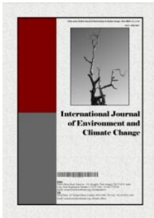

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Review on Dew Process and Its Contribution in Maize Water Requirement at Nalohou (Northern Benin)

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Authors' contributions

This work was carried out in collaboration among all authors. Author BBK managed the work. Author ORY wrote the paper and performed the statistical analysis. Author GKN helped author ORY during the work, corrected the paper and guided as and when required. All authors read and approved the final manuscript.

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ABSTRACT

Climate change is a scientific issue of global interest and Africa is one of the most vulnerable regions in the world strongly affected by its consequences in water resources for agriculture. Adaptation to climate change is one of the fundamental measures for human beings. Therefore, extensive researches on dew process have been carried out worldwide. Based on articles and relevant documents on the subject, this paper reviews the latest researches achievement in several domains of science, including measurements technics and dew possible contribution in plants water requirement satisfaction. A case study in Benin climate (West Africa) compares the probable amount of dew that can be harvested by maize canopy as water during the main stages of its growth cycle. Evaluation of dew amount and maize water requirements are done using the Penman-Monteith equation. The theoretical results show that dew can contribute for about 9 to 10% in the IZEE-W-SR-(ODE-TUWE) corn variety's water requirements. So, future researches on dew can be performed in arid and semi-arid areas as alternative water for agriculture.

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Keywords: Dew history; condensers; water requirements; growth cycle; adaptation.

1. INTRODUCTION

Climate change is a research issue of global interest. The consequences of climate change affect human being in several domains. For examples one can cite water required resources for electrical turbine (energy sector) and agriculture production [1]. These sectors are sensitive for human being [2]. Africa in general and West Africa in particular is one of the most vulnerable regions in the world affected by climate effects [2,3].

Agriculture is a vital sector where almost populations, for the most part, derive their economic and food incomes [4]. Population growths added to the consequences of climate change are factors that must be taken into account when seeking durable solutions for human well-being. Indeed, the world's population is projected to increase from 7.6 billion currently to 9.8 billion by 2050 [5]. From 2050, world's population will increase by 30 million a year and concerns almost entirely the developing countries. This rapid population growth combined to land degradation and the reduction of arable land will be a serious threat to food security [6]. Maize is one of the crops for people in some developing countries as Benin, in West Africa. It plays an important role in Benin's economy. The threats that maize faces are a handicap to increase its yield, especially during years of long drought in semi-arid environments of the country. It is therefore necessary to develop strategies in the current climate contexts to handle the consequences of climate effects. Water control is important for the development of crops in arid or semi-arid lands. Dew is a kind of precipitation, which is not usually explicitly considered in the study of soil moisture [7] so; its quantity does not exceed 0.3 to 0. 5 mm per night on the plant cover. In many parts of the world, dew contributes to a small percentage of annual precipitation. For example, in the southwestern desert areas of Israel, in the northern part of Benin Republic [8,9]. But its presence is recognized as very important for ecosystems since a long [10,11,12,13,14]. Dew process is frequently observed on cold surfaces of certain crops including corn [9]. This water has been shown to be useful for plants and insects in arid and semi-arid areas [12,15,16]. Dew collection is a technique developed by researchers in arid and semi-arid environments using several technics, progressively improved for collecting dew as water for population [9,16,17,18,19,20, 21,22,23].

In desert areas, the presence of water governs the survival of plants and animals [24]. The main benefits of dew are that, it can improve the amount of plant's water requirement by reducing significantly the transpiration of stressed plants and limit their water loss [9,25,26]. For example, Subramaniam et al., (1983) has shown that dew can contribute for about 37% in current rainfall in India. Between 1975 and 1976, dew represents about 37% of the actual seasonal rainfall, and 27% of the usual seasonal rainfall in India. This corresponded to nearly 14% of actual potential evapotranspiration and 18% of the normal potential evapotranspiration [27]. Tuller et al., (1973) found that dew amount can count for 12-14% of monthly precipitation in the country. It can reach up to 15.4% of precipitation in dry periods. In Benin, dew can contribute to maize water requirement during fifteen days of the ripening phase in Nalohou for 43% in this period of its growth cycle [9]. Recently, a survey has been carried out in Guéné (semi-arid region, north Benin) to understand a sociological perception of dew, as alternate source of water for cereal's growers [23]. Growers are said to possess a traditional knowledge in dew water management to produce several varieties of cereals every year (maize, sorghum and millet). The results show that farmer's perception of dew mirrors the scientific literature, though their perceptions are based on practical experiences [23].

The main objective of the current article is to make a review on dew phenomenon: (i) bring a brief scientific history of dew worldwide till now, (ii) repertory diverse dew measurement technics and (iii) assess dew contribution in the satisfaction of maize water requirement in Nalohou a typical site threatened by climate during each phase of its growth cycle.

2. CONDITION OF DEW OCCURRENCE

The amount of dew is an explicit function of certain quantities which variation depends on climatic data. At night and early in the morning, the air is humid and relatively (weak speed). The maximum relative humidity can, on average, reach 100%. The difference between the dewpoint and the air temperature is minimal and varies between 2°C and 3°C during the night, in accordance with the thermal conditions between the dewpoint and the ambient temperature (deviation < 5°C), indicated by [28] for a possibility of condensation. If the air is humid, these ambient conditions are favorable for the formation of dew on an ideal surface, as the canopy, capable to cool deeply if the atmosphere is clear. On the other hand, the daytime temperatures are around 32°C on average, the air is less humid and dewpoint can never be reached. The canopy surfaces can therefore collect dew only during nights with favorable weather conditions for radiative cooling.

As shown by [29,30] in the tropical regions of West Africa in general and confirmed by [19] more specifically in Sudanian environment in Kandi and in Parakou, the average difference between the air temperature and the dew point temperature is maximum at the beginning of the night. The vegetation is warm at the beginning of the night. During the night, the difference temperature between dew point and air temperature is about 3.5°C to 10:PM and only about 1.5°C around 6:AM.

3. SCIENTIFIC HISTORY OF DEW

Dew is a natural phenomenon in which water vapor condenses on various type of surfaces, such as grass, crops, roofs or vehicles [31,32]. Dew occurs at night or early in the morning, when nocturnal radiative cooling leads to surface temperature decrease, and humid air nearby the surface condenses as its temperature falls down below the dew point of the surrounding air [16, 33].

3.1 Beginning of Dew Studies

Dew formation has been the focal point of various scientific researches during many years [15,20,24,34,35,36,37,38]. Charles Le Roi is the first in 1751, who set up the basis of scientific theory about dew process (Charles Le Roy (1726-1779). In: ''Revue d'histoire des sciences et de leurs applications', 1953, Tome 6 n1. pp. 50-59). The author has described dew phenomenon by drawing a parallel between the saturation of water contained in a vase when one dissolves sugar into it, to the way that water exposed to air, vanishes into air until a limit of saturation is reached [38]. Early in the 18^{th}, he explained that, the more air is dry and hot, the more it can absorb water vapor. In consequence, Le Roi has established inversely that, when water (containing the dissolved sugar) is boiling, it evaporates and becomes solid because of the dissolved sugar. Comparetively, when humid air is getting cold, the contained water becomes liquid as soon as a lower temperature is reached. Later, in the 19th, Wells pursue these researches and deeply explained dew occurrence on surfaces by introducing the concept of ''radiative cooling" between the sky and every corps on soil [37]. This definition is used till now in the characterization of dew process [39].

