DESIGN OF A SOLAR-POWERED INTELLIGENT DRIP IRRIGATION SYSTEM FOR GARDEN EGG *(solanum melongena)* and TOMATO (*Solanum esculentum*) IN MINNA, NIGER STATE – PART I

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Abstract

The trend in the advancement of irrigation system in developed nations is rapidly progressing, but reverse is the case in some developing countries with Nigeria inclusive. Irrigation has gone beyond only applying water to plants, but applying good quality water, of the right quantity and at the right time. This can only be achieved when proper design is prioritized. This research paper focuses on the design of a solar-powered intelligent drip irrigation system, which was designed to supply exact water for a small garden egg research plot. Study showed that soil in the study area have higher composition of clay particles, and are therefore classified as clay soil. This was also confirmed by its slow intake rate. The plant water requirements were approximately 4 mmday^{-1}*, time of irrigation is around 40 minutes with an average irrigation interval of 5days. The drip laterals, submain and mainline were designed as 0.40cm, 1.50cm and 1.7cm respectively. The pump capacity in kilowatt was computed as 0.046kW, which is approximately 0.1kW. The system is designed to be powered by 4 deep cycle batteries of 808Ah rating that will be charged by 8 mono-crystalline solar panel of 250W rating and a charge controller of 83.33A. It is recommended that selection of items for installation/construction should not be less in capacity compared with the designed ones.*

Keywords: Charge controller, Drip irrigation system, Nominal battery voltage and photovoltaic energy.

1. Introduction

There is an urgent need to scale up agricultural production in order to meet the needs of both industries and domestic users, especially in less developed countries and poverty-stricken regions, such as Sub-Saharan Africa and Latin America (Molden *et al.*, 2007). Increasing crop water productivity means more crops should be produced per every drop of water (Thakur *et al*., 2018). This has been the genesis of advancement in irrigation systems from the Stone Age manual watering technique to the present-day automated drip system.

Drip irrigation is a system of irrigation in which water is applied at a very low rate to individual plant, and such rates are accomplished through the use of specially designed emitters or porous tubes (Jibril, 2005). Khan *et al.*, (2014) stressed that drip irrigation system is a method with frequent, slow application of water either directly on the land or into the crop root zone rather than the entire land surface, which ensures optimum water content in the root zone. High water use efficiency, precision in water and fertilizers application are features of drip irrigation systems (Ko *et al*., 2009; Bracy *et al.*, 2003).

The design of a drip irrigation system is in two phases: agronomic design and hydraulic design (Egharevba, 2009). In the agronomic design, some specific data are needed (i.e. crop water demand, type of soil and data of drip emitters, among others). The hydraulic design is based on several data (characterization of chosen emitter, field topography, etc.). In order to design an irrigation subunit (drip line and sub main pipes), it is necessary to combine the hydraulic calculation (flow, diameters and pressure of drip line and sub main pipes) with the irrigation net distribution plan. Drip line calculation is the first part in the hydraulic design of a drip irrigation system. The number and the distribution of the emitters are the results of the design (Gyasi-Agyei, 2007). Most of these outlined specifications are lacking in most designs, leading to either over or under-design. This study therefore intends to design a drip irrigation system for eggplants and tomato, as well as the power requirement for the system.

2. Research Methodology

The research took place at the horticulture farmland of the Department of Crop Science, Federal University of Technology, Gidan Kwano Campus, Minna, Nigeria. The study area falls under the Guinea Savanna (i.e., comprising short grasses and scattered trees) of the tropical climate vegetation belt of Nigeria, having two (2) distinct seasons (rainy and dry seasons). The rainfall commences mostly in the months of March-April and terminates around October-November, with an annual rainfall amount of 1229 mm. Average maximum and minimum monthly temperatures are 34 and 27 ºC respectively. The lowest temperature is experienced in the month of August, while the highest is experienced in the month of March. The average daily sunshine hours recorded is 7.0. The geolocation of Minna is on the north and east hemisphere, stationed on Latitude $9^{o}\,36^{I}\,54.86^{II}$ N and Longitude $6^{o}\,32^{I}\,51.94^{II}$ E.

2.1 Design Procedures

2.1.1 *Agronomic design*

The site measurement was done using measuring tape and demarcation was aided with wooden pegs. The soil textural class was determined by the method of particle separation by suspension in accordance with (Globe, 2005). The water infiltration rate into the soil at the two selected points was accomplished by the use of double ring infiltrometer as described in Michael and Ojha (2006). The rate of infiltration was determined using equation 1:

$$I = \frac{d}{t} \qquad 1$$

Where I = infiltration rate in (*cm/min*), d is intake in (*cm*) and t = time taken in (*min*).

