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Original Article

Efficient water use in native potato cultivars (*Solanum tuberosum*) in the Aguarongo Zañe irrigation system, Loja canton

Uso eficiente del agua en cultivares de papa nativa (*Solanum tuberosum*) en el sistema de riego Aguarongo Zañe, cantón Loja

Jorge Luis Jaramillo Condolo [1], Jimmy Javier Cordero Jiménez[1], Narcisa de Jesús Urgiles-Gómez[1], Juan Francisco Sacapi Lareategui[1], Gabriela Natali Abad Calva[1]

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[1] Universidad Nacional de Loja, Facultad Agropecuaria y de Recursos Naturales Renovables, Carrera de Ingeniería Agrícola, Av. Pío Jaramillo Alvarado y Av. Reinaldo Espinosa, código postal 110111, Loja, Ecuador.

Correspondence: jljaramilloc@unl.edu.ec

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Abstract

This study was conducted in response to several challenges faced by farmers in the rural parish of Chuquiribamba, including inadequate irrigation infrastructure, climate variability, a lack of technology, and insufficient knowledge of appropriate water management techniques. In this context, the main objective was to determine the water requirements of native potato crops (*Solanum tuberosum*) to promote efficient water use. Initially, the consistency of meteorological data recorded at the automatic weather station in the area during 2024 was evaluated. Subsequently, irrigation requirements were determined for two planting periods (March–August and September–December). Reference evapotranspiration [ET_o] was calculated using the modified Hargreaves and Penman-Monteith methods. The latter was selected due to its greater accuracy. Crop evapotranspiration [ET_c] was also estimated by adjusting the crop coefficient [K_c] for early varieties, considering a 105-day growing cycle. The results did not reveal any inconsistent data in the analyzed variables. The ET_o ranged from 2.22 to 3 mm day^{-1} using the Penman-Monteith method, and the K_c values were: 0.45 (initial stage), 0.75 (development stage), 1.15 (flowering stage), and 0.85 (tuberization stage). Consequently, the ET_c increased from 1.02 mm day^{-1} in the initial stage to 2.86 mm day^{-1} in the final stage in May-August. In contrast, during the September-December period, the ET_c started at 1.27 mm day^{-1} and reached a maximum of 2.87 mm day^{-1} during the flowering stage. Irrigation requirements reached peak values of 2.62 mm day^{-1} (May–August) and 2.70 mm day^{-1} during flowering (September–December). In conclusion, this study provides valuable information for the planning and sustainable management of water resources in native potato cultivation.

Keywords: crop evapotranspiration, efficient water management, native potato, water requirements, water resources sustainability.

Resumen

Este trabajo se desarrolló, en respuesta a varios desafíos que enfrentan los agricultores de la parroquia rural Chuquiribamba, así como la inadecuada infraestructura de riego, la variabilidad climática, la falta de tecnologías y desconocimiento de técnicas adecuadas para la gestión del agua. Frente a esta situación, el objetivo principal fue determinar los requerimientos hídricos del cultivo de papa nativa (*Solanum tuberosum*) para contribuir al uso eficiente del agua. Inicialmente, se evaluó la consistencia de datos meteorológicos registrados en la estación meteorológica automática de la zona durante el año 2024. Posteriormente, se determinaron las necesidades de riego para dos periodos de siembra (marzo–agosto y septiembre-diciembre), calculando la evapotranspiración de referencia [ET_o] mediante los métodos Hargreaves modificado y Penman-Monteith adoptando el segundo por su mayor precisión; asimismo, se estimó la evapotranspiración del cultivo [ET_c] ajustando el coeficiente del cultivo [K_c] para variedades precoces considerando un ciclo vegetativo de 105 días. Los resultados no revelaron datos inconsistentes en las variables analizadas. La ET_o osciló entre 2,22 y 3 mm día^{-1} con Penman-Monteith y los valores de K_c fueron: 0,45 (inicial), 0,75 (desarrollo), 1,15 (floración) y 0,85 (tuberización). En consecuencia, la ET_c incrementó de 1,02 mm día^{-1} en la etapa inicial, a 2,86 mm día^{-1} en la etapa final en mayo-agosto, mientras que, en septiembre-diciembre la ET_c inicialmente fue de 1,27 mm día^{-1} alcanzando su máximo valor en la floración (2,87 mm día^{-1}). Las necesidades de riego alcanzaron sus valores máximos de 2,62 mm día^{-1} (mayo-agosto) y 2,70 mm día^{-1} en floración (septiembre-diciembre). En conclusión, la presente investigación aporta información valiosa para la planificación y sostenibilidad de los recursos hídricos en el cultivo de papa nativa.

Palabras clave: evapotranspiración de cultivos, gestión eficiente del agua, papa nativa, requerimientos hídricos, sostenibilidad de recursos hídricos.

1. Introduction

Water resources are essential for the development of sustainable agricultural production, especially in rural zones where weather disparity and inadequate irrigation infrastructure limit crop yield (Abbade et al., 2024; Becerra-Perenguez et al., 2024). It is estimated that an adequate balance of water requirements in agriculture would save substantial quantities of water globally, reaching up to 48%. This increase could improve agricultural production by 41% and could reduce the yield gap by 62% (Jägermeyr et al., 2016; Rosa et al., 2020). Jägermeyr et al. (2016) mentioned that an inadequate application of irrigation sheets in crops causes significant damage due to excess or deficit in water. Among the main problems, there is radicular asphyxia, fungal disease development and limitation in nutrient absorption that result in low yields and quality of crops.

In Ecuador, the native potato crop has cultural, social and nutritional importance, and it is produced for local consumption (Monteros et al., 2005). Production directly contributes to biodiversity conservation and food sovereignty of local farmers, becoming a key economic support for the family (Araujo et al., 2021). According to Araujo et al. (2021), 351-500 native potato varieties are cultivated nationally, and approximately 81% are freshly commercialized, while the rest are used by industries for processing (Espinoza et al., 2011). Particularly, in the Tungurahua province, 65% of the native potatoes harvested are used for local commercialization, 10% are used for self-consumption, and the remaining 25% are used as seeds (Pallo et al., 2021).

