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Review Article

State of the Art of Agricultural Water Footprint in Colombia

Estado del arte de la huella hídrica agrícola en Colombia

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Spanish version

Abstract

Introduction: The water footprint is an environmental metric that quantifies the total volume of water used in the production of goods or services. In agriculture, it is measured in cubic meters per ton of product (m^3/ton) and comprises three components: green (rainwater), blue (surface or groundwater), and grey (polluted water). This metric helps assess the water-use efficiency of crops.
Objectives: This study aimed to examine water use in Colombian agriculture through a systematic review, focusing on water resource management and its relevance for guiding decisions on the optimal geographic distribution of crops based on their water requirements.
Materials and Methods: A systematic review was conducted, analyzing 37 scientific studies on agricultural water footprints in Colombia, covering a total of 44 crops across various production regions. Reported values for the water footprint per crop were examined, along with the proportional distribution of green, blue, and grey water components.
Results: The most frequently studied crops were vegetables (20%), coffee and cocoa (19%), fruits (17%), flowers (12%), cereals (10%), and others (22%). On average, 72% of the total water use corresponded to green water, 15% to blue water, and 13% to grey water, indicating a high reliance on rainwater in Colombian agriculture.
Conclusions: The findings underscore the importance of evidence-based water planning to enhance water-use efficiency in Colombia's agricultural sector, thereby supporting sustainable production and improved resource management.

Keywords: Water Footprint, Agriculture, virtual water, sustainability, water resources.

Resumen

Introducción: La huella hídrica es una métrica ambiental que cuantifica el volumen total de agua utilizado en la producción de bienes o servicios. En la agricultura, esta se mide en m^3 por tonelada de producto (m^3/ton) y se divide en tres componentes: verde (agua de lluvia), azul (agua superficial o subterránea) y gris (agua contaminada). Esta métrica permite evaluar la eficiencia hídrica de los cultivos.
Objetivos: Este estudio tuvo como objetivo examinar el uso del agua en la agricultura colombiana mediante una revisión sistemática, enfocándose en la gestión del recurso hídrico y su utilidad para orientar decisiones sobre la ubicación óptima de cultivos según sus necesidades de agua.
Materiales y métodos: Se realizó una revisión sistemática de 37 estudios científicos sobre huella hídrica agrícola en Colombia, que en conjunto cubren 44 cultivos distribuidos en diferentes regiones del país. Se analizaron los valores reportados de huella hídrica por cultivo y su distribución entre los tres componentes mencionados.
Resultados: Los cultivos más estudiados fueron: hortalizas (20%), café y cacao (19%), frutales (17%), flores (12%), cereales (10%) y otros (22%). En promedio, el 72% del agua utilizada corresponde al componente verde, el 15% al azul y el 13% al gris, lo que indica una alta dependencia del agua de lluvia en la agricultura nacional.
Conclusiones: Los resultados destacan la necesidad de una planificación hídrica basada en evidencia, que permita mejorar la eficiencia del uso del agua en el sector agrícola colombiano, contribuyendo así a su sostenibilidad.

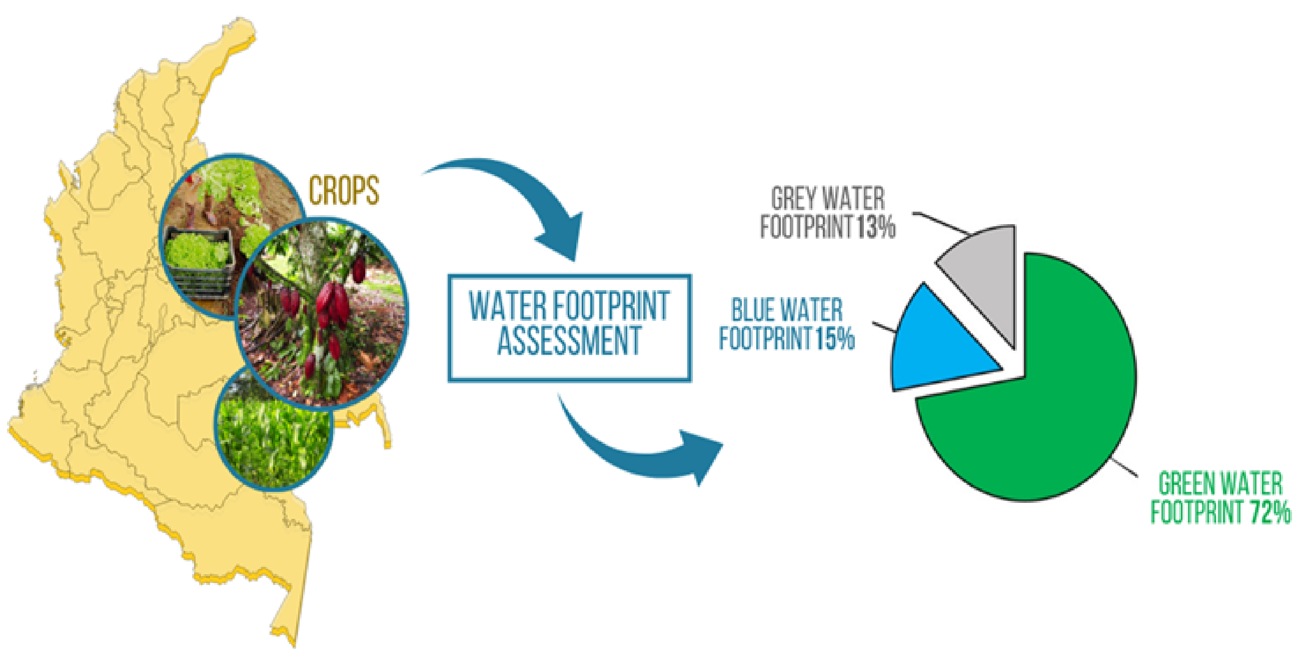
Palabras clave: Huella Hídrica, Agricultura, Agua Virtual, Sostenibilidad, Recurso Hídrico, Demanda hídrica.

