International Journal of Energy and Power Engineering
2023; 12(2): 29-35
http://www.sciencepublishinggroup.com/j/ijepe
doi: 10.11648/j.ijepe.20231202.12
ISSN: 2326-957X (Print); ISSN: 2326-960X (Online)

Determination of the Characteristic Parameters of a Pump for the Irrigation of Large Surfaces

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To cite this article:
Monsieur Moussa Cheikh Mall, Amadou Seidou Maiga, Ndongo Mamoudou. Determination of the Characteristic Parameters of a Pump for the Irrigation of Large Surfaces. *International Journal of Energy and Power Engineering*. Vol. 12, No. 2, 2023, pp. 29-35.
doi: 10.11648/j.ijepe.20231202.12

Received: April 25, 2023; **Accepted**: May 26, 2023; **Published**: June 20, 2023

Abstract: From human motricity, to electric motricity, moving on to animal and mechanical motricity, man has always sought to satisfy his water needs while using appropriate technologies. To meet its needs, equipment is installed that will transport water from one intake point to another recovery point with a certain speed. Having chosen the type of hydraulic structure (well, borehole or body of water) and the mode of consumption (human, animal or plant), the sizing of suitable equipment is necessary for optimal use of water. Plant water consumption is governed by heat exchanges between the ambient air and the surface of the water and then from the latter to the subsoil. Thus the nature of the ecosystem (subsoil, surface of the water, the plant, the immediate atmosphere, the geographical area, etc.) will be decisive in calculating the water needs of the plant. As much, it can be said that the water height also obeys the laws of fluid dynamics, particularly the equation of the Bernoulli theorem applied under specific conditions in this article. Among its aforementioned technologies, photovoltaic solar pumping is increasingly becoming the most advanced in the context of climate change and sustainable development in regions where sunshine and insolation are not restrictive. Usually, an electric pump coupled with solar panels via an inverter is used to pump water from a source through a reservoir or into a distribution network. In general, in small scale and/or deep water irrigation the characteristic parameters of the pump are determined from pumping tests, whereas in large scales the capacity of the pumping system is determined from the meteorological conditions of the site. In this article, our calculations are made under specific conditions (drainage on surface water, centrifugal pump, high-flow irrigation.) to determine the characteristics of the pump flow rate (Q) and total head (HMT).

Keywords: Irrigation, Evapotranspiration, Solar Pump, Rice, Characteristics Parameters of a Pump, Irrigation

1. Introduction

In general, to calculate the capacity of a pumping system, the two characteristic parameters of the pump must be determined, in particular the flow rate Q and the man metric height HMT (Bnmokhtar Aness, Ben Kemchi Zakarya 2022) [1].

In the case of surface water dewatering, the flow Q is very preponderant in front of the HMT which remains relatively low so as not to influence the capacity of the pumping system.

To determine the pump that will be used to irrigate a rice plot, we use the Evapotranspiration (ETP) correlation with the Q and HMT parameters. Characteristics of the pump, the flow (Q) and the total head (HMT).

Very few studies have been conducted to determine a solar pump using the climatic variability of water requirements.

In this study, we will consider a centrifugal pump, powered by photovoltaic solar power and whose two characteristic parameters (Q, HMT) depend on the climatic variability of the operating site.

To do this, we will first determine the water needs of the plant Q based on the ETP parameter alone and in a second step, determine the HMT in the same way.

2. Determination of the Characteristic Parameters of a Pump

2.1. Determination of Rice Water Requirement (Q)

According to Itier Bernard and, Thiverval Grignons (2022)

[2] “To grow the plants cultivated or not - need water. In effect, to fix the carbon necessary for photosynthesis, the pores located on the surface of the leaves, called stomata, must be open. This opening of the stomata puts the constituent water of the tissues in contact with the air and causes evaporation and transpiration by the plants through these stomata. Evapotranspiration is therefore a loss of water necessary for all vegetation’’.

It is also the volume of water consumed during the entire development cycle of the plant, from irrigation to harvest. According to the document of the International Council of the French Language entitled "Vocabulary of Hydrology and Meteorology" the following definitions are accepted: [3]

Total evapotranspiration (ET) is defined as being all the phenomena of evaporation (physical processes) and transpiration (biological phenomena), similar to that considered by Jamal Elfarkh (2021) [4]. Either, the whole combination of all the processes by which soil water is transferred to the atmosphere, evaporation from water at the soil surface and water intercepted by plants plus that transpired by their aerial organs.

