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Article

Green and Blue Water Footprint Accounting for Dry Beans (*Phaseolus vulgaris*) in Primary Region of Mexico

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Abstract: Water shortages are a key obstacle to the sustainable supply of food to the world population, since agriculture has the largest consumptive water use. The Water Footprint (WF) has been developed as a useful tool to assess the contribution of goods and activities to water scarcity. This concept is being used around the world to improve agricultural water management. This paper analyzes climate data in order to estimate green and blue WFs for dry beans in the dry beans primary region of Mexico under both irrigation and dryland conditions. The quantification of green WF is very important in this area, since 95% of the crop is obtained in dryland conditions. Standard methodology was used to assess the crop WF. Five different sowing dates were considered: two for irrigation (15 April and 15 May) and three for dryland (1 and 15 July and 1 August). It was found that the optimum sowing date for dryland conditions is 1 August, with a WF of 1839 $m^3 \cdot Mg^{-1}$ (1 Mg equal to 1000 kg) in the sutheastern part of the region; nevertheless, results show that the largest green water availability occurs around the first days of July. Under irrigated conditions the best sowing date is 15 May, with a decrease in crop evapotranspiration of 10.1% in relation to 15 April; which means a reduction of 36.1% of blue water use in the northwestern region mainly.

Keywords: dry beans; green and blue water footprint; crop water use

1. Introduction

Increasing world population brings about environmental problems, such as resource scarcity, pollution, erosion, and deforestation. In the particular case of water resources, a struggle has been triggered among farmers, industries and households: these sectors require more and more water in order to satisfy increasing demands. Agriculture stands as the largest consumptive water user worldwide: it needs massive amounts of water to produce agricultural products. When it comes to producing crops under water stress conditions, detailed analyses are required to characterize water requirements (evapotranspiration losses and water use efficiency) and water availability. Such analyses have been reported to lead to improvements in agricultural water management policies [1] by implementing strategies to reduce effects that on environmental resources could provoke people, organizations and products since it is critical for sustainability [2]. In this sense, standard indicators have been developed to evaluate human demand on natural resources. Hoekstra *et al.* [3], based on the studies of virtual water (VW) performed by Allan [4], laid out the concept of water footprint (WF). This term can be defined as the total volume of freshwater used during the production and consumption of goods and services, measured at the place where the product was actually produced [5,6].

For any well-defined group of consumers or producers, WF can be calculated as the sum of the water used along the full production chain. WF was established as a multi-dimensional indicator, allowing the geographical and temporal water consumption evaluation by source [3,7]. Water consumptive use is measured in terms of the water volume consumed (evaporated) and/or polluted per unit of time; as a consequence, WF has been split into three components (green, blue, and grey water). Green water (the portion of rainfall that is stored as moisture in the soil [8]) and blue water (surface and groundwater) refer to consumption/evapotranspiration during the production of a good; grey water quantifies the volume of freshwater that is required to assimilate the load of pollutants based on local environmental water quality standards [9]. Regarding crop production, an accurate knowledge of crop water requirements (CWR) during all phenological stages is called for in order to reach optimal yields. For a specific crop, CWR mainly depend on the climatic conditions [10] of the zone where the crop is established. CWR are usually computed from crop evapotranspiration (ET_c) [11], and account for the net water depletion produced by the crop. Once crop evapotranspiration is calculated, it is possible to estimate the green and blue water components contribution to crop growing. Recognizing rainfall as the only source of water for dryland conditions, it is critical to identify the optimum growing period for the crop: when the expected water deficit is minimized. Following this view, WF expresses the water needed to produce a crop, but also the optimum period of the year to grow it.

To understand the water use impacts of crops grown all through the world, agricultural products, such as cotton, wheat, tomato, coffee and rice, have been assessed following the WF methodology. Aldaya and Hoekstra [7] determined WF for wheat, tomato and mozzarella cheese production, as the main ingredients to make pasta and pizza, two of the most important dishes for the Italian diet. Concerning water use in Italy, the authors concluded that: (a) agriculture uses about 72% of the WF in terms of green and blue water; (b) the average production of tomato and wheat are about 7.4 and 6.8 million $Mg \cdot year^{-1}$, using 30% of the total water resources; and (c) per capita consumption of these crops is 150 and 62 $kg \cdot year^{-1}$, respectively, as well as 77% of households consume mozzarella cheese (58% of them consume it at least once a week). The average world production of tomatoes (between

2000 and 2010), about 130 million Mg·year^{-1} [1], was used to estimate its WF. Chapagain and Orr [12] stated that just in Spain the annual water consumption to cultivate 4 million Mg·year^{-1} of this vegetable is 297 Mm^3, from which 18%, 81%, and 1% correspond to green, blue, and grey water, respectively. Besides, these authors reported that this country exports 957 million Mg·year^{-1} of tomatoes to other countries of the European Union, equivalent to 78 Mm^3·year^{-1} of consumed water. Bulsink *et al.* [13] assessed water use for agricultural products, such as rice, coconut, corn, and coffee. These authors reported that Indonesia used 335 Gm^3·year^{-1} in these crops, from which 80% of the water requirement was satisfied by rainfall (green water), and 15% by blue water allocations. Only 5% of the water was used to cover the grey water. In Mexico, Farrel *et al.* [2] assessed wheat WF; they found that the grey water component represented the largest share (10,311 m^3·Mg^{-1}), while blue and green water only represented 1140 and 72 m^3·Mg^{-1}, respectively. In the same country, wheat WF was evaluated by other researchers [9,14], with estimates some eleven times smaller than those of Farrel *et al.* [2]. These studies did not consider the global irrigation efficiency of 36% in the Mexican irrigation districts where wheat is typically grown.

