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Original Article

Impact of coffee farm certifications on water quality conservation in southern Colombia[1]

Impacto das certificações de fazendas de café na conservação da qualidade da água no sul da Colômbia

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HIGHLIGHTS:
The byproducts generated by wet milling of coffee are the main source of water pollution.
The voluntary sustainability standards adopted by coffee farms have a positive impact on water resources.
Multicertification of coffee farms does not ensure effective water resource management.

ABSTRACT: Colombian coffee is recognized for its high quality due to the biogeographical conditions in which it is grown and the postharvest processes that the fruit undergoes in the farms until the dry parchment coffee (dpc) is obtained. For example, wet milling, a process widely implemented in Colombia, uses large volumes of water, which generates large amounts of byproducts and wastewater. In Colombia, coffee farms have adopted various certification programs or voluntary sustainability standards, which are consistent with the environmental criteria for efficient water management. Thus, this study was conducted to evaluate the impact of the standards required by six of these certification programs and six combinations of programs on the water resources used in coffee farms in southern Colombia. Such an impact was evaluated through indices related to the management of domestic wastewater, the efficient management of the resource, and the environmental quality of the residual water generated during wet milling of beans, comparing groups of certified and noncertified farms using the propensity score matching method in a sample of 461 farms. The findings of this study indicated that the combination of Café Practice and Fairtrade Labelling Organizations International and the application of CPr and Organic programs alone are the best indicators. However, in general, certification has a positive impact on the management of water resources on coffee farms with regard to reduced consumption and pollution.

Key words: voluntary sustainability standards, byproducts, certified coffee farms, wastewater

RESUMO: O café colombiano é reconhecido por sua alta qualidade, devido às condições biogeográficas em que é cultivado e aos processos pós-colheita pelos quais o fruto passa nas fazendas até a obtenção do café em pergaminho seco. Um desses processos, o mais amplamente implementado na Colômbia, é o moinho de processamento úmido, que utiliza grandes volumes de água e gera grandes quantidades de subprodutos e águas residuais. Na Colômbia, as fazendas de café adotaram vários programas de certificação ou padrões voluntários de sustentabilidade, que, em seus critérios ambientais, exigem uma gestão eficiente da água. Este estudo avaliou o impacto dos padrões exigidos por seis desses programas de certificação e seis combinações de programas sobre os recursos hídricos usados em fazendas de café no sul da Colômbia. O estudo foi realizado para avaliar o impacto por meio de índices relacionados à gestão de águas residuais domésticas, à gestão eficiente do recurso hídrico e à qualidade ambiental da água residual gerada durante o processamento úmido dos grãos, comparando grupos de explorações agrícolas certificadas e não certificadas utilizando o método de correspondência de pontuação de propensão numa amostra de 461 explorações agrícolas. Os principais resultados sugerem que os programas com os melhores indicadores foram a combinação de Café Practice (CPr) e Fairtrade Labelling Organizations International (FLO), e individualmente os programas CPr e Orgânico (Org). No entanto, conclui-se que, em geral, a certificação tem um impacto positivo sobre a gestão dos recursos hídricos nas fazendas de café, reduzindo o consumo e a poluição.

Palavras-chave: padrões voluntários de sustentabilidade, impacto ambiental, fazendas de café certificadas, contaminação da água

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Introduction

Coffee production is the main livelihood for millions of farmers globally (Pham et al., 2019). In Colombia, it is the main pillar of the agricultural economy, being the second-largest coffee-producing country worldwide, with 12.8 million coffee bags produced in the 2023/2024 coffee year (ICO, 2024). Over 22% of Colombian coffee is produced in the department of Huila, which includes five of the top 10 coffee-producing municipalities of this country (Agronet, 2022).

The rising global demand for coffee has led to increased freshwater use. Between 15 and 40 L of water are consumed to process 1 kg of coffee (Sengupta et al., 2020; Rodríguez et al., 2021), stressing local watersheds (Sporchia et al., 2023). Colombian coffee is rainfed because of favorable agroclimatic conditions (Camacho & Uribe, 2018; Rodríguez, 2020). However, the wet processing method used contributes to high water use and contamination. Pollutants such as honey and husks generated from this process can pose a risk to human and animal health because of their high organic load, pesticides, fertilizers, and high chemical oxygen demand (COD) (Desai et al., 2020; Sengupta et al., 2020; Rodríguez et al., 2022; Said et al., 2023).

