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TECHNICAL FEASIBILITY OF USING SOLAR ENERGY IN SMALL-SCALE IRRIGATION IN TILLABÉRI, NIGER REPUBLIC

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ABSTRACT

The objective of this work is to analyze the technical feasibility of solar pumping systems for their expansion in small-scale irrigation in Tillabéri (Niger Republic). The study area concerned all irrigable listed land in that region. The agro-climatic data, contained in the CLIMWAT 2.0 software, allowed to analyze the environment's solar energy potential on the one hand, and to estimate the tomato, onion, potato and pepper crops water needs by using the CROPWAT 8.0 software, on the other hand. The solar energy requirements, the power of the photovoltaic generator and the number of required panels by the generator to cover the crops water needs during the peak periods, were determined according to the total hydraulic head to be overcome by the pumping system. This results in monthly average sunshine duration values ranging from 7 hours/day in August to 8.5 hours/day in May. The solar energy is 5 kWh/m^2/day in December and 6.22 kWh/m^2/day in May. The required energy for the irrigation water lifting during the peak periods, the power of the photovoltaic generator and the number of panels required for the generator varied according to the total hydraulic head (H_t) across different crops. Thus, for H_t between 15-120 m, the required energy varies between 3.62-29.00 kWh/day/ha for tomato; 3.56-28.48 kWh/day/ha for onion; 3.23-25.83 kWh/ha/day for potato and 2.74-21.89 kWh/day/ha for pepper. The required power for the photovoltaic generator varies between 1.08-8.64 kW/ha for tomato; 1.06-8.48 kW/ha for onion; 0.96-7.69 kW/ha for potato and 0.82-6.52 kW/ha for pepper.

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Likewise, the number of panels varies between 4-27 panels/ha for tomato and onion; 4-25 panels/ha for potato and 3-21 panels/ha for pepper. These results indicate a considerable solar energy potential, characterized by a relatively high duration of sunshine throughout the year and a high energy production capacity per square meter. This would promote the proper functioning of the solar pumping systems as well as their expansion. However, the cost of acquiring the panels required for the generator can be an obstacle to the expansion of this technology, especially in conditions of considerable groundwater depth.

Keywords: small-scale irrigation; productivity and sustainability; Solar energy pumping system;

1. INTRODUCTION

In Niger republic, as in all Sahel countries, the irrigation sector plays an important role in improving food security and the resilience of populations. Rain-fed agriculture is often inefficient due to pedoclimatic constraints that lead to recurring fodder and cereal deficits balance sheet (WFP, 2010; PARM, 2016, Ministère du Plan, 2016). Thus, the development of irrigation has long been at the center of the Niger State’s development strategy and several types of irrigation have been developed with the aim of reducing agriculture's dependence on climatic hazards, which allows, on the one hand, to increase production and complete the deficits (Ministère du Développement Agricole, 2005; Banque mondiale, 2009) and on the other hand, to improve people’s incomes. The small-scale irrigation sub-sector is particularly being developed because of the low cost of its implementation and the simplicity in managing its systems (Ministère de l’Agriculture, 2015; Tillie et al. 2019), however, improving the productivity of these systems remains a challenge.

The cost related to the energy consumption for the irrigation water mobilization and distribution through the thermal pumping use or the electrical energy, is one of the main operating costs in the implementation of irrigated production systems, and particularly in small-scale irrigation (Diop et al., 2020; Adres et al. 2019; Naroua et al. 2021). The solar pumping system or photovoltaic pumping system (PPS) for the irrigation water dewatering is an alternative in the search for solutions to reduce the operating costs of these production systems and thus, it contributes to their sustainability (Closas et Rap, 2017; Otoo et al. 2018; Lefore et al. 2021; Singh et al. 2021). The solar pumping system technology has other benefits than the operating costs reduction, such as the greenhouse gas emissions reduction, long useful life, a reduced maintenance cost, and its energy source is inexhaustible (Bouzidi et al., 2006; Hossain et al., 2015; Shouman et al., 2018; Deli et al., 2018). However, its very high initial investment cost makes it difficult to be acquire by the small producers, who has very low financial capacity (Diop et al., 2020; Wazed et al., 2018; Wydra et al., 2019).

