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Evaluation of tomato crop water demand through three evapotranspiration estimation methods in the agro-climatic context of Dschang, Cameroon

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ABSTRACT

The management of irrigation for vegetables, specifically tomatoes, is essential, which involves defining the quantities and frequencies of supply aimed at increasing plant productivity and quality while maximizing water use efficiency. This study evaluated the agronomic performance, irrigation water productivity, and economic profitability of tomato (Solanum lycopersicum L.) cultivated under three evapotranspiration-based irrigation scheduling methods: Penman–Monteith, Blaney–Criddle, and Turc, combined with two irrigation frequencies (daily and every two days) in Dschang, West Cameroon. The experiment was conducted at the University of Dschang's experimental area from November 2021 to March 2022. A split-plot experimental design was used, with methods of ETP determination as the principal factor and frequency as the secondary factor. Tomato growth parameters, yield components, irrigation water use efficiency (IWUE), and economic profitability indicators were assessed throughout the production cycle. Results showed that irrigation dose and frequency had no significant effect on vegetative growth parameters but significantly influenced ($p < 0.05$) fruit yield, irrigation water productivity, and economic returns (value–cost ratio ≥ 2). The highest marketable yield (81.4 t ha^{-1}) was obtained with the Penman–Monteith method applied every two days, while the greatest irrigation water use efficiency (15.92 kg m^{-3}) was achieved with the Blaney–Criddle method applied every two days. All irrigation–fertilization combinations were economically profitable (value–cost ratio ≥ 2), with the Penman–Monteith method applied every two days offering the best compromise between yield maximization and economic return.

Contribution/Originality: This study contributes to the existing literature by evaluating and comparing three evapotranspiration-based irrigation scheduling methods under tropical highland conditions to optimize water use efficiency and profitability. It is among the few studies integrating agronomic performance, water productivity, and economic analysis for tomato production in Cameroon.

1. INTRODUCTION

Vegetable production plays a crucial role in food security, income generation, and employment in developing countries. Market gardening contributes over 33% to global agricultural production and employs 800 million people, which helps reduce unemployment [1]. Several crops are grown in vegetable gardens worldwide, including tomato (*Solanum lycopersicum*). L. 1753). According to the Food and Agriculture Organization of the United Nations (FAO) [2], tomatoes are produced in more than 170 countries, with an estimated annual production of 182.3 million tons.

Tomato production in Cameroon is around 1.2 million tons, cultivated on approximately 93,000 hectares. Compared to the 2018 production figures reported by the Food and Agriculture Organization of the United Nations [3], this tomato availability remains constant. Indicators show a stagnation in production; average tomato yields are around 12.9 t/ha [4], which can be considered low compared to the yields of 45-65 t/ha for a good tomato crop, according to Sys et al. [5]. This yield gap is largely attributed to poor crop management practices, particularly inefficient irrigation management.

Proper irrigation management involves determining appropriate water application rates and frequencies to maximize crop productivity and water use efficiency [6]. Both water deficit and excess irrigation affect tomato growth by inducing physiological stress, reducing nutrient uptake, and causing root asphyxiation [7]. Indeed, it would be interesting to see the yields we obtain from irrigated crops in our ecosystem, considering that during the dry season, water application to agricultural plots is haphazard, meaning that the appropriate doses for each growth stage are not respected, and the application frequency is poor. This is particularly true in the Western Highlands of Cameroon, which, despite the availability of water resources, are poorly managed. Thus, to increase production for this crop during the off-season, it is essential to use a water application method and frequency adapted to this area. To do this, it is necessary to assess the crop's water requirements in order to determine the volumes of water to be applied through irrigation during the growing season [7, 8] for the planning of effective irrigation, which will ultimately lead to optimized yields.

The dose and frequency of irrigation required for crops depend on the local climate, the amount of water that can be stored in the soil after irrigation, the depth of the plant's root system, and the area of soil covered. Several researchers have demonstrated the effect of good irrigation management and its contribution to increasing crop yields and improving product quality [9]. Determining crop water requirements involves estimating the potential evapotranspiration of the growing area. Evapotranspiration can be estimated using several empirical methods or formulas, depending on the available climatic parameters.

Several methods have been developed to estimate reference evapotranspiration [10], including the Penman–Monteith, Blaney–Criddle, and Turc methods. While the FAO Penman–Monteith method is widely recommended as a standard, its application requires extensive climatic data, which are often unavailable or unreliable in many developing regions. Simpler methods such as Blaney–Criddle and Turc may offer practical alternatives; however, their agronomic performance, water productivity, and economic implications remain insufficiently documented under tropical highland conditions. However, limited studies have compared these three methods in terms of agronomic performance, water productivity, and economic profitability under tropical highland conditions. Moreover, few studies integrate agronomic and economic analysis for smallholder farmers in central Africa.

This study aimed to evaluate the effects of three evapotranspiration-based irrigation scheduling methods combined with two irrigation frequencies on tomato growth, yield, irrigation water use efficiency, and economic profitability in the western highland of Cameroon. The specific objectives were to:

- Assess the influence of irrigation dose and frequency on tomato growth and yield parameters.
- Compare irrigation water productivity among the different evapotranspiration methods.
- Identify the most agronomically efficient and economically profitable irrigation strategy for off-season tomato production under tropical highland conditions.

