Bionatura Journal
Ibero-American Journal of Biotechnology and Life Sciences

Short Articles

# Determining Consumptive Water Use for Corn Cultivation at High Altitudes: A Comparative Study of Three Methods.

*Juan Sebastián Silva Orozco* [1*], *Robinson Fabricio Peña Murillo* [2], *Yénica Cirila Pachac Huerta* [3], *Alazne Salomé Arias Torres* [4]

[1] *Facultad de Recursos Naturales, Escuela Superior Politécnica del Chimbrazo, Riobamba, Ecuador; juan.silvaso@espoch.edu.ec*
[2] *Universidad Técnica de Ambato, Ambato, Ecuador. rf.pena@uta.edu.ec.*
[3] *Universidad Nacional Santiago Antunez de Mayolo, Perú; ypachach@unasam.edu.pe.*
[4] *Universidad Técnica de Cotopaxi, Latacunga, Ecuador; alazsalo1205@gmail.com.*
* *Correspondence: juan.silvaso@espoch.edu.ec*



## ABSTRACT

A desirable water supply in agriculture requires quantitative methods to determine crop requirements. Determination of hydric request of maize Var INIAP 102 is promising, mainly at altitudes over 2000 meters above sea level. This study analyzed three methods (lysimeter, evaporimeter tank, and empiric formula FAO) to determine Chimborazo province's hydric requirements for Var INIAP 102. Vegetative and yield variables were recorded, and the effect of different water films on the vegetative growth of maize was determined. When water was more available in the soil, the vegetative growth, yield, and pod weight per plant of maize Var INIAP 102 were higher. This study is of great importance because determining the hydric requirement of maize Var INIAP 102 was done for the first time in Chimborazo province and will support farmers in better water use for irrigation.

**Keywords:** irrigation sheet, lysimeter, sweet corn, water requirements, evaporation tank

## INTRODUCTION

Irrigation is one of the indispensable activities in agriculture, especially in places where rainfall does not meet the water demands of crops. Aedo [1] states that there is no need to justify water use; the increase in yields in irrigated crops is undeniable. "Irrigation is a tool in every agricultural strategy..." it alone generates complex and tecnified processes. In its statistics, the Food and Agriculture Organization (FAO) 2 records South America has an area equipped for irrigation of 17,798,500 hectares.
"Irrigation use is the primary volume used but carried out under inefficient conditions. Deficiency in irrigation water management is observed in all system components, from capture to application in the fields, through conduits, storage, distribution, and parcel irrigation methods."[3]
Global water scarcity is caused by demands from industries and the domestic sector, economic limitations to develop new water resources, climate change, and reduced water availability. The large volumes of water

required by agriculture also play a role, highlighting the importance of properly managing the available water for irrigation. [4]

For proper management, water in agriculture requires the application of methods that determine the quantity needed by the crop. According to García et al. [5], demand refers to crop evapotranspiration in soil without a water deficit. When this process occurs under suitable conditions, it is called the crop coefficient (Kc). To execute this management, it is necessary to know the crop's phenology and water consumption at each stage of development. [6]

Maize (*Zea mays* L.) is one of the highest-producing crops in Ecuador. Data from the National Institute of Statistics and Census (INEC) [7] report that over 400,000 hectares were planted with various types of maize, resulting in a production exceeding 1.4 million tons. Production is closely correlated with climatological variables and crop water availability. [8] Understanding the water requirements of this crop is essential, especially for the variety INIAP 102 "Blanco Blandito Mejorado," which, according to Silva et al. [9], is characterized by high yield and adaptation to altitudes above 2000 meters above sea level. Over 25,000 hectares of soft maize are planted annually in the province of Chimborazo. Therefore, it is considered necessary to determine, using three methods, the water requirement of the maize variety INIAP 102 in the canton of Riobamba, Chimborazo province.

## MATERIALS AND METHODS

The present research will be carried out at the Escuela Superior Politécnica de Chimborazo, in the Centro Experimental de Riego (CER), located at 2710 meters above sea level, with an average temperature of 14°C, in the canton of Riobamba, Chimborazo province, Ecuador.