The water footprint of Colombian coffee considering a full cycle is approximately 4457 L kg^{-1} of green coffee (Rodríguez, 2020). Leal & Tobón (2021) estimated a green water footprint of 8746 L kg^{-1} and a gray water footprint of 7000 L kg^{-1}, which is linked to wastewater generated from wet processing, affecting the Cauca and Magdalena river basins (Tejeda-Benitez & Olivero-Verbel, 2016; Tejeda-Benítez et al., 2023).

After Vietnam, Colombia has the smallest water footprint in coffee production (Leal & Tobón, 2021). This footprint varies by biogeographical factors and production methods, and it decreases with the increase of planting density and yield (Rodríguez, 2020; Byrareddy et al., 2020). Ecofriendly processing techniques can also decrease the gray water footprint, mitigating environmental impact (Beyene et al., 2012).

In addressing the current challenges, including agricultural pressure on water resources, environmental sustainability measures have been adopted (Rodríguez et al., 2021; Sporchia et al., 2023). For example, voluntary sustainability standards or certification programs have been implemented in good agricultural practices and fair trade (Partzsch et al., 2021). These programs promote efficiency in water use, compliance with discharge regulations, and safe wastewater handling to protect water quality and food safety (Jas, 2005; Ra, 2017; Utz, 2017; USDA, 2018; Fairtrade, 2019).

From an environmental perspective, coffee certification schemes systematically incorporate criteria for the protection and sustainable management of water sources. They encourage water saving practices among coffee growers (Milder & Newson, 2015) and support ecosystem services such as carbon storage, water purification, and flow regulation (Tscharntke et al., 2015). However, the effectiveness of such criteria varies by geographic and socioeconomic contexts. For example, studies in Vietnam and Ethiopia showed that certification programs have no significant effects on irrigation efficiency or water protection (Partzsch et al., 2021; Ho et al., 2022). By contrast, studies in Costa Rica showed a correlation between reductions in wastewater generation and certification (Ibañez & Blackman, 2016).

In Colombia, the positive impact of certified coffee farming on water resources is well documented. Previous studies emphasized the implementation of water conservation measures and reduced water contamination (Hughell & Newson, 2013; Rueda et al., 2015; Grabs et al., 2016; Caviedes et al., 2023). The reforestation of microwatersheds within coffee farms contributes to hydrological regulation and biodiversity conservation (Bosselman et al., 2009; Jha et al., 2014). Certified producers also reduce the use of agrochemicals, adopt waste minimization practices, and optimize water use during wet processing, thereby reducing wastewater pollutants (Galindo et al., 2012; García et al, 2014; Ibañez & Blackman, 2016; Grabs et al., 2016; Valbuena-Calderón et al., 2017).

Thus, this study aimed to evaluate the impact of the standards required by six certification programs and six combinations of certification programs on the water resources used in coffee farms in southern Colombia.

Material and Methods

The study was conducted on 461 coffee farms (*Coffea arabica* L.) in the municipality of Pitalito, which is part of the department of Huila in southern Colombia (Figures 1A and B) and is recognized in the last 12 years as the region with the highest coffee production in the country. The territory of Pitalito covers an area of 625.54 km^2 (1° 52′ N and 76° 02′ W) in the Colombian massif (Suárez et al., 2021), immersed in the biogeographical district of San Agustin of the ecoregion called "Montane Forest of the Magdalena Valley" (Olson et al., 2001; Brand et al., 2021). Pitalito corresponds to the agroecological zones ZAE5 and ZAE6 of the department of Huila (CENICAFÉ, 2019), with homogeneous climatic conditions ranging from cold humid to the predominant dry temperate climate in 77.3% of the territory, where coffee cultivation mainly takes place (Sánchez & Acosta, 2015; CENICAFÉ, 2019), accounting for approximately 29% of the territory of this municipality. The evaluated farms are located at an altitude range of 1200–2000 m, where coffee varieties

Figure 1. Maps showing the location of Colombia (A) and the municipality of Pitalito in the south of the Huila department (B)

such as Typica, Bourbon, Tabi, Caturra, Castillo, Colombia, Geisha, and Maragogype are grown (Sánchez & Acosta, 2015).