Contribution to the literature

Why was it conducted?
Finding the most important Agricultural Water Footprint studies in the Colombian setting was the primary goal of this research. To accomplish this, a comprehensive analysis was carried out to assess the water needs of agricultural production, taking into account various crops and their respective production methods. The distribution of the Agricultural Water Footprint, the components that were evaluated, and the water footprint in different regions were also compared.

What were the most relevant results?
Green water footprint, which includes precipitation water that is directly absorbed by crops, accounts for the lion's share of the nation's agricultural water footprint, according to the study's most important findings. The blue water footprint represents irrigation water, and the grey water footprint is the last one. It is worth mentioning that not all documents incorporate all three aspects of the water footprint. For example, some may make reference to chemical fertilizers used in organic agriculture. Since the majority of crops in the country rely on rainwater to meet their water needs, these findings suggest that, generally speaking, there is little competition for water resources. But this may cause ecosystems and other productive activities to compete with humans for water resources.

What do these results contribute?
These findings shed light on the current status of Colombia's agricultural Water Footprint by comparing the water needs of various agricultural products. Here, data on crop water consumption is compiled for use in agricultural planning, which is an important document for those making decisions about agricultural production systems and water resource management. Lastly, this data inspires more studies in fields where there is a dearth of information about the agricultural water footprint.



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Introduction

Water is a crucial natural resource for societal subsistence and development, serving as a foundation for human progress, the natural environment, and the economy (1,2). Moreover, water resources are essential for agriculture and the quality of life in rural communities (3). Water consumption is estimated to have increased at double the rate of population growth, resulting in various regions experiencing water stress. By 2050, it is projected that 52% of the global population will live in regions experiencing water stress (4). The sustainable management of water resources and the assurance of food security are essential for the advancement of human society (5). The Sustainable Development Goals (SDG) incorporate targets concerning water resources, specifically in SDG 6 “Clean water and sanitation” and SDG 12 “Sustainable production and consumption” (6,7,8) These objectives acknowledge the significance of tackling the escalating issue of water scarcity, alongside the rising demand and strain on water resources (9,10).

Human activities necessitate substantial water resources for development, with agriculture accounting for the majority of usage at 91%, followed by industrial and domestic consumption at 5% and 4%, respectively (11,12). Population and economic growth are driving water resources to unsustainable limits, exacerbated by irrational usage, ecological degradation, and climate change (13,14). At a global scale, the availability of fresh water is problematic due to overexploitation, resulting in environmental issues (15). Recent years have seen an increase in the impact of human activities on natural resources, leading to a focus on the use of environmental indicators to quantify these effects. The aim is to mitigate these impacts and implement comprehensive management of natural resources.

Hoekstra and Hung (16) developed a methodology known as the water footprint to quantify and analyze water consumption, aiming to understand water use in human productive activities and assess the pressure on water resources. The water footprint serves as an indicator assessing the impact of human activities on freshwater resources (16). The water footprint model encompasses both the direct consumption by individuals and the indirect utilization of water resources (17). The water footprint consists of three components: green, blue, and grey. The green water footprint represents the effective precipitation utilized by crops; the blue water footprint pertains to the surface and groundwater resources utilized during production; and the grey water footprint indicates the fresh water required to dilute pollutant loads to achieve natural background concentrations and adhere to environmental regulations (11).

This term denotes the volume of water utilized in the production of a good or service, encompassing the entire supply chain (16). This indicator is essential for advancing the sustainable management of water resources, particularly in the agricultural sector (18). The water footprint serves as a multidimensional indicator reflecting the volume of water consumed by source and the volume affected by contamination, categorized by type. The components of water consumption are delineated in both geographical and temporal contexts (11). This serves as a metric for both consumption volume and water contamination levels. The water footprint does not correlate with the severity of local environmental impacts resulting from water consumption (19,11).