The term evapotranspiration is often used when it is impossible to separate evaporation from plant transpiration. This practical definition is used in many agricultural, hydrological and climatological applications.

These water needs must cover: evapotranspiration (ET), infiltration and percolation (I and P).

Lateral infiltration and vertical percolation constitute the movement of water through the soil. These two variables are also difficult to measure separately, which leads to measuring them together (IP). Therefore, the water requirements of rice are defined as being the sum of ET and IP throughout the period of its growth, following the equation described by (Brij and Early 1981). [5]

$$Bwt=ET+IP \quad (1)$$

Bwt: Water requirement of rice

ET: Total evapotranspiration

IP: Infiltration + percolation

For Haingovololona Rakotoarimanana (2021) [6] Irrigated rice requires 100 to 725 mm for land preparation and 800 to 900 mm for rice growth, giving a total of between 900 mm and 1,625 mm per campaign.

There are several formulas for determining water needs, but the following formula is one of the most shared.

The water balance equation (2) of a rice field was used to express the water requirement of irrigated (submerged) rice.

For Youssouf Dembélé, Jean Duchesne, Sibiri Ouattara, Zacharie Zida in " Evolution of the water needs of irrigated rice according to the dates of transplanting" (Burkina Faso, central region) (1999) [7] the equation (2) of the water balance of a rice field was used to express the water requirements of irrigated rice (submerged)

$$B_{WT} = ET + P_{er} + P_{sol} - P_{eff} + D_r \quad (2)$$

P_{er} : Effective rains

Perc: Percolation

Psol: Ground penetration

Dr: Drainage

The Per_ are not taken into account, it is about the irrigation except wintering

$$B_{WT} = ET + P_{er} + P_{sol} + D_r \quad (3)$$

In this equation all the components are determined singularly and the operation becomes additive.

**EXAMPLE JUSTICATION FOR SIMPLIFICATION*

The following table 1 summarizes the seasonal water balance of Pont Gendarme.

Table 1. *Seasonal water balance Gendarme bridge (see table in appendix).*

Psol	1750	
Perc	2451	
Dr	8931	
Subtotal	13132	B
ETM (Max NB: ETM (Max)(cf data analysis)*	13520	A
α= B/A	0,971	
B_{wt}=ETM +0,971 ETM	26 647,2	

NB: ETM (Max) (cf Figure 5) * (In sizing we choose the max value)

In the specific conditions above, we can reduce the whole calculation to a single variable in order to arrive at a much narrower and simply workable formulation

Thus, we can make equation (3) dependent on the single ET component by admitting that

$$P_{erc} + P_{sol} + D_r = \alpha ET \text{ avec } 0 < \alpha \leq 1 \quad (4)$$

so

$$B_{wt} = ET + \alpha\, ET = (1 + \alpha)ET \quad (5)$$

2.1.1. Notions of Evapotranspiration

Energy is the driving process of evapotranspiration. Evapotranspiration is proportional to the increase in temperature, solar radiation, wind and decreases with increasing humidity.

It can be estimated indirectly by one of several methods based on meteorological parameters. Some use equations that are based on methods such as aerodynamics or mass transfer, energy balance (Bowen's ratio method) and the combination between the two. The energy balance method is the best method in this approach Islem Hajji (2020) [8] but the latter require complex instrumentation Tala Kanso (2021) [9].

(i). Maximum Actual Evapotranspiration (ETRM)

This is the maximum amount of water that the crop is able to evapotranspiration when the soil is sufficiently moist (maximum plant transpiration plus soil evaporation).

When the soil dries out, the plant will have to "pump up" more strongly retained water (near the "withering point"), the stomata close and the actual evapotranspiration (ETR) becomes lower than the ETRM.

The measurements of the ETRM require complex tools that only a few laboratories possess. ETRM must be estimated using approximate formulas.