Potato crops are cultivated between 2,600 to 3,500 m a.s.l. in three regions: north, in Carchi and Imbabura provinces; center, in Pichincha, Cotopaxi, Tungurahua, Chimborazo, and Bolivar provinces; and in the south, in Cañar, Azuay and Loja provinces with temperatures of 10 to 15 °C, and annually rainfall of 750 to 2,000 mm (Monteros et al., 2010; Araujo et al., 2021). In the Ecuadorian highlands, the production levels are vastly affected by a lack of planning and non-technical water distribution due to climate change, which is responsible for the changes in meteorological variables with prolonged droughts and heavy rains in short periods of time. Moreover, historical weather data for high Andean zones is necessary to generate information about quantity and irrigation needs (Ayala et al., 2017; Nieto et al., 2018). This is exposed in frameworks of Banco Mundial (2017), which describes that only 13.8% of the agricultural surface has technified irrigation systems. According to Sánchez et al. (2024), the lack of technification significantly restricts the efficient use of water resources and limits their potential exploitation for crop production. In this context, Yuan et al. (2003) support that potato constitutes one of the crops with the highest sensitivity to water supply imbalances because of the limited depth of its radicular systems during physiological phases of tuberization and tuber filling, which demands a uniform and adequate water supply for its development. Insufficient irrigation is associated with negative effects, such as deformations, a reduction in the number of tubers, and size reduction. While excessive irrigation increases crop vulnerability to important phytosanitary diseases, such as *Phytophthora infestans*, *Rhizoctonia solani* and *Fusarium sambucinum*.

The inadequate application of crop water requirements is directly associated with significant reductions in productive yield, as evidenced by studies conducted under diverse agroclimatic conditions. In agricultural plots evaluated in Lima, Peru, those with severe drainage limitations received between 20% and 35% less water than required levels, which resulted in yield reductions ranging from 20% to 50% across different growing cycles (Trebejo & Midmore, 2009; Pérez et al., 2024). Similar results have been reported in Canada, where daily losses ranging from 3.1% to 3.4% were recorded, as well as in New Mexico, where the application of a 20% water deficit caused a 22.1% reduction in yield compared with optimal irrigation schemes (Li et al., 2023; Shrestha et al., 2024). Additionally, the application of irrigation depths exceeding 120–140% of estimated evapotranspiration is associated with yield declines ranging from 7.1% to 22%, while also causing physiological and sanitary disorders such as tuber rot, hollow heart, and brown spots—factors that compromise the quality and commercial value of potato production (Shrestha et al., 2023; Ma et al., 2024).

In line with these arguments, Barona et al. (2022) highlights the importance of using meteorological stations for the systematic measurement of atmospheric variables, the analysis of which enables the development of strategies aimed at the efficient use of water resources in production systems. Likewise, atmospheric demand is influenced by factors such as temperature, relative humidity, solar radiation, and rainfall; therefore, the precise determination of these parameters constitutes a fundamental input for estimating the actual water requirements of crops, optimizing irrigation application, and enhancing agricultural productivity by preventing both deficits and excesses that may compromise plant growth and yield (Valderrama et al., 2021).

Within the territorial scope of the parish of Chuquiribamba, the Aguarongo–Zañe irrigation system has an area of influence of 98.30 ha, of which 81.7% corresponds to areas effectively supplied with irrigation, making it possible to meet the water demand of the crops established by potato producers in the area; however, the limited technical knowledge regarding the management and allocation of water applied to each crop results in practices that constrain productive performance and affect the sustainability of local agricultural systems (Chamba-Ontaneda, 2021).

Based on this context, the research is aimed at generating technical knowledge that contributes to improving irrigation efficiency in native potato cultivars in rural areas, strengthen farmers' productive resilience and promote sustainable water resource management. To this end, it proposes evaluating the consistency of meteorological records obtained from the automatic weather station in Chuquiribamba to estimate evapotranspiration and define irrigation requirements adjusted to the conditions of the study area.

2. Materials and Methods

The Aguarongo–Zañe irrigation system is in the region of Chuquiribamba, which belongs to the canton of Loja, at an altitude between 2,500 and 2,900 meters above sea level, defining a physical environment characteristic of the southern Ecuadorian highlands (Figure 1). The system's area of influence is bound by the UTM coordinates 684079.37 m E and 684322.08 m E, as well as 9574786.36 m N and 9576913.66 m N, corresponding to Zone 17 South, and covers an

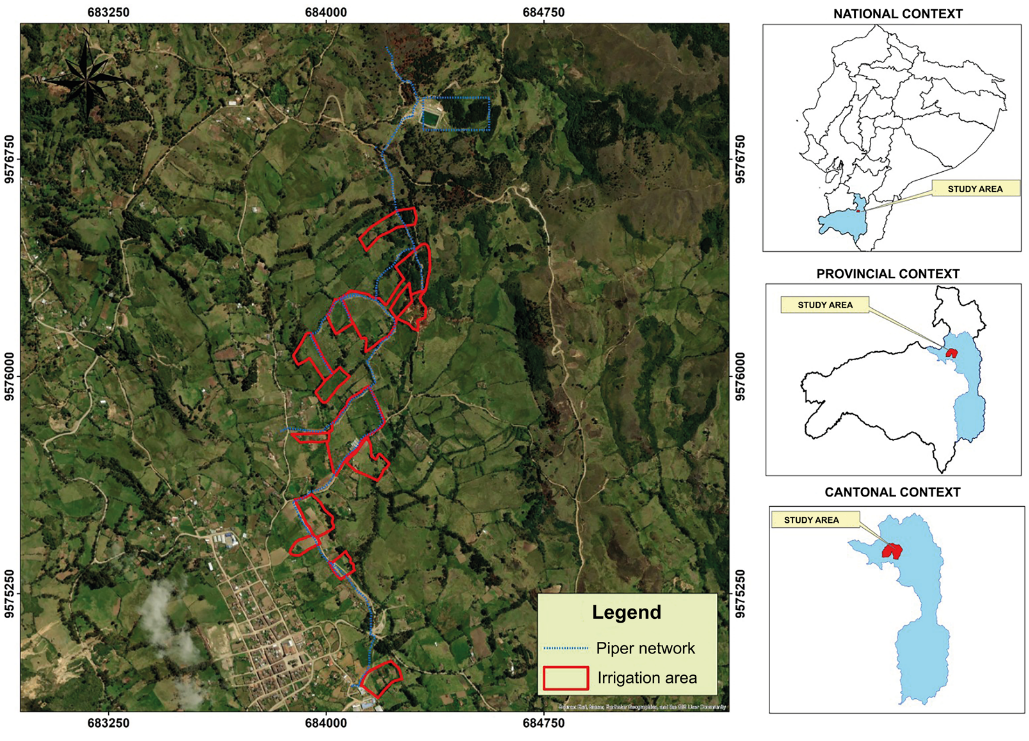

Figure 1. Location of the Aguarongo–Zañe irrigation system

approximate area of 107 hectares dedicated to agricultural activity. Under these spatial conditions, climatic characteristics are marked by an average annual rainfall of approximately 1,050 mm and an average temperature of around 12.7 °C, whose irregular distribution affects the system's water availability, generating scenarios of surplus and deficit that directly influence the growth, development, and yield of crops and pastures established in the area.