### Experimental Design

A Completely Randomized Block Design (CRBD) was employed, with three treatments and three replications (Table 1).

| Treatment Name | Description |
|---|---|
| **T1 (Lysimeter)** | Evapotranspiration of the crop was calculated using drainage lysimeters, and irrigation was applied once the lysimeter stopped draining. |
| **T2 (Evaporation Tank Type A)** | Evaporation from the pan was measured, and irrigation was applied based on evaporation once 25% of the available water was consumed. |
| **T3 (FAO Empirical Formula) [10]** | Calculation was performed, and irrigation was applied once the available water was consumed. |

**Table 1. Irrigation Treatments and their Descriptions**

In each treatment, a sample of 10 plants was taken to evaluate vegetative and reproductive variables (Table 2).

| Designation | Description |
|---|---|
| **Plant Emergence** | Evaluated at 30 days after planting (dap). |

| | |
|---|---|
| **Plant Height** | They were recorded at 50, 100, and 150 daps using a tape measure, measured from the base of the stem to the plant's apex. |
| **Stem Diameter** | They were recorded at 50, 100, and 150 daps using a Vernier caliper, measured at the base of the stem. |
| **Ear Height** | Height from the base of the stem to the first ear formation, measured with a tape measure. |
| **Number of Ears per Plant** | Recorded the number of ears per plant at harvest. |
| **Ear Weight per Plant** | Each ear was weighed using a scale. |
| **Yield** | The weight of the ears determines it in the net plot. |

**Table 2. Plant Growth and Productivity Measurements**

### Statistical Analysis

Differences between treatments in the variables under study were determined using a simple Analysis of Variance (ANOVA). In cases where significant differences were observed, the Tukey test was applied at a 5% significance level.

## RESULTS

### Total Water Depth Applied

When calculating the crop's water requirements under Riobamba, Ecuador, a significant difference between methods was observed. The results from the Type A evaporation tank method require the application of a total water depth for the entire crop cycle of 1015 L $(m^2)^{-1}$, while the two remaining treatments establish lower water requirements demanded by the maize (Figure 1.).

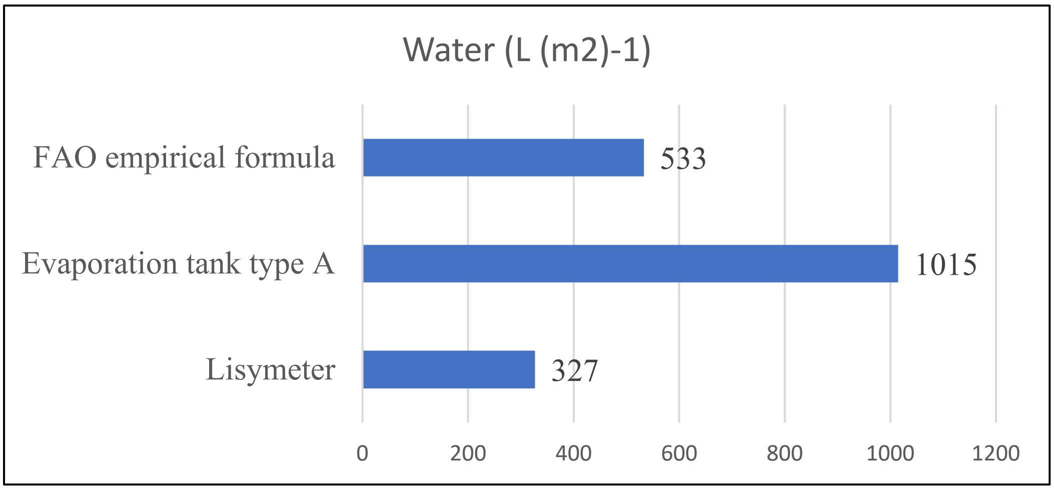
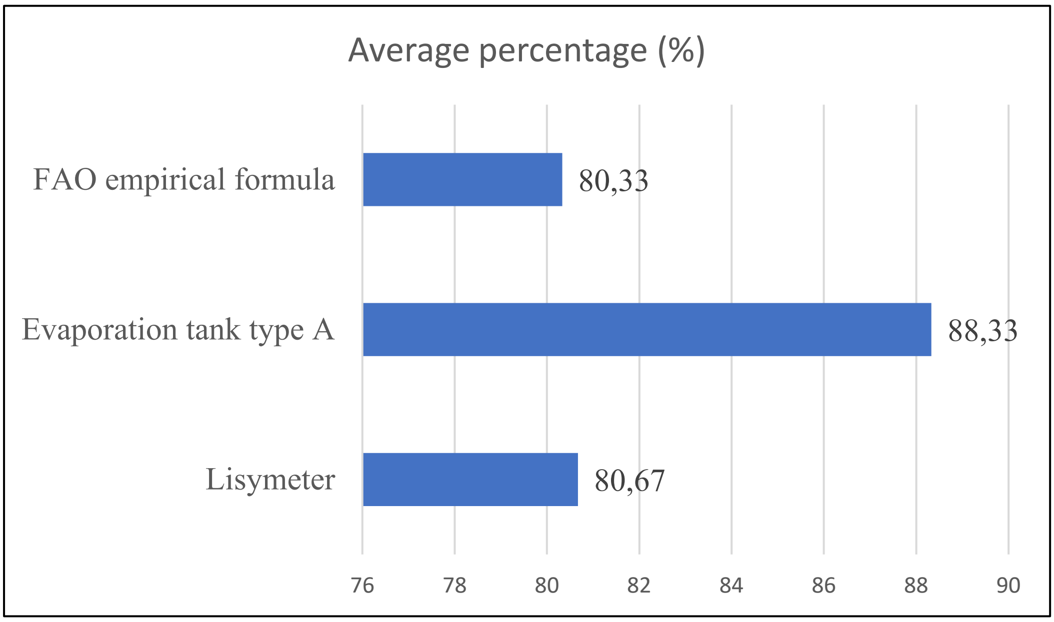