(ii). Estimation of Maximum Evapotranspiration (ETM)

Maximum evapotranspiration is the maximum climatic water demand of a crop without limiting factors such as water factor, parasitic factor, etc. It is defined at different stages of development of a given crop under optimal agronomic conditions Mahdi Al kaissi (2000) [10] That is to say without disease and without water or nutritional stress. The principle of the FAO-56 method for estimating the ETM is based on the multiplication of a coefficient specific to each crop (Kc) the potential evapotranspiration where the effects of the different meteorological conditions are included. In effect, ETM is linked to ETP via a cultural coefficient which takes into account the physical and physiological difference between the reference surface and the given crop (Er-raki., 2007) [11]. The formula for calculating ETM is as follows:

$$ETM = kc * ETP \quad (6)$$

ETM: Maximum evapotranspiration
kc: Crop coefficient related to each plant species
ETP: Reference evapotranspiration

(iii). Procedure for Determining the Crop Coefficient

The crop coefficient (Kc) is the ratio between maximum evapotranspiration and potential evapotranspiration. Its value is largely affected by the nature of the crop, its height, the length of its cycle, and its growth rate. The frequency of rainfall or irrigation at the start of the crop cycle also affects Kc. It is therefore always established experimentally at the beginning, for a given region and culture, and then confined in tables for later use in the same region or in a similar region. Depending on the method used to calculate the ETM or depending on the amplitude of the differences between the culture and that of the reference, the Kc obtained experimentally may slightly exceed the value of 1 (Dorian H., 2003; Simonneaux, al., 2007). [12]

The figure 1 relating to the crop cycle shows four growth phases:

1) The initial phase which extends from sowing to around 10% soil cover;
2) The plant cover development phase ending when the ground cover is complete;
3) The mid-season, which ends with the onset of fall or senescence of the leaf cover;
4) The late season or maturation phase.

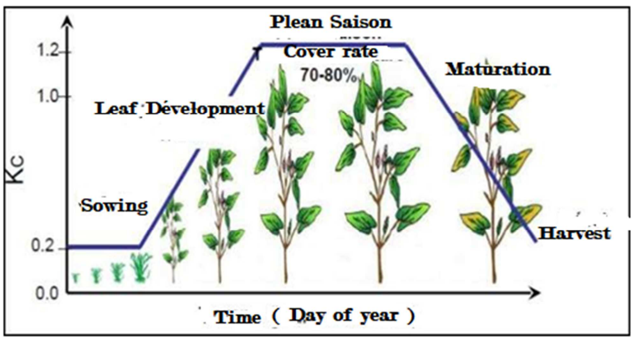


Figure 1. *Development cycle of a culture (In, Er-Raki., S, 2007) [11].*

In this approach, the effect of plant transpiration and soil evaporation is confined to a single coefficient.

The calculation of the maximum evapotranspiration goes through four stages (Matteo Rolle, Stefania Tamea and Pierluigi Claps 2022) [13]:

1 Identify the growth phases of the crop and the corresponding durations, and select the corresponding crop coefficients;
2 Adjust crop coefficients for climatic conditions during the same growth phases (Allen et al. 1998): [14]
3 Build the crop coefficient curve, Kc;
4 Calculate ETM as a product of: ETP * Kc.

2.1.2. Energy Balance and Micro Climatological Methods

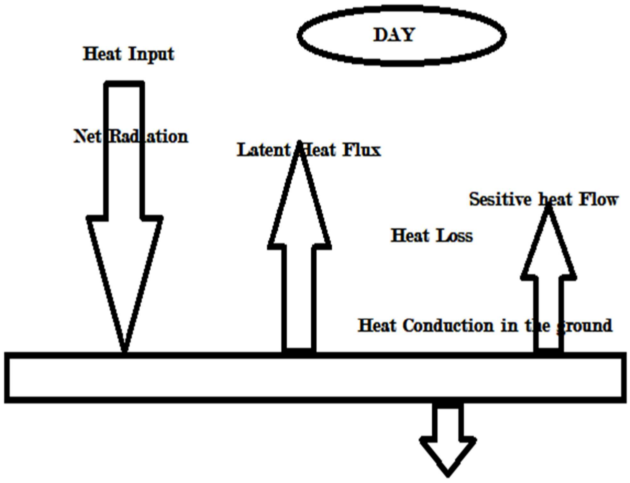


Figure 2. *Energy balance of a surface.*

On a given surface, evaporation and transpiration are governed by a process of energy exchanges between the ambient environment and the plant-hydric surface and between this surface and the subsoil. By applying the principle of conservation of energy, the energy balance translates into incoming energy equal outgoing energy.

