საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 18, №3, 2024
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 18, no. 3, 2024

Soil Science

Determination of Control Evapotranspiration Error between Penman-Monteith and FAO-24 Methods on the Example of Lomtagora

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Quantitative determination of irrigation needed is carried out by the main hydrophysical characteristic of the active soil layer, according to the marginal water capacity. Obviously, in this case, the individual biological properties of the plant in terms of water demand are not taken into account. Therefore, it is necessary to assess the intensity of the physicogeographical processes with the criterion of evapotranspiration, which integrally depicts the capacity of the plant's water needs and enables the operation of the irrigation systems by applying the principle of rational use of water. In recent years, scientists around the world have developed numerous methods for calculating evapotranspiration (ET_0) from various climatic data. Testing all these methods under different conditions is quite a time-consuming process. With account of the dynamics of productive water consumption there are four well-known methods of evapotranspiration determining the irrigation rate: Blaney-Criddle, Radiation, Penman, and Pan evaporation methods, each of which requires different climatic data. Upon further analysis it indicates that the FAO-24 Penman (ET_0) estimates are generally 20 to 50% higher than the Penman-Monteith estimates. However, the FAO-24 Radiation and Penman-Monteith methods give similar daily (ET_0) values. Unlike Penman-Monteith, which also requires wind speed data, the FAO-24 radiation method estimates ET_0 from temperature and sunshine hours. Thus, the FAO-24 radiation method can be used as a surrogate for Penman-Monteith to estimate daily ET_0 in areas where wind speed data are not available. The Blaney-Criddle method, which utilizes only temperature data, provides an estimation of the monthly reference evapotranspiration (ET_0) similar to the Penman-Monteith method. Therefore, it is suitable for applications that require only approximate values of ET_0. Comparisons also indicate a significant correlation between the data derived from the Blaney-Criddle method and Penman-Monteith ET_0.

evapotranspiration, water demand, coefficient of income

Rural agricultural production is directly linked to climate change, which increases risks and negatively impacts the livelihoods of rural agricultural communities, as well as their economic and social well-being. Therefore, the establishment of climate-resilient rural communities is of great importance. Adaptation to climate change and the mitigation of its impacts are crucial aspects in this regard.

In the face of the globally observed climate change, problems directly related to climate's global variations have emerged in various areas. Ecosystems, affected by temperature and humidity regimes that deviate significantly from the norm over thousands of years, have begun to deteriorate. In response to the changing conditions of agro-climatic regions, an urgent need has arisen for new approaches in rural-agricultural production, breaking away from stereotypical perspectives.

The issue at hand involves the familiar and well-established principles of agro-techniques and the adjustments required in light of our knowledge and critical understanding of ecological processes. Both hydro-techniques and agro-techniques are called upon to make corrections.

The intelligent use of water resources is a key focus in hydrotechnology. In order for water resources, which can be utilized to a greater extent, to be effectively used in sustainable development, it is necessary to implement complex measures within the water management framework. Currently, since rural development is the most water-dependent sector, rational water usage and supply contribute not only to the efficient utilization of water resources but also to the normal growth and development of the environment [1].

In order to obtain the mentioned results, the goal of our research was to determine the parameters of the irrigation regime, taking into account the plant's water demand (evapotranspiration), water-air regimes, soil-ground characteristics and natural-climatic factors, which ensures the optimal use of irrigation water, getting a programmed harvest and maintaining the maximum balance of agro-ecosystems.

By applying the Blaney-Criddey method and considering the factor *f* associated with temperature and day length, the control evapotranspiration (ET_o) for the given month can be calculated. Additionally, it is essential to utilize general data on humidity, sunshine duration, and wind speed in order to predict improved climate data and determine the correction factor *c* (adjustment factor which depends on minimum relative humidity, sunshine hours and daytime wind estimates). This correction factor depends on the minimum values of relative humidity, hours of sunshine, and daily wind, ensuring accurate adjustments [2,3],

$$ET_0 = c\left[p\left(0.46T + 8\right)\right] \text{ mm/days.} \quad (1)$$

To obtain the wind speed, the 24-hour average wind data need to be multiplied by 0.33. Once ETo is calculated, ETcrop can be predicted by applying the suitable crop coefficient (kc),

$$ET_{\text{crop}} = kc \cdot ET_0. \quad (2)$$

The radiation method is recommended for locations where the available climatic data include air temperature, sunlight duration, cloudiness or radiation, and where estimates for humidity and wind speed must be obtained from published weather data, extrapolated from nearby areas, or sourced locally. The radiation method is considered more reliable compared to the presented Blaney-Cridley approach,

$$ET_0 = c\left(\frac{W}{R_s}\right) \text{ mm/days,} \quad (3)$$

where ET_0 – reference crop evapotranspiration in mm/day for the periods considered; R_s is solar radiation in equivalent evaporation in mm/day; W – weighting factor which depends on temperature and altitude.