Scientific interest in dew had also an equally long history as it's mentioned in certain passages of the bible: dew is associated to esoteric and spiritual knowledge (2 Samuel 17:12; Psalms 110:3), it's a precious and life supporting phenomenon source of great fertility (Genesis 27:28), a symbol of wealth an emblem of brotherly love and harmony (Psalms 133:3), rich of spiritual blessings (Hosea 14:5). In Judaism, blessings are offered to rain and dew in daily prayer, and there are many other references to dew throughout the Old Testament, books of Genesis and Isaiah. The collection of dew is done with systems known as dew condensers. Several devices are made to collect dew with. Earlier condensers are known as massive condensers. Several testimony believe in the existence of atmospheric condensers in ex-URSS (sort of embankment for building), in England (dew pond), in Canary island (conical condensers for wine plants). Since the 20th century, F. Zibold discovered in Crimee (Ukraine) massif dew condensers of ≈ 600 m^3 that he thougth may be able to condense huge amount of dew serve as clean water to the population of the ancient Feodesia. The discovery inspired L. Chaptal to build a sort of pyramid as dew condenser in 1929 to collect dew with [33]. He collected ≈ 100 Litters of dew during six months. Also, Knapen made a massif aerial condenser in provence which hadn't succed as well as he thought. Figs. 1-3 presents, the picture of both, Zibold, Chaptal and Knapen's massive condensers [40,41]. All these condensers end in failure because of their huge mass and the working layer of the stones that were used to build the condensers [18]. These experiments turned out to be inconclusive and led to perform new generation of dew condensers gradually performed.

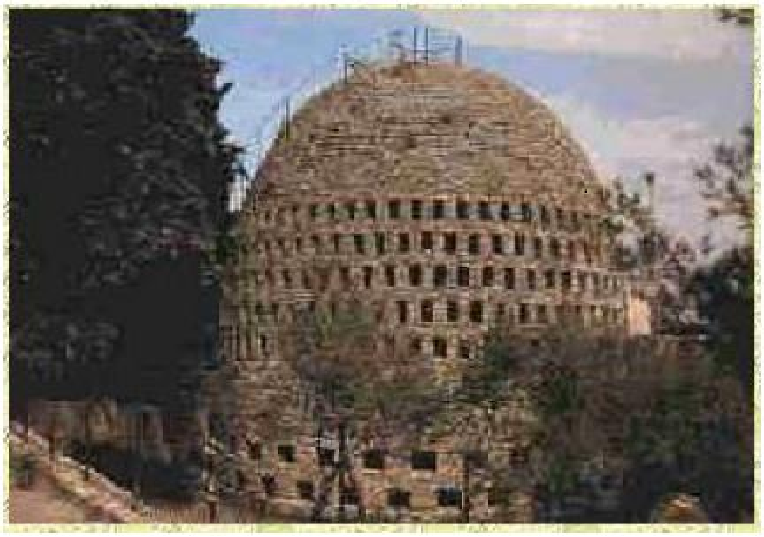

Fig. 1. Sight sud/est of the "bell" of the air well with its 5 line of partly high ventilation

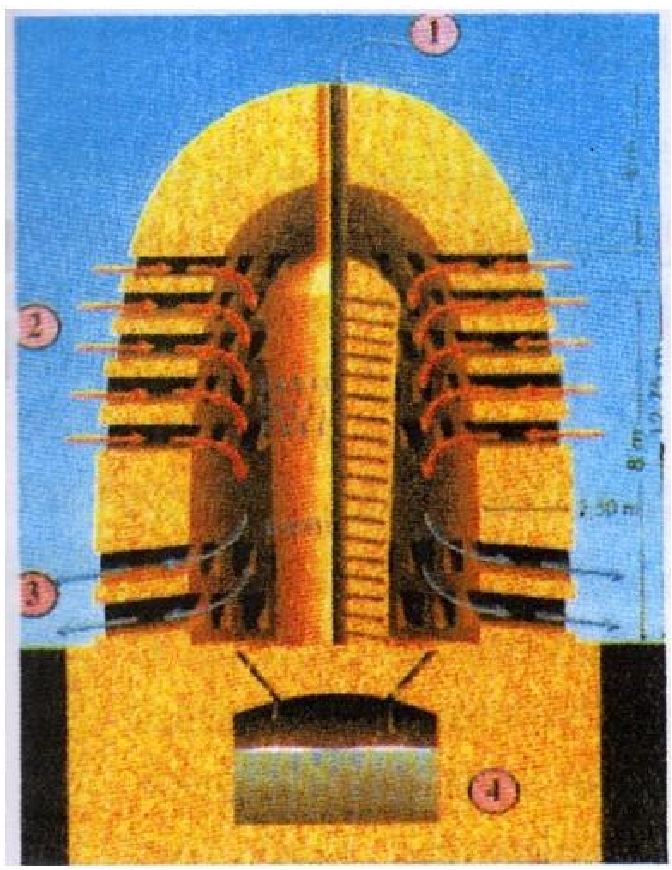

Fig. 2. Diagrammatic cut of the air well (1) top of the bell with the metal pipe which takes the air outside (2). Five lines of higher openings (3) Two lines of lower openings (4) Sat work and bulk storage tank of water. Document extracted the booklet of the Tourist office the Trans one in Provence

Fig. 3. Model of the condenser produced by F Zibold in Feodosia (Ukraine) Photo D. Vinçon

Fig. 4. State of the air well carried out by F Zibold in Féodosia

The agro-meteorologists were interested in dew formation and its nature [42,43,44]. Some investigate dew on the banana plantations [45]. Other studied dew like acid pollutant on the environment [46,47]. Wells made experiments which presented the conditions of formation and quantification of dew leading to the single formula connecting the quantity of dew in a point to extend from the visible sky of this point [35]. According to the tradition Judeo-Christian, dew is source of plants' life in arid areas. It is regarded as a phenomenon invaluable and alive [48], a source of great fertility (Genesis 27:28, Deutéronome 33:13), a symbol of richness (Zacharie 8:12; 2 Samuel 17:12), emblem (brotherly love and the harmony) (Psalms 110:3; Psalms 133:3), and of rich spiritual blessings (Dared 14:5).

3.2 Recent Studies on Dew

Since the ninety's 90s, the International Organization for Dew Utilization (Opur) is working on effective foil-based condensers to collect dew with in regions where rain or fog cannot cover water requirements. New technics of dew collection are build and experiments on dew were carried out. Figs. 5 and 6 present new divices of dew collection.