2.1. Data processing

The climatic variables used in this research were recorded using a *Davis Vantage Pro2*™ model 6162 automatic weather station, identified in the field as "UNL_ST_CHUQUIRIBAMBA", which is installed in the parish of Chuquiribamba at UTM coordinates 684111.69 m E and 9575790.86 m N. The station was configured to perform measurements at 15-minute intervals, which made it possible to capture in detail the daily variability of the main meteorological variables required for estimating evapotranspiration and crop water requirements.

The recorded data were downloaded from the *WeatherLink* platform in CSV format and processed using the R programming language and the RStudio IDE, where data cleaning, quality control, and validation procedures were carried out to identify inconsistencies, outliers, and potential measurement errors.

2.2. Consistency Analysis

The consistency analysis of the meteorological variables corresponding to the year 2024 was carried out following the method proposed by Meek and Hatfield (1994), later validated by Shafer et al. (2000), which is based on the internal control of logical consistency among variables recorded by a single meteorological station. In the first stage, outliers and improbable records were identified by descriptive statistics, considering measures of central tendency and dispersion, particularly the mean and standard deviation of each variable. Subsequently, logical relationships and physical limits were evaluated among physically related meteorological variables, such as the condition Tmin < Tmean < Tmax and the consistency between average and maximum wind speeds, with records that did not meet these criteria being discarded (Table 1). Finally, the Pearson correlation coefficient was applied to variables with direct physical dependence to verify the statistical consistency of the data and ensure the reliability of the information used in subsequent analyses.

2.3. Reference and crop evapotranspiration

Reference evapotranspiration [ET_o] was estimated using the Penman–Monteith method, considering its ability to jointly integrate the main meteorological variables that control the evaporative demand of the soil–plant–atmosphere system. Based on these values, crop evapotranspiration [ET_c] was calculated using the methodology established in the FAO guidelines (equation [1]), as proposed by Allen et al. (2006), which made it possible to obtain estimates adjusted to the agroclimatic conditions of the study area.

$$ET_c = ET_o * k_c \quad [1]$$

2.4. Crop coefficient [K_c]

The crop coefficient [Kc] was established based on the methodology proposed by the FAO, as described by Allen et al. (2006), considering the specific characteristics of early-cycle native potato varieties, as expressed in equation [2].

$$K_c = \frac{ET_o}{ET_c} \quad [2]$$

The definition of the crop's phenological stages was based on the study conducted by Zamata-Quispe (2019), which establishes a total production cycle duration of 105 days, organized into four clearly differentiated phenological stages, as described in Table 2.

2.5. Effective rainfall

For the estimation of effective rainfall [ER], precipitation records obtained directly from the automatic weather station installed in the study area were used, ensuring the spatial representativeness of the climatic information used. On this basis, the calculation was

Table 1. Variables for checking the consistency of meteorological variables.

Control of consistency*	T_{max}	T_{min}	T_{mean}	Td	$V_{max.d}$	$V_{max.f}$	V_{mean}
Tmin (day i) < Tmean (day i) < Tmax (day i)	X	X	X				
Tmean = (Tmax + Tmin)/2	X	X	X				
Vmean ≤ Vmax						X	X

* **Tmax:** Daily maximum temperature, **Tmin:** Daily minimum temperature, **Tmean:** Daily average temperature, **Td:** Dew point, **Vmax.d:** Direction of the daily maximum wind, **Vmax.f**: Speed of the daily maximum wind, **Vmean:** Average wind speed.

performed using the method proposed by the United States Department of Agriculture (USDA) equation [3], according to Vargas y Escobar (2018), which allows quantifying the fraction of total rainfall that is effectively usable by the crop.

$$ER = \frac{R_{Total}(125 - 0.2R_{Total})}{125} \; for \; R_{Total} < 250 \; mm \; month^{-1}$$

$$ER = 125 + 0.1R_{Total} \; for \; R_{Total} > 250 \; mm \; month^{-1} \quad [3]$$

2.6 Irrigation needs

The calculation of irrigation requirements was carried out for two crop periods, May–August and September–December, using equation [4] proposed by Fuentes (2002), detailed below:

$$Irrigation \; need = ET_c - ER \quad [4]$$

Where, ER: effective rainfall (mm $month^{-1}$), ET_c: crop evapotranspiration (mm $month^{-1}$).

3. Results

3.1. Evaluation of the data consistency of the automatic meteorological station

3.1.1. Consistency between minimum, medium and maximum daily temperatures

Table 3 indicates that no questionable data were found in the internal consistency analysis between daily temperatures. Similarly, the correlation analysis shows high coherence, thereby reinforcing the quality of the recorded data.

3.1.2. Consistency of the maximum, medium and minimal wind velocity

The consistency analysis of maximum, average, and minimum wind speed showed no questionable data. Likewise, a correlation analysis was also performed among the wind speed variables described in Table 4, for which the correlation coefficient is extremely reliable.

3.2. Determination of the evapotranspiration and irrigation needs for potato cropping in Chuquiribamba

3.2.1. Evapotranspiration potential [ET_o]

The monthly reference evapotranspiration [ET_o], estimated using the Penman-Monteith method, presented values ranging between 2.22 mm day^{-1} and 3.00 mm day^{-1}, with the minimum recorded in June and the maximum in October. In contrast, the application of the modified Hargreaves method yielded lower ET_o values, with a range varying from 1.16 mm day^{-1} to 1.64 mm day^{-1} for the same months. The observed difference between the two methods is associated with the ability of the Penman-Monteith approach to integrate a greater number of meteorological variables into its formulation, which allows for a more accurate representation of the prevailing atmospheric conditions in the study area, where the presence of strong winds favors water vapor transport and, consequently, increases the estimated evapotranspiration rates, as shown in Figure 2.

Table 2. Phenological stages for native potatoes.

Phase	Days
Initial phase	25
Development phase	30
Flowering phase	30
Tuberization phase	20
Total	**105**

Source: (Zamata-Quispe, 2019)

Table 3. Pearson correlation coefficient between temperatures.

Variables	Coefficient of correlation	Interpretation
Tmin – Tmean.	0.99	Very high
Tmin – Tmax.	0.99	Very high
Tmean – Tmax.	0.99	Very high

3.2.2. Crop coefficient

Figure 3 shows the variation of K_c for early-cycle native potato, calculated from ET_o estimated using the Penman-Monteith method, evidencing a behavior associated with the crop's phenological stages. In the initial stage, K_c presents values close to 0.45, which progressively increased during vegetative development until reaching approximately 0.75, because of increased leaf cover and plant physiological activity. The maximum coefficient value is recorded during the flowering and tuber formation stage, with a K_c close to 1.15, associated with a higher water demand derived from the processes of tuber growth and filling. Subsequently, K_c decreases to values near 0.85, a behavior related to leaf senescence and reduced transpiration, which reflects a lower water requirement of the crop towards the end of the cycle.