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Numerous studies have examined the Water Footprint of agricultural crops to assess the water consumption associated with major crops cultivated in various regions (20,21,22). The concept and its application have been utilized to deliver pertinent information regarding the sustainable utilization of water resources in agricultural production (18). The methodology utilized within agricultural frameworks typically assesses the green and blue water footprint. In certain regions of Latin America, the authors indicate that predominantly green water is utilized for crop development (23), which is the most significant component for agricultural growth. The green water footprint has the largest volume relative to the other types of footprints. In contrast to other factors, there is not always an impetus to minimize it, as it does not create direct competition for water resources. Nonetheless, it suggests competition for territorial use, as evidenced by the expansion of the agricultural frontier (24). The water footprint of crops is typically quantified as yield per unit volume, expressed in cubic meters per ton (m^3/ton) or liters per kilogram (L/kg). The water footprint of agricultural crops is defined as the total volume of freshwater utilized, both directly and indirectly, to produce a product. This includes water consumption and pollution associated with each stage of the production chain (11).

The water footprint serves as an indicator of the pressure exerted on water resources, quantified in terms of water volume based on its usage. This necessitates the implementation of instruments that facilitate decision-making for the comprehensive management of water resources, considering the involvement of stakeholders and institutions (25). This review study aims to analyze the concept of Water Footprint as it pertains to agricultural crops, specifically within the Colombian context, with the following objective: Review the state of the art of agricultural water footprint in Colombia, contrasting the water footprint across various crop systems. This approach aims to generate a comprehensive tool for agricultural planning, offering valuable insights into sustainable water use in different production systems.

Materials and methods

Data collection

The literature review data were sourced from the Scopus, Google Scholar, and Springer Open databases. An approach was adopted to conduct the review of the water footprint in agricultural crops. The review's scope was delineated, concentrating on the systematic assessment of the water footprint across various crops. The employed keywords were: "Water Footprint" AND "Agriculture" AND "Crops" AND "Water Use". Articles in English and Spanish, published from 2003 to 2024, were selected.

The subsequent phase of the review concentrated on the water footprint of agricultural crops in Colombia. Comprehensive searches were performed in databases including Scopus, Web of Science, and Google Scholar, utilizing keywords such as: "Water Footprint," "Agriculture," "Sustainability," and "Agricultural Crops." References included scientific articles, undergraduate theses, and reports published in the last decade in English and Spanish, concentrating on the application of the water footprint in agricultural crops in Colombia. Using Microsoft Excel, data from every publication was methodically gathered and painstakingly arranged, therefore enabling a thorough and rigorous examination.

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Inclusion and exclusion criteria

The inclusion criteria for this research included studies on the agricultural water footprint in Colombia that used thorough, repeatable methodology. Priority was given to works in Spanish or English that provided extensive and accurate data for comparison and critical analysis. In contrast, research that did not primarily focus on Colombia's agricultural sector, employed faulty or insufficient methodology, or did not provide full access to its data and finding was rejected. Research pertaining to the water footprint of corporate, community, or livestock production was excluded from the review to preserve the emphasis on agricultural crops.

Results and Discussion

Agricultural Water Footprint in Colombia

Colombia possesses significant global water resources; however, this resource is jeopardized by inadequate planning, unequal distribution, and climate change, resulting in constraints on water utilization (24,26). In 2020, national water demand comprised 43.25% for agriculture and post-harvest activities, while the remainder was allocated to non-agricultural uses, including hydropower, domestic consumption, livestock, and industry (27). In recent years, numerous studies have been conducted on water in Colombia, primarily concentrating on water resource management, utilization, and quality. These have been conducted in significant regions within sectors characterized by heightened agricultural and industrial activity (24,28).

A total of 37 documents were identified (Fig. 1) that address the calculation of the water footprint of agricultural crops in Colombia. Of these, 47% pertain to undergraduate theses, 45% to scientific articles, and the remaining 8% to institutional reports.

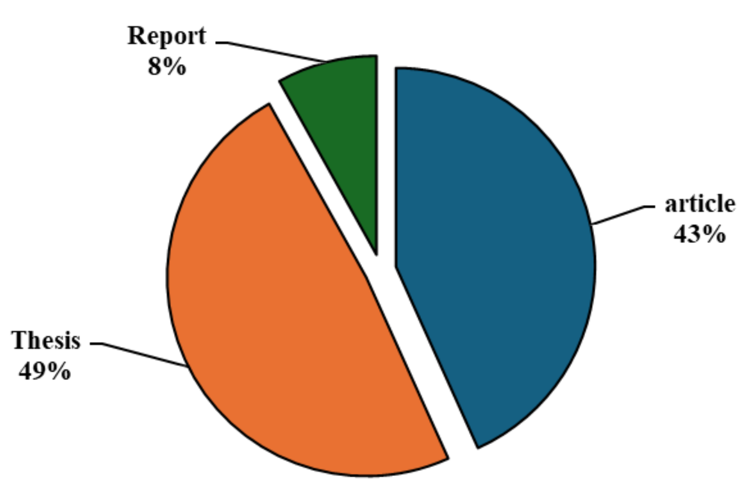

Figure 1. Type of publication of Water Footprint of agricultural crops in Colombia.