**Figure 1. Total water depth applied in the crop cycle**

**Plant Emergence**

The highest plant emergence occurred in treatment two, with 88.33%, corresponding to the area receiving the most water (Figure 2.).




*means with different letters differ significantly (p≤0,05) (CV 3,32)

**Figure 2. Plant Emergence.**

**Plant Height**

At 50 DDS, there were no significant differences in the height of maize plants among the treatments under study.

| **Treat.** | **Denomination** | **Plant height (cm)** | |
|---|---|---|---|
| | | 100 dds | 150 dds |
| **1** | Lisymeter | 110.03 b | 150.27 b |
| **2** | Evaporation tank type A | 136.23 a | 181.87 a |
| **3** | FAO empirical formula | 126.53 a | 168.93 a |
| ***C. V.*** | | *3.78* | *3.68* |

* means with different letters differ significantly (p≤0,05)

**Table 3. Effect of Irrigation Treatments on Plant Height at 100 and 150 Days After Planting**

However, at 100 and 150 DDS, it was observed that the plants in treatments 2 and 3 had the most remarkable growth with significant differences compared to treatment one (Table 3.).

**Stem Diameter**

Significant differences were observed in stem diameter. Plants irrigated under the regime established by the results of the Type A evaporation tank (Treatment 2) had thicker stems at all evaluation times compared to the other treatments (Table 4.).

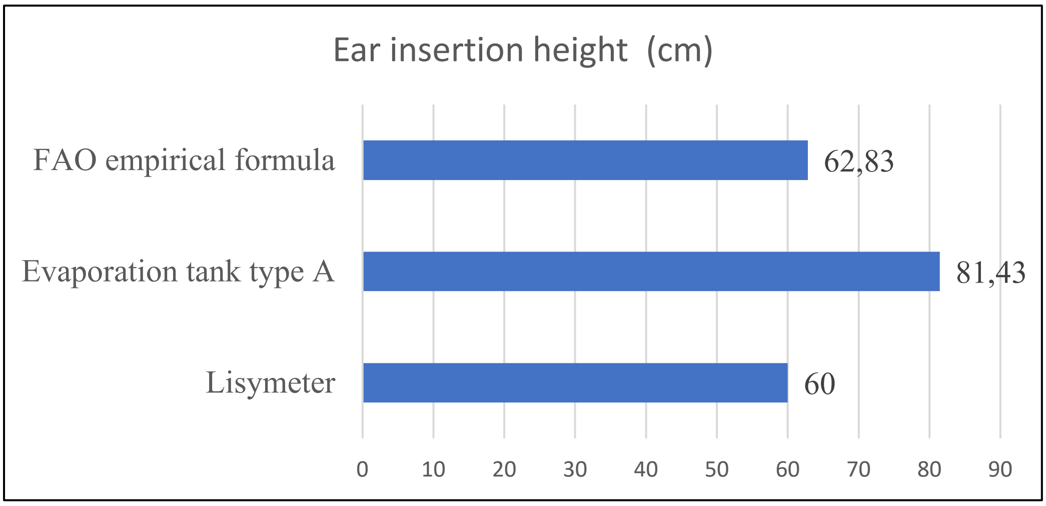
| Treat. | Denomination | Stem diameter (mm) | | |
|---|---|---|---|---|
| | | 50 dds | 100 dds | 150 dds |
| **1** | Lisymeter | 8.13 c | 16.77 c | 17.13 c |
| **2** | Evaporation tank type A | 11.1 a | 23.97 a | 24.7 a |
| **3** | FAO empirical formula | 9.67 b | 19.0 b | 19.57 b |
| ***C. V.*** | | *4.38* | *5.36* | *2.79* |