The impact of certification programs with voluntary sustainability standards, which were adopted by coffee farms in the municipality of Pitalito (Huila), on water resources was evaluated in 461 farms. The included farms were categorized into 12 groups with different certification programs or combinations of certification programs and a group of uncertified farms (Table 1). Each group consists of 30 certified coffee farms, and one group consists of 101 uncertified farms located in the districts of Bruselas, Criollo, Charguayaco, and Regueros in the municipality of Pitalito.

An index of measures for the conservation of water bodies on coffee farms (IMCW) was determined from the responses obtained from a survey conducted in each agricultural production unit, which contained a multiple-choice question that included a series of measures for the conservation of springs, wetlands, streams, or creeks within the farm, following the methodology proposed by DANE (2013) and FAO & UPM (2021). The measures with the highest number of repetitions were selected, accounting for eight measures. Then, the total number of measures selected as a response by the farm owner was listed. This value was divided by 8, which corresponds to the total number of measures, to obtain a value ranging from 0, indicating that no measures are taken for the conservation of water bodies on the farm, to one 1, indicating that sufficient measures are taken for the conservation of water bodies.

The impact of the certification programs adopted by the coffee farms was assessed by evaluating three indices, namely, domestic wastewater treatment efficiency index (DWTEI), water management index in the wet processing of coffee (WMIWPC), and environmental quality index in the wet processing of coffee (EQIWPC), following the methodologies proposed by Rodríguez et al. (2015), Malacatus et al. (2016), and Rodríguez et al. (2021).

DWTEI was determined by identifying each of the units of the domestic wastewater treatment system that each coffee farm evaluated in this study. In the field, their existence and their state, that is, whether they were functional or not, were corroborated. Each of the units was evaluated using the percentage of organic matter removal, which is measured as COD, as the reference (Table 2). All the domestic wastewater

Table 1. Programs or combinations of certification programs in the evaluated voluntary sustainability standards

Number of certifications	Certification or group of certifications	Number of farms evaluated
1	RA	30
1	Org	30
1	CPr	30
1	FT	30
1	4C	30
2	Utz + CPr	30
2	RA + CPr	30
2	FT + CPr	30
2	RA + FT	30
3	RA + FT + CPr	30
3	RA + Utz + CPr	30
4	RA + FT + Utz + CPr	30
0	NC	101

RA - Rainforest Alliance certified; FT - Fairtrade Labelling Organizations International; Utz - UTZ certified; Org - Organic; CPr - Coffee Practice; 4C - 4C Certification; NC - Uncertified

Table 2. Percentage of chemical oxygen demand (COD) removal for different units of domestic wastewater treatment systems found on coffee farms

Treatment unit	% COD Removal	References
Grease trap	10–20	Sánchez & Matsumoto (2016)
Septic tank	30–40	Rodríguez et al. (2018)
Stone filter	60–80	MDE (2002)
Anaerobic filter	60–80	Rodríguez et al. (2018)
Artificial wetland	70–80	Rodríguez et al. (2019)
Green filter	65–75	Rodríguez et al. (2022)
Biodigester	70–90	Lansing et al. (2008); Pin et al. (2020)

treatment units observed are also presented. The references were primarily published by researchers from the National Coffee Research Center (CENICAFÉ).

The index values ranged from 0 to 1 and corresponded to the fraction of organic matter measured as COD, which can be removed by the domestic wastewater treatment system available at the farm. Thus, the closer the value of the index is to 1, the higher its efficiency.

WMIWPC is an environmental indicator in the coffee production process used by CENICAFÉ to quantify the amount, savings, and efficiency in water consumption during wet processing of coffee (Rodríguez et al., 2015). It involves assigning a weighted value at each stage of the process carried out on a farm. Thus, it compares the water consumption of the device available at each stage of the farm's processing facility, using the consumption in the same stage of the process by conventional processing as a reference, thereby determining water savings (Eq. 1) (Rodríguez et al., 2021).

$$VP_e = ak_w^{-1} \quad (1)$$

where:

VPe - indicates the weighted value of each stage;

a - indicates the water savings in the specific processing stage in L kg^{-1} of dpc; and,

k_w - indicates the constant corresponding to the average value of water consumption during conventional processing, which is equivalent to 40 L kg^{-1} of dpc.