2. MATERIALS AND METHODS

2.1. Study Area

The experiment was conducted at the Research and Application Farm (FAR) of the University of Dschang (Figure 1), located in the western highlands of Cameroon (5°26′ N latitude and 10°4′ E longitude) at an altitude of approximately 1410 m above sea level. The area belongs to Agro-Ecological Zone III and is characterized by a bimodal rainfall pattern with a rainy season extending from mid-March to mid-November and a dry season from mid-November to mid-March.

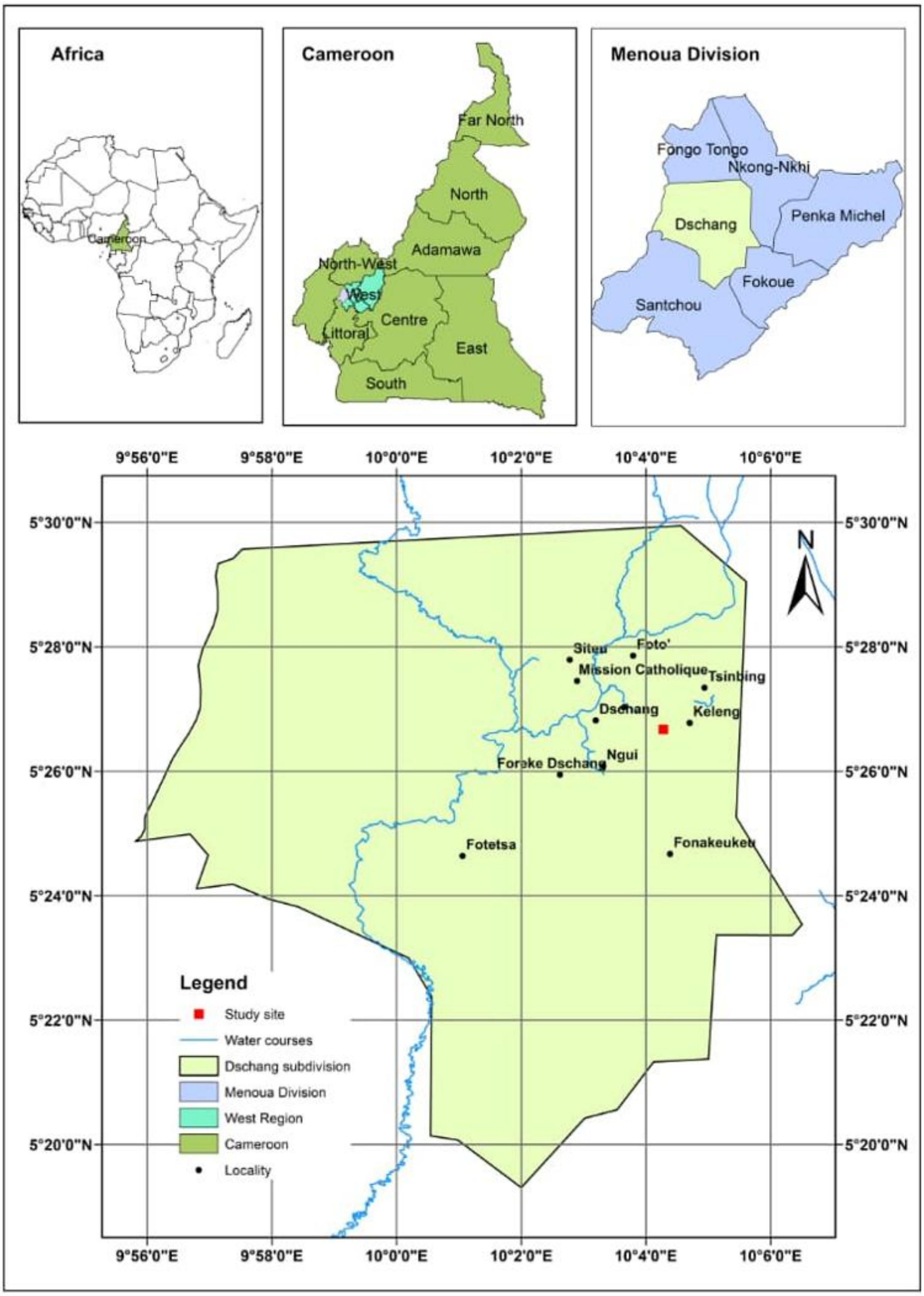

Figure 1. Location of study area.

2.2. Soil Characteristics

The experimental site is characterized by well-drained red ferralitic soil classified as an Oxisol with a gently rolling landscape of small hills, on which terraces have been created to allow for efficient cultivation. The soil was acidic with good organic matter but a poor amount of phosphorus and potassium [11].

2.3. Plant Material

The plant material used in this study was the Cobra 26 variety, a highly productive F1 hybrid with multiple branches. This variety can reach a height of 1.30 m and produces round fruit. Cobra 26 is an early variety with a 75-day cycle to begin production after transplanting, and it is also characterized by its resistance to several diseases.