* means with different letters differ significantly (p≤0,05)

**Table 4. Effect of Irrigation Treatments on Stem Diameter at 50, 100, and 150 Days After Planting**

**Ear insertion height**

Compared to the other treatments, treatment two (evaporation tank) resulted in significantly taller plants with ears inserted at a greater height, indicating a positive impact on plant growth and potential yield.




* means with different letters differ significantly (p≤0,05) (CV 5,26)

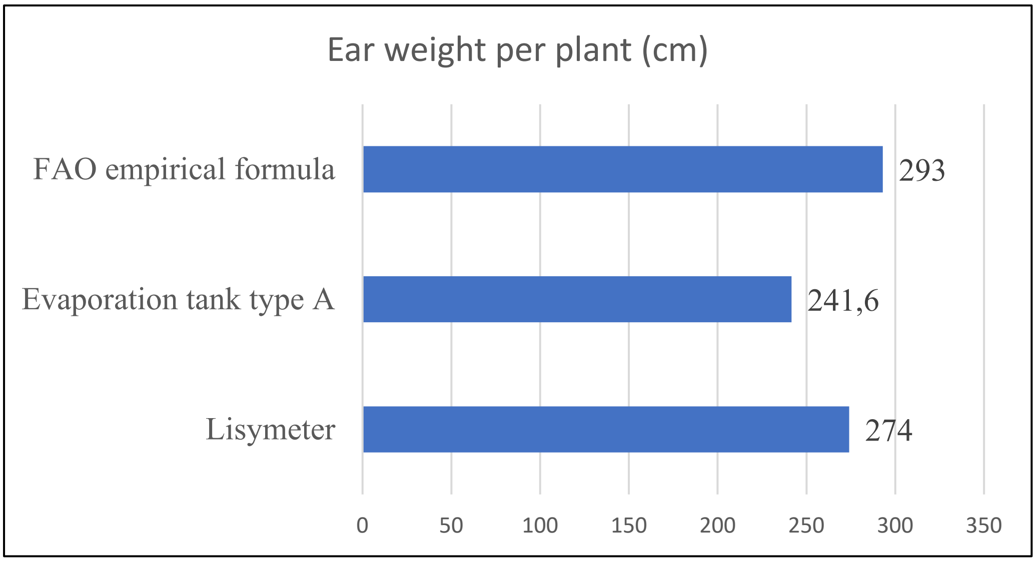
**Figure 3. Ear insertion height**

**Number of ears per plant**

The treatments had no significant differences in the number of ears per plant.

**Ear weight per plant**

The ear weight per plant was higher in treatments 2 and 3, with 274.0 and 293.0 g, respectively. This yield parameter does not correlate linearly with the vegetative aspects' performance or the amount of water applied (Figure 4).

