Water Footprint from Growing Potato Crops in Cuba

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Abstract

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This article determines the water footprint from the potato crop in Cuba between the years 2009 and 2012 using the CROPWAT model. Climate, yields and fertilization data are specific to each of the areas where the crops were grown. The results are compared with previous works in other countries in Latin America and the Caribbean. In the case of Cuba, the results show a difference of 25% with respect to international reports developed with data related to climate and average crops in the country. Other countries in the region have similar levels, although with a smaller gray component and a larger green component. The water footprint from potato crops is also compared with other crops in Cuba, finding that potatoes represent the fourth largest water demand.

Keywords: Water foot print, Cuban agriculture, potatoes crop, water use in agriculture, potatoes crop in Caribbean.

Resumen

Cabello, J. J., Sagastume, A., López-Bastida, E., Vandecasteele, C., & Hens, L. (enero-febrero, 2016). Huella hídrica del cultivo de la papa en Cuba. Tecnología y Ciencias del Agua, *7(1), 107-116.*

En el artículo se determina la huella hídrica de la cosecha de la papa en Cuba entre los años 2009 y 2012 utilizando el modelo CROPWAT. Los datos climáticos, de rendimiento y de fertilización son específicos de cada una de las áreas donde se realiza la cosecha y los resultados obtenidos se comparan con los de trabajos anteriores realizados en otros países de América Latina y el Caribe. En el caso de Cuba los resultados muestran diferencias de un 25% respecto a los obtenidos en reportes internacionales elaborados a partir de datos climáticos y de la cosecha promedios del país. Respecto a otros países de la región tienen niveles similares aunque con menor componente gris y mayor componente verde. También se compara la Huella Hídrica de la cosecha de la papa con la de otros cultivos en Cuba estableciéndose que la papa ocupa el cuarto lugar en demanda de agua.

***Palabras clave**: huella hídrica, agricultura cubana, cosecha de la papa, cosecha de papas en el Caribe.*

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Introduction

Globally the water demand to produce food, supply industries and sustain urban and rural populations increases continuously since many years. Moreover an increasing number of regions in the world face freshwater scarcity (Hoekstra, Mekonnen, Chapagain, Mathews, & Richter, 2012).

Agriculture uses about is responsible for 86% of the world's freshwater use in the world. One of the main challenges of planetary sustainability is to achieve a balance between the increasing demand of water for food production and its social and environmental impacts (Chapagain & Orr, 2009).

Also in Cuba agriculture is the main water consumer with 55% of the total fresh water withdrawals, 63% from surface water and 47% from ground water (ONEI, 2013a). The planning of water use is focussed is on satisfying the water demand, merely by increasing the supply.

The Water Footprint (*WF*) is a comprehensive indicator of water use: "the water footprint is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use". (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011). *WF* assessments have been used finding solutions and contributing to a better management of water resources (Aldaya & Hoekstra, 2010).

Using indicators as the *WF* in Cuba contributes to the evaluation and analysis of the water supply in the country (Garcia & Cantero, 2008). The importance of using indicators for Latin American countries was pointed out by Vazquez and Buenfil (2012).

Potato accounts for about 10 percent of the Cuban production of tubers and roots it is the only fully irrigated crop during the dry season. Potatoes are grown in particular and limited areas, which facilitates the calculation of their *WF*.

This study aims calculating the green, blue and grey *WF* of the potato production in Cuba and its comparison with other crops in Cuba and with *WF* of the potatoes farmed in other Caribbean and Latin-Americans countries in order to identifying its environmental significance for the country.

Materials and Methods

Water Footprint

The *WF* provides a framework to analyse the link between human consumption and the appropriation of the freshwater. It consists of three components: (Mekonnen & Hoekstra, 2010) Blue water: the volume of surface and groundwater consumed as a result of the production of a good or service. Green water: the volume of water evaporated from the global green water resources (rainwater stored in the soil as soil moisture). Grey water: the volume of freshwater required to assimilate the load of pollutants based on ambient water quality standards.