The diet of the low-income Mexican population is based on three staple crops: corn, chili and dry beans. Beans combine high protein content and the relatively easy access when compared to alternative protein sources. Relevant surface and groundwater water resources are allocated to irrigated agriculture in Mexico. However, this water is used to irrigate cash crops. Consequently, dry beans are commonly grown under rainfed conditions, a fact that causes a large temporal and spatial variability on crop yield, as these parameters depend mostly on the precipitation received during the crop season [15]. Since dry beans have been established as a mostly rainfed crop, by obtaining the WF it would be possible to apply policies to improve water resources management. WF varies depending on the sowing date, as climatic conditions change with time and space. If WF of dry beans can be obtained for different sowing dates, a major certainty can be provided in terms of crop yield [2]. The global production of dry beans is about 15 million Mg·year^{-1}. This means about 1% of the global crop production WF [16]. Regarding the production of this crop in Mexico, it amounts to 1.05 million Mg·year^{-1}. The Mexican Government considers dry beans as a traditional and strategic product to develop the countryside, since Mexicans are one of the six most important world consumers [15]. Furthermore, the per capita bean consumption is around 13 kg·year^{-1}, which requires a production of 14,300 Mg·year^{-1} [17]. Consequently, this legume is the third largest crop for Mexico, just after corn and sorghum, and represents 7.17% of total farm production. Moreover, dry beans represent 15.3% of the national production if compared with basic grains (corn, rice, and wheat). Another important fact is that 36% of the total production is for self-consumption. This means that dry beans is both a basic product for Mexican diet and an economic activity supporting the development of the country.

In Mexico, this crop is mainly produced under dryland conditions. The primary region of Mexico (DBM) produces about 95% of dry beans production; this fact leads farmers to look for best conditions that rainfall could provide. The geographical location of this zone provokes that potential evapotranspiration is higher than precipitation. Therefore, crop yield is almost always lower than potential. It is important for farmers to identify the sowing time assuring the highest WF for the regional climate.

This article sets out to characterize the WF of dry beans produced in the Primary Region of Mexico (DBM, see Section 2), as a tool to assess the crop freshwater use. Four objectives were pursued: (a) to analyze local climate using data from weather stations monitored by the Mexican government; (b) to determine crop evapotranspiration and effective precipitation; (c) to estimate the green and blue water fooprints of dry beans; and (d) to define the optimum sowing date in dryland conditions.

2. Materials and Methods

Between 20 and 23 Mha are anually farmed in Mexico, from which 16.4 to 18.9 Mha are rainfed land, while irrigation is applied on 3.6 to 4.1 Mha [18]. Dry beans are cultivated in 12% of the total of agricultural land. Most of this area is rainfed (1.6 Mha), while only 0.3 Mha is irrigated. The current yields are 0.53 $Mg \cdot ha^{-1}$ and 1.53 $Mg \cdot ha^{-1}$ for rainfed and irrigation conditions, respectively [19]. Factors such as crop genetics, soil physics, fertilizer use, and water stress affect crop production [20]. Tyagi *et al.* [21] noticed that in irrigated agriculture, corn and berseem yields and quality were affected by poor water supply and by unsuited, anarchical irrigation schedules. Therefore, understanding the evolution of ET_c through the crop season in order to calculate crop water requirements can help to improve irrigation management. Dry beans are grown all over the country during spring-summer season (1.45 Mha cultivated); the main producers are the states of Zacatecas, Durango, and San Luis Potosi (DBM). In Fall-Winter season (0.27 Mha cultivated), the main producers are Chiapas, Nayarit, Veracruz and Sinaloa.

2.1. Study Area Delimitation

This research was conducted in the dry beans primary region of Mexico (Figure 1), which is located in the Northern region of the country between extreme geographical coordinates 21°30′30.7″N latitude and 100°25′22.5″W longitude, and 21°30′32.6″N latitude and 100°25′23.5″W longitude. The climate is semiarid, with minimum and maximum mean monthly temperatures of 6.5 °C (December and January), and 29.6 °C (May), respectively. Average annual precipitation is approximately 350 mm, of which 80% occurs from June through September.

Dryland crop area in the region is as follows: in the northwestern region, 153,857 ha; in the central region 273,251 ha; and in the southeastern region 59,736 ha. The irrigated crop area is 3131 ha in Durango; 8311 ha in Zacatecas; and 6225 ha in San Luis Potosi [22]. Producers choose a specific sowing date according to regional customs; farmers who irrigate tend to sow as early as possible to take advantage of the market (high prices for early producers). Sowing dates range from 15 April to 15 May. Farmers who do not irrigate wait for the best opportunity that precipitation can provide, choosing the sowing date empirically after the first significant rainfall. The sowing period oscillates between 1 July and 1 August. WF was estimated taking into account the entire crop area (for each one of the considered sowing dates), not considering the natural time variability among specific farms. Average yields for DBM are: Durango, 0.64 $Mg \cdot ha^{-1}$; Zacatecas has 0.59 $Mg \cdot ha^{-1}$ and San Luis Potosi 0.42 $Mg \cdot ha^{-1}$ for dryland conditions. As for irrigation the values are 1.50 $Mg \cdot ha^{-1}$, 1.72 $Mg \cdot ha^{-1}$ and 2.11 $Mg \cdot ha^{-1}$ in the same order [17].