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The existence of untapped irrigable soil potential and shallow groundwater resources are favorable to the expansion of irrigated production systems in Niger (Cochand et Jaubert, 2012; Nazoumou et al., 2016). This potential for irrigable land is estimated at more than 10 million hectares, more than half of which has a groundwater depth of between 0 and 15 m (Ministère de l'Agriculture, 2021) and in particular, the region of Tillabéri abounds in 1/5 of the total potential of the country, thus, it represents a highly agricultural region. Similarly, the implementation of development standards, including the irrigation water catchment and raising systems sizing control, also promotes the expansion and the sustainability of this irrigation sector. In this sense this work contributes to improving the productivity and sustainability of production systems, through a technical feasibility analysis of solar pumping systems for their expansion in small-scale irrigation in the Tillabéri region of Niger Republic.

2. MATERIALS AND METHODS

2.1 PRESENTATION OF THE STUDY AREA

The region of Tillabéri is located in the extreme west of Niger Republic territory between 11°50 and 15°45 north latitudes and, 0°10 and 4°20 east longitude. It covers an area of 97251 km², either 7.7% of the national territory for a population estimated on December, 2012, at 2,722,482 inhabitants of which 49.5% of men and 50.5% of women, or 15.9% of the Nigerien population. The population growth rate is 3.2% between 2001 and 2012. Like the other regions of the country, there are principally two (2) seasons in Tillabéri, namely: a dry season from November to May and a rainy season from June to October. Thus, temperatures vary according to the seasons. They are between 19 ° C and 27 ° C in a dry cold season; compared to 24°C and 45°C in the dry hot season. In the rainy season, temperatures vary between 28°C and 31°C. In addition, the climate of the Tillabéri region is characterized by a great interannual variability of rainfall which results in recurrent dry years that became more and more frequent since 1968 (CNEDD, 2009). The environment remains austere and ecosystems are facing enormous difficulties linked in particular to climate variability but also to a rapid increase in population. The region is subdivided into five (5) agro-ecological zones or macro zones: the river zone, composed mainly of the Niger River, its floodplain and alluvial terraces; the Nord Dallol Bosso area composed of large fossil valleys; the Gorouol which is the largest tributary of the river with many permanent ponds, the Azawagh valley and the W National Park located in the extreme south of the region (INS, 2016).

The study area concerns all the listed irrigable lands of the Tillaberi region, classified according the aquifer depth into four groups as follows (Fig. 1): depth of 0-15 m, 15-30 m, 30-50 m and greater than 50 m. The region's groundwater potential is estimated at tens of billions of cubic meters. In addition, there are important water bodies including the Niger River (450 km longer in

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the region) and its 7 tributaries (Gorouol, Dargol, Sirba, Gouroubi, Diamangou, Tapoa and Mékrou) and 145 ponds, 51 of which are permanent (INS, 2016). Thus, there are two main cropping systems in the Tillabéri region: the rainfed production system characterized by the dominance of millet and the irrigated production system with rice cultivation on hydro-agricultural development and vegetable crops.