The VPe values are summed up to obtain WMIWPC (Eq. 2), which ranges from 0 to 1, with 0 being the highest water consumption, with no savings, and values close to 1 corresponding to processes with greater savings, efficient water use, and low consumption.

$$WMIWPC = \sum_{i=1}^{n} VPe \quad (2)$$

EQIWPC was designed by considering the stages of coffee processing in which contaminating byproducts are obtained from organic matter quantified as COD. This index aimed at assessing the environmental impact caused by the handling, disposal, and treatment of such byproducts (Rodríguez et al., 2015). It assigns a weighted value to each stage of the process corresponding to the impact generated by the byproduct (pulp or mucilage). Such an impact is related to the reduction in the contaminating potential of the byproduct based on the devices or structures available at the processing facility in its different stages and to water consumption and other practices of the process. The index values range between 0 and 1. Values equal to or close to 0 indicate a negative environmental impact. Conversely, values close to or equal to 1 indicate that an adequate management and treatment of the byproducts generated during the process is carried out on the farm, which reduces or minimizes the ecological impact (Rodríguez et al., 2021).

A valid counterfactual was determined for the 12 groups of certified coffee farms, and the difference in their IMCW, DWTEI, WMIWPC, and EQIWPC was measured to determine the impact of certification programs on water quality conservation. In this study, the observations in the control group with a p-score lower than the minimum p-score in the treatment group and the observations in each treatment group with a p-score higher than the maximum p-score in the control group were initially eliminated (Ruben & Fort, 2012). Then, the propensity scores of the treatment group for each observation with values ranging from 0 to 1 were estimated, which indicates the probability of obtaining the certification being directly proportional to the score obtained. The following covariates were used: the age of the owner, gender, years of education, land tenure, participation in associations or cooperatives of coffee growers, altitude of the farm, area of the coffee plantation, the percentage of the farm area cultivated with coffee, the age of the crop, and the distance from the farm to the nearest populated center. Then, the average treatment effect on the treated (ATET) was calculated from the common support area between each treatment group and its respective control group (Dietz et al., 2020; Estrella et al., 2022).

The MPS results were evaluated using the kernel algorithm, which structures the counterfactual result obtained from the weighted average of the individuals in the control group and the nearest neighbor match, selecting an individual from the control group with a similar or close propensity score. In this case, the weighted average of two neighbors was used, obtaining matching with replacement; therefore, a farm can be matched on multiple occasions (Baser, 2006; Ruben & Fort, 2012; Estrella et al., 2022).

The propensity score matching (PSM) test was performed using R version 4.2.2. through the independent platform for statistical analysis R Studio utilizing packages Ade4, Ggplot2, Magrittr, Dplyr, and FactoMineR.

Results and Discussion

The IMCW values on coffee farms in the municipality of Pitalito significantly differ from those on uncertified farms (Table 3). Organic (Org) farms adopt the most measures for the conservation of water bodies in their territory compared with their uncertified counterparts, as corroborated by the highest ATET value, followed by coffee farms with RA + FT and RA certification schemes. On the contrary, coffee farms with RA + FT + Utz + CPr, RA + Utz + CPr, 4C, FT + CPr, and RA + FT + CPr schemes rank third. The RA and FT programs have the highest number of criteria aimed at water management and conservation. The third place is supported by the fact that they are mainly multicertification schemes, which include all RA and FT programs. The most adopted measure by the coffee growers surveyed in this study (98%) was avoiding spraying near water bodies or storage during agrochemical application, followed by the conservation of protective strips around springs and water sources (57%). This result is consistent with the findings of previous studies on organic certification in Colombia (Ibañez & Blackman, 2016) and with coffee farming under voluntary sustainability standards (Caviedes et al., 2023).

The measurement of DWTEI for certified coffee farms in comparison with their uncertified counterparts yielded a counterfactual with statistically significant differences for all certification schemes (Table 4). The index shows that the systems designed to treat wastewater on certified coffee farms have treatment units that provide greater efficiency than those of uncertified farms. The coffee farms with FT + CPr and CPr certifications evaluated in this study have the most efficient treatment systems when compared with their noncertified counterparts, resulting in higher removals and lower pollutant discharge. The other certification scheme that shows high efficiency, with regard to its counterfactual, corresponds to Org, followed by the RA + FT and RA schemes. By contrast, the multicertification schemes RA + FT + Utz +

Table 3. Certification schemes evaluated and compared on the basis of the values of the index of measures for the conservation of water bodies on coffee farms