Figure 1. Area of dry beans primary region of Mexico. Source INEGI 1997 [23].

2.2. Blue and Green Water Footprints

This study evaluates the volume of green and blue water utilized in dry beans production following the methodology proposed by Hoekstra *et al.* [3]. The fraction of WF corresponding to green and blue water components of a certain crop can be obtained from Equation (1). The research skips the calculation of grey water, since most dryland Mexican producers of DBM do not use fertilizer to improve yields (mainly for economic reasons). Consequently, local soils do not need leaching to eliminate the pollution originated by these agrochemicals [24].

$$WF = WF_{green} + WF_{blue} \tag{1}$$

where WF_{green} and WF_{blue} ($m^3 \cdot Mg^{-1}$) are the green and blue water footprints during the crop season, respectively. These values are computed as the ratio between crop water use (CWU, $m^3 \cdot ha^{-1}$) and average crop yield (Y, $Mg \cdot ha^{-1}$). The Mexican Goverment has implemented a statistical program for monitoring qualitative and quantitative annual agricultural indicators. This program is called Agricultural, Food and Fisheries Information Service (SIAP) [19]. SIAP data for the period 2006–2009 were used to estimate WF. In irrigated conditions, it is possible to satisfy the entire CWR with both PEF (green water) and irrigation water (blue water). In this sense, CWR is entirely covered, so that, for this case it can be assumed that CWU is equal to ET_c and the planted area. In this case both footprints, blue and green, are present, since the fraction of water that is not satisfied by rainfall is taken from a surface or groundwater source. In dryland conditions, CWU is typically lower than ET_c, as the only water source is green water, which usually is not enough to satisfy crop water requirements.

In arid and semiarid regions, where rainfall is not enough to satisfy crop evapotranspiration, the missing water volume is fulfilled with blue water component if available. This amount of water is the net irrigation water requirements (NIWR, $m^3 \cdot ha^{-1}$), determined as the difference between CWU and effective precipitation (PEF, $m^3 \cdot ha^{-1}$). Effective precipitation is the portion of total precipitation that is retained by the soil so that it is available for crop production [1]. Hoekstra *et al.* (2011) [3] indicate that green water evapotranspiration (ET_{green}) can be equated to the minimum of ET_c and PEF (Equation (2)), while blue water evapotranspiration (ET_{blue}) is the result of ET_c minus PEF in the analyzed period, but it will take a zero value if PEF is larger than crop evapotranspiration (Equation (3)).

$$ET_{green} = \min(ET_c, PEF) \quad (2)$$

$$ET_{blue} = \max(0, ET_c - PEF) \quad (3)$$

2.3. Dry Beans Evapotranspiration (ET_c) and Crop Coefficients (K_c)

ET_c is calculated as the product of reference evapotranspiration (ET_0) and a crop coefficient (K_c) [11]. K_c varies along the crop phenological development, *i.e.*, K_c can be plotted as a function of time during the crop season. Different methodologies have been proposed to determine K_c curves. The Food and Agriculture Organization of the United Nations (FAO) proposed defining four phenological stages (initial, development, mid-season, and late or final stages), estimating three K_c values (at the initial, K_{cini}; mid-season, K_{cmid}; and late-season, K_{cend}), and connecting straight line segments through each of the four growth stages [11]; horizontal lines are drawn through K_c in the initial and mid-season stages, while diagonal lines are drawn from K_{cini} to K_{cmid} within the course of the development stage and from K_{cmid} to K_{cend} within the course of the late-season stage. The K_c curves and length of stages recommended by FAO [11] for dry beans were used in this work to estimate the K_c values. The K_c values used for initial season, mid-season and late season were $K_{cini} = 0.40$, $K_{cmid} = 1.15$, and $K_{cend} = 0.35$, respectively, with lengths of 40 days for initial stage, 25 days for development stage, 25 days for mid-season stage, and 30 days for late stage.

2.4. Reference Evapotranspiration (ET_0)

Several methodologies can be found in the literature to estimate ET_0. However, the most widely accepted one is the proposal by Allen *et al.* [11], which is based on the application of the Penman-Monteith equation (Equation (4)), which involves factors, such as net radiation, soil heat flux, vapor pressure deficit of the air, mean air density at constant pressure, specific heat of the air, slope of the saturation vapor pressure temperature relationship, psychrometric constant, surface, and aerodynamic resistances.

$$ET_0 = \frac{0.408D(R_n - G) + g\frac{900}{T+273}u_2(e_s - e_a)}{D + g(1 + 0.34u_2)} \quad (4)$$

where ET_0 is reference evapotranspiration (mm·day^{-1}); R_n is net radiation (MJ·m^{-2}·day^{-1}); G is soil heat flux (MJ·m^{-2}·day^{-1}); T is average air temperature at a height of 2 m (°C); u_2 is air speed at a height of 2 m (m·s^{-1}); $e_s - e_a$ is vapor pressure deficit of the air (kPa); D is the slope of the curve of the saturation vapor pressure temperature relationship (kPa·°C^{-1}); and g is psychrometric constant (kPa·°C^{-1}). The National Research Institute for Forestry, Agriculture and Livestock of Mexico (INIFAP) monitors the variables mentioned previously and processes these data in order to obtain the corresponding ET_c.