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Crops

A total of 44 agricultural crops were identified and classified based on their system (Fig. 2). The majority of the publications concentrate on semi-annual crops, comprising 17 documents, with maize, rice and sugar cane as the principal crops. Fifteen perennial crops were documented, with cocoa, coffee, avocado, and cotton being the most prominent. Eight greenhouse crops were identified, including notable varieties such as flowers, tomatoes, and strawberries. Ultimately, one pertinent document was located regarding forest crops.

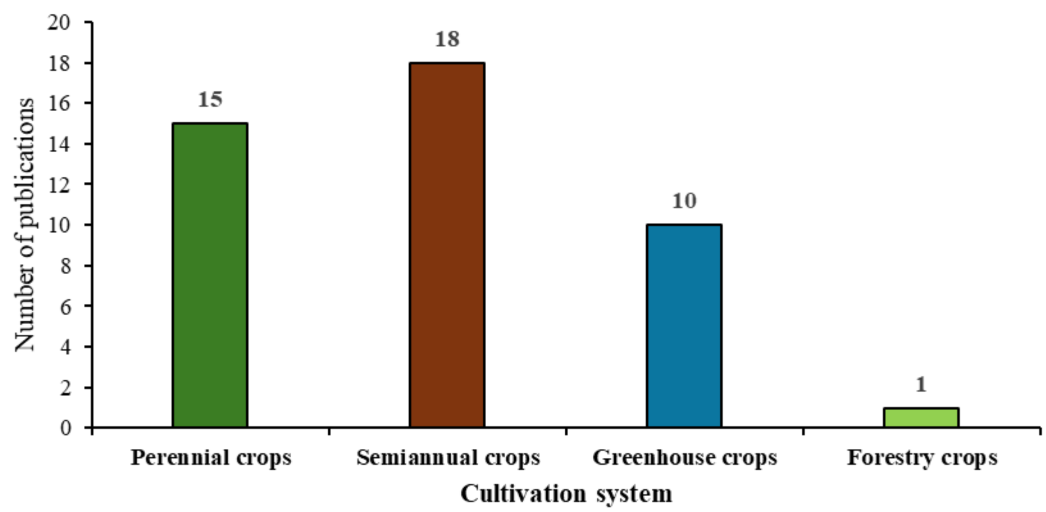

Figure 2. Agricultural cropping systems in water footprint studies in Colombia. Source: Authors.

Spatial distribution of agricultural crops

A total of 33 study areas were identified across Colombian territory, distributed among various departments. The various crops were categorized collectively. This categorization facilitates enhanced visualization and analysis of the spatial distribution of various crop types (Fig. 3). The Cundinamarca department is distinguished by eight study areas, while Tolima and Boyacá each possess four locations. The departments of Meta, Santander, and Huila each have three study areas, whereas Antioquia has two. Arauca, Nariño, Quindío, Valle del Cauca, and Córdoba each possess a singular study area, indicating the geographic dispersion of Agricultural Water Footprint research in Colombia.

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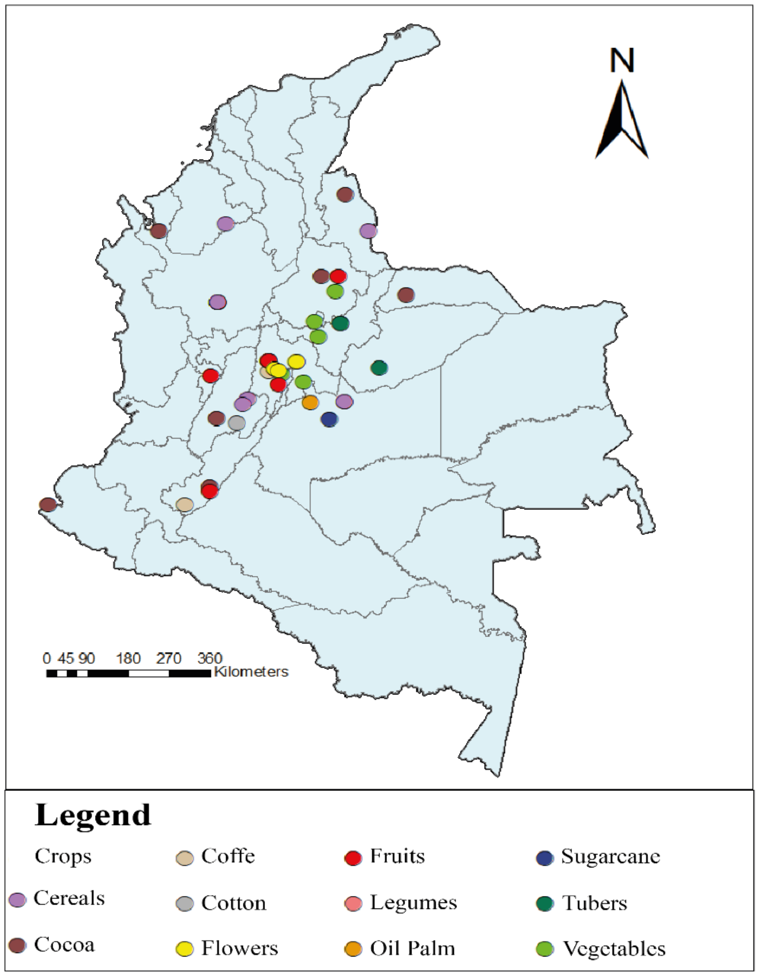