3.2.3. Effective rainfall

The average ER values for the period between March and December are presented in Figure 4, where marked variability in their distribution is evident. The highest water contribution is recorded in December, with a value of 5.72 mm day^{-1}, while the lowest corresponds to August, with 0.33 mm day^{-1}, reflecting an irregular availability of water resources throughout the analyzed cycle.

Table 4. Pearson correlation coefficient between wind speed.

Variables	Coefficient of correlation	Interpretation
V min – V mean	0.98	Very high
V min – V max.	0.97	Very high
V mean - V max.	**0.99**	Very high

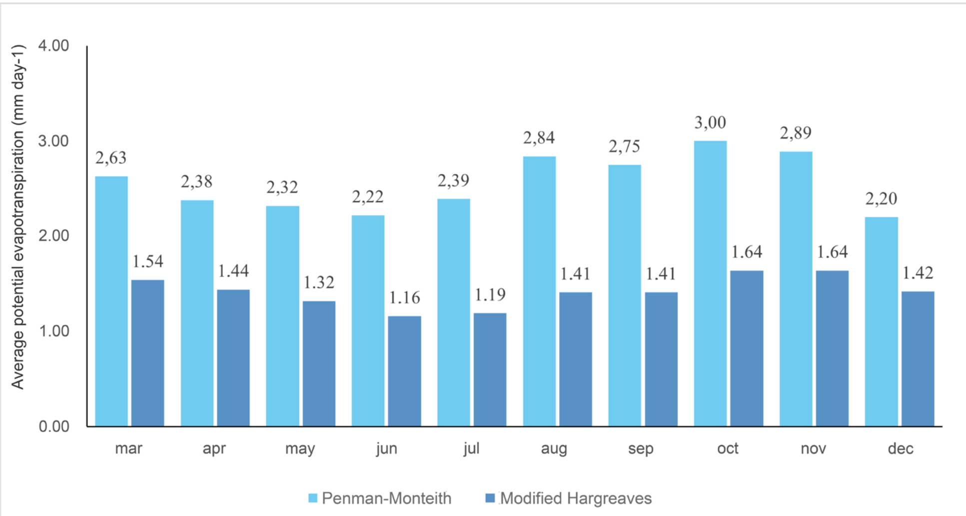

Figure 2. Average potential evapotranspiration in mm day-1.

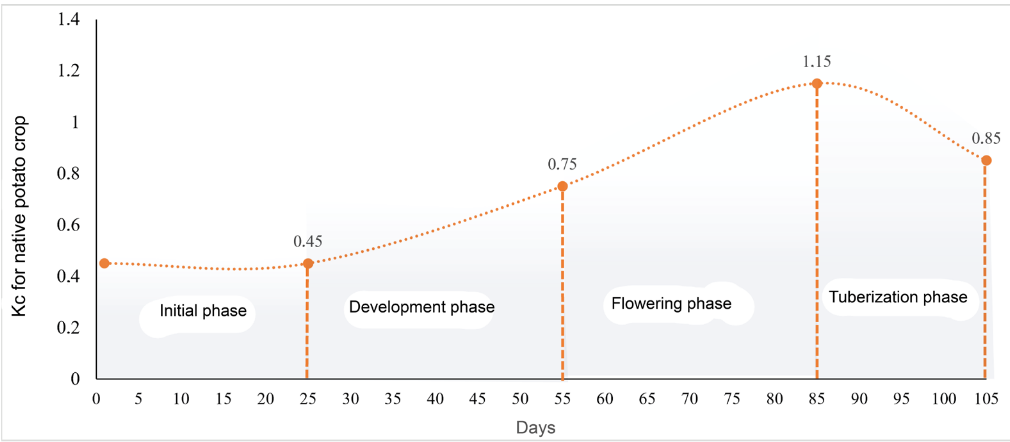

Figure 3. K_c for early varieties of native potato.

Source: Adapted from Zamata-Quispe, (2019).

3.2.4. Crop evapotranspiration

Figure 5 shows the dynamics of the ET_c of native potato throughout its phenological phases, comparing two planting periods corresponding to May–August and September–December, where variation in water demand is evident depending on the physiological development of the crop. During the initial phase, average ET_c values remain relatively low, with records of 1.02 mm and 1.27 mm for the May–August and September–December periods, respectively, reflecting limited vegetative cover and lower transpiration activity. In the development phase, ET_c presents a moderate increase, reaching average values of 1.42 mm in the first period and 1.83 mm in the second, associated with the increase in leaf area and metabolic activity of the plants.

The highest water requirement is concentrated during the mid-season stage, corresponding to flowering and tuber filling, where ET_c reaches average values of 2.08 mm for the May–August cycle and 2.87 mm for the September–December cycle, evidencing the crop's greatest water demand at this stage. Subsequently, in the final stage, ET_c shows a relative decrease, with average values of 2.86 mm and 2.21 mm for each period, a behavior attributed to the progressive senescence of the foliage and the reduction in transpiration.

3.2.5. Irrigation needs

The estimated irrigation requirements for the native potato crop, presented in Figure 6, show a progressive increase in water demand depending on the phenological state of the crop, with marked differences between the two planting periods analyzed. In the May–August cycle, the average irrigation requirement during the initial stage remains at values close to 0.49 mm day^{-1}, increasing during the development stage to approximately 1.01 mm day^{-1}, then reaching higher values in the flowering stage, with an average of 1.54 mm day^{-1}, and a maximum of 2.62 mm day^{-1} during the tuberization stage, which translates into a maximum accumulated total requirement of 5.66 mm day^{-1}.

In the September–December period, irrigation requirements show consistently higher values throughout all phenological phases, starting with an average of 1.03 mm day^{-1} in the initial phase and increasing to 1.47 mm day^{-1} in the development phase, with the maximum requirement recorded during the flowering stage, where the average need reaches 2.70 mm day^{-1}, followed by a slight reduction in the tuberization stage, with values close to 1.31 mm day^{-1}. In this period, the maximum accumulated irrigation requirement was 6.53 mm day^{-1}.