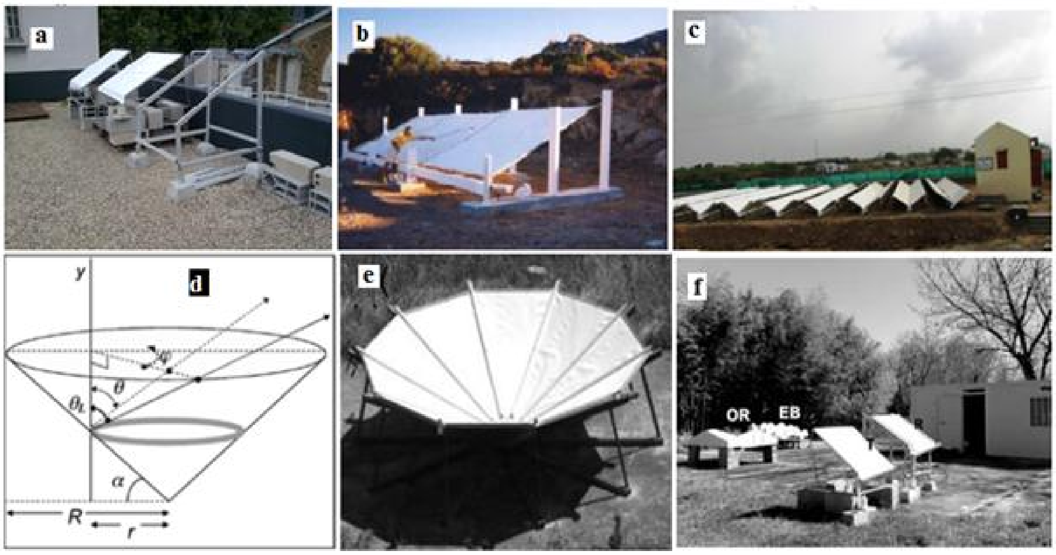

Fig. 5. (a) Installation of the planar condensers; (b) Vignola dew condenser; (c) Fully finished dew plant;(d) Integration scheme for the funnel shape (0<θ <θL , 0<φ <360 and 0 < r < R);(e) Photo of the funnel-shaped condenser (7.3 m surface area with 60 ° cone angle, 30 ° from horizontal); (f) "Egg Box" (EB) and "Origami" (OR) type condensers with the planar reference condenser (R). (T is an additional planar condenser)

Fig. 6. (a) CRSQ – 0.25 ; (b) CRQ – 0.30 tilted by 15°; (c) CRQ – 1 tilted by 30°; (d) CRQ – 30 tilted by 30° [49]

Researchers of OPUR concluded that ancient types of condensers were not optimal for condensation. They develop new structure with new radiative materials (foil) to enhance dew yield on condensers. Several models exist: the model CRSQ and CRQ with different surfaces and various angles of inclination [49] are presented (Figs. 5 and 6).

Fang and al (2013) review dew effects in several domain of research such as eco-hydrology, water and plants growth, survival of small animals, microbiotic crusts, soil moisture balance, ground water recharge and anthropogenic utilization. The author concluded by summarizing three main reasons that may cause diverse opinions about the role of dew water for plants: (i) their perception are opposite because studies are not conducted in the same climate, (ii) the diversity and accuracy of the methods used by authors to evaluate dew amount lead to different conclusions and, (iii) different objectives leads to different conclusions. The authors propose suggestions such as estimation of regional ecological water requirements as a valid water source for future research on dew [24].

Natural condensers are systems found in nature. Plants in general constitute natural condensers by excellence. Observations show that in the early morning, dew settles on their leaf surfaces. Laurent Jauze (2003) has shown in his article entitled: "Fog water: an alternative resource for the highlands of Reunion Island ", the importance of condensation water directly mobilized by plants [50]. The author relates the particularity of certain plants to mobilize suspended water into the atmosphere as fog or mist. These are plants with natural properties favorable to the capture of atmospheric humidity [50]. OPUR, in its article entitled: "but where does the dew come from?" reports the existence in Namibia of meadow grass [39]. It’s a drought tolerant herb at dew, it develops during the dry season in an arid environment and constitutes a food fundamental for herbivores during pastures [39]. In the Canary Islands, in the region from Lanzarote, the vine grows thanks to the collection of atmospheric humidity [29]. Of holes in the shape of inverted cones are dug in the ground to facilitate the trapping of humid air and the condensation of moisture on the lateral face of these holes as on the foliage of vines. It is in their cavity (bottom of the cones) that the vines grow which benefit from favorable conditions for moisture retention thus created. Experiments are conducted for optimizing the amounts of dew directly used by plants. It is easily emissive plastic materials placed along the ridges to collect dew. Numerous trees, in high-altitude regions favorable to fog, constitute also natural condensers. For example, the cypress (Cupressus sempervirens) allows, in the port region of Taiwan, the collection of fog that it accumulates from of its leaves [51]. In Benin, in the Allada region, the pineapple (ananas comosus) constitutes an efficient natural condenser [19]. The whole formed by its foliage resembles a cone truncated permanently open to the atmosphere. This set allows the plant to trap humidity for a long time. The authors assume that the dew contributes significantly to the compensation of the plant transpiration [51,52]. Some nights, under clear sky, the dew would be more precious.

The gap between day and night temperatures in hot and dry climates is very important and the flat radiator cannot condense naturally the atmospheric humidity [19]. The radiator which can be used must maintain a cold calm air over it. The shape of the system adopted and built by Kounouhewa et al (1999) is a truncated cone condenser. It is a structure in the form of inverted cones with symmetry of revolution, capable of canceling the direction of the wind nearby and especially to limit free convection by stagnation of cold and dense air towards its bottom [29,30]. It constituted a radiator combined to two plates having different orientations of 60°, 65° and 70° respectively, with regards to the zenith direction. Later in 2012, Koto n’gobi (2012) experimented, a truncated cone condenser to collect dew water and water corn plants under water stress. The prototype of truncated cone condenser tested by Koto n’gobi (2012) is shown in the Figs. 7 and 8.

The authors have noticed that the power exchanged in this direction giving these angles is maximum. They also listed the advantages of the shape of condensers: (1) It occult a part of the celestial vault mainly in the horizontal direction where the clear sky emissivity tends to one (2) The external plate has to keep the air calm on the system. So, on it the convection exchanges are forced convection with a light speed of the air. It has the property to cool the air a little, to reduce its motion and to change forced convection to a natural convection. (3) On the internal plate the convection exchanges become natural and the air which is cooled a little by the external plate slides around it and becomes colder. Its temperature is near the dewpoint temperature. When touching the condenser a part of the humidity of this air is condensed.