Mekonnen and Hoekstra (2011) ranked countries according to their *WF* during the period 1996-2005. Industrialized countries have a *WF* per capita ranging between 1 250 and 3 550 m^3/year. The United Kingdom shows the lowest *WF* with 1 255 m^3/year, while the United States of America are the biggest water consumers with a calculated *WF* of 2 842 m^3 /year. The *WF* of developing countries varies widely: from 550 to 3 500 m^3/year per capita. The Democratic Republic of Congo with 552 m^3/year shows the lowest *WF*, while Bolivia with 3 500 m^3/year shows the highest value. The Cuban *WF* is estimated at 1 687 m^3/year per capita. Consequently Cuba ranks as number 36 among 208 countries studied. The Cuban *WF* is 21% above the global average which is surprisingly high. Among the 19 Latin American countries, Cuba ranks seventh (Vázquez & Buenfil, 2012).

The main component of the Cuban *WF* is the agricultural production which accounts for 1 519 m^3/year, 90% of the total, 85% of this account (1 305 m^3/year) is internal and result from Cuban resources. The components of the agricultural internal *WF* include: 1 189 m^3/year of green (91%), 74.9 and 41.4 m^3/year per capita blue and grey respectively (Mekonnen & Hoekstra, 2011a and 2011b).

García and Cantero (2008), and Gonzalez (2012) link the high *WF* in Cuba with: 60% of the water is for irrigation, inefficient technology for irrigation, inadequate irrigation planning, climatic factors of the tropics: plenty precipitation and high evaporation, and evapotranspiration and limited crop yield.

Water Footprint of Crops

The *WF* of a crop is the sum of the green, blue and grey amounts of water used for its produc-

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tion. Applied to potatoes in Cuba the following calculation is used (Hoekstra *et al*., 2011).

$$WF = WF_B + WF_G + WF_{Gr} \quad (1)$$

Where: *WF* is the total water footprint of the potato crop (m^3/t). WF_B is the blue *WF* of the potato crop (m^3/t) and WF_G is the green *WF* of the potato crop (m^3/t). WF_{Gr} is the grey *WF* of the potato crop (m^3/t).

The blue and a green *WF* values are calculated by:

$$WF_B = \frac{CWU_B}{Y_P} \quad (2)$$

$$WF_G = \frac{CWU_G}{Y_P} \quad (3)$$

Where: CWU_B is the blue water used (m^3/ha). CWU_G is the green water used (m^3/ha). Y_P is the yield of potatoes (t/ha).

The green and blue water used growing potatoes is calculated by integrating the daily evapotranspiration (*ET*, mm/day) over the growth period:

$$CWU_B = 10 \bullet \sum_{i=1}^{lgp} E_{TB} \quad (4)$$

$$CWU_G = 10 \bullet \sum_{i=1}^{lgp} E_{TG} \quad (5)$$

Where: E_{TB} is blue daily evapotranspiration (mm/day); E_{TG} is green daily evapotranspiration (mm/day); *lgp*-length of growth period (days).

To convert water depth in millimetres into water volume per unit of land (m^3/ha) a factor 10 is used. Evapotranspiration is estimated using the CROPWAT model (Allen, Pereira, Raes, & Smith, 1998) which provides two ways: crop water requirement (CWR), assuming optimal conditions and the irrigation schedule (IS), including the possibility to specify actual irrigation supply in time (Hoekstra *et al*., 2011). CWR is less accurate and simpler than the IS and it is more often used (Chapagain & Hoekstra, 2011).

The "optimal conditions" require that crop evapotranspiration (ET_C) equals CWR, that the harvest is disease-free, that crops are properly fertilized, and grown under optimal soil and water conditions, and achieving a maximal production (Allen *et al*., 1998), maximal yield and the lowest value of the WF_G. Calculating the CWR only needs climate and crop data.

The evapotranspiration is calculated as:

$$ET_C = Kc \times ET_O \quad (6)$$

Where: *Kc* is the crop coefficient, which incorporates crop characteristics and averaged effects of evaporation from the soil. ET_O is evapotranspiration from a hypothetical grass reference grown under conditions of sufficient water availability (mm/day).

ET_C is estimated with a ten day interval and over the total growing season, using the effective rainfall (Hoekstra *et al*., 2011).