The wetted perimeter was determined by field planimetry method using the bucket type LPDI on the experimental plot with a single lateral line as described in (Awe *et al*., 2017). The wetted volume was obtained using equation 2.

$$V = \frac{\pi}{12} d^2 \left[2z + h - \frac{h^3}{(z-h)^2} \right] \qquad 2$$

Where, maximum diameter achieved of the wetted soil ellipsoid is denoted as (d) and maximum depth achieved is denoted by (z). Distance from the soil surface up to the maximum diameter is denoted by (h). The total available water content (TAWC) was determined in the laboratory in accordance with (Palada *et al.*, 2011). A known quantity of soil sample was first oven dry at 105 ºC and the weight noted. It is then wrapped in a light clothing material, socked in water until no visible bubbles seen. The sample was then removed and hanged; re-weighing was done after free water has completely drained. The difference in weight is determine and values recorded. Then total available water content (TAWC) in a gravimetric form is determined using equation 3:

$$\theta_g = \frac{(M_w - M_d)}{M_d} \qquad 3$$

Where, θ_g is gravimetric water content of the soil in g/g, M_w is the mass of moist soil, and M_d is mass of oven dried soil. Culturally, readily available water content (RAWC) is usually 50% of the total available water content (TAWC) (Doorenbos and Pruitt, 1977; Allen *et al.*, 2006; Palada *et al.*, 2011 and Dukes, 2012). The submissions of the above quoted authors were also utilized in this study. The plant water requirement was determined using the Modified Penman Monteith Equation as described in FAO (56) Manual (Allen *et al.*, 2006; Ighadun, 2012 and Alebachew, 2017):

i.e. $ET_c = ET_o\ X\ k_c$ 4

But,

$$ET_o = \frac{0.408\Delta(R_n G)+\gamma\frac{900}{T+273}U_2\left(e_{s-e_a}\right)}{\Delta+\gamma(1+0.34U_2)} \qquad 5$$

Where, *ETo* is reference evapotranspiration [mm day^{-1}], *Rn* is net radiation at the crop surface [MJ m^{-2} day^{-1}], *G* is soil heat flux density [MJ m^{-2} day^{-1}], *T* is mean daily air temperature at 2 m height [°C], U_2 is wind speed at 2 m height [ms^{-1}], e_s is saturation vapour pressure [kPa], e_a is actual vapour pressure [kPa], e_s-e_a is saturation vapour pressure deficit [kPa], Δ is slope vapour pressure curve [kPa °C^{-1}], *γ* is psychometric constant [kPa °C^{-1}], *ETc is* crop water requirement [mm day^{-1}] and K_c is crop coefficient.

The time of irrigation was determined using equation 6 as presented by (Khalifa, 2006):

$$T_i = \frac{V_w}{Q_e} \qquad 6$$

Where; T_i is time of irrigation in hours, V_w is volume of water applied in liters, and Q_e is emitter discharge in liters per hour.

The irrigation interval was determined as (Doorenbos and Pruitt, 1977; Richard *et al.*, 2006, Michael and Ojha, 2006) using equation 7:

$$I = \frac{d}{ET_c} \qquad 7$$

Where, *d* is depth of application at a defined time, ET_c is the crop water requirement of the specific plant under study; and *I* is the irrigation interval or irrigation frequency.

2.1.2 *Hydraulic design*

This is one of the most important aspects of drip irrigation system design, as it has to do with pipe sizes, their networking and water carrying capacities at a given time as well as the pumping unit that will provide the needed pressure required by the entire system. The drippers selected for this study are the button-necked pressure compensating type with a design discharge rate of 4 litres per hour, and was only one dripper per plant. Drippers of this discharge rate are chosen considering the soil type (clay loam) with slow intake rate, as well as volume of water held in the plant root zone. The expected number of dripper per lateral length of seven (7) meters was determined using equation (Palada *et al.,* 2011 and Naglic, 2014).

$$N_{dl} = \frac{L_l}{P_s} \qquad 8$$

Where, N_{dl} is the number of drippers per lateral line, L_l is the length of lateral line in meters (m), and P_s is the spacing between laterals in centimeters (cm). The lateral line diameter was designed using the Williams and Hazen Equation according to (Dasberg and Bresler, 1985) as presented by equation 9. However, lateral line spacing was maintained at 1m in accordance with the work of (Wondatir, Belay and Desta, 2013).

$$\Delta H = 14.03 \left[\frac{Q^{1.852}}{D^{4.871}}\right] L \qquad 9$$

Where; Q is the total flow into the lateral pipe *l*/s; D is the inside diameter of the lateral pipe, cm; L is the length of lateral pipe, m and; ΔH is total energy drop at the end of lateral or submain pipe, m.

The number of lateral line per submain line was determined using equation 10:

$$NL_s = \frac{L_s}{S} \qquad 10$$

Where, NL_s is the number of lateral line per submain line, L_s is the length of submain in meters, and S is the spacing between laterals in meters. The size of submain and mainline were also determined as the lateral line.

The system is expected to be the drum type Low Pressure Drip Irrigation System (LPDI), consisting of a 1000liters capacity drum with a major supply from a 2000liters capacity thermoplastic reservoir tank as shown in Figure 1. Water from the 2000liters on the surface will always be pumped to the 1000liters drum at a static head of 4 m.