It is recommended to calculate it by considering the average humidity, daylight hours, and wind speed based on the data of solar radiation (R_s).

Radiation (R_a) represents the amount of radiation received at the top of the atmosphere and depends on the latitude. Solar radiation (R_s) is the portion of radiation that reaches the Earth's surface. (R_s) can be derived from recorded sunshine duration measurements using the following method:

$$R_s = \left(0.25 + 0.50\frac{n}{N}\right)R_a. \quad (4)$$

The ratio of the practical duration of sunlight to the maximum possible day length (hours) is represented by *n/N*. Both n and N are expressed as average daily values in hours. Additionally, Eto can be determined using the weighting factor (*W*) and the correction factor (c), as mentioned in [4].

Country: Georgia. Meteorological station: Marneuli (Lomtagora). Elevation: 406 m a. s. l.

RH_{mean} – the average maximum and minimum temperature fluctuation,

$$RH_{\text{mean}} = \frac{RH_{\max} + RH_{\min}}{2}. \quad (5)$$

Penman method is suggested in areas where climatic data on temperature, humidity, wind, sunshine duration, or radiation is available.

Experimentally determined harvest coefficients range from 0.4 in winter months to 1 in summer months.

The Penman equation consists of two sets of climatic parameters: energy (radiation) and aero-dynamic (wind and moisture). The relative importance of each climatic parameter varies according to climatic conditions.

In calm weather, the aerodynamic limiting factor is less important than the energy limiting factor. However, in windy conditions and especially in drier regions, the aerodynamic factor becomes relatively more important.

The Penman equation for determining ET_0 is proposed in a modified form that includes a corrected coefficient for the wind function. This method utilizes average daily climate data, as both daytime and nighttime weather conditions significantly affect evaporation.

The calculation procedures for ET_0 may seem quite complicated because the formula contains components that are not directly available from the measured climatic data and need to be calculated.

For example, in areas where direct net radiation data are not available, they can be obtained by observing measured solar radiation, sunshine duration, cloudiness, humidity, and temperature. Penman method takes the following form,

$$ET_0 = c\left[W \cdot R_n + (1 - W) \cdot f(u) \cdot (ea - ed)\right] \quad (6)$$

The radiation and the aerodynamic methods are used to calculate evapotranspiration ET_0 in mm/day. ET_0 is determined based on various factors: the weight factor W associated with temperature, net radiation R_n in equivalent evaporation mm/day, the function (f(u)) related to wind, and the difference between the saturation vapor pressure of the current air temperature and the average actual vapor pressure of the air $(ea - ed)$ in bars. Additionally, a correction factor (c) is applied to account for the effects of day and night weather conditions [2].

The wind function proposed is applicable to summer conditions with moderate winds, $RH_{\max}$ around 70%, and a day-to-night wind ratio ranging from 1.5 to 2.0. No adjustment is necessary for these conditions. However, if 24-hour wind sums are utilized, ET_0 estimates will be underestimated by 15 to 30% in areas where daytime winds significantly exceed nighttime winds, $RH_{\max}$ approaches 100%, and radiation levels are high. Conversely, in regions with moderate to strong winds, low nighttime humidity ($RH_{\min}$), and low radiation, the ET_0 calculated from such data will be excessively inaccurate. It is under these circumstances that the correction factor (c) should be applied (Table).

The description of the variables and their calculation is as follows:

(a) vapor pressure $(ea - ed)$: air humidity affects ET_0 and humidity is expressed as the saturation vapor pressure deficit $(ea - ed)$, which is the difference between the average saturation

Table. The determination of ET_0 using average monthly data from Lomtagora (Kvemo Kartli region) for the year 2022 was performed according to the FAO-24 and FAO-56 methods, considering the average monthly climate data

Months	0ct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July
1.Blaney Criddle Metod - ETo (mm/day) (FAO -24)	3.5	2.8	1.9	1.8	1.6	1.7	5.5	6.5	8.2	8.7
2. Radiation Metod – ETo (mm/day) (FAO-24)	4.4	3.3	3.1	2.2	2.9	3.3	8.2	10	7.3	8.3
3.Penmam Metod – ETo (mm/day) (FAO-24)	4.5	3.3	3.0	3.5	3.8	3.5	4.0	6.0	9.7	9.2
Penman-Monteiths method ETo (mm/day) (FAO-56)	3.0	2.7	2.2	1.9	2.01	2.2	2.45	3.9	6.1	7.6

water vapor pressure (ea) and the actual average water vapor pressure (ed). The relative humidity of the air is represented as a percentage by RH_{max} and RH_{min}. Actual vapor pressure is a relatively constant factor, and even one measurement per day may be adequate (pressure expressed in bars).