For plants, Delgado-Baquerizo et al., 2013 found that biological soil crusts (BSCs) can retain and use water from dew to increase the concentration of dissolved organic nitrogen (N) associated with the fixation of atmospheric N 2 by BSC-forming cyanobacteria and cyanolichens. Diverse view points are discussed in literature about dew effect for plants and vegetables prolonging life seedlings under simulated drought stress conditions and other domains [24]. Scientists have also discussed about the efficiency of the adopted technology for dew collection. For example one can cite Trahtman et al., 2003 who has announced a doubtful yield of thousands of liters that may be generated in Feodosia by Zibold passive dew condenser to produce water from dew [53]. Beysens et al. 2006 largely

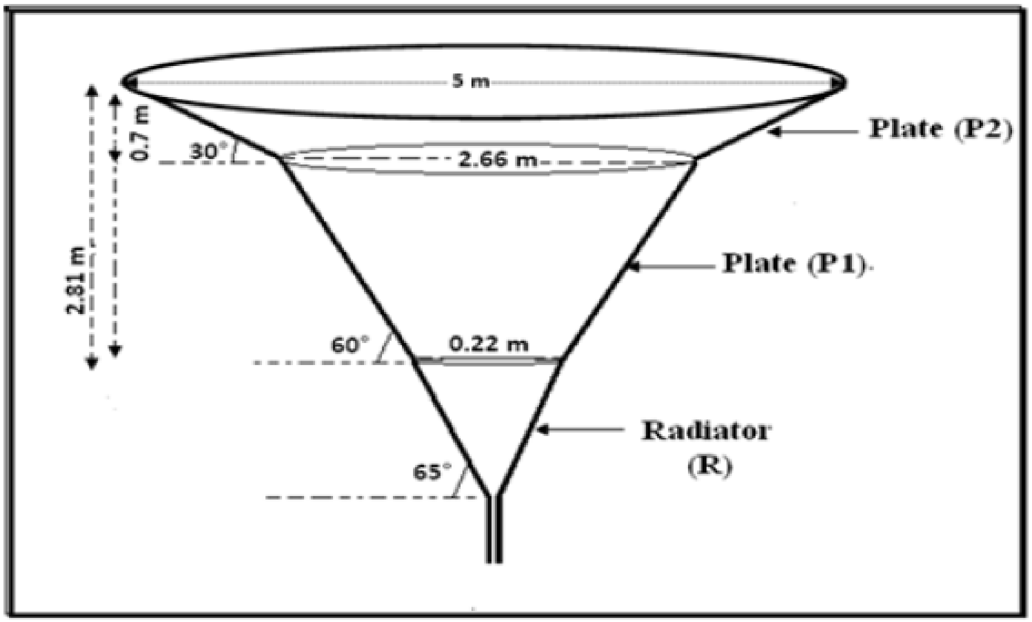

Fig. 7. The prototype of the experimental truncated cone condenser (Koto n'gobi, 2012)

commented and contested that after an international expedition in Feodosia [20]. A lot of literatures approve that, even though dew amount is small, it can be beneficial to human [17,18,21,54]. Dew water can be used as fresh water [55] and can give additional water to plants and desert animals, not only in arid and semi-arid areas [13,14,15,56,57,58,59], but also in humid regions where drought can occur for more than weeks or months during the dry seasons. Nilsson (1994) developed polyethylene pigment foils for radiative cooling. It has optimized the optical properties of the foils for condensation applications through radiative cooling. A study of foils dispersion using the convection law is made to show that reflexivity and transmittance are high for this type of foils in the infrared atmospheric window. Of all the foils used as a pigment, he found that only ZnS prevents heating of the underlying black body at noon. But the combination of TiO_2 and $BaSO_4$ gives an encouraging result. He also described dew-field trials (in Sweden and in arid Dodoma, Tanzania) in areas where collection is very difficult [60]. He provided a brief summary of the thermodynamics of the condensation process. He also showed that the condensation yield in hot and arid places is related to climatic factors, dew-collector design, and optically selective and adhesive properties of the condensing surface. Awanou et al., established a model for estimating dew from the analogy between the first law of Fick (particle distribution law) and the Fourier law for heat flows and defined the geometry of the condenser for efficient applications in hot and humid climates. The authors have demonstrated that for different geometries (vertical planes, folded planes) the energy exchanges between the condenser and the celestial vault take place, only with about half of the celestial vault, the other half being occulted limiting their efficiency. They conclude that it is necessary to choose an adequate geometry and the radiative properties (of the material) which make it possible to reduce the convective exchanges to the neighborhoods of the system, to lower its temperature and to increase the yields: these are the troncated cone geometry condensers that take into account all the constraints listed above (occulting a part of the celestial vault mainly in the horizontal direction; external plate has to keep the air calm on the system; internal plate make the convection exchanges become natural and Its temperature is near the dewpoint temperature). The condensed atmospheric moisture mass is deduced from the flow of condensing molecules. Kounouhewa et al. (1999) studied two methods for estimating the amount of dew: The method using the radiative properties of the Earth's vault and the method based on Fick diffusion law. He calculated the amount of atmospheric moisture condensed from a layer of air at a certain thickness depending on the type of climate and compared both methods. The results provided a gap of 4% and, the first method is suitable for hot and humid climates, but this is the second method that adheres to heat and dry climate. [61] has developed a set of tools and methods (simulation and modeling) for the experimentation of operational condensers of large areas (roofs, dew plant). They carried out dew measurements for six months in French Polynesia, on the islands of Tahiti and Tikehau (in a humid tropical climate), in Croatia on the island of Bisevo (in the Adriatic Sea) where they erected a demonstration roof, then in India (in the state of Gujarat) where they contributed to the creation of a dew plant with about 850 m 2 of area [61]. The plant would produce up to 300 L of dew per night. Water producted allows the populations of the quoted zones to be supplied daily because this water is recognized as good quality according to WHO standards (World Organization Health). Lekouch (2010) in his thesis has developed an experimental dew collecting protocol consisting of an inclined plane radiative condenser of about 30° of 1 m^2 made from material paint in material made with titanium oxide microbeads and of barium sulphate. The experiment is carried out at Mirleft for one year on the southern coast of Morocco followed by the quantitative analysis of dew. He has also developed dew prediction models for different types of sites using meteorological data (ambient temperature, relative humidity, wind speed and cloudiness). He used dew model to estimate dew in fifteen sites across Morocco. Then, he checked the conformity of the physical and chemical properties with the standard norms of WHO then the bacteriology of dew and rain. The author has reported the presence of harmless bacteria that could be treated by the usual disinfectants. It shows that the amount of water collected by condenser's represents about 40% of the water depths that fell as rain. The collected water is used by people for drinking purposes, after treatment. Beysens et al (2010) showed that the concentrations of major dew and water ions collected at two sites (Zadar and Komiza) for three years respects the standards recommended by WHO. Dew collected represents about 38% of the precipitation during the measurement period. [9] evaluated the amount of condensable atmospheric humidity (dew) on a vegetative cover consisting of the maize crop considered under water stress. The study was conducted over an area of one hectare during the last fifteen (15) days of its ripening phase. He showed that dew obtained could contribute to satisfying about 43% of the water requierement in the period of its developpement cycle. Direct collections of atmospheric humidity were carried out using an improved condenser system (troncated cone) implanted in the same climatic zone.

Fig. 8. System used for measurements in real environment (Koto n'gobi, 2012)

Médéhouénou et al. (2017, 2018) studied the mechanism of mobilization of atmospheric moisture by plants through their aerial root. The author first showed that the current trend of atmospheric humidity variation in Benin will remain unchanged for the RCP4.5 and RCP8.5 scenarios and will therefore available. Then, he studied the influence of the parameters (coefficient of diffusion of water vapor, duration of the exposure of the velamen to the humidity, the thickness of the velamen, the thickness of the boundary layer, and the temperature of the air surrounding the roots) on the adsorption, entry and migration of water molecules in the velamen [62,63]. He comes to the conclusion that:

- ✓ The absorption depends on the radial and axial conductivity coefficients of the xylem, the type of light radiation responsible for photosynthesis, the angle of inclination of the roots, the length of the roots. Thus, the blue radiation and the angle of inclination of 60° favor the crossing of the xylem by water;
- ✓ Under a water potential gradient, the water mobilized by the velamen migrates into the xylem and reaches the leaves;
- ✓ The low temperature and a great thickness of velamen optimize the mobilization of atmospheric moisture.