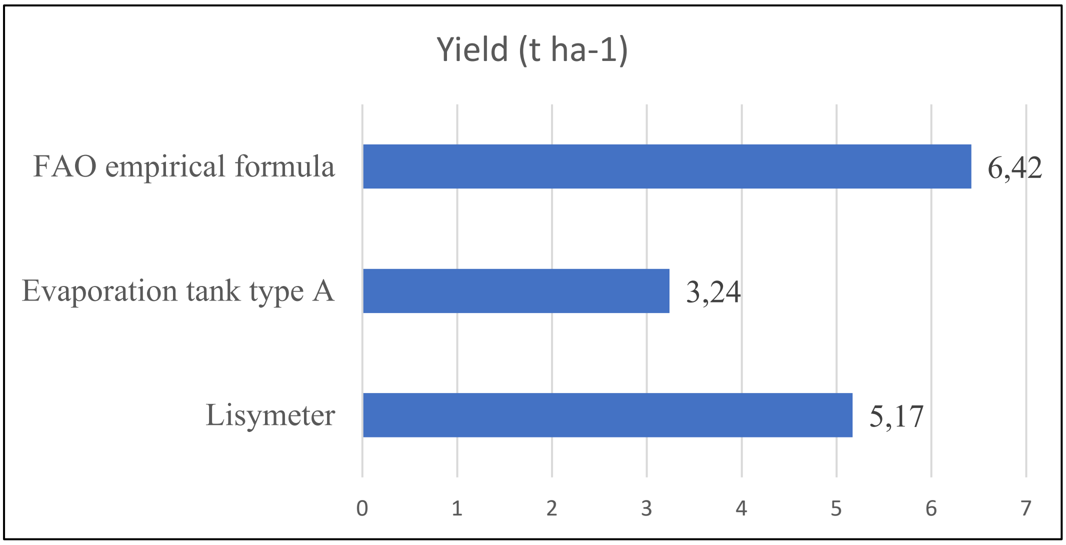



* means with different letters differ significantly (p≤0,05) (CV 3,79)

**Figure 4. Ear weight per plant**

## Yield

In the plots where a total water depth of 533 L $(m^2)^{-1}$ (treatment 3), a yield of 6.42 t $ha^{-1}$ was calculated, which differs significantly from the other two.




*medias con letras diferentes, difieren significativamente (p≤0,05) (CV 8,51)

**Figure 5. Maize yield (t/ha) under different irrigation treatments. Means with different letters are significantly different (p ≤ 0.05). CV = 8.51.**

## DISCUSSION

Research on the water requirements of maize INIAP 102 in Riobamba revealed significant differences in water demand depending on the estimation method used, highlighting the complexity of determining optimal water management in agriculture. The Type A evaporimeter tank method suggested a considerably higher requirement, contrasting with the methods of the lysimeter and the FAO empirical formula. This variability underscores the influence of local conditions and methodology on estimating the water needed for specific crops.

While the evaporimeter tank reflects potential unrestricted evapotranspiration, the lysimeter provides a more direct measure of crop transpiration and soil evaporation, possibly resulting in a lower but potentially more tailored estimate of the actual crop needs. "It is important to carry out water balance modeling, as it can address challenges in resource management and also consider parameters such as water availability." [8] Zamora et al.[11], ensure that in maize, the estimated water depth ranges between 498.4 and 818.8 mm for arid areas.

The relationship between the amount of water applied and plant emergence points to a positive correlation between greater water availability and emergence rate. The treatment with the evaporimeter tank, which involved the most significant water application, achieved the highest emergence rate (88.33%), suggesting that adequate water availability from the early stages may favor a more successful crop establishment. In this regard, Lucas et al.[8], conclude that water balance is linked to climatological variables and has a close relationship with soil water availability, which benefits maize cultivation from planting to harvest.

The analysis of plant height, stem diameter, and ear insertion height reveals that a more generous water supply (treatment 2) favors the vegetative development of maize. These results are consistent with the literature, indicating that water availability is critical for vegetative growth, particularly in rapid development. Rodríguez et al.[13] observed that crop development is affected by an irrigation depth lower than 612 mm. At the same time, Sandez and Romani15 assert that achieving a good plant structure allows better entry of solar radiation to the leaves near the inflorescence. Good ear placement results in a higher yield[14]. However, the absence of significant differences in the number of ears per plant and the counterintuitive lower weight of ears in the treatment with higher water application (treatment 2) suggests that beyond a threshold. These results coincide with those obtained by Inzunza et al.16 and can be explained by the arguments of Geerts and Raes17, who point out that maize yields are affected when they grow under conditions of excess soil moisture.

Surprisingly, treatment 3, which applied an intermediate amount of water based on the FAO empirical formula, yielded the highest yield (6.42 t ha-1). This finding illustrates that balanced water management, avoiding both deficit and excess, can optimize maize yield, possibly by improving water use efficiency and encouraging a more balanced crop development. Rodríguez et al.13 agree in pointing out that maize water needs vary from 481 to 747 mm.