A network composed of 35 automated weather stations (Figure 2) located within the area of study was used to measure daily rainfall, daily average wind speed at 2 m above ground, daily average relative humidity, daily minimum and maximum air temperature, and daily total solar radiation. The weather stations are monitored by the Experimental Fields of INIFAP: Zacatecas [25], Durango [26] and San Luis Potosí [27]; the weather information corresponds to a period from 2006 to 2011. These data were used to estimate ET_0 by the FAO Penman-Monteith method [11].

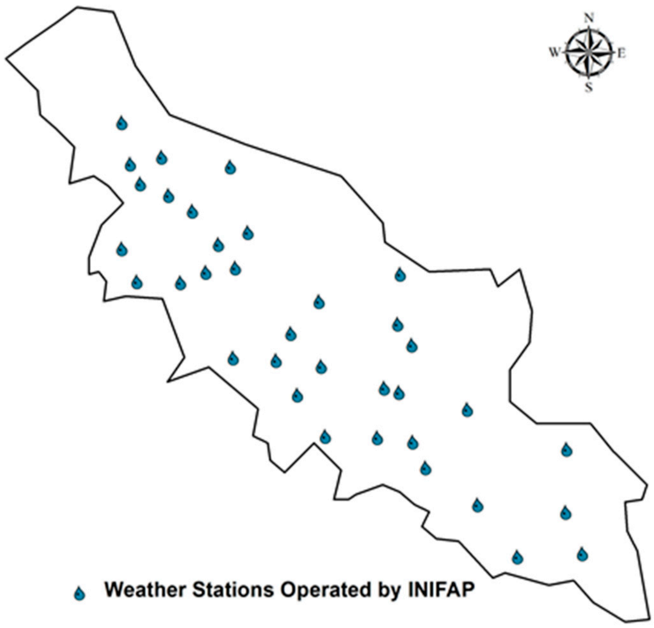

Figure 2. Weather stations of dry beans primary region of Mexico. Source INIFAP 2011 [25–27].

2.5. Irrigation Net Dry Beans Water Requirements

The net irrigation water requirements for dry beans were determined from Equation (3). Daily values were used for the variables above in this research. ET_c and PEF were estimated as follows:

$$ET_c = \sum_{i=t}^{T_s} K_{ci} ET_{0\_i} \quad (5)$$

where ET_{0_i} (mm) is the reference evapotranspiration for day i; K_{ci} is the crop coefficient for day i; t and T_s are the first and last day of the considered period.

$$PEF = 0.75P_s \quad \text{if } P_s > 0.2ET_{0\_s}$$
$$PEF = 0.00 \quad \text{if } P_s \geq 0.2ET_{0\_s} \quad (6)$$

where P_s (mm) and ET_{0_s} (mm) are precipitation and reference evapotranspiration, respectively, for the considered period [28].

In irrigated systems, at least two efficiency parameters must be considered: conveyance efficiency (E_c) and application efficiency (E_a). These parameters permit to assess the potential and/or actual effectiveness of water use by a given system. E_c is defined as the ratio of the volume of water delivered for irrigation to the volume of water placed in the conveyance system [29,30]. E_a can be estimated using the definition by Howell [31]: the ratio between irrigation needed by the crop and water applied to the field. The product of E_c and E_a results in the global efficiency (E_g). The gross irrigation depth (mm) can be calculated as follows:

$$\text{IGD} = \frac{\text{ET}_{\text{blue}}}{\text{E}_{\text{g}}} \quad (7)$$

Several investigations have been performed to estimate the global efficiency in different irrigation zones of Mexico. According to the outcomes obtained in the mentioned works, the global efficiency is between 40% and 60% [32].

2.6. Mapping Parameters to Calculate WF

In order to prepare WF maps of ET_c, precipitation and total water depth, Cartesian coordinates were assigned to each weather station and climatologic information was concatenated with ArcGis 10.2 software. The ordinary Kriging interpolation technique was used with a spherical semivariogram model. These maps allow characterizing the spatial variability of reference evapotranspiration (ET_0), rainfall and total water depth.

3. Results and Discussion

The average meteorological conditions from 2006 to 2011 between April and November are presented in Figure 3, covering the 35 weather stations used in this research. Average air temperature was 18.4 °C; minimum and maximum air temperature values were 10.4 °C and 26.7 °C. Vapor pressure deficit (VPD) ranged between 0.38 and 1.98 kPa, with an average value of 1.27 kPa. Average wind speed was 6.7 $m \cdot s^{-1}$. Monthly ET_0 ranged between 113.4 and 198.1 $mm \cdot month^{-1}$ in the study period. Daily average ET_0 was 5.03 $mm \cdot day^{-1}$. The total average rainfall was 358.3 mm. The minimum and maximum average rainfall were 3.5 $mm \cdot month^{-1}$ in November and 94.5 $mm \cdot month^{-1}$ in September. A large share of precipitation occurred from June to September (88.6%). Figures 4 and 5 present the time evolution of average ET_0 from April to November (covering the crop season). According to information plotted in Figure 4, the lowest ET_0 values were found between the months of September and November (75–120 $mm \cdot month^{-1}$), representing only 40% of the ET_0 computed for the period April to May (200–290 $mm \cdot month^{-1}$), when the highest ET_0 values were recorded. Figure 5 shows the average monthly rainfall in the crop Primary Region of Mexico. The maximum precipitation values were observed in July, August, and September (35–175 $mm \cdot month^{-1}$), while April, May and November accounted for 11.1% of the maximum monthly precipitation value. Regarding the spatial distribution of ET_0, this variable was relatively uniform in the analyzed region for the entire studied period. However, in some months (April, May, September, and November) the northwestern region showed an ET_0 increase of 29% in relation to the southeastern region (Figure 4). As for the distribution of precipitation, the values obtained in April, May, October, and November are uniformly spread, reaching 70 mm. From July to September, precipitation was relatively lower in the southeastern region, with 35–140 mm *vs.* 70–175 mm in the northwestern region.