2.4. Fertilization Management

An organo-mineral fertilizer consisting of chicken manure and a mineral fertilizer (21-8-12) was used in this study. These fertilizers were purchased at the Dschang market for 3,500 FCFA per bag of manure and 600 FCFA per kilogram of mineral fertilizer. This amounted to 17,500 FCFA per 50 kg bag of mineral fertilizer.

2.5. Experimental Design and Treatments

The experimental design used for this study was a split-plot covering a total area of 317 m² (as shown in Figure 2). The study site had a 4% slope. The experimental units measured approximately 2.4 m × 2.4 m, for a total area of 5.76 m². Each unit contained 24 plants spaced 80 × 30 cm apart, resulting in 3 rows of 8 plants and a density of 41,666 plants per hectare (ha). The blocks were perpendicular to the slope, and each consisted of three sub-blocks, each of which comprised two experimental units.

The experimental site presented a space problem, which led to the plot being divided into two. One side contained the main units (18 units), i.e., those that had been fertilized. The other side served as a control plot (receiving no fertilization on one side and only mineral fertilization on the other). The different combinations of factors were as follows;

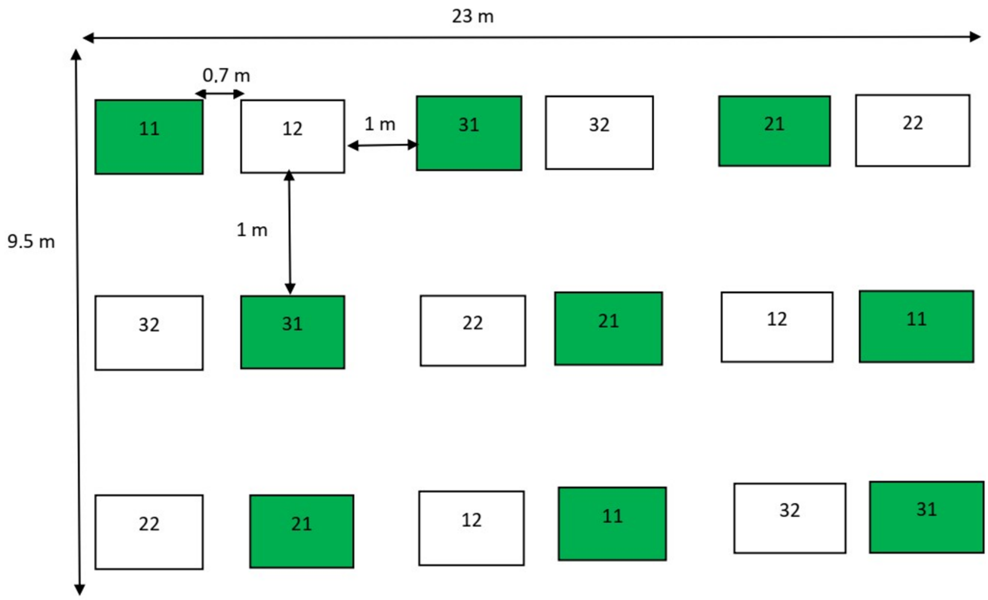

Figure 2. Experimental design.

- 11 PM-D: Penman–Monteith + daily irrigation.
- 12 PM-2D: Penman–Monteith + irrigation every two days.
- 21 BC-D: Blaney–Criddle + daily irrigation.
- 22 BC-2D: Blaney–Criddle + irrigation every two days.
- 31 T-D: Turc + daily irrigation.
- 32 T-2D: Turc + irrigation every two days.

2.6. Methods for Determining Evapotranspiration

Evapotranspiration (ET) is one of the most difficult components of the hydrological cycle to quantify due to its complexity within the soil-land-plant system [12]. Estimating is important for irrigation programs, planning, and water resource management [13]. Consequently, numerous methods have been developed for the indirect estimation of evapotranspiration. Among these methods, we can mention the PENMAN-MONTEITH method (FAO-PM), which has been recommended by the FAO as a standard method, the TURC method, and the BLANEY-CRIDDLE method, among others.

2.6.1. Penman-Monteith Method (FAO-PM)

This method estimates the evapotranspiration of a surface characterized by short, green vegetation (grass), adequately supplied with water, of uniform height (0.12 m), with an albedo of 0.23 and a surface resistance (to water vapor transfer) of 70 s/m [10]. Its formulation is as follows:

Equation 1: PM formula

$$ETO = \frac{[0.408\Delta \times (Rn - G)] + \left[\gamma\left(\frac{900}{T + 273}\right) \times u2(es - ea)\right]}{[\,\Delta + \gamma\,(1 + 0.34\,u2)]} \quad (1)$$

Where ET0 is the reference evapotranspiration (in mm/day), Rn is the global radiation (in MJ/m^2/day), G is the soil heat flux (in MJ/m^2/day), T is the average daily air temperature at a height of 2 m (in °C), u_2 is the wind speed at a height of 2 m (in m/s), e_s is the saturation vapor pressure (in kPa), e_a is the vapor pressure at temperature T (in kPa), Δ is the slope of the saturation vapor pressure curve (in kPa/°C), γ is the psychrometric constant (in kPa/°C), and 900 is a constant for a daily time step.