The equation of an evaporating surface can be written as follows:

$$R_n - G - H - \lambda ET = 0 \quad (7)$$

With:

1 R_n: $net\ radiation\ (radiative\ term)$
2 G: The heat flux on the ground (conductive term)
3 H: Sensible heat (convective term)
4 λET: Sensible heat (convective term)

The different terms can be positive or negative (day or night)

The energy stored or dissipated in the plant, the energy generated by the metabolism and all other exchanges by horizontal advection are not considered in this analysis because they are negligible d=compared to the vertical exchanges. In its conditions, this equation is only valid when it comes to the irrigation of large areas.

(λET) latent heat is the evapotranspiration part of the energy balance is calculated from the knowledge of the climatic parameters (Rn and G measured or estimated) and the sensible heat H obtained thanks to the heat exchanges between the surface and the ambient environment.

2.1.3. Formulation of the Penman-Monteith Equation

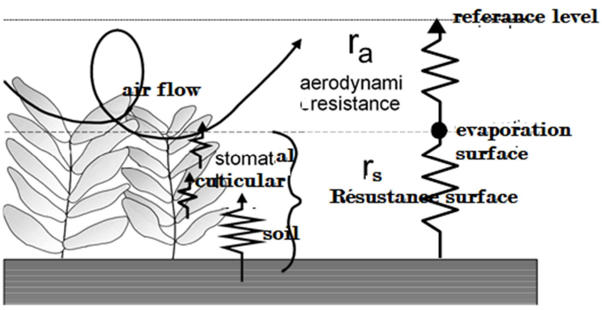


Figure 3. *Representation of aerodynamic and surface heat resistance in the ground.*

Surface resistance, rs, describes the resistance to vapor flow through stomatal openings, total leaf area, and soil surface. Aerodynamic resistance, ra, describes the upward resistance of vegetation and involves the friction of air flowing over vegetative surfaces.

On the following sketch, we can observe the behavior of solar radiation on a plant surface.

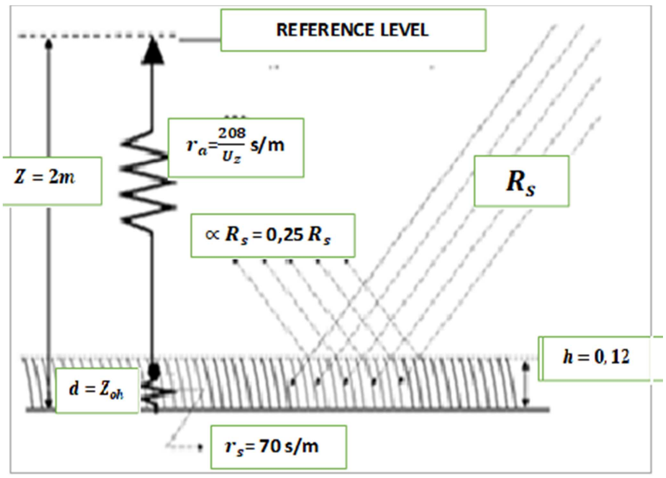


Figure 4. *Representation of incident solar radiation and resistances ra and rs.*

Among the main methods for estimating evapotranspiration, we will focus on the analytical approach of Penman-Monteith, which has proven to be the most accurate.

2.1.4. Analytical Approach

(i). Penman-Monteith Model

Penman's model (1948) modified by Monteith (1965) [15] is written

$$\lambda ET = \frac{\Delta(R_n - G) + \frac{\rho\, Cp(e_{sat}(T_a) - e_a)}{r_a}}{\Delta + \gamma\,(1 + \frac{r_s}{r_a})} \tag{8}$$

With: Δ, ratio between the saturation vapor pressure difference and the corresponding temperature difference (Pa/°K)

D, vapor pressure deficit (Pa). D = (es - ea) γ, psychrometric constant (γ ~ 66 Pa/°K) ra, aerodynamic resistance (s/m) rs, stomatal resistance (s/m)

Rn, the net radiation at the ground surface ($MJ/m^2/h$)

G, the ground heat flux ($MJ/m^2/h$)

The resistance rs is the resistance that the plant cover opposes to the diffusion of water vapor towards the atmosphere and is linked to both crop parameters and environmental parameters (radiation, vapor pressure deficit, etc.).) (Thom, 1975; Howell & Evett, 2004). [16]

(ii). FAO Penman-Monteith Equation

For FAO Allen et al. (1998) [14] made a simplification to the Penman-Monteith equation by making a number of assumptions about parameters which they considered constant and resulted in the most consensual and complete formulation of evapotranspiration and it is written.