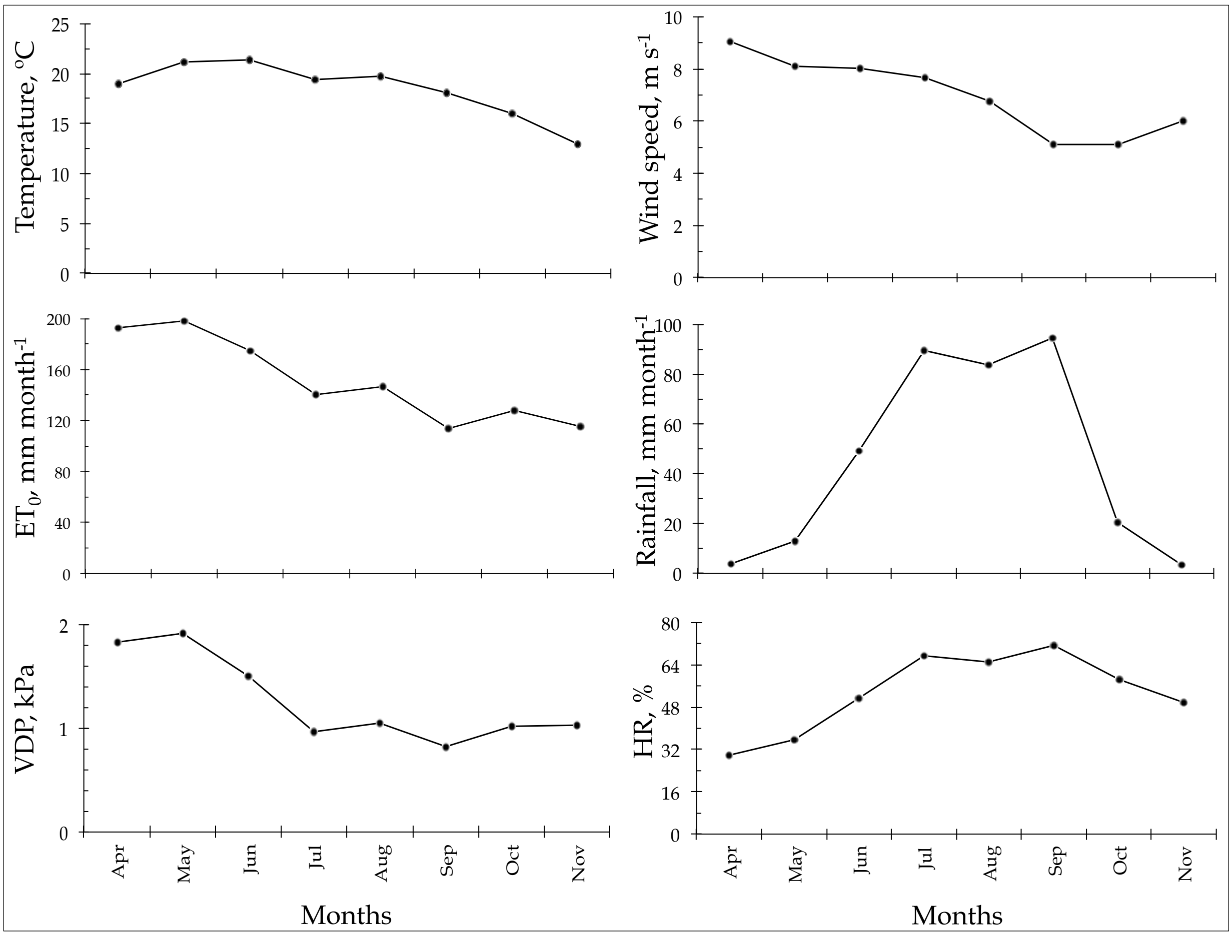

Figure 3. Weather conditions of dry beans primary region of Mexico. Source INIFAP 2011 [25–27].