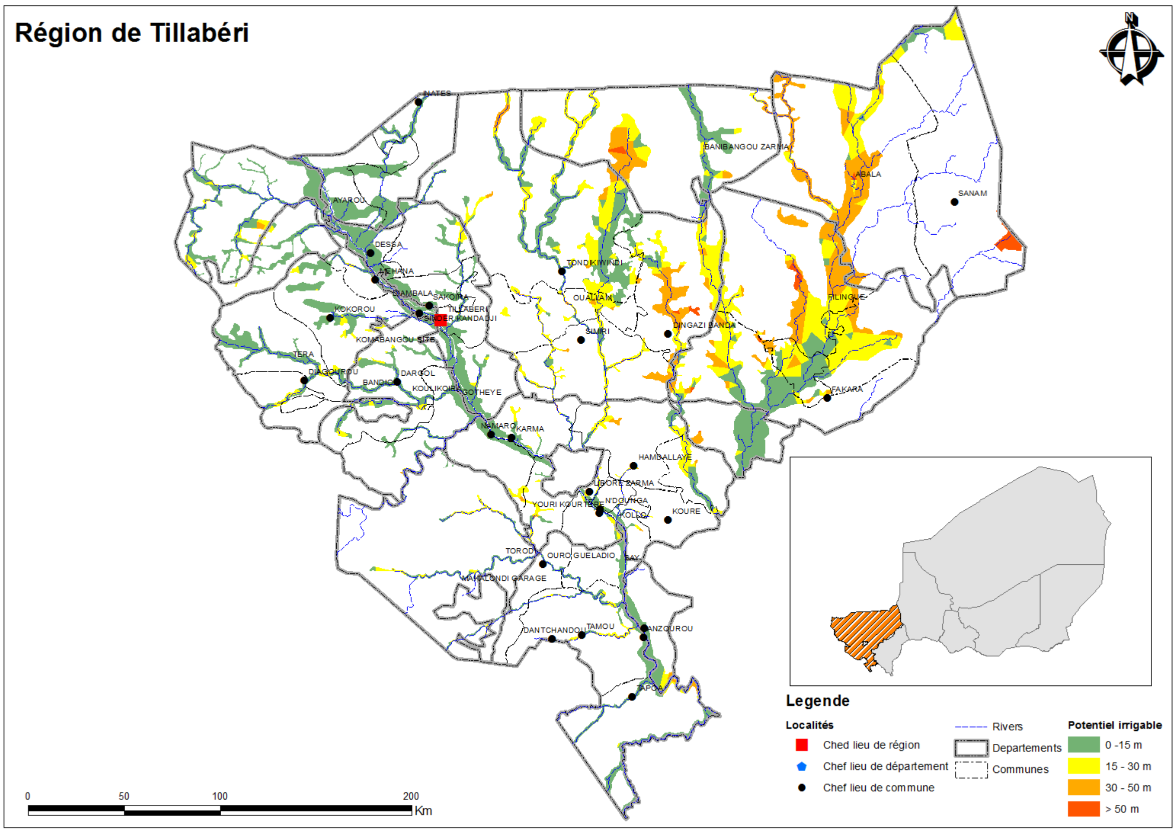

Fig. 1: Irrigable soil potential and groundwater depth in the Tillabéri region (Ministère de l'Agriculture, 2021).

2.2 METHODS

Climate parameter data contained in the software CLIMWAT 2.0 allowed to estimate the monthly average values of solar radiation (R_s) and its duration (D_{rs}) by using the CROPWAT 8.2 software.

Thus, the solar energy (E_s) and the daily power per meter square (P_{es}) were calculated by applying the below formulas. These allow to evaluate on the one hand, the solar energy potential

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of the region and on the other hand, the solar pumping systems capacity to cover the crops water requirements.

$$E_s = 0{,}277778 * R_s$$

$$P_{es} = \frac{0{,}277778 * R_s}{D_{rs}}$$

Where:

E_s(kWh/m^2/day) = daily solar energy per meter square

P_{es}(kW/m^2/day) = daily solar energy power per meter square

R_s (MJ/m^2/day) = daily solar radiation per meter square

D_{rs} (hours/day) = daily solar radiation duration

Onion, tomato, potato and pepper crops are taken into account because of their predominance and high economic value. The daily crop's net water requirements were estimated by using CROPWAT 8.0 software, by considering the usual sowing dates and their life cycle duration (Table1). Similarly, gross water requirements are calculated by assuming an application efficiency of 85%, given that the small-scale irrigation sector is characterized to be the most economical in terms of water consumption.

The water requirements (net and gross) are calculated on different soil types, namely: sandy soil, loamy soil and clay soil in order to take into account the influence of soil type on crop water needs. Subsequently, the water requirements average value of these three soil types were taken into account for the calculation of the solar pumping system sizing parameters. The criterion for irrigation management is to irrigate to field capacity when soil moisture is depleted to the maximum.

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Table 1: Sowing date and crop life cycle

Crop	Sowing date	Duration of the crop life cycle
Tomato	November	150
Potato	October	150
Pepper	September	150
Onion	November	180

The pumping system capacity to cover the crops water needs depends on the energy required to lift the volume of water required per day during the peak period. The peak period corresponds to irrigation days during which the crop's water requirement is maximum.

Likewise, this energy depends on the water volume to be lifted as well as the total hydraulic head which, include the static head (the difference between the water level and the irrigation system), the head losses and the required head for the system operation. The require energy is calculated like follows (Narale et al, 2013; Bouzidi et al., 2006):

$$E_h = \frac{\rho g H_{mt} V}{3{,}6.10^6}$$

Where:

E_h (kWh/day/ha) = hydraulic energy

ρ (kg/m^3) = water density

H_t (m) = hydraulic head total

V (m^3/day/ha) = water volume to be pumped

The photovoltaic generator size and power depend on the energy required per day to cover the crops water needs during the peak periods, the duration of the solar radiation and the system efficiency (Narale et al, 2013; Bouzidi et al., 2006). The total power of the photovoltaic pumping system is calculated as follows:

$$P_{pps} = \frac{E_h}{D_{rs}} \frac{1}{FE}$$

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Where:

E_h (Wh/day/ha)