Certification	Mean	ATET	Std_Error	z	Pr (>|z|)	2.5%–97.5%
With certification	0.34	0.05	0.01	6.68	<0.001	0.0343–0.0627
Org	0.55	0.07	0.01	6.62	<0.001	0.0484–0.0892
RA + FT	0.33	0.06	0.01	6.82	<0.001	0.0428–0.0773
RA	0.33	0.06	0.01	6.86	<0.001	0.0425–0.0765
4C	0.25	0.05	0.01	5.69	<0.001	0.0344–0.0705
RA + FT + Utz + CPr	0.38	0.05	0.01	5.87	<0.001	0.0339–0.0679
RA + Utz + CPr	0.35	0.05	0.01	5.71	<0.001	0.0318–0.0651
FT + CPr	0.35	0.05	0.01	5.62	<0.001	0.0314–0.0650
RA + FT + CPr	0.28	0.05	0.01	5.41	<0.001	0.0288–0.0616
CPr	0.31	0.04	0.01	4.87	<0.001	0.0268–0.0629
RA + CPr	0.33	0.04	0.01	4.09	<0.001	0.0212–0.0603
FT	0.28	0.03	0.01	3.54	<0.001	0.0143–0.0498
CPr + Utz	0.30	0.03	0.01	3.63	<0.001	0.0141–0.0474

ATET - Average treatment effect on the treated; Std_Error - Standard error; Pr(>z) - P value; RA - Rainforest Alliance certified; FT - Fairtrade Labelling Organizations International; Utz - UTZ certified; Org - Organic; CPr - Coffee practice; 4C - 4C certification

Table 4. Treatment effect on the treated based on the domestic wastewater treatment efficiency index

Certification	Mean	ATET	Std_Error	z	Pr(>|z|)	2.5%–97.5%
With certification	0.59	0.13	0.02	7.48	<0.001	0.0959–0.164
FT + CPr	0.53	0.18	0.02	10.21	<0.001	0.1463–0.216
CPr	0.50	0.18	0.02	8.44	<0.001	0.1344–0.216
Org	0.55	0.16	0.02	6.98	<0.001	0.1182–0.211
RA + FT	0.76	0.14	0.02	6.33	<0.001	0.0998–0.189
RA	0.51	0.14	0.02	6.54	<0.001	0.0957–0.178
RA + Utz + CPr	0.65	0.13	0.02	6.51	<0.001	0.0938–0.175
CPr + Utz	0.61	0.12	0.02	5.58	<0.001	0.0793–0.165
FT	0.57	0.12	0.02	6.09	<0.001	0.081–0.158
RA + CPr	0.54	0.11	0.02	4.5	<0.001	0.0602–0.153
4C	0.44	0.10	0.03	4.08	<0.001	0.0542–0.154
RA + FT + Utz + CPr	0.86	0.09	0.02	4.11	<0.001	0.0486–0.137
RA + FT + CPr	0.63	0.08	0.02	3.76	<0.001	0.0374–0.119

ATET - Average treatment effect on the treated; Std_Error - Standard error; Pr(>z) - P value; RA - Rainforest Alliance certified; FT - Fairtrade Labelling Organizations International; Utz - UTZ certified; Org - Organic; CPr - Coffee practice; 4C - 4C certification

CPr and RA + FT + CPr have DWTEI values below 50% of the higher values corresponding to FT + CPr and CPr.

Wet processing of coffee produces a type of coffee known as "washed coffee," which consumes high amounts of water in its different stages. Thus, new coffee processing techniques aim to reduce the use of water resources during the process (Beyene et al., 2012; Alemayehu et al., 2020; Campos et al., 2021). The results of PSM showed significant differences in IMAPBHC values among the groups or certification schemes (Table 5). Farms with FT + CPr and CPr certifications have the lowest water consumption during wet processing of coffee, followed by farms with Org certification and those that adopted RA and RA + Utz + CPr certification schemes. On the contrary, coffee farms with multicertification schemes RA + FT + Utz + CPr and RA + FT + CPr have the lowest WMIWPC values, indicating that farms with these programs are the highest consumers of water resources during wet processing.

These results are in accordance with the requirements established by the programs in their criteria, except for Org, which does not have a criterion with a direct requirement on water resources in the postharvest process. The results indicate that the programs with the greatest positive influence on water resources are CPr, RA, and Org. In particular, the CPr program has the clearest level of demand because it establishes a limit ratio of 1:1 in the volume of water used to the volume of coffee processed (Harris et al., 2017). On the contrary, RA requires the efficient use of water resources during processing and restricts wastewater discharges (RA, 2017). The results of the studies that evaluated the Utz program in Colombia (García et al., 2014), the RA program (Hughell et al., 2013), and the Utz + RA scheme in Colombia, Costa Rica, and Guatemala (Grabs et al., 2016) were consistent with the reduction of water use during wet milling.