The irrigation requirement (*IR*) of the crop is the difference between CWR and the effective rainfall (P_{eff}). The IR is zero if P_{eff} is exceeds the CWR; otherwise is the difference between CWR and P_{eff} is used:

$$IR = \max(0, \text{CWR}-P_{eff}), \text{mm} \quad (7)$$

In case the CWR is fully met by rainfall ($IR = 0$) then its value equals the ET_C. Therefore ET_G will be equal to the minimum value of ET_C, and P_{eff} and ET_B will be equal to zero:

$$ET_C = \text{CWR (mm/day)} \quad (8)$$

$$ET_G = \min(ET_C, P_{eff}) \text{ (mm/day)} \quad (9)$$

In case the CWR is not fully met by rainfall ($IR > 0$), ET_B is the difference between CWR and P_{eff}.

$$ET_B = \max(0, \text{CWR} - P_{eff}) \quad (10)$$

P_{eff} is calculated using the method recommended by Hoekstra *et al*. (2011):

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$$P_{eff} = Pt \cdot (1.25 - 0.2\ Pt\ /125) \quad \text{if } Pt < 250 \text{ mm} \tag{11}$$

$$P_{eff} = 1.25 + 0.1 \cdot Pt \text{ if } Pt > 250 \text{ mm} \tag{12}$$

Where: Pt is monthly accumulated rainfall (mm).

The *Kc* considers the evaporation from the soil and the major factors affecting it are: crop variety, climate and the growth stage. Due to differences in evaporation during the growth stages, *Kc* for a given crop varies during the production period (Chapagain & Orr, 2009). The trends in *Kc* during the growth period are shown in the crop coefficient curve: the initial stage (*Kc* ini = 0.5), the mid-season stage (*Kc* mid = 1.15) and the end of the potato growth (*Kc* end = 0.75).

The Food Agriculture Organization (FAO) defined the duration of these periods (days) for a series of crops (Allen *et al*., 1998). For potatoes are: Initial stage (*L*ini = 25 days), stage of develop (*L*dev = 30 days), middle stage (*L*mid = 30 to 45 days) and final stage (*L*end = 30 days). This provides a total growth period of 115 to 130 days. A regular period to grow potatoes in Cuba is around 100 days, and the stages coincide respectively with: *L*ini = 20, *L*dev = 25, *L*mid = 30 and *L*end = 25 (González, 2012).

The *Kc* curve for potatoes harvested in Cuba is compared with the FAO data in figure 1, the period of the potato crop cycle in Cuba is shorter than that the FAO reported and *Kc* values are different in the development and final. Table 1 are shown the *Kc* values for potatoes crop in Cuba.

The reference crop evapotranspiration (ET_O) values are taken from Mendez, Solano, and Ponce (2012). In Cuba the annual ET_O shows a normal distribution, which is common in tropical and subtropical areas. ET_O behaves as in subarid zone during half a year and during the other half as in the arid subtropics.

Figure 2 shows that the annual average distribution of the ET_O in Cuba behave not

Table 1. Crop coefficient (*Kc*) values for potatoes harvested in Cuba. Source of data: own production.

Period	Days (di)	*Kc* (crop coefficient)
Initial	1 to 20	0.5
Develop	21 to 45	0.5 + 0.04 (di – 20)
Middle	46 to 75	1.5
End	76 to 100	1.5 – 0.03 (di – 75)

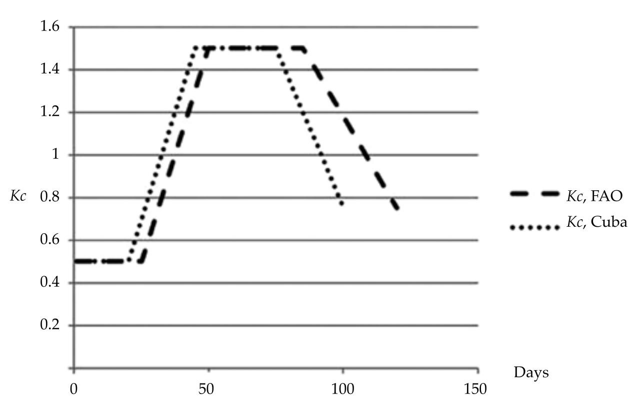

Figure 1. Crop coefficient curve. Source of data: Allen *et al*. (1998), González (2012).

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Figure 2. Average of the ET_O distribution in Cuba. Year 2005. Source of data: Mendez *et al*. (2012).

homogeneously throughout the country and decreases from east to west. Table 2 shows the average monthly ET_O values in the western and central regions of Cuba estimated using the Penman-Monteith equations.