These authors show that dew is a significant resource. Compared to rainfall, its contribution to annual water balances is major. Despite some impurities and contaminations, dew has therefore proven to be a potential drinking water. The atmospheric moisture condensed in the growth of the plant has been proved by several authors. The process of dew includes three phases: the equilibrium cycle between water vapor and liquid water called phase of transition, the phase of formation of dew is called the nucleation of the liquid and the increase phase known as coalescence phase [28,48,64,65]. Each of these three phases is subject to mechanisms that can be improved to optimize the dew process. For example Pierre-Brice Bintein et al. (2019) have shown that the coalescence mechanism makes it possible to reduce dew retention by modifying the distribution of the liquid (coalescence) and therefore accelerates dew rejection significantly on a properly grooved inclined surface [66].

4. DEW MEASUREMENTS MODELS

Dew measurement technics in several places of the world are not standard. Specific for dew produced with different matters according to the result and desired precision have been used [32]. Other are used for of the digital models to evaluate the duration and the quantity of dew when the data of dew are non-existent [32]. These models are applied to surfaces of plants, bare soil [48] and artificial surfaces [16,55,65, 67,68]. Since the years 80s, several formulas were developed to estimate the quantity of dew and the duration of its presence on collecting surfaces starting from the:

- Assessment of exchanged energy [18,25, 69];
- Assessment of moisture [70];
- Diffusion of water vapor [29];
- Scale observation index [16];
- Neurons networks and complex digital simulations of atmosphere [22].

The use of these models requires the knowledge of certain climatic data such as, temperature, pressure of air, relative humidity, total incoming and outgoing solar radiation, wind speed and cloud cover. Among these models one can cite:

✓ Monteith's model

It evaluates the amount of atmospheric humidity condensing on surfaces (condensation and evaporation) in relation to the physical and thermodynamic characteristics of the mixture of air and water vapor. The three-dimensional geometry and the temperature of surface are not taken into account. This model couples the mass of condensed moisture (dew) with the evaporated water mass on plane surfaces (plane condensers) starting from the equation:

$$D_f = \frac{s}{s+\gamma} \times \frac{R_N}{\lambda} - D_r \quad (1)$$

With, D_f (*kg.m* $^{-2}$*.s* $^{-1}$) mass of condensed moisture (dew), *s*(*Pa.K* $^{-1}$), γ (*Pa.K* $^{-1}$), λ (*J.kg* $^{-1}$), R_N (*W.m* $^{-2}$) and D_r (*kg.m* $^{-2}$ *.s* $^{-1}$) respectively represent the slope of the curve of saturation, the psychometric constant, the latent heat which significance is presented below, the net radiation, and evaporated moisture masses which expression is:

$$D_r = \frac{s(R_N + G) + \gamma E_a}{s+\gamma} \quad (2)$$

Where G is the heat flux on the ground and E a is the evaporating capacity of the given air by the formula: $E_a = F(n) \times (e_s - e_a)$ and $F(n) = 0.26 \times (1 + 0.5184 \times u_2)$, u_2 being the speed of the wind at 2 meter of the ground, e_s the saturation vapour pressure, e_a the air vapour pressure and F(n) is an empirical constant.

✓ Nikolayev's model

It is established from the assessment of energy of the condenser, the substrate of condensation and water obtained. It integrates also heat exchange between the condenser and the atmosphere as the equation below:

$$(M_C C_C + mC_e) \times \frac{dT_C}{dt} = R_i + R_{he} + R_{cond} \quad (3)$$

The member of left evaluates the assessment of energy on the level of the condenser with M_C (*kg*), m (*kg*) and C_C (*J.kg* $^{-1}$ *C* $^{-1}$), C_e (*J.kg* $^{-1}$ *C* $^{-1}$) the masses and the specific heat of the condenser and condensate respectively, T_C (*°C*) the temperature of the condenser and t (*s*) the time. Then, the right presents the producing whole of the physical processes of calorific energy coming from the atmosphere or leaving towards him with R_i (*W*) the irradiation, R_{he} (*W*) significant heat and R_{cond} (*W*) the latent heat flux.

- ✓ Awanou's model

It is obtained starting from the analogy between the law of diffusion of the particles and the Fourier analysis for the heat flows. The mass of condensed humidity of the atmosphere is deduced from the flow of molecules condensing according to the equation:

$$\frac{dn}{dt} = -D \times \frac{\partial C}{\partial z} \quad (4)$$

Where n is the density of particles in (*mol. m* $^{-2}$); is the vertical gradient of concentration of the particles and D is the coefficient of diffusion in the atmosphere in (*m* ^{2} *.s* $^{-1}$) depending on air temperature T [71]:

$$D = 0.229 \times 10^{-4} \times \left(\frac{T}{273.15}\right)^{1.75} \quad (5)$$

With T evolving from T_a (surrounding air temperature) to T_C (condenser temperature) with which it comes into contact with the condenser.

- ✓ The Model of Gandhidasan et al.

It expresses the condensate mass according to energy due to the latent heat of vaporization and the coefficient of exchange by convection.

$$m = \frac{q_m}{h_{fg}} \times 3600 \quad (6)$$

This energy is given by the balance of energy expressed as follows:

$$q_c + q_m + q_{cond} + q_r = 0 \quad (7)$$

Where q_c, q_{cond} and q_r respectively represent the energy exchanged by convection between the surface of condensation and the surrounding air, by conduction between the layer of condensation and surface then the radiative exchanges between surface and the sky. This model takes into account the geometry of the system and the intrinsic properties of the air vapour and the material on which it condensed.

- ✓ Energy Balance Equation (EB)

The assessment of energy on the surface of the condenser is given by the equation below:

$$R_N + H + G + \lambda E = 0 \quad (8)$$

In which the term λE called latent heat flux represents the dew if this flux is directed towards the condenser. It can be evaluated as the sum of other three terms of the equation: net radiation (R_N); sensible heat flux (H) and soil heat flux (G).

- ✓ Equation for Turbulent Vapour Transport (TVT)

The latent heat flux can be also calculated by Equation for turbulent vapour transport if air and surface temperatures, relative humidity, wind speed and characteristics of the condenser are known. This equation is expressed as:

$$\lambda E_{TVT} = \lambda \times gv \times \frac{e_a - e_s(T_s)}{P} \quad (9)$$

Where gv is vapour conductance of the air between surface and screen height (*mol.m* $^{-2}$ *.s* $^{-1}$); P is the air pressure.