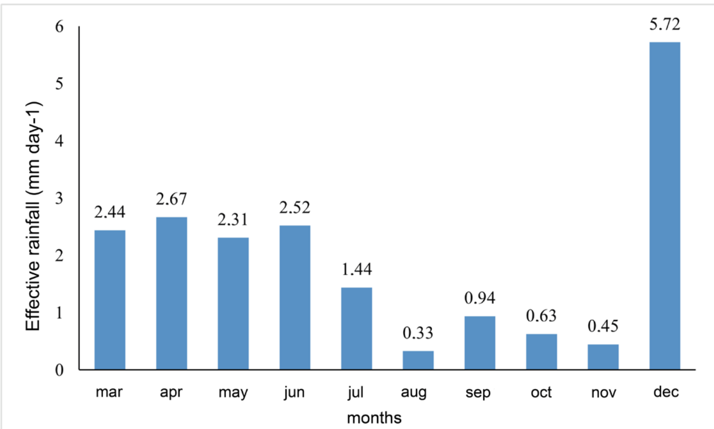

Figure 4. Daily effective rainfall.

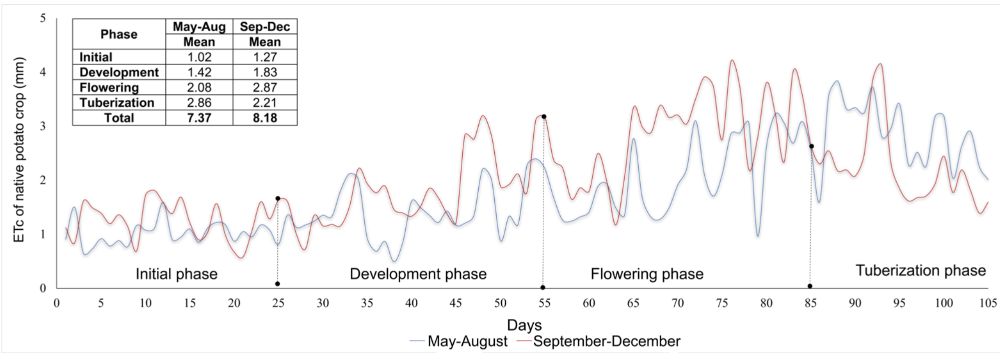

Figure 5. Crop evapotranspiration for early varieties of native potatoes.

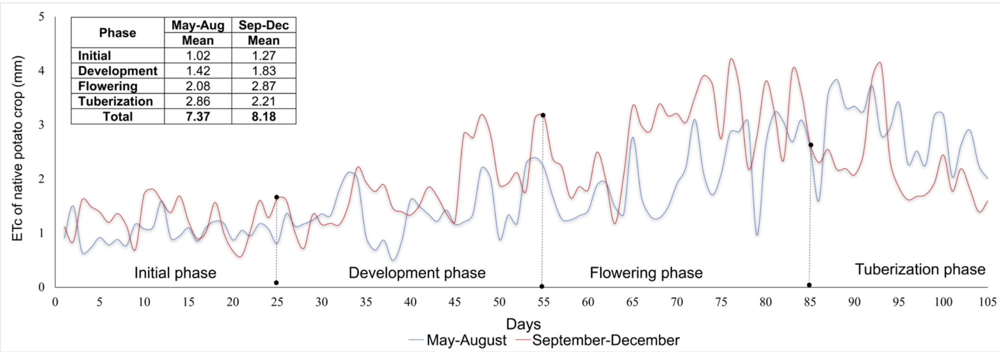

Figure 6. Irrigation requirements for early varieties of native potatoes.

4. Discussion

4.1. Analysis of data consistency

The internal consistency analysis among daily minimum, average, and maximum temperatures described in Table 3 revealed no presence of questionable data; the observed correlation was positive and highly consistent (0.99), indicating that the temperatures are closely related. This agrees with what was noted by Lalinde et al. (2018), who mention that a value close to 1.0 indicates a very strong positive correlation. Similarly, Zaninelli et al. (2015) state that the correlation between temperatures is subject to the influence of various factors such as geographic location, time of year, and the natural variability of the climate.

The consistency between the observed average temperature and the calculated average temperature was evaluated through the analysis of the 0.99 percentile, for which an absolute difference of 0.08 was obtained, with no records considered suspicious being identified within the analyzed dataset. The values of both variables remained within the range established by the determined absolute difference, which confirms the internal consistency of the thermal information used. According to the criterion proposed by Rusticucci and Barrucand (2003), the 0.99 percentile, equivalent to 99.9%, allows verifying the belonging of the data to an ordered and homogeneous set. Under this approach, those average temperature values whose absolute difference between the observed and calculated series exceeds the 0.999 percentile of the total daily differences are considered potentially atypical, a criterion widely adopted in meteorological data quality control processes (Estévez et al., 2011; Veiga et al., 2014).

The consistency analysis of daily average wind speed and recorded maximum wind speed showed no questionable data, and their correlation was very strongly positive at 0.99, indicating that both variables maintain a strong relationship. This behavior agrees with Estévez et al. (2011), who mention that the daily average wind speed should be less than or equal to the maximum observed on that day. Likewise, Veiga et al., (2014) note that any discrepancy may be due to errors in anemometer readings or data transmission.

4.2 Evapotranspiration and irrigation needs

The average ET_o values calculated using the Penman-Monteith method ranged between 2.20 and 3.00 mm day^{-1}, which agrees with estimates reported in studies conducted in Andean regions where the same method and meteorological data from automatic stations were used, which showed similar ET_o ranges when complete climatic variables were considered for their calculation (Córdova et al., 2015; Vásquez et al., 2022). This behavior is consistent with evaluations in mountain landscapes that underscore the robustness of the Penman-Monteith method for estimating evaporative demand under diverse climatic conditions, if quality meteorological data are available (Córdova et al., 2015; Vásquez et al., 2022). In contrast, the ET_o values derived using the modified Hargreaves method, with ranges between 1.16 and 1.64 mm day^{-1}, were lower than those calculated by Penman-Monteith, which reflects the limitations of empirical methods that depend solely on temperature data to estimate evaporative requirement and tend to underestimate ET_o compared to methods that integrate multiple climatic variables.

The observed differences between reference evapotranspiration values are mainly explained by the estimation method used and by the characteristics of the climatic information employed. In this regard, Villazón et al. (2021) and Rosales-Rodríguez et al. (2022) point out that the Penman-Monteith method, by integrating a greater number of meteorological variables such as solar radiation, relative humidity, wind speed, and air temperature, provides more accurate estimates of evaporative demand, whereas the Hargreaves method, being fundamentally based on temperature data and extraterrestrial radiation, tends to generate greater variability and, in certain contexts, an underestimation of evapotranspiration values. Complementarily, Delgado-Ramírez et al., (2023), as well as Ortiz and Chile (2020), indicate that the dispersion of results is also associated with the different sources of climatic information used and the temporal length of the analyzed records, factors that directly influence the consistency and comparability of the estimates obtained.