The WF_{Gr} is an indicator of freshwater pollution caused by growing potatoes, it is the water required to dilute the contamination by fertilizers and pesticides, until the concentrations do not exceed the regulatory defined maximum permissible levels (Hoekstra *et al*., 2011).

The grey component in the WF_{Gr} is calculated as:

$$WF_{Gr} = \frac{1}{Y} \cdot \left(\frac{\alpha \cdot AR}{C_{\max} - C_{\text{nat}}} \right) \left(\text{m}^3/\text{t} \right) \quad (13)$$

Where: AR is Chemical application rate of fertilizer or pesticides (kg/ha); α is leaching-runoff fraction; $C_{\max}$ is maximum acceptable concentration (kg/m^3); C_{nat} is natural concentration of the pollutant (kg/m^3); Y_P – Crop yield (t/ha).

Potato Crops in Cuba

Potatoes in Cuba are grown in the western and central regions of the country (figure 3). These areas are characterized by temperatures, ranging between 18 and 28 °C during the dry season, which is the growth period for this crop. Consequently its production necessitates irrigation (González, 2012).

Table 3 shows the production and yield of potatoes in Cuba during the period 2009-2012.

The yearly yield of potatoes in Cuba averages 19 t/ha, which exceeds the world average of 16 t/ha, but is far from the highest yields: Netherlands (45.8 t/ha), United States (40.6 t/ha), Germany (40.5 t/ha) and the UK (40 t/ha) (Infoagro System SL, 2011).

Cuba has two seasons: a dry one from November to May and a rainy season from May till October. Potatoes are planted between November 20 and December 30. They are harvested by March. Table 4 shows the monthly average

Table 2. Average monthly by region in Cuba, 1960-2000. Source of data: Pacheco, Domínguez and Lamadrid (2006).

Month	**ET_o (mm/day)**		**Month**	**ET_o (mm/day)**	
	West	**Central**		**West**	**Central**
January	2.9	2.5	July	5.1	4.5
February	3.6	3.1	August	5.3	4.1
March	5.0	4.0	September	4.4	3.9
April	6.3	4.5	October	4.1	3.1
May	6.2	4.3	November	3.7	2.7
June	5.5	4.2	December	3.7	2.2

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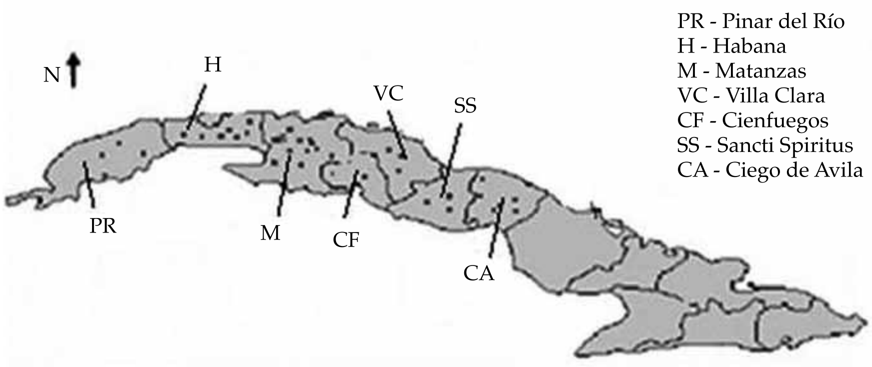

Figure 3. Distribution of potatoes harvest in Cuba. Source of data: Gonzalez (2012).

Table 3. Yearly production and yield of the potatoes in Cuba by provinces. Source of data: ONEI (2013a).

Province		Years				
		2009	**2010**	**2011**	**2012**	**Average**
Pinar del Río	Production (t)	5 900	3 700	2 200	-	3 933
	Yield (t/ha)	24.1	18.7	20.2	-	21
Habana	Production (t)	125 900	87 100	69 700	64 400	94 233
	Yield (t/ha)	20.6	19.1	18.6	20.1	19
Matanzas	Production (t)	52 100	42 900	36 300	26 600	43 767
	Yield (t/ha)	21.0	12.5	17.1	18.6	17
Villa Clara	Production (t)	19 100	15 900	13 600	10 000	16 200
	Yield (t/ha)	24.6	11.8	21.2	22.2	19
Cienfuegos	Production (t)	19 000	10 100	10 500	6 300	13 200
	Yield (t/ha)	23.9	16.8	21.1	22.4	21
Sancti Spiritus	Production (t)	7 000	3 400	3 300	3 200	4 567
	Yield (t/ha)	26.8	16.2	19.8	19.2	21
Ciego de Avila	Production (t)	53 400	32 000	31 700	20 200	39 033
	Yield (t/ha)	20.3	14.4	17.6	21.9	17
Total	Production (t)	282 400	195 100	167 300	130 700	214 933
	Yield (t/ha)	23.0	15.6	19.4	17.8	19

rainfall for the different provinces where potatoes are grown.