- ✓ Penman-Monteith Equation (PM)

Penman has used the equation for turbulent vapour transport and introduced a way to eliminate the temperature of the surface when it is not known. He add and substract the saturation vapour pressure at air temperature ($e_s(T_s)$) from the vapour pressure term in Eq(9) then was refined later by Monteith [25]. The temperature of the condenser is not taken into account but integrate the conditions mentioned above because of night cooling. It is therefore necessary for the condensation of atmospheric moisture. This equation is express as:

$$\lambda E_{PM} = \frac{-s[R_N + G] + C_N \times gv \times [e_a - e_s(T_a)]}{s + P \times \frac{C_P}{\lambda}} \quad (10)$$

C_P, e_a and $e_s(T_a)$ are respectively: Heat capacity of air (J.mol −1 .K −1); vapour pressure of the air (kPa); and vapour pressure of the air at the surface (kPa).

✓ Bowen Ratio Energy Balance Equation (BREB)

This is represent the variation of the energy balance equation. Using the expression $\beta = \frac{H}{\lambda E}$ which give $H = \beta\lambda E$ into the energy balance equation yields:

$$\lambda E_B = \frac{-(R_N + G)}{1+\beta} \tag{11}$$

With β the bowen ratio The passage from one form to another starting from the equation of the assessment of energy depends on the simplification which one wants to bring according to the availability of the parameters entering the simulation of the model [25].

✓ Beysens's Model

The model is based on the scale of observation indexed with n for four levels. The index n is proportional to the volume of dew condensed in mm (h = k×n). The expression of h provided in the literature is:

$$h = \begin{cases} h_0 + 0.06\times(T_d - T_a)\times(1+100\times(1-\exp-\frac{V}{V_0})^{20} & \text{If positive} \\ 0 & \text{If negative} \end{cases} \tag{12}$$

Where h_0 is a function of the rise in the site of observation H (altitude in km) temperature of dew in T_d (°C) and cloud cover N with T_a (°C) the temperature of the ambient air; V is the speed of the wind in ($m.s^{-1}$) measured at 10 meters of the ground and V_0 is the coefficient of speed of the wind in the level of the condenser.

$$h_0 = 0.37\times\left[1+0.204323H - 0.0238893H^2 - (18.0132 - 1.04963H + 0.21891H^2)\times 10^{-3}T_d\right]\times (\frac{T_d + 273.15}{285})^4 \times (1-\frac{N}{8}) \tag{13}$$

5. COMPARISON OF DEW MODELS

The models of simulation used on radiative condensers with their yield according to the literature are presented in the Table 1.

Table 1 presents the yield of dew according to the geometry of the condenser and the model of simulation used to evaluate dew amount. The model of simulation depends on the parameters which influence the formation of dew. These parameters are especially integrated in the components of the model. The obtained equations from the assessment of energy gave more or less nearby results with yield ranging between 0.68% - 0.91% for the planar condensers. Moreover, the quantity of dew calculated from index of observation is slightly higher than that provided by the assessment of energy. In addition, the same models used on condensers of various forms provided different quantities of dew but with a better yield varying between 1.38% - 12.61% for the truncated condensers forms [9,19,29]. Thus, the truncated condenser must be dimensioned taking into account its height and its opening compared to the sky (diameter and angle of inclination relative to the horizontal with the rounded shape of the edges which limit the shocks between the wind and condenser [29]. Radiative cooling is therefore significant for the truncated condenser than for that of the shape planes as shown [72]. Dew quantity assessment models integrate for the physical majority and thermodynamic characteristics of dew condenser. The latter justify their choice. In addition, the models taking into account the three-dimensional geometry are applied for all shapes of condensers and give results in all directions of space at the same moment. On the other hand, those which do not take into account the three-dimensional geometry goes better with the shapes of the planar condenser.

Table 1. Comparison of dew models

Sources and dew simulation models	Main parameters of the model	Geometry of the condenser/place and year of experimentation	Average quantity of dew per night (mm)	yield
[70] Monteith model	mass of condensed moisture (dew), water mass evaporated and energy	plane surfaces/Harlington, England 1953-1954	0.03 - 0.13	0.1 - 0.42
[69] Gandhidasan model	Latent heat of vaporization (balance of energy) and the coefficient of exchange by convection.	plane surfaces / Dhahran (Saudi Arabia) 2004	0.18 - 0.25	0.6 - 0.82
[25] Penman Monteith model (PM)	Energy balance	plane surfaces / Northern Germany 2009	0.25	0.81
[18] Nikolayev model	Both energy and heat exchange between condenser and atmosphere	Plane surfaces/Ajaccio , Corsica island (France) 2000; Conical/Ajaccio 2003; Trapezoidal trenches/Panandhro (Inde) 2003	0.0019 –0.0155 0.04-0.396 0.014 -0.252	0.68 – 0.91 1.38 0.81
[25] energy balance model	Energy balance	plane surfaces / Northern Germany 2009	0.23	0.74
[25] Model for turbulent vapour transport (TVT)	Energy balance	plane surfaces/Northern Germany 2009	0.23	0.74
[25] Model using Bowen ratio energy balance equation (BREB)	Energy balance	plane surfaces/Northern Germany 2009	0.23	0.74
[29] Model using the particle diffusion equation	Particles diffusion and Fourier analysis for the heat flows	plane surfaces / northern Benin 1997 Conical/ northern Bénin 1997 Plane surfaces folded back / northern Benin1997	0.0191 3.91 0.0026-0.0313	0.06 12.61 0.01-0.1
[16] Beysens model	Heat exchange, wind speed, site elevation and cloud cover	plane surfaces / France 2015	0.29	0.94

6. APPLICATION OF DEW COLLECTION IN A TYPICAL CASE OF MAIZE VEGETAL COVER AS CONDENSER TO CROPS WATER REQUIREMENT: COMPARISON OF DEW AMOUNT TO MAIZE WATER REQUIREMENTS IN SEMI-ARID AREAS

Photo 1 shows the most soothing morning dew of meadows, forest edges, clearings ...Due to the cooling of the air, water vapor condenses on objects near the ground and turns into water droplets. This usually happens at night. In Desert regions, dew is an important source of moisture for vegetation. Sufficiently strong cooling of the lower layers of air occurs when, after at sunset, the earth's surface is rapidly cooled by thermal radiation. The favorable conditions for this are clear skies and a surface coating which gives easily releases heat, for example, grass. Particularly strong dew formation occurs in tropical regions, where the air in the surface layer contains a lot water vapor and due to the intense night thermal radiation of the earth is considerably cooled. The objective of this section is to compare dew amount to maize's water requirement as adaptation of maize to the climate change. In particular, assess the amount of dew that settles on a short cycle plant cover of corn (Izee-W-Sr- (ode-tuwe)) throughout its growth cycle, determine the water requirements of the culture and compare the dew collected with the water requirement in order to deduct its contribution to plant's water requirement. The study site is located at Nalohou (latitude: 9.74°N, longitude: 1.60°E, elevation: 449 m) about 10 km from Djougou (Benin) Fig. 9. It is subject to a Sudanian climate, with an average annual rainfall of 1190 mm during the period from 1950 to 2007 [73]. The climate is characterized by the alternation of a rain season (April-May to September-October) and a dry season, the rest of the year. This alternation is due to the displacement of the Intertropical convergence zone which relative position to the site brings moisture through the flows monsoon or dry air by the harmattan winds.