Figure 3. Geographical distribution of crops in the reviewed studies. Source: Authors

A total of 37 studies identified 44 crops. Figure.4 illustrates the categorization of crops based on water footprint assessment in Colombia. The category with the greatest number of studies is coffee and cocoa, accounting for 20%, followed by fruit crops at 17%, which includes Hass avocado, tree tomato, and Valencia orange. Vegetables account for 17% of the total, including onion and tomato, whereas flower crops comprise 13%, featuring astromelia flower, carnation, and gerbera. A separate category encompasses certain cereals, specifically rice and maize, while the remaining 23% pertains to crops with fewer studies, including oil palm, tubers, and forest trees.

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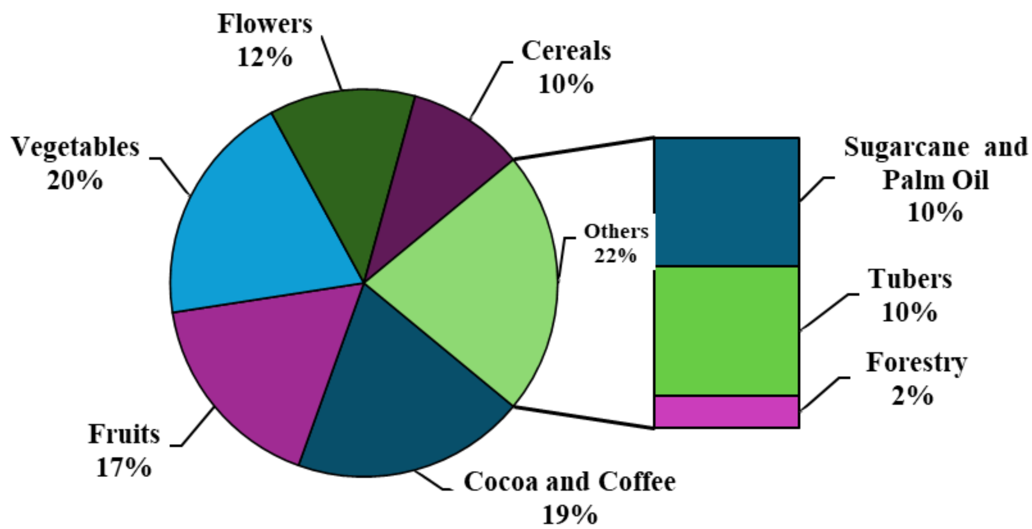

Figure 4. Subdivision of crops analyzed in the reviewed studies. **Source: Authors.**

Assessment of the water footprint in agricultural crops

Numerous studies have been conducted in Colombia regarding the Water Footprint associated with agricultural production. Table.1 displays the primary findings of these studies. The investigations align in assessing water consumption in crops to evaluate sustainability concerning the water supply in the study areas (29,30). The study encompasses variables including crop type, climate, precipitation, and soil, primarily focusing on the measurement of the Blue Footprint and Green Footprint in crops, with a secondary emphasis on the grey water footprint. Several authors have estimated the Water Footprint of crops at the basin level (30), whereas others have focused on controlled environments, such as greenhouse crops (31). Conversely, certain crops cultivated through dryland practices exhibit total green water consumption, resulting in a blue water footprint of zero. However, for crops like coffee, the blue water footprint is attributed to processing and post-harvest activities (24).

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Table 1. Main results of the Agricultural Water Footprint in Colombia

Cultivation system	Crop	Location	GWF	BWF	GWF	Total, WF(m^3/ton)	Reference
Perennial crops	Coffee	Villeta	19.996		1.667	21.633	(32)
	Cotton	Natagaima- Tolima	1.158	749,5	150	2.058	(33)
	Cocoa	Apartadó (Antioquia)				14.344	(34)
		Tame (Arauca)				15.057	
		Garzón (Huila)				13.475	
		Tumaco (Nariño)				13.719	
		San Vicente (Santander				22.758	
		Chaparral (Tolima)				23.239	
	Hass Avocado	Quindío	3630	0	1315	4.945	(35)
	Coffee	(Chinchiná, Venecia, El Tambo, Buenavista)	8746		7000	15.749	(36)
	Cocoa	Porce River Basin (Antioquia)	19.428		346	19.346	(37)
	Cocoa	Norte de Santander	13.189	5687		18.876	(38)
	Coffee	Porce River Basin (Antioquia)				7.500	(37)
	Coffee	Huila	6.328	233,2		6.561	(24)
	Dragon fruit	Palestina (Huila)	467	2444,34		2.911	(39)
	Valencia Orange	Puerto López	19735.8	25634.9	77	45488,6	(40)
	Coffee	Anolaima	7.823	9.11	17.93	7.850.5	(41)
	Tree Tomato	Antioquia	248	31	7	286	(37)
	Oil Palm	Guayuriba River basin, Meta	347,8	141,3		489,1	(42)
	Tahiti Lime	Angula River basin (Santander)	350	82.88	19.51	452,3	(43)