2.6.2. Turc Method (1962)

The estimation of ETP using the Turc method is based on the use of climatic parameters, namely average temperature, global radiation, and monthly insolation, to arrive at a result expressed in mm/month according to the following formulas:

- If RH > 50%, then:

Equation 2: Turc's formula (a)

$$ETP = 0.40\left(\frac{T}{T+15}\right)(Rg + 50) \quad (2)$$

- If RH < 50%, then:

Equation 3: Turc's formula (b)

$$ETP = 0.40\left(\frac{T}{T+15}\right)(Rg + 50)(1 + \frac{50+RH}{70}) \quad (3)$$

Rg = IgA (0.18+0.62 h /) (cal /cm2/day) RH: Relative humidity; h: Insolation duration; H: Day length; Rg: represents the global solar radiation, which can be estimated from the insolation duration h.

2.6.3. Blaney-Criddle Formula (1950)

The Blaney-Criddle method is used when temperature is the only available climate data. It incorporates the monthly percentage of daylight hours (P1) and the average monthly temperature in degrees Fahrenheit (t). It expresses the reference evapotranspiration (ETP) using the following formula:

Equation 4: Blaney-Criddle Formula

$$ETP = \frac{(15+0.84t)H}{100} \quad (4)$$

The duration of day H, expressed in hours, is given according to latitude and time of year.

The BLANEY-CRIDDLE formula tends to underestimate high ETP. It particularly underestimates climatic demand in arid or semi-arid areas, by not taking into account the increase in ETP due to advective phenomena.

2.7. Estimation of Crop Water Requirements

Reference evapotranspiration (ET_0) was estimated using climatic data obtained from local meteorological records. Crop evapotranspiration (ETc) was calculated as:

Equation 5: Crop Water Requirements

$$ETc = ET0 \times Kc$$

$$ETM\ (mm) = ET0\ \times\ kc\ Quantity\ of\ water\ to\ be\ supplied\ (litre)$$
$$= ETM\ \times\ area\ of\ one\ unit\ (\ 5.76m^2\ ) \quad (5)$$

Where Kc represents the crop coefficient, which varies according to the tomato growth stage (Initial, vegetative growth, flowering and fruiting, and maturation). The volume of irrigation water applied to each plot was determined based on ETc and the surface area of the experimental unit, assuming that 1 mm of water corresponds to 1 L m^{-2}.

Rainfall was monitored using a rain gauge installed at the experimental site. Effective rainfall was deducted from irrigation requirements to adjust the applied water volumes accordingly.

2.8. Irrigation Water Use Efficiency

Harmanto et al. [14] stated that irrigation water productivity (IWP) relates the amount of water supplied to the plant to crop yield. Water use efficiency is defined as the yield per unit of water. Optimal efficiency is achieved by minimizing losses due to evaporation, runoff, and infiltration. The concept of water productivity is often used, meaning producing more or obtaining greater benefits with less water. This concept is generally limited to the economic value produced per unit of water consumed. Water productivity in crop production is further clarified by the use of the term Irrigation Water Use Efficiency (IWUE) [9]. The efficiency of irrigation water use is calculated using the following formula:

Equation 6: Water Use Efficiency

$$EUEI(kg/l)\ =\ Y/I \quad (6)$$

Where Y is the marketable yield (kg m^{-2}), and I is the irrigation water applied (L m^{-2}).

2.9. Economic Analysis

Certain indices, such as the productivity index, net profit (NP), and the value/cost ratio, allow for the assessment of the profitability of fertilization. The rate of return and the value/cost ratio were used to evaluate the profitability of the different levels of organic and mineral fertilizers used in the trial. This study takes into account the prices of the various inputs on the Dschang market, their transport costs, the cost of spreading, and the cost of additional labor related to the increased yield resulting from fertilization.

The value/cost ratio (VCR) is the ratio between the cost price of the additional harvest (PRRS) due to the treatment and the total cost 2 (TC2).

Thus, the various costs are listed as follows:

- The price of 21-8-12 mineral fertilizer is 17500 francs per 50kg bag.
- The price of a bag of chicken manure is 3500 francs.
- The transport cost for fertilizer is 250 francs per bag.
- The cost of spreading chicken manure is 35,000 CFA francs per hectare.
- The cost of spreading mineral fertilizer is 25,000 CFA francs per hectare.
- The labor cost associated with the additional harvest is 7.5 CFA francs per kg of tomatoes.
- The interest rate on investment is 4.25% per year in the Cameroonian economy.

- The price of empty crates is 100 francs each.
- The selling price of one kg of edible fruit was 200 CFA francs during the harvest month.

2.10. Data Collection

The main growth and yield data collected on the tomato plants were plant height and stem diameter, number of fruits, and average fruit weight. Height and stem diameter were measured at 7-day intervals following a series of five harvests (Days 21, 28, 35, 42, and 49 after transplanting) during the crop development cycle, while the number and average fruit weight were collected at harvest following a series of six harvests. The first harvest began 75 days after transplanting.

