating into the soil. A water stress factor that takes into account water availability from deeper soil layers, groundwater contributions or run-on from adjacent fields could alter the water footprint calculations and advocates the introduction of a water-availability-at-the-basin approach to the concept of the water footprint.

The water use under rainfed conditions is limited by drought in Belgium and, consequently, water use drops below the requirements for optimum yield. As a result the irrigated area is increasing particularly for potatoes as a better quality crop can be harvested after adequate water supply during the season. In the majority of cases farmers invest in irrigation for vegetables and potatoes for the fresh market. This trend will necessitate recalculations to include the blue water footprint.

CONCLUSION

The water footprint of national crop production in Belgium is subject to a large variability owing to variability in both crop water use and yield between soils and between years for the period 1988-2012. Since arable crop production is rainfed, the green water footprint of the arable crops can be used as a basis to calculate the water footprint of derived crop products based on product value, fractions and processing steps (Hoekstra and Mekonnen, 2012). The water footprint concept has created awareness of crop water use and sustainable water consumption. To this extent water use and water availability should become more integrated when evaluating cropping systems for their sustainable water use.

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