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Semiannual crops	Onion	Samacá	65.28	78.7	52.41	196.4	(44)
	R12 Potato	El Rosal	169.12	32.80	190.99	392.91	(45)
	Spring Onion	Porce River Basin (Antioquia)	402	431	13	846	(37)
	Potato	Porce River Basin (Antioquia)	390	78	11	479	(37)
	Creole Potato	Porce River Basin (Antioquia)	578	105	16	699	(37)
	Onion	Duitama Y Samacá (Boyacá)	151,52	107,3	332,5	591,32	(46)
	Potato	Duitama Y Samacá (Boyacá)	200,5	42,93	251,5	494,93	(46)
	Rice	Espinal (Tolima)	549,26	184,85	32,02	766,13	(47)
	Plantain	Porce River Basin (Antioquia)	2051		39	2.090	(37)
	Sugarcane	Villeta	1.856		323	2.179	(32)
	Sugarcane	Amaime River Basin (Valle del Cauca)	117	37,44		154.51	(48)
	Corn (Maize)	Villeta	2.095		1458.3	3554.2	(32)
	Bean	Porce River Basin (Antioquia)	4269		187	4.456	(37)
	Rice	Guamo (Tolima)	204,3	1345,6	1033,36	2583,2	(49)
		Cúcuta	179,3	1284,6	1713,24	3177,2	
		La apartada (Córdoba)	362,6	2007,4	1581,55	3951,6	
		Puerto López (Meta)	241,3	1987,3	1900,66	4129,3	
	Corn (Maize)	Porce River Basin (Antioquia)	5.696		141	5.837	(37)
	Cassava	Villeta	405		277.8	683	(32)
	Plantain	Villeta	2.394		547	2.941	(32)
Greenhouse crops	Alstroemeria Flower	Facatativá	1.76	0.95	0.77	3.5	(50)
	Tomato	Fomeque	87.84	13	233.56	334.4	(51)
	Tomato (Greenhouse)	Alto Ricaurte (Boyacá).				1207.4	(52)
	Tomato (open field)	Alto Ricaurte (Boyacá).				17411.6	(52)
	Gerbera	Facatativá	3.12	1.34	0.82	5.28	(53)
	Estatice Flower	Tocancipá	0.62	3.78	1.94	6.34	(54)
	Liatris Flower	Tocancipá	1.32	0.91	4.27	6.50	(54)
	Strawberry	Sibaté	55.13	22.68	3.84	81.65	(55)
	Carnation	Bogotá	2.967	5.476	97.10	8.540	(56)
Forestry	Eucalyptus	Colombia				1.764	(57)

GWF: Green Water Footprint, **HHA**: Blue Water Footprint, **GWF**: Grey Water Footprint **Source:** Authors.

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The water footprint values for coffee cultivation are 21,633 m^3/ton in the Villeta area of Cundinamarca and 6,561 m^3/ton in the department of Huila. The observed difference is attributable to variations in climatic conditions, including precipitation, and soil types. The first study incorporates the water utilized in the post-harvest process, whereas the second study excludes the grey water footprint (26,17). A study conducted by Bulsink et al. (58) in Indonesia indicates a value of 22,907 m^3/ton for coffee cultivation, comprising 96% green water and 4% grey water. In contrast, eight study areas have been identified for cocoa cultivation, detailing the water consumption of this crop: Apartadó (Antioquia) at 14,344 m^3/ton, Tame (Arauca) at 15,057 m^3/ton, Garzón (Huila) at 13,475 m^3/ton, Tumaco (Nariño) at 13,719 m^3/ton, San Vicente (Santander) at 22,758 m^3/ton, and Chaparral (Tolima) at 23,239 m^3/ton (34). Additional research indicates values in the Porce River basin, Antioquia, and Norte de Santander, recorded at 19,346 m^3/ton and 18,876 m^3/ton, respectively (37,38).

The water footprint of cocoa cultivation in Ecuador is estimated at 24,602.70 m^3/ton. The disparity arises from the utilization of 30.22% blue water and 69.78% green water for crop development in Ecuador (23). In Colombia, water consumption for the crop is derived solely from green water, with no reported values for grey water. In the context of cotton cultivation, the Natagaima area in Tolima reports a value of 2,058 m^3/ton, indicating a substantial blue water consumption of 36.41%. This underscores the necessity of irrigation water for crop development. Chapagain and Hoekstra. (59) conducted a study assessing the total water footprint associated with cotton cultivation across multiple countries. The results revealed values of 1,534 m^3/ton in Greece, 1,325 m^3/ton in Spain, and 2,320 m^3/ton in Turkey. The reported value for Colombia is higher; however, it does not indicate a significant difference when compared to the regions analyzed. The observed difference in values may result from the implementation of more efficient irrigation systems, as indicated by the total value of the blue water footprint (60).