P_{pps}(W/ha) = photovoltaic pumping system power

D_{rs}(hours/day) = duration of daily solar radiation

E (%) = system efficiency assumed to 50%

F (%) = mismatch factor assumed to 85%

The panels number (N_p) to be installed is equal to the ratio between the total power (P_{pps}) required to cover the daily water needs during the peak period and the power of a single panel (P).

$$N_P = P_{PPS}/P$$

For the realization of this study, it was taken into account the polycrystalline module which adapts better to the conditions of high and very variable temperatures such as those of Niger Republic. Thus, it was considered the 320 W panel which is one of the highest powers on the national market and with a unit price of 116000 FCFA. Consequently, the cost of acquiring the panels (C_p) required for the PPS is calculated as the product of the N_p and the unit price of the panel.

3. RESULTS AND DISCUSSION

3.1 THE SOLAR ENERGY POTENTIAL ANALYSIS

Fig. 2, 3 and 4 show respectively the duration of the daily sunshine, the daily solar energy per square meter and the power of the latter.

Fig. 2 reveals a high potential in solar energy, with monthly averages of sunshine varying between 7 hours/day in August and 8.5 hours/day in May. The annual average is 7.9 hours/day.

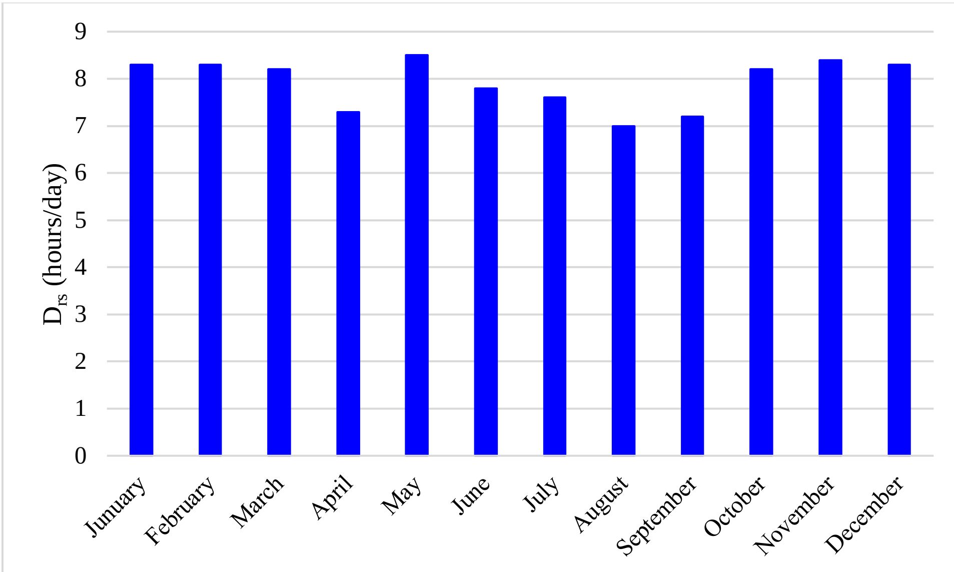

Fig. 2: Average monthly values of the duration of sunshine in the Tillabéri region

The potential of the daily solar energy per meter square varies between 5 kWh/m^2/day in December and 6.22 kWh/m^2/day in May, for an annual average of 5.61 kWh/m^2/day (Fig. 3).