The byproducts generated by wet processing of coffee induce the highest pollutant load in all production stages (Camacho & Uribe, 2018; Ijanu et al., 2020; Gebreeyessus, 2022). The data obtained as a result of PSM indicate significant differences in EQIWPC as a counterfactual of the management and treatment of the byproducts generated by wet processing of coffee in the treatment or certification groups (Table 6). ATET indicates that the coffee farms generating the least environmental impact on water resources because of the management and treatment of the byproducts generated by wet processing of coffee are certified with FT + CPr and only CPr with ATET 0.21 and 0.20, respectively. Farms with Org certifications, RA + CPr, and RA + Utz + CPr also present ATET with values indicating a lower negative impact because of discharges of byproducts generated during wet processing. On the contrary, multicertification indicates a less positive impact compared with the other schemes.

The ATET evaluated with regard to the impact of the byproducts generated during wet processing of coffee has a direct relationship with the CPr program, which, within its compliance criteria that require the recording of the volumes and proportions of water used, as well as the management

Table 5. Treatment effect on the treated based on the water management index during wet processing of coffee

Certification	Mean	ATET	Std_Error	z	Pr(>|z|)	2.5%–97.5%
With certification	0.83	0.21	0.02	11.7	<0.001	0.176–0.246
FT + CPr	0.79	0.27	0.02	12.11	<0.001	0.2238–0.310
CPr	0.76	0.27	0.02	10.78	<0.001	0.2168–0.313
Org	0.88	0.26	0.02	11.4	<0.001	0.2186–0.309
RA	0.78	0.24	0.02	11.02	<0.001	0.1978–0.283
RA + Utz + CPr	0.84	0.24	0.02	11.47	<0.001	0.1991–0.281
CPr + Utz	0.78	0.22	0.02	10.07	<0.001	0.1804–0.268
RA + CPr	0.85	0.22	0.03	8.28	<0.001	0.1663–0.269
FT	0.88	0.20	0.03	7.83	<0.001	0.1500–0.250
4C	0.71	0.18	0.02	7.46	<0.001	0.1343–0.230
RA + FT	0.88	0.17	0.02	7.3	<0.001	0.1248–0.216
RA + FT + CPr	0.89	0.15	0.02	7.75	<0.001	0.1139–0.191
RA + FT + Utz + CPr	0.87	0.11	0.02	5.55	<0.001	0.0694–0.145

ATET - Average treatment effect on the treated; Std_Error - Standard error; Pr(>z) - P value; RA - Rainforest Alliance certified; FT - Fairtrade Labelling Organizations International; Utz - UTZ certified; Org - Organic; CPr - Coffee practice; 4C - 4C certification

Table 6. Treatment effect on the treated based on the environmental quality index during wet processing of coffee

Certification	Mean	ATET	Std_Error	z	Pr(>|z|)	2.5%–97.5%
With certification	0.76	0.16	0.01	10.5	<0.001	0.126–0.184
FT + CPr	0.72	0.21	0.02	11.66	<0.001	0.1721–0.242
CPr	0.72	0.20	0.02	9.58	<0.001	0.1585–0.240
Org	0.81	0.18	0.02	9.14	<0.001	0.1384–0.214
RA + CPr	0.81	0.17	0.02	7.93	<0.001	0.1289–0.214
RA + Utz + CPr	0.76	0.17	0.02	9.86	<0.001	0.1363–0.204
CPr + Utz	0.70	0.16	0.02	9.52	<0.001	0.1303–0.198
RA	0.71	0.16	0.02	8.69	<0.001	0.1243–0.197
4C	0.66	0.16	0.02	7.6	<0.001	0.1155–0.196
FT	0.81	0.15	0.02	6.9	<0.001	0.1091–0.196
RA + FT	0.82	0.12	0.02	5.85	<0.001	0.0784–0.157
RA + FT + CPr	0.82	0.12	0.02	7.01	<0.001	0.0831–0.148
RA + FT + Utz + CPr	0.79	0.07	0.02	4.25	<0.001	0.0377–0.102

ATET - Average treatment effect on the treated; Std_Error - Standard error; Pr(>z) - P value; RA - Rainforest Alliance certified; FT - Fairtrade Labelling Organizations International; Utz - UTZ certified; Org - Organic; CPr - Coffee practice; 4C - 4C certification

of wastewater, aimed at causing negative impacts on the environment (Harris et al., 2023). Studies carried out in different coffee growing regions showed that coffee processing in Colombia includes various technologies, but only 10% of these technologies are considered environmentally friendly (Aristizábal, 2005).