A study on Hass Avocado cultivation indicates a water usage of 4,945 m^3/ton, comprising 73.4% green water and 26.6% grey water associated with Nitrogen contamination. Importantly, in Colombia, this crop does not require supplemental irrigation (35). Comparable research, including that conducted by Cerna and Olivares (61) in Peru, indicates a value of 956 m^3/ton. Conversely, in Chile, the average water footprint of Avocado is 389 m^3/ton (62). A notable difference is evident in the value obtained in Colombia, suggesting variations in the estimation of the water footprint related to the crop's development time. Sugarcane cultivation encompasses two study areas, revealing reported values of 2,197 m^3/ton for Villeta Cundinamarca and 154.51 m^3/ton in the Amaime River basin in Valle del Cauca. The water requirements of the two areas differ due to variations in climatic conditions, soil types, and the timeframes utilized in calculating the water footprint (32,48) In Brazil, sugarcane cultivation yields values of 98 m^3/ton in dry land conditions and 119 m^3/ton under irrigation (63).

Tomato cultivation occurs in two modalities: open field and greenhouse. The water consumption values are 334.4 m^3/ton for open field and 1,207 m^3/ton for greenhouse cultivation. This indicates a significant difference in green and blue water usage, with greenhouse crops requiring a higher volume of blue water throughout their production cycle (52). Mekonnen and Hoekstra (64) report an average water footprint of 214 m^3/ton for tomatoes. Furthermore, in regions like Northwest São

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Paulo, Brazil, the average water footprint for tomatoes is reported to be 94 m^3/ton, comprising 72% green water consumption, 20% blue water, and 8% grey water (65).

Colombian agricultural water footprint colors

Figure 5 illustrates the components examined in the analyzed studies. Sixty percent of these encompass the three components (green, blue, and grey), while twenty-five percent focus solely on the green and grey footprints. The primary contributor to the water footprint in agricultural crops is green water, which is influenced by seasonality and precipitation (5). Most studies on grey water footprint estimates have focused on nitrogen (N) and phosphorus (P) pollution (66). It is noted that 12% of the studies focus exclusively on green and blue water.

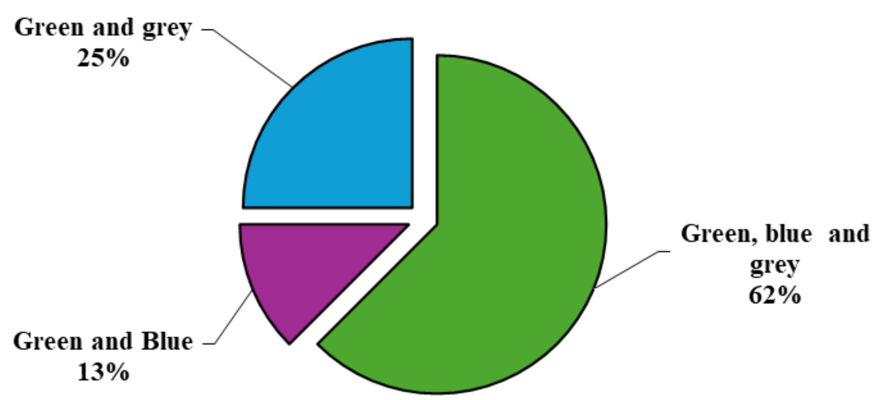

Figure 5. Subdivision according to the components considered in the studies **Source:** Authors.

Distribution of the agricultural water footprint

Studies indicate that green water accounts for the highest water consumption at 72%, followed by blue water at 15%, and grey water at 13% (Fig.6). The National Water Study 2022 indicates that the green water footprint has the highest participation. This is due to the significant rainfall levels, which decrease reliance on irrigation water and lower the opportunity cost of water use in Colombian agriculture (27). The blue water footprint is relatively low, as not all agricultural crops are cultivated using irrigation practices. This value reflects crops with significant water requirements that exceed the available water resources in regions such as Tolima, Huila, and Magdalena (67).

The grey water footprint represents the component with the least contribution. The findings suggest that not all documents disclose their value as a result of employing organic farming practices (42). The calculation of this footprint necessitates specific data, including soil texture, yield, leaching, and environmental factors. This can also be mitigated through precision farming practices and soil conservation (68).

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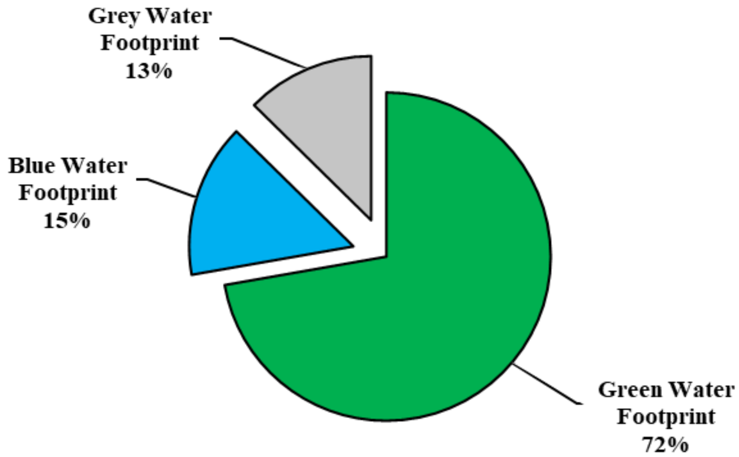

Figure 6. Distribution of the agricultural water footprint in Colombia. **Source:** Authors.