The experiments were carried out using maize which cycle lasts on average 70 days. The recorded average of air temperature and average of relative humidity vary respectively from 15°C to 38°C and from 73.59% to 89.67%. Meteorological data are used in the models for dew and water requirement calculation as the parameters are: air temperature, relative humidity and wind, are collected by 15 min intervals. The second, namely the emissivity of maize leaves [25], cultural coefficient and stress coefficient [74,75] are summarized in Table 2.

Photo 1. Dewdrop of the "early morning". A quite large drop for a so small surface of condensation (https://dekor-ufa.ru/en/)

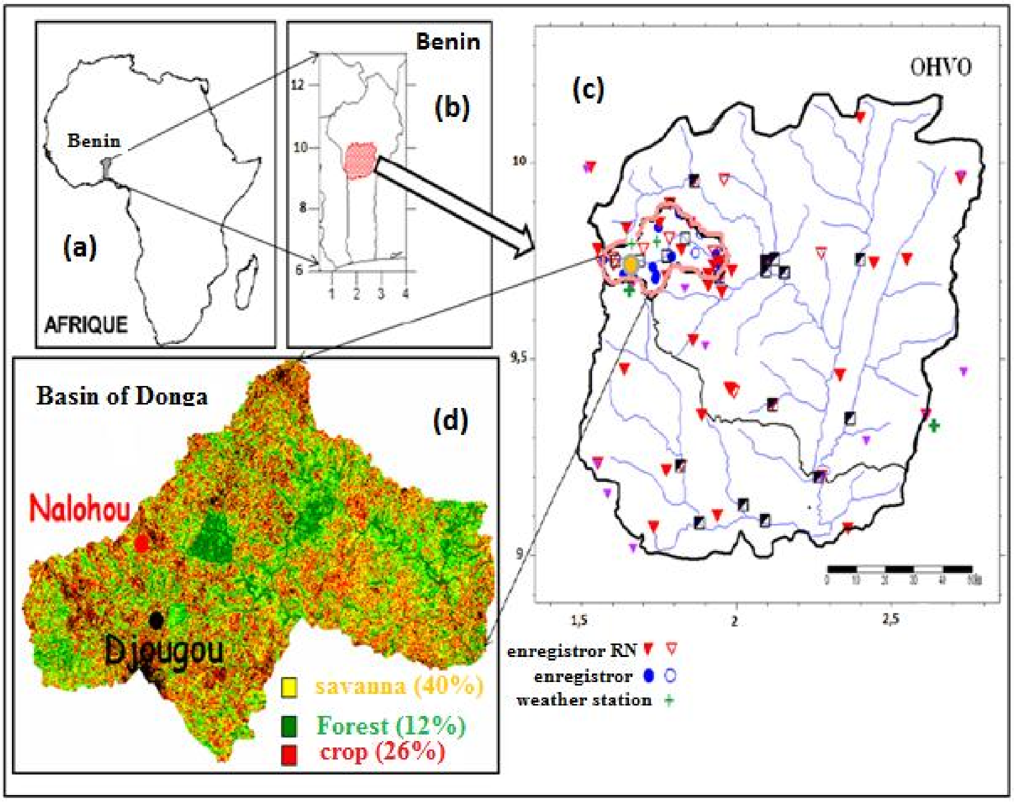

Fig. 9. Localization of the site of Nalohou in Donga: Maps of (a) the Africa, (b) the Benin, (c) and (d) Nalohou area of study

6.1 Canopy's Parameters

The Canopy parameters used in the model are presented in Table 2. It's the emissivity of the canopy regarding the state of growth,

- ✓ The cultural coefficient, and
- ✓ The coefficient of stress

The cultural coefficient is a characteristic number of each crop, representing the ratio between its maximum real evapotranspiration (ETm) and the evapotranspiration of reference. It varies during the cycle depending on the growth state. The water stress coefficient relates actual evapotranspiration to maximum evapotrans-piration.

The Penman Monteith model is used to calculate the amount of dew collected by the canopy of maize. It is an algebraic expression which sign depends on the period of the day. If it is negative, it corresponds to the vaporization of the atmospheric humidity (the day). On the other hand, if this quantity is positive, it represents the atmospheric condensation (nocturnal dew). This model is selected because of its high output compared with the others models from which it rises and the fact that it takes into account a great number of weather parameters. It contains

Table 2. Parameters related to the canopy of maize

Development phase	Emissivity of the leaf [25]	Cultural coefficient kc [74]	Coefficient ks of stress [76]
Initiation		0.5	1
growth		0.7	0.6
Flowering	0.95	1.1	0.8
Grain formation		1.15	0.8
Maturation		0.65	0.2

Table 3. Values of the coefficients used

Coefficients	K	D [77]	Z0 [78]	ω[79]	β[80]	LAI[80,81]	gv= gH [25]
Values	0.4 - 1	0.65h	0.1h	0.4	0.5	1.9	0.0044 - 4

also a term of vapor conductance which can be use without adjustment because its value is low with high relative humidity during dew event. Moreover, in this model, the temperature of the condenser has been eliminated for more simplification. Table 3 presents other parameters used in the model of Penman Monteith to evaluate dew amount and maize's water requirements.

Water requirements of the plant depend on climate on the type of crop. It varies with the duration of the cycle and is equivalent to the amount of water lost through real evapotranspiration (ETR). Its expression is given by the formula of FAO 56 by:

$$W_r = k_s \times ETM = k_s \times k_c \times ET_0 \quad (14)$$

k_c is the cultural coefficient; k_s the coefficient of stress; ETM maximum evapotranspiration and ET_0 reference evapotranspiration, determined by the Penman model [82]:

$$ET_0 = \frac{0.408 \times s \times (R_N + G) \times d + \gamma \dfrac{37}{(T_a + 273.15)} \times u \times (e_w - e)}{s + \gamma (1 + \dfrac{r_s}{208}) \times u} \quad (15)$$

d is the time step and r_s the surface resistance in ($s.m^{-1}$)

- ✓ The different calculations were made with several computer programs such as: MATrix LABoratory (MATLAB, version 13a), it improves the readability of a figure and performs operations on vectors, operations and functions relating to the matrices.

Fig. 10 presents the comparison of dew amount to maize water requirements. From the stage of flowering to grain formation phases, the plant needs 6.263 mm of water. This is equivalent to 69.94% of its water requirements between 25 to 70 days after sowing for early varieties of 65 to 70 days of cultivation. The water requirements for the initialization and growth phases is estimated at 2.931 mm of water; therefore 30.05%. The amount of water required for the ripening and senescence phase is about 0.56 mm, or 5.73%. The crop needs more water per day in a hot and sunny climate than in a cold, cloudy climate [25]. Dew is compared to daily water requirements for maize canopy as shown in Fig. 10. It appears that the proportion of dew is small compared to water requirements. Although this quantity is less than the required water, it's not less negligible. Indeed, the cumulative amount of dew that can be collected, compared to the requirement water of the crop in Nalohou, is as follows: 0.79 mm of dew against a total quantity of 7.94 mm of water requirements for the initiation phase. Dew represents about 10% of water requirements; 2.95 mm of dew against 26.85 mm of water requirements for the growth phase; a percentage of 11%; 2.54 mm of dew against 44.84 mm of water requirements for the flowering phase; a contribution of 5.7%; 2.61 mm dew versus 48.31 mm of water requirements for the grain formation phase; a percentage of 5.4%; 3.29 mm of dew against 12.63 mm of water requirements for the ripening and senescence phase; a percentage of 26%.