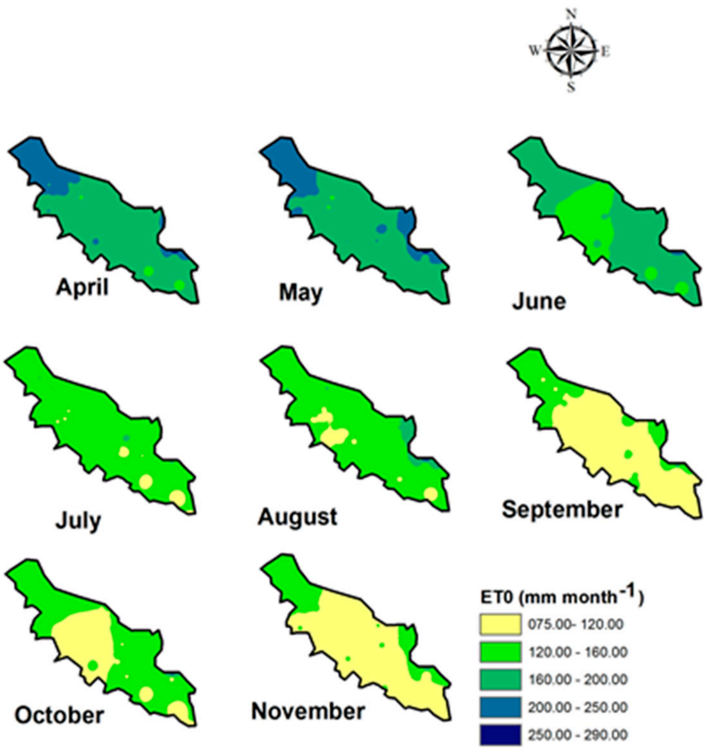

Figure 4. Reference evapotranspiration of dry beans primary region of Mexico.

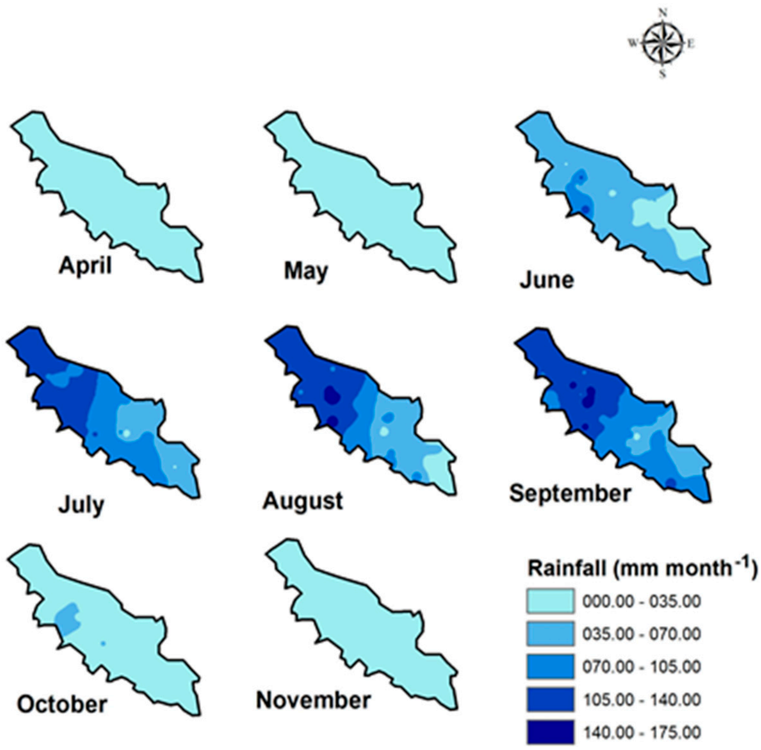

Figure 5. Rainfall of dry beans primary region of Mexico.

3.1. Dry Beans Water Requirements

The reported methodology permitted identifying the most common sowing dates for rainfed and irrigated conditions. The sowing dates considered in this research are the product of the experience that farmers as well as expert technicians in dry beans have been managed historically in DBM. Under dryland conditions, it is to take advantage of rainfall; as for irrigation conditions it is to obtain a major possible economical profit. For rainfed cultivation, the common sowing period extends through the month of July; as for irrigated cultivation, the period ranges between middle April to middle May. Net crop water requirements (ET_{blue}, Equation (5)) were estimated for five different sowing dates, three for dryland (DSD) and two for irrigated land (ISD): (a) 1 July, 15 July, and 1 August for DSD_1, DSD_2, and DSD_3, respectively; and (b) 15 April, and 15 May for ISD_1, and ISD_2, respectively. Figure 6 shows the CWR for each sowing date considered in the study. The Primary Region of Mexico devotes 17,667 ha for dry beans under irrigation, and 486,844 ha under rainfed conditions, allocating an average volume of 3159 $m^3 \cdot ha^{-1}$ from surface or groundwater sources to satisfy blue water requirements. This volume represents about 7% of the withdrawals for agricultural use [24].

Tables 1 and 2 present the corresponding values of ET_c, CWU and WF for dryland as well as for irrigated conditions. According to these results, the minimum ET_c is found when the season starts on ISD_2, with 412 mm in the central region. The northwestern region shows the maximum value, with 512 mm, for ISD_1. As for dryland conditions, on the DSD_3 the minimum is 338 mm in the central region again; on the other hand, the maximum occurs in the northwestern region with 395 mm if the season starts on DSD_1.