The ATETs of the DWTEI, WMIWPC, and EQIWPC indices for each program or certification scheme were added to quantify their impact on water resources (Table 7). IMCW was not included because adopting management measures is not considered an impact, but such measures are considered precursors of impact depending on the rigor of the measure's application by coffee growers.

As shown in Figure 2, the certification of coffee farms has a positive effect on water resources in all evaluated schemes. The CPr + FT certification scheme showed better management of byproducts, greater efficiency and water savings during the process, and greater efficiency in the treatment of wastewater from processing and domestic use, which would translate into discharges with a lower pollutant load to the soil or water sources, thereby reducing the risk of eutrophication to the ecosystem caused by high concentrations of N and P, as well as the level of dissolved oxygen caused by high discharges of organic matter and suspended solids, which can cause toxicity

Table 7. Environmental impact of certified coffee farms on water resources

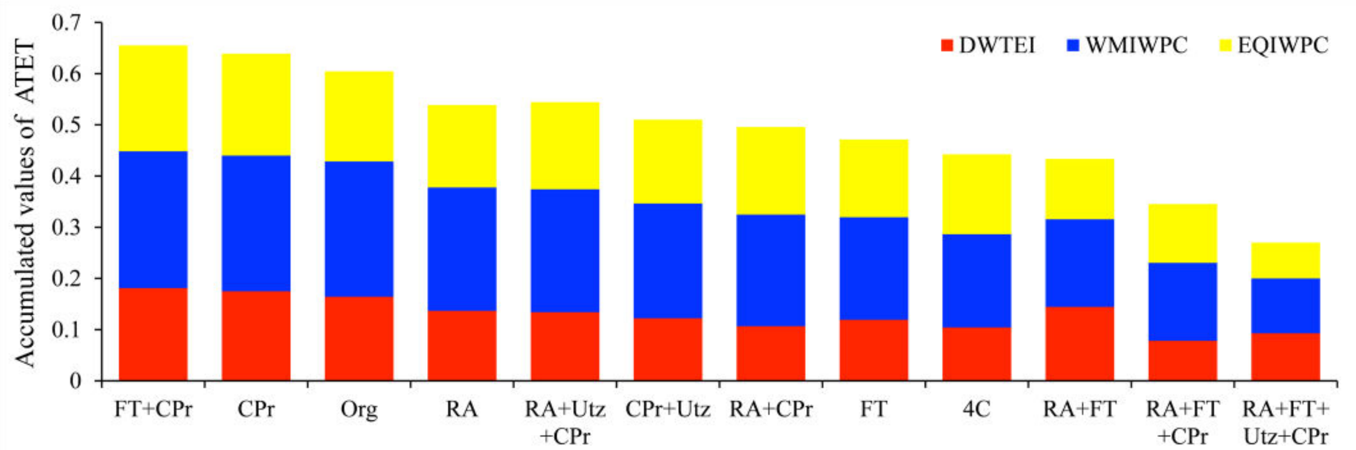
Certification	ATET			ATET
	DWTEI	WMIWPC	EQIWPC	Total
With certification	0.1300	0.2110	0.1550	0.4960
FT + CPr	0.1811	0.2670	0.2070	0.6551
CPr	0.1750	0.2650	0.1990	0.6390
Org	0.1644	0.2640	0.1760	0.6044
RA	0.1367	0.2410	0.1610	0.5387
RA + Utz + CPr	0.1342	0.2400	0.1700	0.5442
CPr + Utz	0.1222	0.2240	0.1640	0.5102
RA + CPr	0.1067	0.2180	0.1710	0.4957
FT	0.1194	0.2000	0.1520	0.4714
4C	0.1043	0.1820	01560	0.4423
RA + FT	0.1445	0.1710	0.1180	0.4335
RA + FT + CPr	0.0783	0.1520	0.1150	0.3453
RA + FT + Utz + CPr	0.0929	0.1070	0.0700	0.2699