These results have important implications for water management in Riobamba agriculture. First, they highlight the need to adapt irrigation practices to specific local conditions, considering crop demands, water availability, and resource sustainability. Additionally, they suggest that estimation methods such as the FAO empirical formula, which incorporates climatic variables and crop characteristics, may offer a more practical guide for irrigation than methods that do not adjust for specific local conditions.

## CONCLUSIONS

The research provides significant field information on the effect of different water depths on the vegetative development of maize variety INIAP 102. The relationship between crop water requirements and its vegetative development is manifested in how variables of this Type studied increased as soil water availability increased throughout the cycle. Yield parameters such as ear weight per plant and yield imply the usefulness of strategies in applying water demanded by the crop. Excess soil moisture throughout the cycle reduced yields by exceeding the maximum limit of the total water depth.

**Authors' contributions:** Juan Sebastián Silva Orozco: Led and executed the research project. He formulated the research objectives, participated in the analysis of the results and made a critical review of the manuscript.

Robinson Fabricio Peña Murillo: Responsible for supervising and leading the planning and execution of the research activities, including advising the team responsible for taking the experimental data, contributed in the application of the statistical techniques used to analyze or synthesize the study data obtained. She made a critical revision of the manuscript.

Yénica Cirila Pachac Huerta: Participated in the research activities and applied the statistical techniques used to analyze or synthesize the study data obtained. She made a critical review of the draft.

Alazne Salomé Arias Torres: Participated in the research activities and the analysis of the results. She participated in the journal's proposal for publication, made a critical review of the manuscript, and wrote the final version of the manuscript.

**Funding:** This research is funded by research projects of the Escuela Superior Politécnica de Chimborazo.

**Declaración de la Junta de Revisión Institucional:** No aplicable

**Declaración de consentimiento informado:** No aplicable

**Conflictos de intereses:** The authors declare no conflicts of interest.

## REFERENCES

1. Aedo, M. 2020. "Enfoque NEXO en Centroamérica: nuevas estrategias para promover el desarrollo del riego en áreas rurales. Diagnóstico y propuesta de fomento del riego en la agricultura familiar de El Salvador", Documentos de Proyectos (LC/TS.2020/181), Santiago, Comisión Económica para América Latina y el Caribe (CEPAL). https://repositorio.cepal.org/bitstream/handle/11362/46582/S2000870_es.pdf?sequence=1&isAllowed=y
2. FAO (Organización de las Naciones Unidas para la Alimentación y la Agricultura) 2018. Datos sobre alimentación y agricultura. Ganadería. FAOSTAT. http://www.fao.org/faostat/es/#data/QA
3. Nieto C., C., Pazmiñi Ch., E., Rosero, S., *et al*. 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. Sierra, 5(1): 51-70. https://dialnet.unirioja.es/servlet/articulo?codigo=6724757
4. Dingre, S. K., Gorantiwar, S. D. 2020. Determination of the water requirement and crop coefficient values of sugarcane by field water balance method in semiarid region. Agriculture Water Management, 232, 106042. https://doi.org/10.1016/j.agwat.2020.106042.
5. García V., J., Huahuachampi, J., Soto, L. 2017. Determinación de la demanda hídrica del cultivo de quinua QML01 (*Chenopodium quinoa* Willd) en la Molina. Anales Científicos, 78(2): 200-209. http://dx.doi.org/10.21704/ac.v78i2.1057
6. Falcón C., S. C. 2020. Determinación de la demanda hídrica y parámetros biométricos para la aplicación del riego del maíz amarillo dk7088 (*Zea mays* L.) en La Molina. Tesis de Grado. Universidad Nacional Agraria La Molina, Lima, Perú. https://repositorio.lamolina.edu.pe/bitstream/handle/UNALM/4437/Tesis%20de%20Ingeniera%20Meteor%c3%b3loga-Samy%20Falc%c3%b3n%20C%c3%a1ceres.pdf?sequence=1&isAllowed=y