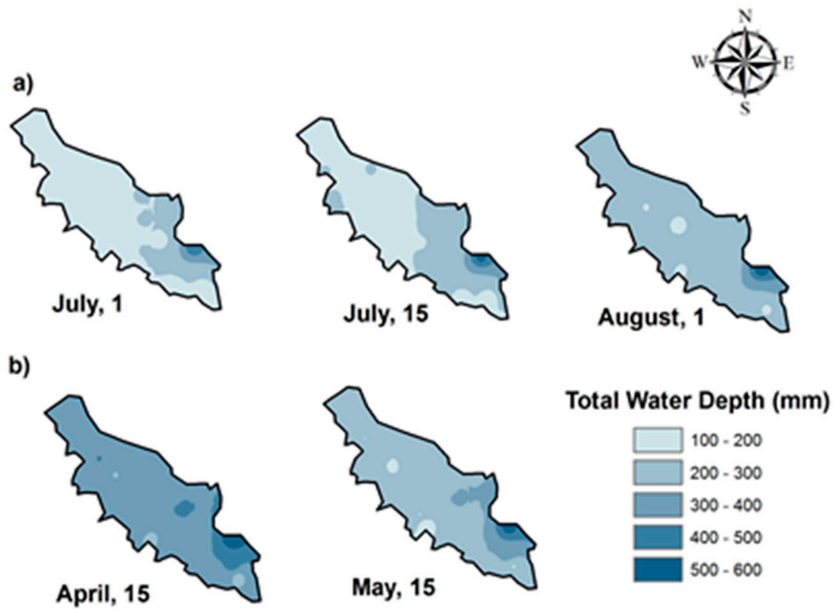

Figure 6. Dry beans water use for each sowing date considered: (**a**) rainfed crop and (**b**) irrigation crop.

Table 1. ET_c, CWU and WF in dryland season.

State	Sowing Date	ET_c (mm)	Green Water (mm)	CWU ($m^3 \cdot ha^{-1}$)	WF ($m^3 \cdot Mg^{-1}$)
Durango		395.0	263.1	2631	4085
Zacatecas	1 July	351.0	197.0	1971	3345
San Luis Potosi		365.8	114.8	1148	2734
Durango		388.4	220.8	2208	3429
Zacatecas	15 July	342.9	167.5	1675	2845
San Luis Potosi		362.2	98.0	980	2333
Durango		383.3	176.9	1769	2746
Zacatecas	1 August	338.1	133.7	1337	2269
San Luis Potosi		363.0	77.2	772	1839

Crop evapotranspiration, ET_c; Crop Water Use, CWU; Water Footprint, WF.

Table 2. ET_c, CWU and WF in irrigation season.

State	Sowing Date	ET_c (mm)	Green Water (mm)	Blue Water (mm)	CWU ($m^3 \cdot ha^{-1}$)	WF ($m^3 \cdot Mg^{-1}$)
Durango		512.1	152.7	359.4	5121	3426
Zacatecas	15 April	452.8	124.7	328.1	4528	2631
San Luis Potosi		471.7	59.4	412.2	4717	2231
Durango		460.4	230.8	229.6	4604	3079
Zacatecas	15 May	411.6	179.9	226.8	4116	2392
San Luis Potosi		426.5	87.3	339.3	4265	2018

Crop evapotranspiration, ET_c; Crop Water Use, CWU; Water Footprint, WF.

As shown in Table 1, CWU is the only available water source for dryland areas. CWU is typically lower than ET_c, because the available water is not enough to satisfy the dry beans water requirements.

Under dryland conditions, CWR is hardly achieved, in such a way CWU can be considered equal to green water.

The Mexican Government monitors dry beans yield, both dryland and irrigation, through SAGARPA [17]. This work has taken these data in order to obtain the dry beans yield occurred in DBM from 2006 to 2009 (Table 3). It can be observed that for the irrigation period the average yield is 2.114 $Mg \cdot ha^{-1}$, meanwhile dryland season performs an average of 0.644 $Mg \cdot ha^{-1}$. In order to simplify data presentation, since it is not possible to identify which part of harvested land area is used for each sowing date.

Table 3. Yields of dry beans primary region of Mexico.

Year	Season	Durango ($Mg \cdot ha^{-1}$)	Zacatecas ($Mg \cdot ha^{-1}$)	San Luis Potosi ($Mg \cdot ha^{-1}$)
2006	Dryland	0.816	0.670	0.541
2007		0.535	0.446	0.234
2008		0.558	0.520	0.525
2009		0.668	0.721	0.381
Average		0.644	0.589	0.420
2006	Irrigation	1.252	1.771	1.978
2007		1.914	1.833	2.223
2008		1.449	1.677	2.377
2009		1.365	1.602	1.879
Average		1.495	1.721	2.114

3.2. WF for Dryland Environments

Dry beans cultivated under rainfed conditions depend only on green water. Such circumstance leads, in the case of the study area, to a water deficit, which affects crop growth. All regions present water deficit independently of the sowing date. Nevertheless, variations are present along the region. In the case of the northwestern region, deficits are 33.4% (DSD_1), 43.2% (DSD_2) and 53.8% (DSD_3), respectively; in the central region, DSD_1 has a deficit of 43.87%, DSD_2 of 51.2% and DSD_3 gets the maximum (60.5%); as for the southeastern region, deficits are 68.6% (DSD_1), 72.9% (DSD_2) and 78.7% (DSD_3), respectively.