2.11. Data Analysis

The data were entered using Microsoft Office Excel 2016. This same software was used to create the tables. Statistical analyses were performed using IBM SPSS version 23.0. This software generated the ANOVA (Analysis of variance) tables.

3. RESULTS

This section presents the effects of irrigation scheduling on climatic conditions, vegetative growth, yield components, water use efficiency, and economic profitability.

3.1. Climatic Conditions and Irrigation Water Requirements

The experiment period extended from November 2021 to March 2022, covering approximately five months from transplanting to the final harvest. The rainfall, temperature, and humidity that prevailed during this growing period are presented in Table 1:

The total irrigation water supplied varied substantially depending on the evapotranspiration estimation method. Over the entire crop cycle, cumulative water inputs were highest with the Penman–Monteith method (573.2 mm), followed by the Turc method (526.5 mm), and lowest with the Blaney–Criddle method (452.4 mm) as seen in Tables 1 and 3. These differences resulted in contrasting irrigation doses applied at each growth stage, with the flowering and fruiting stage requiring the largest water volumes.

Table 1. Climatic conditions recorded during the test.

Month		November	December	January	February	March
Relative humidity in %		82.75	73.06	68.33	69.47	77.27
Maximum temperature in °C		28.62	30.45	30.62	31.41	29.06
Minimum temperature in °C		17.77	15.63	18.23	19.53	18
Average temperature in °C		23.19	23.04	24.4	25.47	23.53
Rainfall depth in mm		93.48	16.51	0	9.09	35.9
Irrigation in mm	PENMAN-MONTEITH	//	46.35	155.22	151.56	65.10
	BLANEY-CRIDDLE	//	35.10	106.94	105.90	49.48
	TURKISH	//	42.19	141.84	127.60	59.90
Total quantity of water in mm	PENMAN-MONTEITH	//	62.86	155.22	160.65	101
	BLANEY-CRIDDLE	//	51.61	106.94	114.99	85.38
	TURC	//	58.7	141.84	136.69	95.8

Table 2 presents the monthly climatic characteristics of the study area, including temperature, relative humidity, wind speed, precipitation, and reference evapotranspiration values, which determine irrigation water requirements.

Table 2. Climatic conditions of the study area.

Settings/Month	Jan	Feb	March	April	May	June	July	August	Sep	Oct	Nov	Dec
Tmax(°C)	27.97	28.89	28.13	26.84	26.15	25.21	24.09	24.05	24.54	24.78	25.98	27.00
Tmin (°C)	16.51	17.71	19.24	19.82	19.60	18.87	18.17	18.07	18.39	18.68	18.25	16.69
Average temperature (°C)	22.24	23.30	23.69	23.33	22.88	22.04	21.13	21.06	21.47	21.73	22.12	21.85
Relative Humidity (%)	68.51	69.15	78.77	86.2	87.68	88.81	90.76	91.06	89.97	89.5	83.71	73.51
U_2	0.83	0.81	0.72	0.65	0.65	0.71	1.01	1.08	0.80	0.69	0.73	0.80
Precipitation (mm/day)	0.72	1.49	4.28	7.08	7.25	9.27	10.14	11.86	11.37	10.3	3.73	1.1
Δ	0.163	0.172	0.175	0.172	0.168	0.161	0.154	0.153	0.156	0.159	0.162	0.16
ϒ	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058
es	2.673	2.846	2.919	2.849	2.772	2.649	2.502	2.494	2.543	2.591	2.658	2.606
ea	1.831	1.968	2.299	2.456	2.430	2.353	2.271	2.271	2.288	2.319	2.225	1.916
Ra	33.9	35.9	37.5	37.5	36.4	35.5	35.7	36.8	37.3	35.4	34.3	33.2
Rn (Rs)	18.4	19.2	17.9	15.9	14.9	14.3	13.9	14.4	14.8	14.0	15.3	17.1
H	11.7	11.8	11.9	12.1	12.2	12.3	12.3	12.2	12.1	11.9	11.8	11.7
ET0(PENMAN-MONTEITH)	5.7	5.9	5.5	4.8	4.4	4.2	3.9	4.1	4.3	4.1	4.6	5.2
ET0(TURKISH) mm/day	5.3	4.9	5.0	4.4	4.2	3.9	3.8	3.9	3.9	3.9	4.1	4.7
ET0(BLANEY-CRIDDLE)	3.9	4.1	4.2	4.2	4.2	4.1	4.0	3.9	3.9	3.9	3.9	3.9

Note: Tmax: Maximum temperature; Tmin: Minimum temperature; U_2: Wind speed at 2m above the earth surface; Δ: slope of the saturation vapor pressure curve (in kPa/°C); ϒ: Psychrometric constant (in kPa/°C); es: Saturation vapor pressure (in kPa); ea: Vapor pressure at temperature T (in kPa); Ra: Global solar radiation; Rn (Rs): Global radiation (in MJm2/day); H: Day length; ET0: Reference evapotranspiration.

Table 3. Water requirements for the three methods according to development stages.