The K_c values estimated for the different phenological stages of native potato show a progressive increase associated with vegetative development and the intensification of the crop's physiological processes, with values of 0.45 in the initial stage, 0.75 during the development stage, 1.15 in the mid-stage, and 0.85 in the final stage, evidencing a higher water demand as leaf cover and transpiration increase. These results are in close agreement with the values reported by Zamata-Quispe et al. (2019), who, using tensiometers and Watermark sensors in native potato crops with a vegetative cycle of similar duration, obtained crop coefficients ranging between 0.41 and 0.50 for the initial stage, 0.60 and 0.66 for the development stage, 1.12 and 1.18 during the flowering stage, and 0.79 and 0.81 during the tuberization stage, which confirms the consistency of the observed patterns when field instrumental methodologies are used to estimate crop water demand. The similarity between the values obtained in this study and those reported in high-Andean regions of Peru is explained by the correspondence of the prevailing agroclimatic conditions, characterized by high altitudes, moderate temperatures, and marked water variability, factors that directly influence evapotranspiration dynamics and crop phenological development.

The total ET_c was determined for a crop cycle of early native potato varieties adapted to a 105-day crop cycle, resulting in 183.06 mm for the first planting period (May–August) and 259.04 mm for the second (September–December). These findings differ from Rojas (2018), who estimated a higher ET_c of 487.45 mm $cycle^{-1}$ in Peru, and similarly from López-Olivari et al, (2022), who obtained similar values between 370 and 390 mm $cycle^{-1}$ in Chile. In the present study, an increase in ETc was recorded from the initial stage to the mid-stage. According to Soto-Bravo and Rodríguez-Ocampo, (2021), this increase in evapotranspiration from the initial stage is due to crop growth; as crops grow, their leaf area increases, which tends to raise the amount of water that evaporates and transpires. From the perspective of López-Olivari et al. (2022), factors specific to each zone, such as temperature, humidity, radiation, and crop variety, directly influence the determination of ET_c.

The estimated irrigation requirements for the native potato crop in the study area ranged between 141.17 mm and 177.73 mm per crop cycle, corresponding to the May–August and September–December periods, respectively, values that reflect a water demand associated with local agroclimatic conditions and the phenological characteristics of the crop. These estimates are lower than those reported by Pacheco and Pérez (2010), who indicate that in tropical climates approximately 273 mm of water is required to achieve optimal potato crop development and yield, a difference that can be attributed to the thermal, altitudinal, and rainfall particularities of each region. Similarly, Velásquez et al. (2022) indicate that in inter-Andean zones of Ecuador, located around 3,000 meters above sea level, the potato crop may demand between 600 and 700 mm of water distributed uniformly throughout the vegetative cycle, while Araujo et al. (2021) report even higher requirements, ranging between 450 and 900 mm from planting to harvest in production systems of the Ecuadorian highlands. These differences confirm that the water requirements of the crop respond directly to the interaction between climate regime, altitude, duration of the phenological cycle, and the type of plant material used, which explains the variability observed in different agroecological contexts.

5. Conclusions

Consistency checks of meteorological data provide reliable information for the precise estimation of crop water requirements, a key aspect for improving irrigation management in areas with irregular topography, where the spatial variability of climatic conditions can affect water use efficiency.

The variation of crop evapotranspiration throughout the phenological stages highlights the need to schedule irrigation differently according to crop development, which helps reduce losses due to runoff and percolation on sloping terrain, optimizing water resource application.

The implementation of irrigation strategies based on local climatic data and water requirements adjusted to the actual conditions of the crop constitutes an effective tool for improving irrigation efficiency, strengthening productive sustainability, and minimizing the limiting effects of adverse topography in agricultural systems of high-Andean zones.

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Contributor roles

- Jorge Luis Jaramillo Condolo: conceptualization, methodology, formal analysis, investigation, supervision, writing — original draft, writing — review & editing.
- Jimmy Javier Cordero Jiménez: conceptualization, formal analysis, visualization, writing — review & editing.
- Narcisa de Jesús Urgiles Gómez: funding acquisition, project administration, supervision, writing — review & editing.
- Juan Francisco Sacapi Lareategui: investigation, data curation, formal analysis.
- Gabriela Natali Abad Calva: investigation, methodology, visualization, writing — original draft, writing — review & editing.

Data availability

Data will be made available on request.

Use of Artificial Intelligence

The authors declare that no artificial intelligence has been used in the preparation of the manuscript.

Ethical Implications

The authors declare that during the interaction with the farmers there were no conflicts or situations of ethical interest, since the participants did so of their own free will and no personal data were collected. The conversations focused on the importance of conserving native potatoes from their territory.

Conflict of Interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

References

Abbade, E., Basso, L., Mota, C., & Paulsen, S. (2024). *Recursos hídricos*. Instituto de Pesquisa Econômica Aplicada (Ipea). https://doi.org/10.38116/9786556350752cap3

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (2006). *Evapotranspiración del cultivo - Guías para la determinación de los requerimientos de agua de los cultivos*. FAO. https://openknowledge.fao.org/handle/20.500.14283/x0490s

Araujo Jaramillo, M. A., Cartagena Ayala, Y. E., Castillo C., C., Cuesta, H. X., Monteros, J. C., Paula, N., Racines Jaramillo, M. R., Rivadeneira Ruales, J. E., Velásquez Carrera, J. S., León Ruiz, J., Panchi, N., & Andrade Piedra, J. L. (2021). *Manual del cultivo de papa para pequeños productores* (3th ed.). INIAP-EESC. http://repositorio.iniap.gob.ec/handle/41000/5672

Ayala, M. F., Carrera-Villacrés, D., & Tierra, A. (2017). Relación espacio-temporal entre estaciones utilizadas para el relleno de datos de precipitación en Chone, Ecuador. *Revista Geográfica Venezolana*, *59*(2), 298-313. http://bdigital2.ula.ve:8080/xmlui/handle/654321/1502

Banco Mundial. (2017). *El riego tecnificado, una opción que mejora la calidad de vida de los pequeños y medianos agricultores en Ecuador*. Banco Mundial. https://www.bancomundial.org/es/news/feature/2017/05/04/riego-tecnificado-ecuador

Barona-Posligua, H. D., Àllo-Morillo, G. J., & Ponce-Jara, M. A. (2022). Estación meteorológica automática y medición de variables atmosféricas. Revista Científica *FINIBUS - Ingeniería, Industria y Arquitectura*, *5*(9), 2-8. https://publicacionescd.uleam.edu.ec/index.php/finibus/article/view/420