7. Instituto Nacional de Estadística y Censos [INEC] (2020). Encuesta de Superficie y Producción Agropecuaria Continua. https://www.ecuadorencifras.gob.ec/estadisticas-agropecuarias-2/
8. Lucas Z., M. E., Chavarría P., J. E., Duicela G., L. A. 2021. Evaluación multianual de las variables climatológicas y su relación con el balance hídrico para el cultivo de maíz duro. Dilemas contemporáneos: educación, política y valores, 8(spe2), 00021. https://doi.org/10.46377/dilemas.v8i.2604
9. Silva, E., Dobronsky, J., Caviedes, M., *et al*. 2000. INIAP-102 "Blanco Blandito Mejorado", variedad de maíz blanco harinoso para la provincia de Chimborazo. Plegable Divulgativo No. 181. Quito, EC: INIAP, 5p. https://repositorio.iniap.gob.ec/handle/41000/2585
10. Hargreaves, G. H., Samani, Z. A. 1985. Reference Crop Evapotranspiration from Temperature. Applied Engineering in Agriculture, 1, 96-99. http://dx.doi.org/10.13031/2013.26773
11. Zamora S., S., Ruiz E., F. H., Beltrán M., F. A., *et al*. 2011. Régimen hídrico del maíz en una zona árida, determinado en porcentajes de evaporación. Tropical and Subtropical Agroecosystems, 13(2):181-186. https://www.redalyc.org/articulo.oa?id=93917767013
12. Torretta B., J. J. 2017. Cálculo de los requerimientos hídricos del maíz y ajuste del Kc mediante el uso de lisímetros de drenaje en el Valle Inferior del río Negro. Tesis de Grado. Universidad Nacional, Argentina. https://rid.unrn.edu.ar/bitstream/20.500.12049/496/1/Torretta_Bassi_Joaquin-2017.pdf
13. Rodríguez P., R. A., Cánepa, P., Burgos, M., Echeveste M., G. 2017. Necesidades hídricas y programación de riego en los cultivos de maíz, soya y sorgo en la localidad de Salto, Uruguay. Acta Iguazu, 6(1): 23-32. http://e-revista.unioeste.br/index.php/actaiguazu/article/view/16557/11207
14. Castillo R., J. D., Saravia R, J. M. 2017. Evaluación de tres dosis de nitrógeno sobre el crecimiento y rendimiento de dos híbridos de maíz (*Zea mays* L.), bajo riego por pivote central, Tisma, Masaya 2016. Tesis de Grado. Universidad Nacional Agraria, Nicaragua, Managua. https://repositorio.una.edu.ni/3508/1/tnf04c352e.pdf
15. Sandez, A., Romani, M. R. 2018. Variaciones en la estructura de planta de maíz en híbridos tropicales y templados y su efecto sobre la intercepción de radiación a través de la ventana de siembra para el área de riego del rio dulce, Santiago del estero. XI Congreso Nacional de Maíz. 21-24 de agosto, Santiago del Estero, Argentina. https://inta.gob.ar/sites/default/files/trabajo_1_0.pdf
16. Inzunza I., M. A., Villa C., M. M., Catalán V., E. A., *et al*. 2018. Rendimiento de grano de maíz en deficit hídrico en el suelo en dos etapas de crecimiento. Revista Fitotecnia Mexicana, 41(3): 283-290. https://doi.org/10.35196/rfm.2018.3.283-290
17. Geerts S., Raes, D. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agricultural Water Management, 96(9): 1275-1284. https://doi.org/10.1016/j.agwat.2009.04.009.

**Received:** 20 December 2023/ **Accepted:** 25 July 2024 / **Published:** 15 September 2024

Citation: Peña Murillo R F, Silva Orozco J S, Pachac Huerta Y C, Arias Torres A S.Determining Consumptive Water Use for Corn Cultivation at High Altitudes: A Comparative Study of Three Methods. Bionatura Journal 2024; 1 (3) 9. http://dx.doi.org/10.70099/BJ/2024.01.03.9

Correspondence should be addressed to *juan.silvaso@espoch.edu.ec*

**Peer review information.** Bionatura thanks anonymous reviewer(s) for their contribution to the peer review of this work using https://reviewerlocator.webofscience.com/

**ISSN. 3020-7886**

All articles published by Bionatura Journal are made freely and permanently accessible online immediately upon publication, without subscription charges or registration barriers.

**Publisher's Note:** Bionatura Journal stays neutral concerning jurisdictional claims in published maps and institutional affiliations.