Growth stages/duration	Period	Month	Kc (Cultural coefficient)	ETP (mm/day)			Quantity of water to be supplied (l/ 576. m²)		
				P	T	B	P	T	B
Initial stage (10 days)	13-23	December	0.4	5.2	4.7	3.9	12	11	9
Stage of growth or development (20 days)	24-31	December	0.7	5.2	4.7	3.9	21	19	16
	01-13	January	0.7	5.7	5.3	3.9	23	21	16
Flowering and fruiting stage (30 days)	14-31	January	1.05	5.7	5.3	3.9	35	32	24
	01-12	February	1.05	5.9	4.9	4.1	36	30	25
Maturation and harvest stage (45 days)	13-28	February	0.8	5.9	4.9	4.1	27	23	19
	01-15	March	0.8	5.5	5.0	4.2	25	23	19

Note: ETP: Potential Evapotranspiration; P: Penman-Monteith; T: Turc; B: Blaney-Criddle.

3.2. Vegetative Growth Parameters

Irrigation dose, irrigation frequency, and their interaction had no significant effect ($p \geq 0.05$) on plant height or stem diameter throughout the growing period (As shown in Tables 4 and 5). Nevertheless, a progressive increase in both parameters was observed as the irrigation dose increased.

Maximum average plant height (62.4 cm) was recorded under the Turc method, while the Penman–Monteith method resulted in slightly lower values despite higher water application. These results indicate that vegetative growth was less sensitive to irrigation scheduling than yield parameters.

Table 4. Summary of ANOVA of the effect of doses and frequencies of water application on Stem Diameter.

Source of variation	ddl	Probability				
		SD				
		21DAP	28DAP	35DAP	42DAP	49DAP
BLOCK	2	//	//	//	//	//
Water doses	2	0.553 ns	0.716 ns	0.169 ns	0.319 ns	0.492 ns
Block×Water doses	4	//	//	//	//	//
Frequency	1	0.389 ns	0.500 ns	0.115 ns	0.236 ns	0.328 ns
Water doses×frequency	2	0.812 ns	0.479 ns	0.199 ns	0.235 ns	0.719 ns
Error	6	//	//	//	//	//
Total	18	//	//	//	//	//
CV(%)	//	7.79	7.58	5.82	6.25	7.73
Significance	//	ns	ns	ns	ns	ns

Note: Ddl: Degree of freedom; CV: Coefficient of variation; SD: Stem Diameter; ns: Non-significant; DAP: Days After Planting.

Table 5. Summary of ANOVA of the effect of doses and frequencies of water application on Plant height.

Source of variation	ddl	Probability				
		PH				
		21DAP	28DAP	35DAP	42DAP	49DAP
BLOCK	2	//	//	//	//	//
Water doses	2	0.425 ns	0.557 ns	0.503 ns	0.526 ns	0.254 ns
Block×Water doses	4	//	//	//	//	//
Fréquences	1	0.830 ns	0.968 ns	0.416 ns	0.146 ns	0.067 ns
Water doses×frequency	2	0.484 ns	0.500 ns	0.374 ns	0.597 ns	0.828 ns
Error	6	//	//	//	//	//
Total	18	//	//	//	//	//
CV(%)	//	7.84	11.75		7.61	5.18
Significance	//	ns	ns	ns	ns	ns

Note: ns: Non-significant; PH: Plant Height; DAP: Days After Planting; CV: Coefficient of variation.

3.3. Yield Components and Marketable Yield

The number of fruits per plant was significantly influenced by irrigation dose at the sixth harvest ($p < 0.05$), while irrigation frequency alone had no significant effect. However, the interaction between irrigation dose and frequency significantly affected fruit number at the final harvest ($p \leq 0.01$) (as summarized in Table 6).

Cumulatively, the highest number of fruits (312 fruits) was obtained under the Penman–Monteith method applied every two days, followed by the Turc method with daily irrigation (287 fruits). The lowest fruit number (212 fruits) was recorded under the Turc method applied every two days.

Marketable yield was strongly affected by irrigation scheduling. Irrigation dose had a highly significant effect ($p < 0.01$) on yield at most harvests and cumulatively, while irrigation frequency had a very highly significant effect ($p < 0.001$) on cumulative yield. The interaction between the two factors was also highly significant (Table 7).

The highest cumulative marketable yield (81.4 t ha^{-1}) was achieved with the Penman–Monteith method applied every two days. This was followed by the Turc method with daily irrigation (71.9 t ha^{-1}) and the Blaney–Criddle method applied every two days (71.7 t ha^{-1}). The lowest yield (52.5 t ha^{-1}) was obtained with the Blaney–Criddle method applied daily.

Table 6. Summary of ANOVA of the effect of doses and frequencies of water application on the number of fruits per plant.