Becerra-Perenguez, D. Y., Acosta-Astaiza, C. P., & Leyton-Luna, J. (2024). Gestión del recurso hídrico en la ruralidad, mediante estrategias de fortalecimiento comunitario. *Entramado*, *20*(1), 1-16. https://doi.org/10.18041/1900-3803/entramado.1.10054

Chamba-Ontaneda, M. (2021). Caracterización agrosocioeconómica y biofísica del área de influencia del sistema de riego Aguarongo – Zañe (Loja – Ecuador). *CEDAMAZ*, *11*(2), 87-92. https://doi.org/10.54753/cedamaz.v11i2.1175

Córdova, M., Carrillo-Rojas, G., Crespo, P., Wilcox, B., & Célleri, R. (2015). Evaluation of the Penman-Monteith (FAO 56 PM) method for calculating reference evapotranspiration using limited data. *Mountain Research and Development*, *35*(3), 230-239. https://doi.org/10.1659/MRD-JOURNAL-D-14-0024.1

Cuesta, X., Monteros, C., Racines, M., & Rivadeneira, J. (2022). *Catálogo de variedades de papa del Ecuador* (2ª ed.). Instituto Nacional de Investigaciones Agropecuarias (INIAP). https://repositorio.iniap.gob.ec/server/api/core/bitstreams/67a96ddc-b96e-43c9-b759-d6cc45dc60b7/content

Delgado-Ramírez, G., Bolaños-González, M., Quevedo-Nolasco, A., López-Pérez, A., & Estrada-Ávalos, J. (2023). Estimation of reference evapotranspiration in a semi-arid region of Mexico. *Sensors*, 23(15), 7007. https://doi.org/10.3390/s23157007

Espinoza, S., Montesdeoca, L., Vásquez, P., Pallo, E., Acosta, M., Quishpe, C., López, J, Monteros, C., Haro, F., Yumisaca, F., & Andrade-Piedra, J. (2011). *Papas nativas de colores: un negocio con responsabilidad social*. Instituto Nacional de Investigaciones Agropecuarias. https://repositorio.iniap.gob.ec/server/api/core/bitstreams/ecefaad9-e8ce-48b2-bdbd-28d5b0f8fb9b/content

Estévez, J., Gavilán, P., & Giráldez, J. V. (2011). Guidelines on validation procedures for meteorological data from automatic weather stations. *Journal of Hydrology*, *402*(1), 144-154. https://doi.org/10.1016/j.jhydrol.2011.02.031

Fuentes, J. (2002). *Curso de riego para regantes* (1st ed.). Ediciones Mundi-Prensa. https://catalogo.utc.edu.ec/cgi-bin/koha/opac-detail.pl?biblionumber=7658&shelfbrowse_itemnumber=8754#shelfbrowser

Jägermeyr, J., Gerten, D., Schaphoff, S., Heinke, J., Lucht, W., & Rockström, J. (2016). Integrated crop water management might sustainably halve the global food gap. *Environmental Research Letters*, *11*(2), 025002. https://doi.org/10.1088/1748-9326/11/2/025002

Lalinde, J. D. H., Castro, F. E., Rodríguez, J. E., Rangel, J. G. C., Sierra, C. A. T., Torrado, M. K. A., Sierra, S. M. C., & Pirela, V. J. B. (2018). Sobre el uso adecuado del coeficiente de correlación de Pearson: Definición, propiedades y suposiciones. *Archivos Venezolanos de Farmacología y Terapéutica*, *37*(5), 587-595. https://saber.ucv.ve/ojs/index.php/rev_aavft/article/view/16165

Li, S., Kupriyanovich, Y., Wagg, C., Zheng, F., & Hann, S. (2023). Water deficit duration affects potato plant growth, yield and tuber quality. *Agriculture*, *13*(10), 10. https://doi.org/10.3390/agriculture13102007

López-Olivari, R., Mora Sanhueza, R., Meier Romero, S., & Méndez Leal, P. (2022). Requerimientos hídricos de la papa consumo para la zona sur de Chile. *Revista Papa*, *34*(11), 14-17. https://biblioteca.inia.cl/server/api/core/bitstreams/14073ff0-3b9d-4571-a35b-7da1174d4150/content

Ma, Y. Z., Pan, N., Su, W., Zhang, F. J., Ye, G. J., Pu, X. Q., Zhou, Y., & Wang, J. (2024). Soil water stress effects on potato tuber starch quality formation. *Potato Research*, *67*(4), 1829-1848. https://doi.org/10.1007/s11540-024-09720-5

Meek, D. W., & Hatfield, J. L. (1994). Data quality checking for single station meteorological databases. *Agricultural and Forest Meteorology*, *69*(1), 85-109. https://doi.org/10.1016/0168-1923(94)90083-3

Monteros, C., Cuesta, X., Jiménez, J., & López, G. (eds.). (2005). *Las papas nativas en el Ecuador. Estudios cualitativos sobre oferta y demanda* (1st ed.). INIAP. https://repositorio.iniap.gob.ec/items/b7ed41e6-e863-40ec-b802-a647ea3c3c4a

Monteros, C., Yumisaca Jiménez, S. F., Andrade-Piedra, J., & Reinoso R., I. A. (2010). *Cultivares de papas nativas de la Sierra Centro y Norte del Ecuador: Catálogo etnobotánico, morfológico, agronómico y de calidad*. INIAP/CIP. http://repositorio.iniap.gob.ec/handle/41000/3224

Nieto, C., Pazmiño, E., Shubert, R., & Quishpe, B. (2018). Estudio del aprovechamiento de agua de riego disponible por unidad de producción agropecuaria, con base en el requerimiento hídrico de cultivos y el área regada, en dos localidades de la Sierra ecuatoriana. *Siembra*, *5*(1), 51-70. https://doi.org/10.29166/siembra.v5i1.1427

Ortiz, R. S., & Chile A., M. (2020). Métodos de cálculo para estimar la evapotranspiración de referencia para el Valle de Tumbaco. *Siembra*, 7(1), 070-079. https://doi.org/10.29166/siembra.v7i1.1450

Pacheco, J., & Pérez, A. (2010). Evaluación del manejo del riego de la papa en la Empresa de Cultivos Varios "Valle del Yabú", Santa Clara, Cuba. *Revista Ciencias Técnicas Agropecuarias, 19*(3) , 47–52. https://revistas.unah.edu.cu/index.php/rcta/article/view/161

Pallo, E. L., Guapi Auquilla, A. P., & Mullo Paucar, M. V. (2021). Agrobiodiversidad de papa nativa en la provincia de Tungurahua. *Siembra*, *8*(1), e2273. https://doi.org/10.29166/siembra.v8i1.2273