ATET - Average treatment effect on the treated; RA - Rainforest Alliance certified; FT - Fairtrade Labelling Organizations International; Utz - UTZ certified; Org - Organic; CPr - Coffee practice; 4C - 4C certification. DWTEI - Domestic wastewater treatment efficiency index; WMIWPC - Water management index in the wet processing of coffee; EQIWPC - Environmental quality index in the wet processing of coffee

to aquatic biota and humans (Woldesenbet et al., 2014; Dori, 2017; Said et al., 2023). The second and third schemes that generate less impact are CPr and Org, respectively. However, the multicertification scheme RA + FT + Utz + CPr showed the highest adverse impact among all the certification schemes evaluated in this study, after being compared with its uncertified counterparts and despite being the fifth scheme indicated to have a higher number of measures adopted compared with its uncertified counterparts.

In Colombia, the norm that regulates the maximum discharge values (Resolution 631 of 2015 of the Ministry of Environment and Sustainable Development) presents broader values than the limits of regulations in countries such as Malaysia, India, Brazil, and even those established by the World Health Organization (Said et al., 2023). During processing, coffee farming in the Huila region discharges an average of 337 g of COD and consumes 17.1 L of water for each kilogram of dpc, which is higher than the Colombian average (302 g of COD and 15.26 L for each kilogram of dpc) (Rodríguez-Valencia et al., 2022). However, the study region shows the prevalence of processing systems typified as "ecological processing" because of their low water consumption (<10 L kg^{-1} of dpc and categorized from E1 to E8, with E8 being zero discharge) (Rodríguez et al., 2021). In addition, 80% of the processing facilities are classified between E1 and E4 and 11% transition to ecological, and only 7.6% of the farms in the study present structures and devices with zero discharges (E8). Nevertheless, they represent a higher amount than the national percentage, which is only 1.5% (Sporchia et al., 2023).

According to Fernández et al. (2020), in the western region of the department, the process is traditionally developed by a high proportion of coffee growers. However, it does not expose the segmentation of certified and uncertified farms. Studies conducted in Colombia and Ethiopia by Partzsch et al. (2021) comparing FT, RA, 4C, and Org programs showed that no program limits the amount of water to be used, regardless of the physical limits of water resources. However, they are demanding proper management of wastewater from processing, although they do not set requirements for its treatment. Therefore, such programs only represent selective improvements in certified farms, and their results do not represent wide differences.



ATET - Average treatment effect on the treated; RA - Rainforest Alliance certified; FT - Fairtrade Labelling Organizations International; Utz - UTZ certified; Org - Organic; CPr - Coffee practice; 4C - 4C certification

Figure 2. Accumulated values of domestic wastewater treatment efficiency index (DWTEI), water management index in the wet processing of coffee (WMIWPC), and environmental quality index in the wet processing of coffee (EQIWPC) to determine their impact on water resources of certified coffee farms

Efficient water use, mainly for irrigation in countries such as Vietnam, Kenya, or Tanzania, does not show effects that are attributed to certification (Van der Vossen et al., 2005; Ho et al., 2022). Globally, the water footprint per irrigation of coffee cultivation ranges between 0.15 and 0.27 m^3 eq L^{-1} of coffee (Usva et al., 2020). However, in the south of the department of Huila, coffee plantations are not irrigated (Leal & Tobón, 2021; Agronet, 2022). Therefore, impact measurement was ruled out in this study, which projects Colombian coffee as a more sustainable product with regard to water resource management because of the biogeographical conditions in which it is grown.

It is important for coffee growers and environmental authorities to conduct studies on the flow of the basin in relation to the frequency and volume of discharges from the production unit. Adopting a circular economy approach by implementing low-consumption and high-water-efficiency devices in coffee processing, which lead to zero discharges or efficient and low-cost treatments, is essential to comply with environmental regulations and to reduce the impact of coffee farming in the region (Matuk et al., 1998; Dadi et al., 2018; Alemayehu et al., 2020; Rodríguez-Valencia, 2023; Said et al., 2023).

Conclusions

1. Certification schemes promote the sustainability of coffee farming in water resource management.

2. The effectiveness of the measures depends on the commitment of coffee growers and the resources available for implementation.

3. Voluntary sustainability standards reduce water consumption and pollutant discharge.

4. The effect of adopting certification programs on water resource management is independent of the number of certifications held by the farm.

5. Multicertification does not ensure the effectiveness of the measures applied for water resource management.

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