Source of variation	ddl	Number of fruits per plant						
		Probability						
		1st	2nd	3rd	4th	5th	6th	Cumul
BLOCK	2	//	//	//	//	//	//	//
Water doses	2	0.761 ns	0.676ns	0.811ns	0.169ns	0.903ns	0.042*	0.511ns
Block×Water doses	4	//	//	//	//	//	//	//
Frequency	1	0.942ns	0.391ns	0.770ns	0.783ns	0.516ns	0.543ns	0.668ns
Water doses×frequency	2	0.553ns	0.181ns	0.314ns	0.067ns	0.290ns	0.004**	0.099ns
Error	6	//	//	//	//	//	//	//
Total	18	//	//	//	//	//	//	//
CV(%)		56.61	39.61	27.69	16.04	27.67	8.39	18.89
Significance		ns	ns	ns	ns	ns	s	ns

Note: ddl: Degree of freedom; CV: Coefficient of variation *: Significant at 5% (P<0,05); **: Significant at 1% (P<0.01); ns: Non-significant.

Table 7. Summary of ANOVA of the effect of doses and frequencies of water application on fruit yield.

Source of variation	ddl	Yield						
		Probability						
		1st	2nd	3rd	4th	5th	6th	Cumul
BLOCK	2	//	//	//	//	//	//	//
Water doses	2	0.002**	0.022*	0.004**	0.0***	0.157ns	0.024*	0.0***
Block×Water doses	4	//	//	//	//	//	//	//
Frequency	1	0.106ns	0.550ns	0.004**	0.001**	0.700ns	0.257ns	0.0***
Water doses×frequency	2	0.0***	0.002**	0.0***	0.0***	0.473ns	0.069ns	0.0***
Error	6	//	//	//	//	//	//	//
Total	18	//	//	//	//	//	//	//
CV(%)		11.98	22.89	6.08	2.81	31.42	23.03	1.40
Significance		s	s	s	s	ns	ns	s

Note: CV: Coefficient of variation; ddl: Degree of freedom; *: Significant at 5% (P<0.05); **: Significant at 1% (P<0.01); ***: Significant at 0.1% (P<0.001); ns: Non-significant.

3.4. Irrigation Water Use Efficiency

Irrigation water use efficiency (IWUE) varied considerably among treatments. The highest IWUE (15.92 kg m^{-3}) was recorded under the Blaney–Criddle method applied every two days, followed by the Penman–Monteith method applied every two days (14.13 kg m^{-3}). Treatments receiving higher irrigation volumes generally exhibited lower IWUE values.

These results indicated that lower irrigation doses combined with moderate irrigation frequency improved water productivity, although this did not always correspond to maximum yield.

Table 8. Water use efficiency.

Combination	Yield (kg/m²)	IWUE (kg/l)
11	6.3	10.99
12	8.1	14.13
22	7.2	15.92
21	5.3	11.72
31	7.2	13.68
32	5.9	11.21

3.5. Economic Profitability

Based on FAO considerations [15], Table 9, concerning marketable fruit yield, shows that all combinations are economically profitable (RVC ≥ 2). The highest profitability was achieved with the Penman–Monteith method applied every two days, corresponding to the highest yield and a profitability rate exceeding 800% (Table 9). The results provide evidence that optimized irrigation scheduling is a key driver of improved growth and yield and enhanced economic profitability.

Table 9. Economic profitability.

Combinations	Manure	NPK	RCMT (kg/ha)	RS (kg/ha)	Cen (fcfa)	CT (fcfa)	Cep (fcfa)	CMRS (fcfa)	CCE (fcfa)	CT1 (fcfa)	II (fcfa)	CT2 (fcfa)	PRRS (fcfa)	RVC	RT %
11	0	0	14656.0	-	-	-	-	-	-	-	-	-	-	-	-
12	0	0	21432.0	-	-	-	-	-	-	-	-	-	-	-	-
21	0	0	9354.0	-	-	-	-	-	-	-	-	-	-	-	-
22	0	0	12123.0	-	-	-	-	-	-	-	-	-	-	-	-
31	0	0	12876.0	-	-	-	-	-	-	-	-	-		-	-
32	0	0	11327.0	-	-	-	-	-	-	-	-	-	-	-	-
12	0	300	36102.6	14670.6	105000	1200	25000	110029. 5	73353	313383	959	314342	2934120	9.334	833.4
11	5	300	63265.0	48609.0	542500	21200	60000	364567. 5	243045	1210113	3704	1213817	9721800	8.009	700.9
12	5	300	81455.3	60023. 3	542500	21200	60000	450174. 8	300117	1352792	4141	1356933	12004660	8.847	784.7
21	5	300	52520.7	43166. 7	542500	21200	60000	323750. 3	215834	1142084	3496	1147010	8633340	7.527	652.7
22	5	300	71721.3	59598. 3	542500	21200	60000	446987. 3	297992	1347479	4124	1351603	11919660	8.8 19	781.9
31	5	300	71905.0	59029. 0	542500	21200	60000	442717. 7	295145	1340363	4103	1344466	11805800	8.781	778.1
32	5	300	58755.0	47428. 0	542500	21200	60000	355710. 0	237140	1195350	3659	1199009	9485600	7.9 11	691.1

Note: ACTY: Average cumulative tomato yield (kg/ha); AH: Additional harvest (kg/ha); CF: Cost of fertilizers (FCFA); THC: Total harvest cost (FCFA); CFA: Cost of fertilizer application (kg/ha); LCRAH: Labor cost related to the additional harvest (FCFA); CECP: Cost of empty crates and their packaging (FCFA); TC1: Total cost 1 (FCFA); II: Interest on the investment rate (FCFA); TC2: Total cost 2 (FCFA); CPRAH: cost price related to the additional harvest; VCR: Value-to-cost ratio; RT: Profitability (Return).