The sustainable management of water resources is a primary focus of Colombia's public policies, especially in sectors like agriculture. The 2018 CONPES 3934 document, entitled "Green Growth Policy," emphasizes the necessity of implementing production practices that safeguard this essential resource, meeting present demands without jeopardizing its future availability (69). Nonetheless, inconsistencies between environmental and agricultural policies endure, resulting in substantial deficiencies in the shift towards sustainable production models, as observed by Forero and González (70). Current policies predominantly emphasize the oversight of water usage; however, a more profound integration of water supply and demand in critical productive sectors is necessary. Moreover, instruments such as the National Climate Change Adaptation Plan (PNACC) and Law 1931 of 2018 advocate for water adaptation measures but encounter obstacles including inadequate institutional coordination, constrained funding, and limited local engagement (71). This highlights the necessity to enhance territorial planning and improve water governance that effectively integrates public policies with rural development and environmental conservation.

Since 1998, the National Water Studies (NWS) (Estudios Nacionales del Agua ENA) conducted by IDEAM have emerged as a crucial instrument for water resource management in Colombia. The 2014 national study introduced the concept of water footprint, facilitating an analysis of water consumption in agriculture. Key crops such as coffee, sugarcane, and oil palm were emphasized, indicating that agriculture in Colombia predominantly relies on green water, with minimal dependence on blue water or irrigation. The ratio of green to blue water footprints differs between regions and hydrographic subzones (72).

The 2018 NWS estimated the water demand and blue and green water footprints of Colombia's agricultural sector by quantifying crop water requirements and assessing the available water sources in each region. This resulted in the development of national maps depicting green and blue water footprints, categorized by hydrographic subzones. The analyzes highlighted the significant water consumption of crops including irrigated rice, plantain, and oil palm (73).

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In its 2022 NWS, IDEAM subsequently introduced the Basin Water Return Index (IARC), which pertains to the water footprint. This indicator demonstrates the ability of hydrographic subzones to support water usage stemming from activities such as agriculture. Furthermore, the Water Pressure Index on Ecosystems (IPHE) was integrated. This index evaluates the green water footprint of the agricultural and forestry sectors within a hydrographic subzone, juxtaposing it with the availability of green water during the corresponding timeframe. The sustainability of the agricultural sector at the national level was evaluated through this index. The research additionally encompassed forecasts of water usage by productive sectors until 2040 (27).

The National Water Studies have served as essential instruments for national public policy, employing the Water Footprint as a criterion to assess agricultural water consumption. These studies examined water usage linked to different cropping systems, producing comprehensive maps that illustrate each element of the Water Footprint. They presented a lucid depiction of the strain agricultural production exerted on water resources, thereby establishing a robust basis for sustainable water management within the agricultural sector (27).

Conclusions

The review permitted the establishment of the current state of the art in terms of agricultural water footprint in Colombia. The majority of bibliographic production is for undergraduate and postgraduate theses, which may indicate a need to review the precision of the results and methodologies used, particularly when compared to scientific research in the same field.

It was discovered that the water footprint of various crops has been quantified in different regions, with the green water footprint accounting for the majority of the total water footprint. This is due to the fact that the main crops are grown using rainfed practices in areas with high rainfall rates. Agriculture stands out as an activity that captures and uses rainwater, which accounts for a significant portion of agricultural production in Colombia. Although the green water footprint does not imply direct competition for water consumption, it does result in competition for land use as the national agricultural frontier expands.

In Colombia, using rainwater in agriculture reduces the need for irrigation while also promoting sustainability. It is recommended to use efficient technologies that prioritize this source, in line with SDG 12. Furthermore, assessing the water footprint contributes to reducing fertilizer contamination and preserving water quality, which aligns with SDG 6. Understanding water requirements and availability is critical for avoiding resource constraints and promoting sustainable use, emphasizing the need for future research in agricultural water management.

The agricultural sector in Colombia necessitates the implementation of policies that emphasize the sustainable utilization of water, thereby ensuring a harmonious equilibrium between production requirements and the conservation of environmental resources.

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CrediT authorship contribution statement

Conceptualization - Ideas: Andrés Felipe Góngora Duarte, Juan Manuel Trujillo Gonzalez. Data Curation: Andrés Felipe Góngora Duarte. Formal analysis: Andrés Felipe Góngora Duarte. Investigation: Andrés Felipe Góngora Duarte. Methodology: Andrés Felipe Góngora Duarte. Project Management: Andrés Felipe Góngora Duarte. Resources: Andrés Felipe Góngora Duarte, Supervision: Juan Manuel Trujillo González. Validation: Andrés Felipe Góngora Duarte, Juan Manuel Trujillo González. Writing - original draft - Preparation: Andrés Felipe Góngora Duarte, Juan Manuel Trujillo González. Writing - revision and editing - Preparation: Juan Manuel Trujillo González.

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