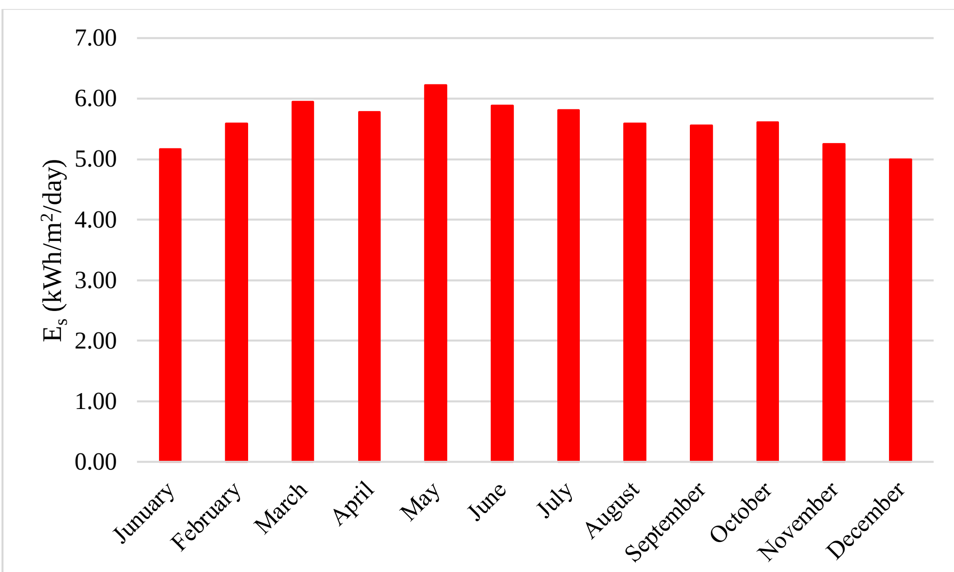

Fig. 3: Average monthly values of daily solar energy per meter square in the Tillabéri region

In addition, the daily available power per square meter (Fig. 4) varies between 0.6kW/m^2/day in December and 0.8 kW/m^2/day in August. The average annual power is 0.71 kW/m^2/day.

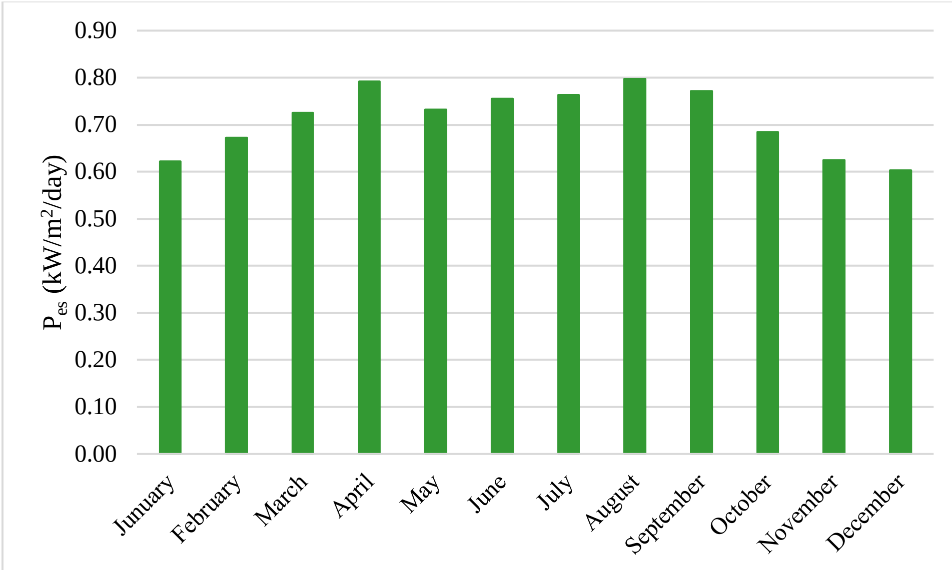

Fig. 4: Monthly average values of daily solar power per meter square.

These results agree with those of Dankassoua et al. (2017) who obtained solar energy values ranging between 2.62 and 7.96 kWh/m^2 for a solar radiation duration of about 12 hours/day during pre-monsoon and monsoon periods in the Niamey region. They agree also with those of Ogutcu and Gado (2016) who presented values between 5 and 7 kWh/day and a sunshine duration of 8.5 hours/day in Niger Republic. The values of sunshine and daily solar energy per square meter provide a significant daily operating time of solar pumping systems. They also indicate a strong capacity of the environment to produce large quantities of energy over meter square. This is in line with the study of Ibrahim et al. (2020) who found a solar energy value of 5.5 kWh/m^2/day for the sizing of a solar pumping system in Egypt. This is an excellent asset for the pumping systems operating in general, and for the irrigation water mobilization in particular.

3.2 VARIABILITY OF ENERGY REQUIREMENTS AS A FUNCTION OF CROP WATER REQUIREMENTS AND GROUNDWATER DEPTH

Fig. 5 shows the daily volumes of water required per hectare, during peak periods depending on the crop. They are equivalent to 88.68; 79; 87.08 and 66.95 m^3/day/ha respectively for tomato, potato, onion and pepper crops. These values are similar tothose of the study of Get.invest (2019) in which, for the configuration of a solar pumping system, it was considered a volume of 70 m^3/day/ha to cover the water needs of vegetable crops in Senegal. In addition, they are higher than that presented by Chilundo et al. (2018) in Mozambique (46200 l/ha/day for tomatoes).