Based on the results of research conducted by the research institutes of the European Union, the Penman-Montaigne method has been recommended by the FAO as the sole standard approach for determining evapotranspiration. The calculation of evapotranspiration using this method takes the following form [5]:

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \frac{900}{T+273} U_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)}, \quad (7)$$

where ET_0 is a control evapotranspiration (mm.day-1); R_n – culture surface radiation neto (MJм-2 days-1); G – density of the heat flow of the soil (MJм-2 days-1); T – medium day-night temperature (°C); u_2 – wind speed up to 2 m in height (ms-1); Δ – saturated steam pressure curve rock (kPa °C-1); γ – psychometric constant (kPa °C-1); e_s – actual vapor pressure (kPa); e_a – saturated vapor pressure (kPa); (e_s - e_a) – saturated vapor pressure deficiency (kPa).

Therefore, in order to effectively utilize irrigated areas, it is essential to allocate irrigation water rationally and implement an optimal irrigation regime. The existing methods for determining the irrigation regime are region-specific, meaning they are primarily applicable to the conditions under which they have been developed and tested for specific meteorological conditions.

This paper was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSF) [grant number RNSF/YS 21-444].

ნიადაგმცოდნეობა

Penman-Monteith-ისა და FAO-24-ის მეთოდებს შორის საკონტროლო ევაპოტრანსპირაციის ცდომილების განსაზღვრა ლომთაგორის მაგალითზე

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ნაშრომის მიზანია მორწყვის ნორმის რაოდენობრივი განსაზღვრა, რაც დღეისთვის ხორციელდება ნიადაგის აქტიური შრის ძირითადი ჰიდროფიზიკური მახასიათებლით, ზღვრული წყალტევადობის მიხედვით. ცხადია, ამ შემთხვევაში არ არის გათვალისწინებული მცენარის ინდივიდუალური ბიოლოგიური თვისებები წყალმოთხოვნილების თვალსაზრისით. ამიტომ, ფიზიკურ–გეოგრაფიული პროცესის ინტენსივობის შეფასება საჭიროა მოხდეს ევაპოტრანსპირაციის კრიტერიუმით, რაც ინტეგრალურად გამოსახავს მცენარის წყალმოთხოვნილების უნარიანობას და შესაძლებლობას იძლევა სარწყავი სისტემების ფუნქციონირება წარიმართოს წყლის რაციონალური გამოყენების პრინციპის რეალიზაციით. ბოლო წლების მანძილზე მთელს მსოფლიოში, მეცნიერთა მიერ შემუშავებულია ევაპოტრანსპირაციის (ETo) გაანგარიშების უამრავი მეთოდი სხვადასხვა კლიმატური მონაცემის მიხედვით. ამა თუ იმ მეთოდის გამოცდა სხვადასხვა პირობებში საკმაოდ შრომატევადი პროცესია. აქედან გამომდინარე, მორწყვის ნორმის განსაზღვრისათვის შემოთავაზებულია პროდუქტიული წყლის ხარჯვის დინამიკის გათვალისწინებით ევაპოტრანსპირაციის ოთხი ცნობილი მეთოდი: Blaney-Criddle, Radiation, Penman და Pan აორთქლების მეთოდები, რომელთაგან თითოეული მოითხოვს განსხვავებულ კლიმატურ მონაცემებს. ანალიზები მიუთითებენ, რომ FAO-24-ის Penman-ის მეთოდის შეფასებები, ზოგადად, 20-დან 50%-ით აღემატება Penman-Monteith-ის შეფასებებს. თუმცა, FAO-24 Radiation და Penman-Monteith მეთოდები იძლევა მსგავს ყოველდღიურ ET_0-ის მნიშვნელობებს. Penman-Monteith-გან განსხვავებით, რომელიც ასევე მოითხოვს ქარის სიჩქარის მონაცემებს, FAO-24 Radiation მეთოდი აფასებს ETo -ს ტემპერატურისა და მზის ნათების საათებიდან. ამგვარად, FAO-24 რადიაციული მეთოდი შეიძლება გამოყენებულ იქნეს, როგორც სუროგატი Penman-Monteith-ის ყოველდღიური ETo-ის შესაფასებლად, იმ ადგილებში, სადაც ქარის სიჩქარის მონაცემები არ არის ხელმისაწვდომი. FAO-24 Blaney-Criddle მეთოდი, რომელიც იყენებს მხოლოდ ტემპერატურულ მონაცემებს, იძლევა

მსგავს ყოველთვიურ ETo-ს, შეფასებულია როგორც Penman-Monteith და, შესაბამისად, ადეკვატურია იმ აპლიკაციებისთვის, სადაც საჭიროა მხოლოდ გრძელვადიანი ETo-ის შეფასებები. შედარებები ასევე აჩვენებს, რომ არის დამაკმაყოფილებელი კორელაცია Blaney-Criddle Method-ის მონაცემებსა და Penman-Monteith ETo-ს შორის.

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Received June, 2023