Results and Discussion

For this study December 10th has been chosen as the date when potatoes are planted. December 10th is the median between November 20 and December 30. An estimated 100 days later, on March 20 the potatoes are expected being harvested (Gonzalez, 2012).

Blue and Green Water Footprint

The evaporation is calculated on a day-by-day basis, whereas the rainfall is calculated over longer periods. The CROPWAT model (Allen *et al.*, 1998) assumes that the mean monthly rainfall

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Table 4. Average monthly rainfall in the potato season in Cuba. Source of data: ONEI (2013b).

Province	Average monthly rainfall (mm)			
	January	February	November	December
Pinar del Río	46.95	39.35	67.95	42.83
Habana	130.35	53.30	71.25	70.70
Matanzas	43.30	47.83	39.55	14.75
Villa Clara	65.30	76.03	110.65	53.23
Cienfuegos	78.18	41.20	39.60	51.93
Sancti Spiritus	40.90	59.65	87.63	58.93
Ciego de Avila	13.08	44.88	50.30	20.13

occurs during a six days interval events and that the rain is uniformly distributed over the month. Several studies use ten days intervals to calculate the effective rainfall and the irrigation needs (Hoekstra *et al*., 2011). In this study a 5 day interval is used, in analogy with the work of Aldaya and Hoekstra (2010).

The results of the average WF_G and WF_B for the last four years in the different Cuban provinces, are shown in table 5. The average value of the WF_G is 104.45 t/m^3, a 30% higher than the WF_B, but has less variability over the provinces with a mean standard deviation of 22.12 against 32.5 of WF_B.

Despite potatoes are grown during the dry season (winter), the average rainfall contributes 64% to the CWR. The WF_G is about 30% higher than WF_B.

Grey Water Footprint

Nitrogen is used as an indicator for the impact of fertilizers and pesticides on the WF_{GR} evaluation (Chapagain & Hoekstra, 2011). The amount of nitrogen that reaches the water bodies is assumed to be 10% of the amount of fertilizer applied. The recommended maximum value of nitrate (NO_3) per liter in surface and groundwater, according to the World Health Organization and the European Union, is 50 mg of nitrate per liter and according to the US-EPA is 10 mg per liter (Mekonnen & Hoekstra, 2010). In Cuba there is a permissible standard of 50 mg of NO_3 per liter (Gonzalez, 2012). In this study a naturally occurring concentration of 4 mg nitrate for litter is used (Betancourt, Suarez, & Jorge, 2012).

Table 5. WF_G and WF_B for potatoes crop in Cuba by province. Average 2009-2012.

Province	Et_c	P_{eff}	IR	ET_G	ET_B	WF_G m^3/t	WF_B m^3/t
	mm/period	mm/period	mm/period	mm/period	mm/period		
Pinar del Río	392.9	198.8	194.1	198.8	194.1	94.6	92.4
Habana	392.9	344.3	48.5	246.4	116.4	145.5	61.3
Matanzas	392.8	150.9	241.9	150.1	241.1	88.8	142.3
Villa Clara	320.5	303.3	17.2	263.8	56.7	138.8	29.8
Cienfuegos	320.5	224.9	125.1	195.4	125.1	93.0	59.6
Sancti Spiritus	320.5	244.3	108.7	211.8	108.7	100.9	51.7
Ciego de Avila	320.5	125	195.5	124.9	195.5	73.5	115.0
Cuba	351.5	242.9	130.9	204.3	147.2	104.5	78.6

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To grow potatoes in Cuba between 120 and 160 kg of fertilizer per ha is recommended (Gonzalez, 2012). This research uses a value of 140 kg/ha.