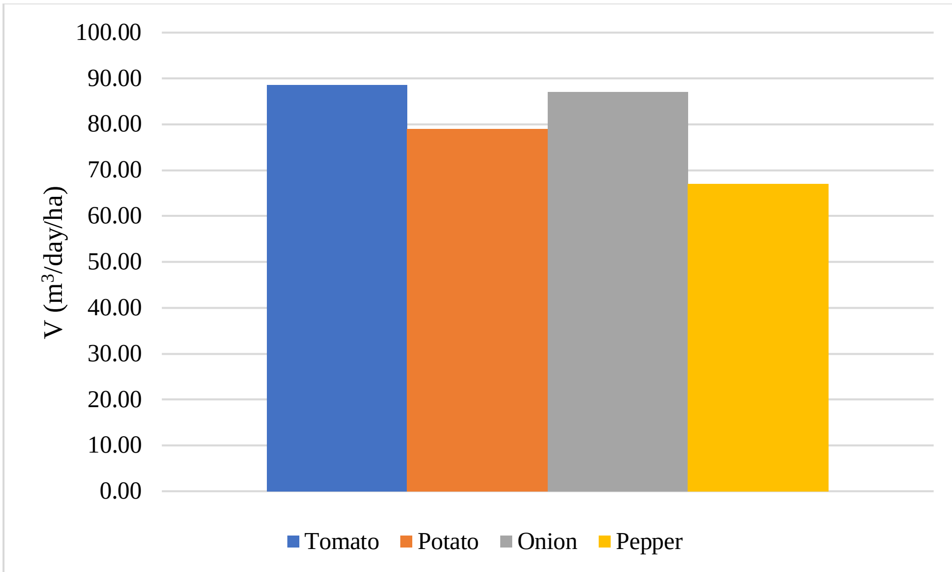

Fig. 5: Daily volume of required water during peak periods depending on the crop

Fig. 6 shows that tomato crop is the most energy demanding for its water requirements coverage during the peak periods (3.62 kWh/day/ha at 15 m of the H_t and 29.00 kWh/day/ha at 120 m of H_t) followed respectively by onion crop (3.56 and 28.48 kWh/day/ha); potato (3.23 and 25.83 kWh/day/ha) and pepper (2.74 and 21.89 kWh/day/ha). These results are higher than the values presented by RADHORT (2012) which were 1 kWh/day/ha for an irrigation water volume of about 70 m^3/day and an H_t of 5 m.