Thus, they assumed constant, λ the latent heat flux of vaporization. They fixed the resistance of the vegetation cover rc at a value of 70 s/m and simplified the expression of the aerodynamic resistance by approximating it by an inverse function of the wind speed (ra = 208/u) (Howell & Evett, 2004). [16]

$$ETP_o = \frac{0{,}408 * \Delta.(R_n - G) + \gamma \frac{90}{Tmoy} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0{,}3 * U_2)} \tag{9}$$

With:

ETo, reference evapotranspiration (mm/d) T, air temperature (°C)

U2, wind speed at 2 m above the ground (m/s)

Δ, ratio between the vapor pressure difference and the corresponding temperature difference (kPa/°C)

γ, psychrometric constant (γ ~ 66 Pa/°K) Rn, the net radiation at the ground surface ($MJ/m^2/d$)

G, the ground heat flux ($MJ/m^2/d$)

e_a vapor pressure (kPa)

e_s saturation vapor pressure at the reference temperature To (kPa)

The FAO Penman-Monteith formula gives the evapotranspiration of a grassy surface, well watered, with a height of 0.12 m, a surface resistance of 70 s/m and an albedo of 0.23 (Allen, 2000). [17]

HYPOTHESES

To size a pumping system, we consider the maximum needs.

$$\text{Et } \alpha = 1$$

$$B_{eau} = 2 * ETP_{max} \tag{10}$$

$$B_{eau} = 2 * K_c * ETP_o \tag{11}$$

K_c : crop coefficent vegetative stage

ETPo: reference evapotranspiration

$$Q = B_{eau} = 2 * K_c * ETP_o \tag{12}$$

Table 2. *FAO crop coefficients of irrigated rice in Burkina.*

GROWTH STAGES	Kc FAO
Vegetative	1,10
Reproductive	1,10
Maturation	0,25

Si Kc= 1,10 for the rice (FAO)

Step daily G=0

$$Q = B_{wt} = \frac{0{,}8976\ \Delta.R_n + \gamma\frac{198}{Tmoy}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0{,}3 * U_2)}\ \text{(mm/j)} \quad (13)$$

With:

ETo, reference evapotranspiration (mm/d)

T, air temperature (°C)

U2, wind speed at 2 m above the ground (m/s)

Δ, ratio between the vapor pressure difference and the corresponding temperature difference (kPa/°C)

γ, psychrometric constant (γ ~ 66 Pa/°K) Rn, the net radiation at the ground surface (MJ/m^2/d)

e_a vapor pressure (kPa)

e_s saturation vapor pressure at the reference temperature To (kPa)

2.2. HMT Modeling

According to Bernoulli's theorem the HMT (total head), [18]

$$\text{HMT} = \text{Hgeo} + \Delta\text{H} \quad (14)$$

Hgeo Geometric height

$$\Delta\text{H} = \Delta H_r + \text{s}\ \Delta H_s \text{ Pressure drops} \quad (15)$$

HYPOTHESES

The subject deals with surface pumping by centrifugal pump (The geometric height is low: Hgeo negligible).

In the case of pumping stations for rice irrigation, the suction and discharge length is very short, because the water, once sucked up, is discharged into a main channel: The regular pressure drops are low compared to the singular ones.

Taking these considerations into account, the HMT can be written in the form: [18]

$$\Delta H_s = \sum K_i\ Q^2 \text{ Singular head losses} \quad (16)$$

They are caused by meters, valves, elbows, tees, check valves, strainers, section changes, etc.

They are also a function of the flow and the diameter of the pipe, but above all of the degree of deformation of the section due to the singularity: degree of opening of the valve, curvature of the elbow, etc.

$$\text{HMT} = \Delta H_s \quad (17)$$

Singular head losses are essentially due to pipeline accidents, that to say any modification of a straight path.