Table 6 shows the values of the WF_{GR} for the last four years in the provinces where potatoes are grown.

The WF_{GR} values have a low variability because the fertilizer application is implemented according to recommendations by the national planning.

Comparison of the WF *of Potato with the* WF *of other Crops in Cuba*

The mean value of crop potatoes *WF* for the period 2009-2012 in Cuba is 202 m^3/t. Table 7 shows the comparison between the results obtained in this study and the reported by Mekonnen & Hoekstra (2011) for potatoes crop and others selected crops in Cuba. Also a result reported by Carmona (2010) about the WF_{Gr} for potatoes grown in Cuba is shown.

The different between values confirm the point raised by Herath (2013) about the need for more accurate measurements and calculations of the *WF* prior to its use as an effective tool to manage sustainability locally.

The *WF* of potatoes in Cuba is smaller than this of most other crops reported by Mekonnen & Hoekstra (2011a and 2011b). Differences amount to a factor 15 in comparison with sugar cane. This is mainly related with the lower values of the WF_G because potatoes are a dry season crop. On the contrary, potatoes show higher blue water values than half of the other crops, mainly because all production areas are irrigated. Potatoes show also high grey water values highlighting the environmental significance of this assessment. Cuban agriculture is subject to over fertilization, despite the financial problems of the country and the transition towards an ecological agriculture.

Table 8 shows that the WF_G values are similar in these countries with similar climates. Also the WF_B should show similar values, but more blue water is consumed in Jamaica, Cuba and Mexico. The WF_{GR} shows the highest value in Jamaica where a lot of fertilize (1.5 t/ha), while the lowest value is recorded in Haiti where the fertilizer use is minimal (an application rate of 1.5 t/ha) (Carmona, 2010). Nevertheless, both

Table 6. Average WF_{GR} of potatoes, 2009-2012.

Province	PR	H	M	VC	Cf	SS	CA	Cuba
WF_{GR} (m^3/t)	16.56	17.90	20.62	18.12	16.88	16.62	19.95	17.99

Table 7. Comparison between the WF of potato and other crops in Cuba.

Crop	WF_G[1] (m^3/t)	WF_B[2] (m^3/t)	WF_{GR}[3] (m^3/t)	WF[4] (m^3/t)
Potatoes (this study)	105	79	18	202
Potatoes (Carmona, 2010)	-	-	47.9	-
(Mekonnen & Hoekstra, 2011)				
Potatoes	70	75	5	150
Rice	2 235	214	152	2 601
Sweet potatoes	943	9	0	952
Sugar cane	2 814	394	17	3 225
Soya beans	1 998	55	17	2 409
Tomatoes	310	88	250	648
Roots others	857	1	0	858

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Table 8. Comparison of the yield and the *WF* of potatoes in some countries. Source of data: FAO (2012); Mekonnen and Hoekstra (2011a and 2011b).

Country	WF_G (m³/ha)	WF_B[2] (m³/ha)	WF_{GR} (m³/ha)	*WF* (m³/ha)	Yield (t/ha)	WF_S[6] (m³/t)
Mexico	128	102	32	150	27.8	5.4
Costa Rica	193	5	54	262	24.9	10.5
Dominican Republican	152	8	27	252	22.3	11.3
Cuba (this study)	105	79	18	202	19.0	10.6
Jamaica	114	25	93	232	14.2	16.3
Haiti	131	2	6	139	12.5	25.4

countries obtain similar yields. The other countries in table 8 show WF_{GR} values in between those of Jamaica and Haiti, while they realize higher yields. Finally, the WF_S values show that Mexico consumes the least amount of water per ton of produced in Costa Rica, Dominican Republic and Cuba consume similar amounts of water; and Jamaica and Haiti show the highest consumption.

Conclusions

This study evaluated the *WF* of potatoes in Cuba, it shows that despite potatoes are harvested is in dry season and grown in irrigated areas exclusively, the rain could meet on average more than 60% of crop demand. Also is the crop with less difference between WF_G and WF_B.

The *WF* of potatoes in Cuba is less than in countries like Costa Rica and the Dominican Republic, although *WFs* are similar, the WF_{GR} is much smaller achieving a more efficiency in fertilize use.

The significant differences between the results of the *WF* based in local Cuban data and reported in international studies highlight the importance of local studies for the implementation of more sustainability management of agriculture.

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