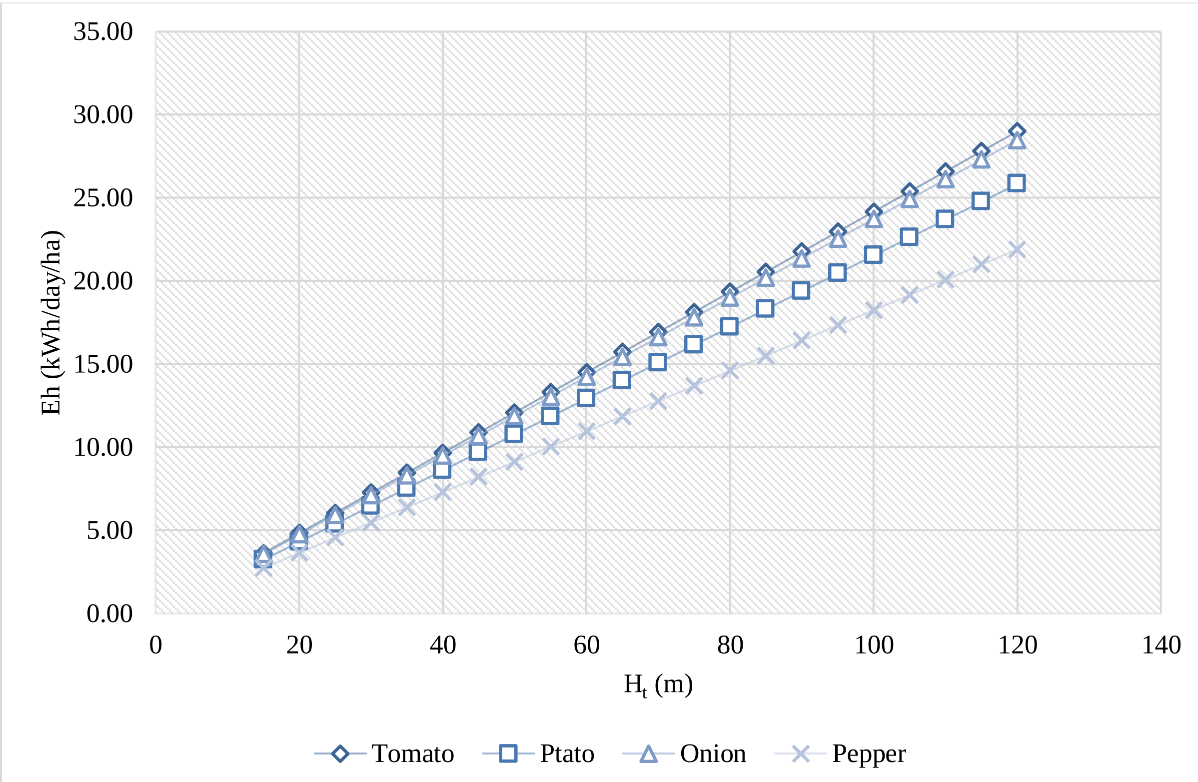

Fig. 6: Variation in required hydraulic energy to lift the required water volume during the peak periods as a function of H_t

Fig. 7 shows the variation of the P_{pps} as a function of the H_t. The same trend of the required hydraulic energy (E_h) is observed. Thus, the P_{pps} varies from 1.08 kW/day/ha for an H_t of 15 m to 8.64 kW/day/ha for 120 m of the H_t for tomato crop; against 1.06 and 8.48 kW/day/ha for onion; 0.96 and 7.69 kW/day/ha for potato and 0.82 and 6.52 kW/day/ha for pepper.

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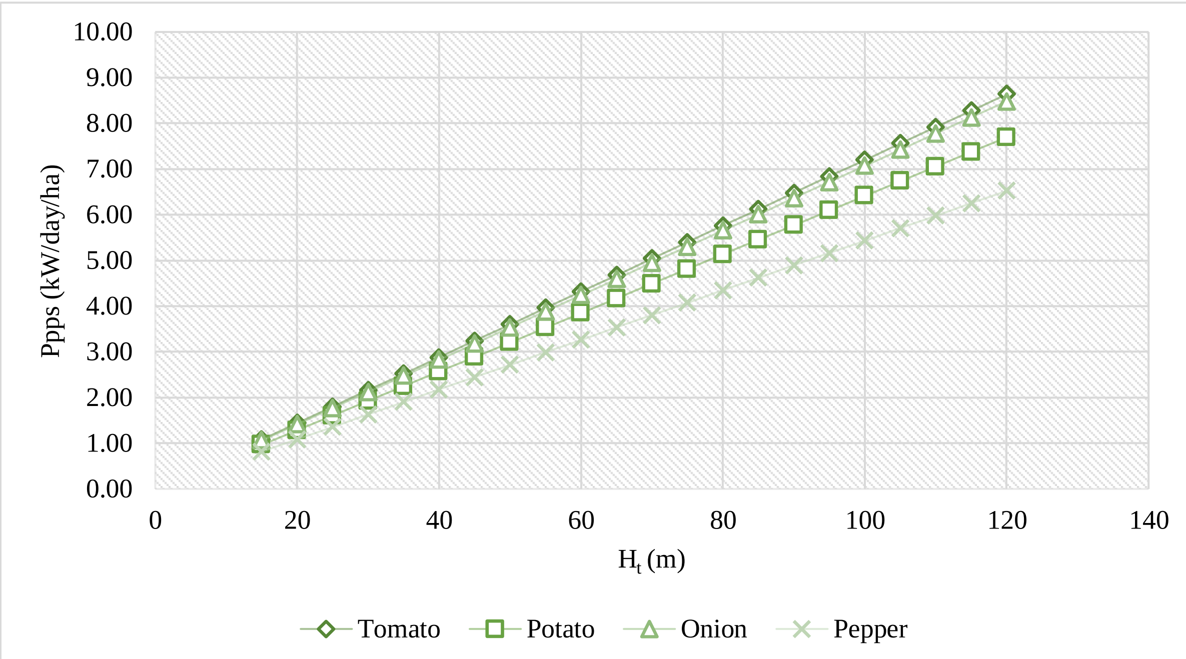

Fig. 7: Variation of the of required photovoltaic generator power to lift the required water volume during the peak periods, depending on the H_t

Fig. 8 shows the number of solar panels (Np) with a power of 320 W, needed for the photovoltaic pumping system to cover the crops water needs during the peak periods, based on the total hydraulic head. Thus, the N_p varies from 4 panels per 15 m of H_t to 27 panels per 120 m of H_t for both tomato and onion crops. For potato, this number varies from 4 to 25 panels against 3 to 21 panels for pepper. These results are in line with those of Kelley et al. (2010) who presented a relationship of proportionality between the area to be covered by the panels and the depth of the wells for a given crop water requirement.