The results show that dew can contribute for: (a) 10% to 11% in maize water requirements during the initiation and growth phases, (b) 5% to 6% during the flowering stage and seed formation phases, (c) 34% to 35% of maize water requirements for the ripening and senescence phase. Considering the entire cycle, the percentage of water requirement satisfaction is around 8.67%.

Climate change has huge consequences on human beings worldwide, mainly for agriculture, one of the main economic and food incomes in West Africa. The total accumulated dew, obtained in Nalohou shows that the canopy is favorable for dew collection. The analysis of this results shows that there are nights when the amount of dew is important. But, radiative cooling of surfaces of canopy cover is not the same. It increases according to the plants of growth, the cloud cover and the speed of wind [32]. Radiative cooling of the canopy from one day differs to the next. The expression of vapor conductance contains parameter such as wind speed which variations significantly influence the amount of

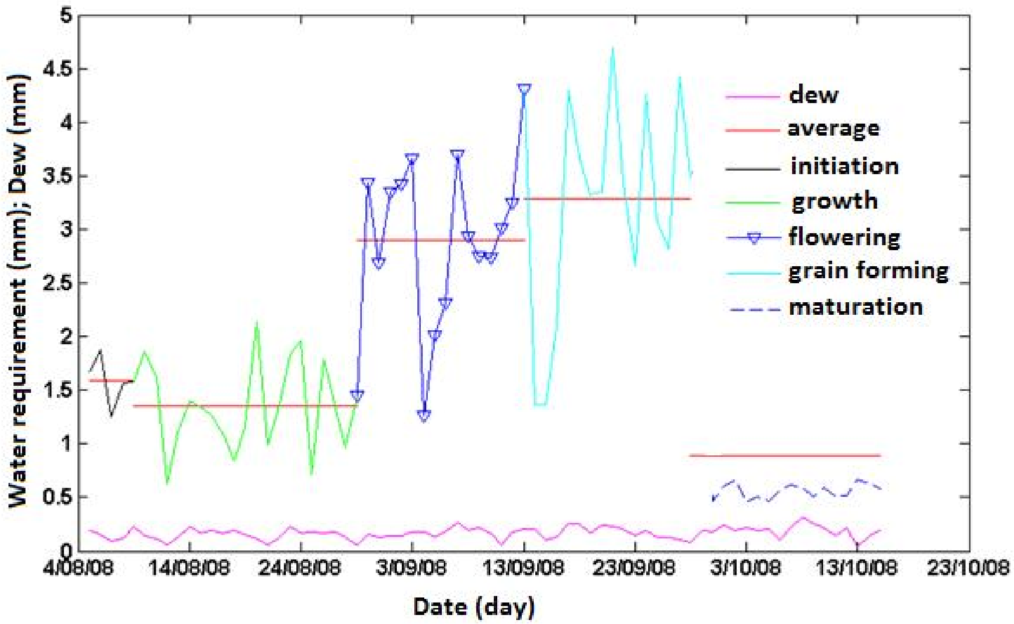

Fig. 10. Comparison of water requirements and dew amount from 5/08/08 to 15/10/08

dew obtained from the model. The results indicate that dew can contribute about 11% to water requirements during the growth phase. The remaining 89% of its water requirement should be filled by rainfall. Yield of cereals is strongly linked to good management of the water balance by vegetative phase. As for the maturation and senescence phases, approximately 35% of the water requirement will be met. This is confirmed by [9] who estimated on average the water requirement per day (for a period of 15 days) at 2.29 mm, equivalent to a total of 34.29 mm for the maturation phase requirement. The water requirements of the initiation and growth phases are 1.589 and 1.342 which are weak compared with the flowering and grain formation phases [9]. This is explained by the fact that the vegetative state of the canopy for the first two phases is less dense. Indeed, the difference between the cultural coefficient (1.15 or 0.65) and stress coefficient (0.8 or 0.2) of these two phases are high compared to those of the other phases (0.5 - 0. 7) and (1 - 0.6) respectively. This could explain the decrease of water requirement. The amount of estimated dew at Nalohou alone cannot satisfy the water requirements of maize for it whole growth cycle. However, its contribution to the total water requirement cannot be neglected. According to [56,83], dew mobilized overnight would be more important for plant cover and plants than the same amount of rain that fell during the day. Thus, dew obtained can contribute enormously to the development of maize at Nalohou. Similarly, [14] has shown that at night or early in the morning, dew provides well-being to plants; this could also be the case at Nalohou. Like fog in mountainous regions [84], dew can represent a major ecological stake for corn. Indeed, the observations made by Koto n'gobi (2012), show that a large part of the dew (on the plant cover) dribbles gravitationally through the foliage to the foot of the plant and its surroundings. As a result, the superficial roots could directly benefit from the plant's diet.

7. CONCLUSIONS

This study was motivated by making a review on dew phenomenon in order to assess dew contribution in the satisfaction of maize water requirement in Nalohou a typical site threatened by climate during each phase of its growth cycle. Charles Le Roi is the first in 1751, who set up the basis of scientific theory about dew process. It has established a parallelism in evaporation and condensation since the beginning of the 18th century. Later in the 19th century, Well introduced the concept of Radiative cooling between the sky and any object on the ground. This concept is used till now in the characterization of dew process. Earlier condensers end in failure because of their huge mass and the working layer of the stones that were used to build the condensers and the experiments turned out to be inconclusive and led to perform new generation of dew condensers gradually performed. Radiative cooling is therefore significant for the truncated condenser than for that of the shape planes.

There are no standard methods or instruments for measure dew water. Dew study is of significance in ecology, agriculture and some other disciplines. Dew can supply water resource especially in arid area, and determine the survival of plants. All the methods of study of dew are into perpetual evolution and provide diversified developments. The models taking into account the three-dimensional geometry are applied for all shapes of condensers and give results in all directions of space at the same moment. On the other hand, those which do not take into account three-dimensional geometry goes better with the shapes of the planar condenser. In Benin, the new generations of condensers used and applied to Awanou's models gave a good yield.

Application focuses on the search for adaptation strategies of our cultural practices to climate change in West Africa. Its main objective is to investigate dew collection as for agriculture through the maize development cycle. It attempts to show the ability of maize canopy to mobilize dew for its own water requirement.

The water requirements of maize are compared to the amount of dew actually collected by the plant cover. It shows that the amount of dew remains lower than the water requirements of the crop during all the periods considered in Nalohou. The simulations show that the amount of dew obtained represents about 9% of the water requirements in Nalohou for all the whole growth cycle. However, these models have some limitation. None of them provide dew profile according to altitude. Further research is thus needed on dew to perform the dew profile in arid and semi-arid areas as alternative water for agriculture.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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