4. DISCUSSION

4.1. Influence of Irrigation Scheduling on Tomato Growth

The results indicated that plant height and stem diameter were moderately influenced by irrigation dose and frequency, showing a generally linear response to water application, which is in agreement with Etissa et al. [17]. The Penman-Monteith dose was probably excessive and, consequently, may have depleted the root zone, thus reducing root growth and nutrient uptake. In general, the results showed that growth (plant height and stem diameter) decreased with a reduction in the amount of irrigation water. Unlike diameter, height increases with a reduction in irrigation frequency, and vice versa [17]. These results imply that low amounts of irrigation water and low frequency reduce shoot development and, consequently, vegetative development [18].

4.2. Yield Response to Irrigation Dose and Frequency

Boamah et al. [16] concluded that drought reduces fruit growth and development, and excessive fluctuations in soil moisture can induce physiological disorders such as flower drop, which reduces the number of fruits and consequently the yield. This is consistent with our study.

The study demonstrated that the yields obtained at different levels of the factors studied varied significantly. The highest number of fruits was obtained with combination 22 (Penman-Monteith + every two days), with a yield of 312 fruits, followed by 287 fruits for combination 31 (Turkish + every day), and 259 fruits for combination 22 (Blaney-Criddle + every two days), with a minimum of 212 fruits for combination 32 (Turkish + every two days). This corroborates the results of Etissa et al. [17] and Marouelli et al. [18], which state that tomato crop yields are influenced by the amount of water and the frequency of irrigation.

According to Patanè et al. [19] the best performance of the tomato is observed at a water supply frequency corresponding to every two days for the same quantity of water, which corroborates with the results obtained during this study with a maximum yield of 81.4t/ha for combination 22 (Penman-monteith + every two days) which is much higher than that obtained by combination 11 (Penman-monteith + every day) 63.2t/ha.

Water stress, combined with poor water management and low soil moisture, can cause flowers to abort and fall off, thus reducing the number of fruits on the plant [20, 21].

Excess water is a limiting factor for high yields, as confirmed by Neto et al. [20], who concluded that the more a plant is exposed to water deficit, the greater the potential for yield reduction. Thus, as Boamah et al. [16] suggest, adequate water supply and relatively moist soil are required for high yields throughout the growing season.

4.3. Irrigation Water Productivity Trade-offs

Table 8 shows that for daily irrigation, EUEI increases with decreasing irrigation water volume, except in combination 21. This indicates that low irrigation water volume reflects soil water stress [14], resulting in low yields for this treatment. Similarly, with an irrigation frequency of every two days, EUEI increases with a decrease in the amount of water applied. Combination 22 exhibits a higher EUEI than combination 32 despite its lower water quantity. This finding is due to accidental rainfall that disrupted the irrigation frequency. It can be concluded here that among the different doses tested, the lowest dose does not always guarantee the best EUEI. However, the highest water dose results in a low EUEI, which is consistent with the research of Neto et al. [20] and Zhang et al. [22].

4.4. Economic Profitability

According to the Food and Agriculture Organization of the United Nations [16] and ASHC [23], only combinations with a Reference Value (RVC) ≥2 in a region where rainfall is not a constraint are suitable for widespread adoption by producers. Therefore, it can be said that all the treatments used in this trial are suitable for widespread adoption by tomato producers in the region. However, to be reasonable, only treatments with minimal production costs should be considered for widespread adoption, taking into account the current socio-economic conditions. In this regard, for soil with the same characteristics and the same tomato variety, the application of 300 kg of 21-8-12 per hectare, applied every two days using the Penman-Monteith method, is the recommended treatment for producers because it provides the best yield (833.4%).

5. CONCLUSION

At the end of this study, which generally aimed to evaluate the impacts of three water supply methods on the performance and economic profitability of a tomato crop in the city of Dschang, it appears from this study that; the growth performance of a tomato crop is not significantly influenced by a variation in both the supply dose and the frequency, nor by the interaction of these two factors.

However, both yield performance and economic profitability are influenced by the amount of water applied to the plot. Furthermore, the water dose had a significant effect on the number of fruits at the sixth harvest, thus demonstrating the significant effect of the interaction between these two factors on the number of fruits at that harvest. Frequency, on the other hand, had a highly significant effect on yield alone. Furthermore, the interaction of the two factors had a highly significant effect on yield over multiple harvests and cumulatively. The results showed a maximum yield of 81.4 t/ha for combination 22, followed by 31 with a yield of 71.9 t/ha, then 22 with 71.7 t/ha, then 11 with 63.3 t/ha, 32 with 58.7 t/ha, and 21 with 52.5 t/ha.

The study demonstrated that for better irrigation water use efficiency, water should be applied to the plot using the Blaney-Criddle method at a frequency of every two days, which corresponds to a quantity of 452.4mm of water.

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