In all the cases below, it results from the passage of the liquid at the singular point a loss

$$\Delta H_s = K\frac{V^2}{2g} \text{ avec K} = \sum K_i \quad (18)$$

Per unit area (V=Q) so $\Delta H = K * \frac{Q^2}{2g}$ (19)

Hypotheses Kmax = 1 with 2 singularities from upstream to downstream of 45° curvature then HMT becomes:

$$HMT = \Delta H = \frac{Q^2}{g} \quad (20)$$

3. Conclusion

At the end of this study we have shown that the two characteristic parameters of a pump used in irrigation of large areas depend on a single variable: the pumping flow rate Q. This pumping rate Q depends more on the weather conditions of the operating site than on the nature or type of the plant.

This climatic variability of water requirements is justified if the operation is carried out on a large scale, otherwise on small plots, from one site to another the climatic conditions have little influence on the variation in water requirements.

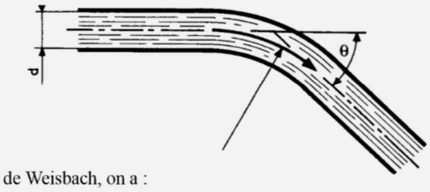
Appendix

Table 3. *Station of Pont Gendarme.*

OiS	Pompe 1		Pompe 2		Pompe 3		Volume Total m
	Heure	m‘	Heure	m’	Heure	mJ	
Juillet	101	75 634	177	78 744	181	80 523	234 901
Aout	336	251 615	454	201 975	434	193 078	646 669
Septembre	222	166 245	355	157 933	292	129 904	454 082
Octobre	409	306 282	374	166 385	217	96 539	569 206
Novembre	241	180 474	75	33 366	291	129 461	343 301
TOTAL	1309	980 250	1435	638 403	1415	629 502	2 248 158
Debit (1/s)	208		124		124		455
	Volume en m'/ha						
Volume prélevé	9 676						
Pluies Efficaces	2 998						
Volume total	12 674						

Table 4. *Singular head loss.*

θ° \ $\frac{r}{d}$	1	1.5	2	2.5
11° 25	0.037	0.021	0.018	0.017
22° 5	0.074	0.043	0.036	0.034
30°	0.098	0.057	0.048	0.046
45°	0.147	0.085	0.073	0.069
90°	0.294	0.170	0.145	0.138
180°	0.588	0.341	0.291	0.275



k : voir ci-après ; $\Delta h = k \dfrac{V^2}{2g}$

k est donné par le tableau suivant, en fonction de

r = rayon de courbure du coude en mètres ;

d = diamètre intérieur du tuyau en mètres ;

θ = déviation en degrés.

d'après la formule de Weisbach, on a :

$$k = \left[0{,}131 + 1{,}847 \left(\frac{d}{2r}\right)^{3{,}5}\right] \frac{\theta}{90}$$

Table 5. *Seasonal water balance (according to SAED technical bulletins N° 6811 st SAED April 1999) (Village of PONT GENDARME).*

		WINTERING	
		DELTA	
		INTERMEDIARE ARRANGEMENT	
	PERIMETER	*PONT GENDARME*	*PONT GENDARME*
	Campaign	HIV 90/91	HIV 91/92
	Area (ha)	19	155
	Irrigation	18648	19707
VOLUME BROUGHT (m^3/Ha)	*Effective rainfall*	1112	1827
	Sum	17760	21534
	Imbibition	1750	1750
	ET Rice	8301	8401
	percolating	2200	2451
VOLUME USED (m^3/Ha)	*Oil changes*	1800	
	Water needs at the plot	14061	12602
	(Oil changes) and loss	3709	8931
	Sum	15960	21533
	Field application efficiency	56	61
IN%	*Distribution efficiency*	78	56
	Total efficiency	43	33

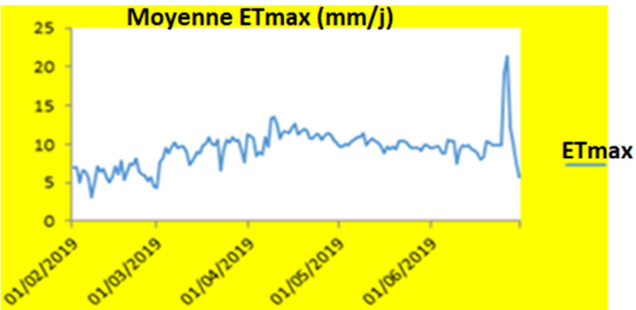


Figure 5. *Courbe de l'évapotranspiration année 2019 (Station Africa Rice Ndiaye).*

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