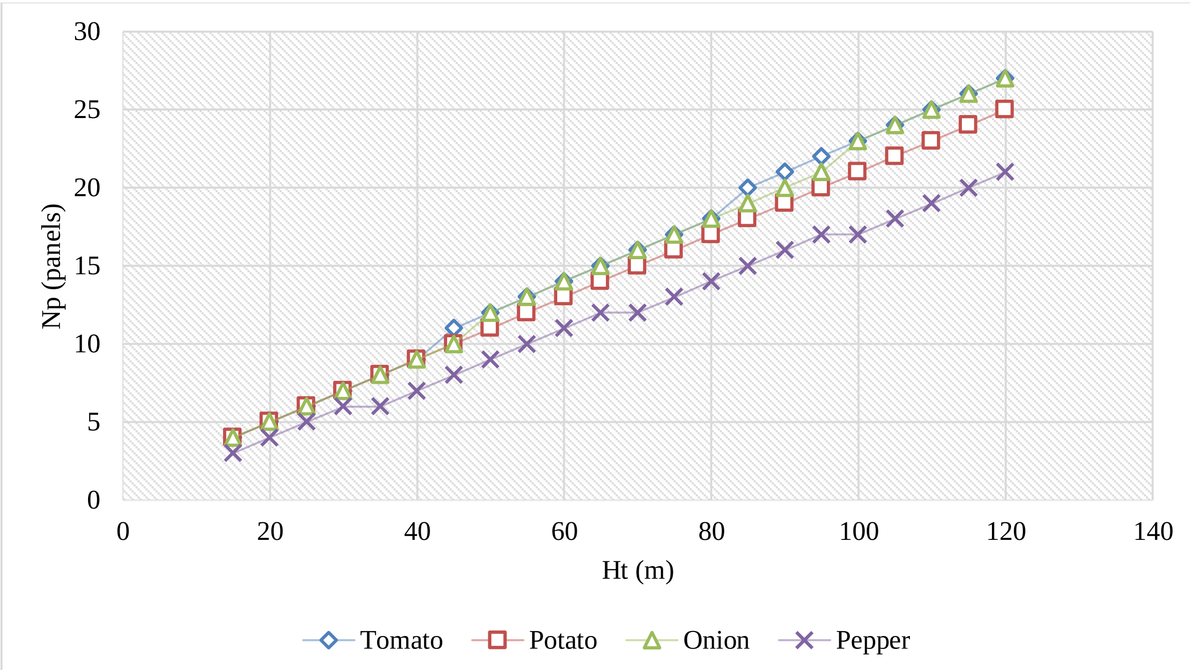

Fig. 8: Variation in the number of panels required for the PPS according to the H_t

In short, for a given cropped water requirement, there is an increase in the E_h and that of the P_{pps} when H_t increases. This corresponds to an increased demand for energy and power of the photovoltaic generator to cover the crop water need during the peak periods, when the value of the water table depth rises. Likewise, the number of panels needed to install this generator as well as the cost of their acquisition increase. Therefore, the photovoltaic generator sizing, which takes into account other aspects (such as inverters and other accessories) in addition to the cost of acquiring the panels, becomes much more demanding both from a technical and financial point of view in areas of high groundwater depth. Subsequently, the implementation of this technology (photovoltaic pumping system) by small producers who are very often of limited financial capacity in Niger and in the Tillabéri region in particular, becomes very difficult in conditions of high groundwater depth.

4. CONCLUSION

At the end of this work, it appears that there is an enormous potential in solar energy throughout the year in the Tillabéri region of, characterized by a high duration of sunshine on the one hand, and a high capacity of production of solar energy of the environment per meter square, on the other hand. This would promote the proper functioning of solar generators as well as the popularization of solar pumping technology. This has also a great importance in improving the productivity and sustainability of small-scale irrigation in Niger by the fact that the solar energy pumping systems have a low operating cost. It is also an alternative to fossil fuels in a context of climate change. However, the number of panels required for this generator and consequently, the cost of their acquisition, condition the sizing and installation of these photovoltaic pumping systems in conditions of high groundwater depth. This would constitute a constraint in terms of investment for smallholders who are often of limited financial capacity. Hence the need to deepen the reflections aimed at facilitating the accessibility of solar pumping system technology to producers, in order to promote the expansion and sustainability of small-scale irrigation and boost its productivity.

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