Pérez, E., Rafael-Rutte, R., & Osorio, G., (2024). Estrés hídrico en el crecimiento y rendimiento de cultivares comerciales de papa (*Solanum tuberosum L.*) en la región centro del Perú. *Revista de Investigaciones Altoandinas*, *26*(1), 46-55. https://doi.org/10.18271/ria.2024.587

Rojas, R. A. (2018). Análisis de información satelital y mediciones in-situ en el modelamiento de la evapotranspiración en cultivos andinos—Ayacucho 2017. *Investigación, 26*(1), 21-28. https://doi.org/10.51440/unsch.revistainvestigacion.2018.1.54

Rosa, L., Chiarelli, D. D., Rulli, M. C., Dell'Angelo, J., & D'Odorico, P. (2020). Global agricultural economic water scarcity. *Science Advances*, *6*(18), eaaz6031. https://doi.org/10.1126/sciadv.aaz6031

Rosales-Rodríguez, O. A., Alfonso-Valdés, J. E., Santana-Amar, I., Socorro-García, A., & Duarte-Díaz, C. E. (2022). Comparación de métodos de estimación de la evapotranspiración del cultivo del tomate en casas de cultivo. *Ingeniería Agrícola*, *12*(2), 20-27. https://revistas.unah.edu.cu/index.php/IAgric/article/view/1577

Rusticucci M., & Barrucand, M. G. (2003). Climatología de temperaturas extremas en la Argentina. Consistencia de datos. *Meteorologica, 26*, 69-83. https://bicyt.conicet.gov.ar/fichas/produccion/en/6043307

Sánchez Palacios, L. E., Martínez Alcivar, F. R., Torres Sánchez, S. T., Lascano Montes, A. C., & Terán Guajala, G. N. (2024). Agricultura de Precisión en El Ecuador. *Ciencia Latina Revista Científica Multidisciplinar*, *8*(1), 1532–1542. https://doi.org/10.37811/cl_rcm.v8i1.9547

Shafer, M. A., Fiebrich, C. A., Arndt, D. S., Fredrickson, S. E., & Hughes, T. W. (2000). Quality assurance procedures in the Oklahoma Mesonetwork. *Journal of Atmospheric and Oceanic Technology*, *17*(4), 474–494. https://doi.org/10.1175/1520-0426(2000)017<0474:QAPITO>2.0.CO;2

Shrestha, B., Darapuneni, M., Stringam, B. L., Lombard, K., & Djaman, K. (2023). Irrigation water and nitrogen fertilizer management in potato (*Solanum tuberosum* L.): A Review. *Agronomy*, *13*(10), 2566. https://doi.org/10.3390/agronomy13102566

Shrestha, B., Stringam, B. L., Darapuneni, M. K., Lombard, K. A., Sanogo, S., Higgins, C., & Djaman, K. (2024). Effect of irrigation and nitrogen management on potato growth, yield, and water and nitrogen use efficiencies. *Agronomy*, *14*(3), 560. https://doi.org/10.3390/agronomy14030560

Soto-Bravo, F., & Rodríguez-Ocampo, G. A. (2021). Crecimiento, evapotranspiración y uso de nutrientes en cultivo hidropónico de *Eryngium foetidum*, en dos diferentes ambientes y niveles de nutrición. *Agronomía Costarricense, 45*(1), 19–40. https://hdl.handle.net/10669/82767

Trebejo, I., & Midmore, D. J. (2009). Effect of water stress on potato growth, yield and water use in a hot and a cool tropical climate. *The Journal of Agricultural Science*, *114*(3), 321-334. https://doi.org/10.1017/S0021859600072713

Valderrama, M. D., Vásquez, V. D., León, E. L., Vásquez, V. D., & León, E. L. (2021). Cambios en patrones de precipitación y temperatura en el Ecuador, región costa. *Dilemas Contemporáneos: Educación, Política y Valores*, *8*, 25. https://doi.org/10.46377/dilemas.v8i.2609

Vargas, J. G., & Escobar, N. (2018). Cálculo de la precipitación efectiva a través del modelo cropwat bajo condiciones de Los Llanos Occidentales Venezolanos. ¿Cuál método utilizar?. *Revista Unellez de Ciencia y Tecnología*, *36*, 8-16. http://revistas.unellez.edu.ve/index.php/ruct/article/view/1391

Vásquez, C., Célleri, R., Córdova, M., & Carrillo-Rojas, G. (2022). Improving reference evapotranspiration (ETo) calculation under limited data conditions in the high Tropical Andes. *Agricultural Water Management*, *262*, 107439. https://doi.org/10.1016/j.agwat.2021.107439

Veiga, H., Skansi, M., & Herrera, N. (2014). *Control de calidad de la Base de Datos del Centro Regional del Clima para el Sur de América del Sur*. Centro Regional del Clima para el Sur de Sudamérica. https://www.crc-sas.org/es/pdf/Reporte_CRC-SAS_FINAL_calidad_7jul23.pdf

Velásquez, J. S., Araujo, M. A., Andrade, V., Rivadeneira, J. E., Cuesta, H. X., Racines, M. R., & Tinoco, K. I. (2022). *Manual de producción de tubérculo-semilla de papa* (2ª ed.). Manual nº 124. Instituto Nacional de Investigaciones Agropecuarias (INIAP). http://repositorio.iniap.gob.ec/handle/41000/6124

Villazón Gómez, J. A., Noris Noris, P., Vázquez Montenegro, R. J., Martín Gutiérrez, G., & Cobo Vidal, Y. (2021). Comparison of empiric methods for the estimation of the reference evapotranspiration on Holguín, Cuba. *Idesia (Arica)*, 39(3), 103-109. https://doi.org/10.4067/S0718-34292021000300103

Yuan, B.-Z., Nishiyama, S., & Kang, Y. (2003). Effects of different irrigation regimes on the growth and yield of drip-irrigated potato. *Agricultural Water Management*, *63*(3), 153-167. https://doi.org/10.1016/S0378-3774(03)00174-4

Zamata-Quispe, C. (2019). *Determinación del coeficiente de cultivo (kc) de la papa (Solanum tuberosum) variedad Unica utilizando lisímetro de drenaje en La Molina*. Universidad Nacional Agraria La Molina. https://hdl.handle.net/20.500.12996/4309

Zaninelli, P. G., Menéndez, C. G., & Carril, A. F. (2015). Explorando Temperaturas Máximas y Mínimas en diferentes reanálisis. Parte 2: Variabilidad en diferentes escalas temporales. *Meteorologica, 40*(1), 59-76. https://www.scielo.org.ar/scielo.php?pid=S1850-468X2015000100004&script=sci_arttext