In the northwestern region, DSD_1 requires an average of 4083 $m^3 \cdot Mg^{-1}$ of water during the full season; if the crop season starts on DSD_2, WF is 3427 $m^3 \cdot Mg^{-1}$; DSD_3 has 2745 $m^3 \cdot Mg^{-1}$ for WF. The central region shows a similar behavior: (a) if the season begins on DSD_1, WF results are 3344 $m^3 \cdot Mg^{-1}$; (b) the DSD_2 has a WF of 2843 $m^3 \cdot Mg^{-1}$; and (c) for the DSD_3, it was found a WF of 2268 $m^3 \cdot Mg^{-1}$. Conditions in the southeastern region of the region are: for a season that starts on DSD_1, WF is 2732 $m^3 \cdot Mg^{-1}$; if the season beginning is DSD_2, WF is 2332 $m^3 \cdot Mg^{-1}$; the DSD_3 displays a value of 1839 $m^3 \cdot Mg^{-1}$ for WF. Therefore, under these conditions the best sowing date is 1 August (DSD_3).

The highest available water is found for DSD_1, since the northwestern region has a CWU of 2631 m^3 ha. The central region presents a CWU of 1970 m^3 ha. Finally, the southeastern region only has a CWU of 1148 m^3 ha. According to the obtained results, the best date to establish the dry beans under rainfed conditions at the Primary Region of Mexico is around 1 July. This permits to take advantage from the weather in the entire studied area.

3.3. WF for Irrigation Environments

For ISD_1 and ISD_2 it is observed that the best conditions according to ET_c and PEF, were present when the crop season started on ISD_1. During this period the impact on blue water is the smallest. The northwestern region shows that if the season starts on ISD_1, the average WF is 3426 $m^3 \cdot Mg^{-1}$, with a blue water contribution of 70.2% of the total requirement. Starting on ISD_2 results in a blue water requirement of 49.9%, since WF amounts to 3079 $m^3 \cdot Mg^{-1}$. The central region presents similar conditions: for a season starting on ISD_1, WF is 2631 $m^3 \cdot Mg^{-1}$, resulting in 72.5% of blue water. If the season begins on ISD_2, WF is 2392 $m^3 \cdot Mg^{-1}$, with 56.6% of blue water. As for the southeastern region, starting on ISD_1 results in a WF of 2231 $m^3 \cdot Mg^{-1}$, with blue water amounting to 87.4% of the total. Starting on ISD_2 results in a WF of 2018 $m^3 \cdot Mg^{-1}$ (blue water represents 79.5% of the total). Although we found that the best sowing date was 15 May, farmers tend to plant the crop as early as possible in order to maximize opportunities in the market. It must be mentioned that for dry beans, the part of WF corresponding to blue water, increases between 40% and 60% as a result of the conditions in the irrigation systems in Mexico, expressed in terms of global efficiency.

Mekonnen and Hoekstra [16] presented an average global WF for dry beans. The values presented by these authors were 3945 $m^3 \cdot Mg^{-1}$, 125 $m^3 \cdot Mg^{-1}$, and 983 $m^3 \cdot Mg^{-1}$ for green, blue, and grey WF, respectively. Comparing these results with those obtained in this study, it was found some similarity in the green water footprints of Mekonnen and Hoekstra [16] (1.4 times the average value obtained in this study). Nevertheless, blue water shows an opposite behavior, since the study area presents 14 times the global average.

4. Conclusions

In the dry beans primary region of Mexico farmers are used to sow dry beans between April and May for irrigated land. As for dryland, the sowing dates oscillate between July and August. That is why this paper analyzes five different sowing dates: two for irrigated land (15 April and 15 May), and three for dryland (1 July, 15 July and 1 August). The region is divided in three areas: the northwestern region (Durango), the central region (Zacatecas) and the southeastern region (San Luis Potosi).

For irrigated conditions, the best sowing date is 15 May. In the northwestern region a decrease in ET_c was observed of 10.1% and a decrease in blue water consumption of 36.1%, in comparison with 15 April. In the central region the decreases in ET_c and blue water consumption were 9.1% and 31%, respectively. In the southeastern region the decreases in ET_c and blue water were 9.6% and 17.7%, respectively, comparing with 15 April. The obtained outcomes show that WF values were 3079 $m^3 \cdot Mg^{-1}$, 2392 $m^3 \cdot Mg^{-1}$ and 2017 $m^3 \cdot Mg^{-1}$, in the northwestern, central and southeastern regions, respectively.

Regarding dryland cultivation, in all the dates and locations a deficit in fulfilling crop water requirements was found. In the three parts of the region the best sowing date was 1 July. The later the date, the larger the deficit: in the northwestern region it was 33.4%, in the central region it was 43.9% and in the southeastern region it was 68.6%. The dryland analysis permits concluding that the best planting date is 1 August, with values of 2745 $m^3 \cdot Mg^{-1}$ in the northwestern region, 2268 $m^3 \cdot Mg^{-1}$ in the central region and 1838 $m^3 \cdot Mg^{-1}$ in the southeastern region.

These results are subordinated to crop yield estimates. The average yield for irrigated land was 1.8 Mg·ha^{-1}, while for dryland it was barely 0.5 Mg·ha^{-1}. The main result of this research was the identification of the best sowing date for dry beans, particularly under rainfed conditions. Farmers can take advantage of the most suitable green water conditions around 1 July in the whole Primary Region of Mexico.

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Author Contributions

Both authors have collected and processed data, mapped images and written throughout the manuscript equally working to develope this research.

Conflicts of Interest

The authors declare no conflict of interest.

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