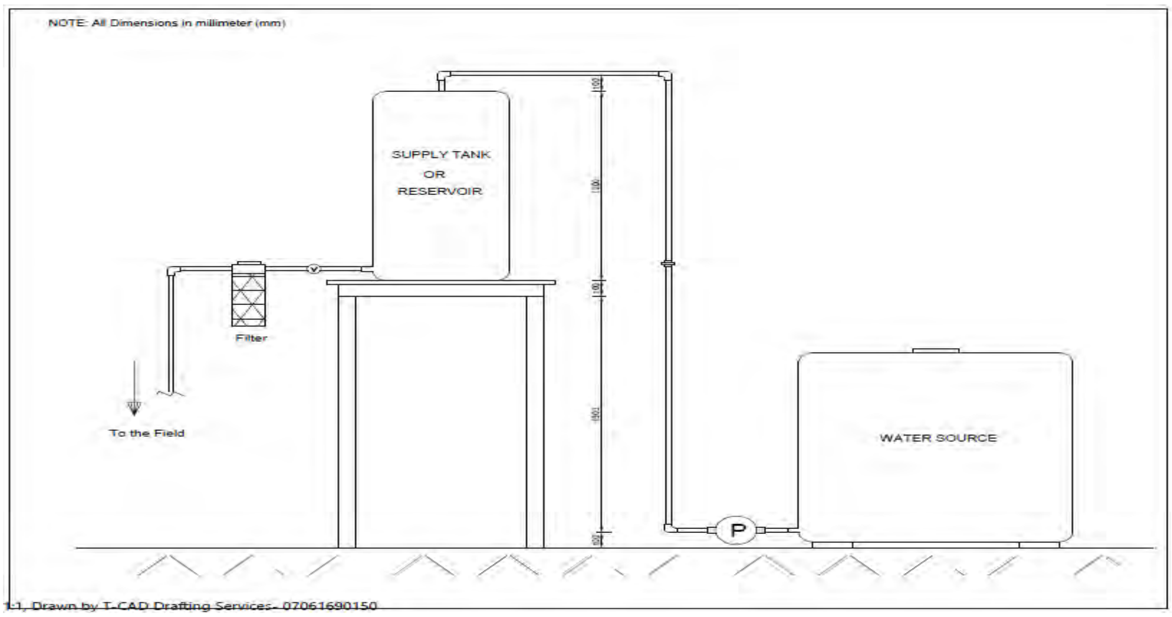

Fig. 1: System Reservoir Set-up

For this study, the pump capacity was determined using equation 11:

$$P_e = 9.81\frac{QH}{\eta} \qquad 11$$

Where; P_e is power required by the pump, Q is volume of water that must be lifted by the pump in a given time, and H (H_{st} + H_L + H_v) is total dynamic head. However, H_v is usually very small and could be neglect (Punmia *et al.*, 2002). This submission was also obeyed in this study. Also, the volume (Q) of water that must be lifted in a given time is determined using Lea equation presented as equation 12.

$$D = a\sqrt{Q} \qquad 12$$

Where, D is conveyance pipe diameter (m), and a, is constant which ranges between 0.97 and 1.22.

2.1.3 *System power requirement*

Automation simply implies replacing manual irrigation scheduling, which basically depends on human efforts with the smart system (i.e. machine-based). Items that will be connected together to accomplish all these functions of scheduling with little or without human aid are collectively termed hardware component of the system. For this study, the hardware components used include: Micro controller boards (i.e. Arduino board), soil moisture sensors, temperature and humidity sensors, automatic valves, water meters, relays and water level sensors.

The system power design was obtained by first determining the total load on the individual units of the system (Emmanuel, 2009; Al-Shamani, Othman, Mat, Ruslan, Abed and Sopian, 2017). They include the D.C pump, the arduino boards and its connected accessories, and solenoid valves. The D.C pump capacity is 0.37kW, and is expected to work for at most, one hour a day. The daily wattage-hour determined was noted and documented. The power to be consumed by the 40 solenoid valves was also determined by multiplying the power rating of each board by the time of usage. Power rating of each board is 10W, and since it is like the brain box of the system, it is expected to work 24hours each day. The solenoid valves are also 40 pieces, their total power rating was determined to be 200W, and are expected to work for one hour in every 5 days (that is, 0.2hour in a day). Daily wattage-hour for all was determined and documented. Total load connected was determined according to (Geofrey *et al.*, 2015) using equation 13:

$$L_T = L_P + L_A + L_S \qquad 13$$

Where, L_T is the total load on the system, L_P is the load by the pump, L_A is the load by the Arduino boards and L_S is the load by the solenoid valves. The total PV energy was determined by multiplying the total load connected by the losses as in Dhanne *et al*., (2014). Since PVs are not 100% efficient, a factor of 1.3 was considered in accordance with the solar energy best practices (Dhanne *et al.*, 2014). Total wattage of PV capacity was determined by dividing the total PV energy by the illumination per day. The average illumination per day was 7 hours (NiMet, 2015). Total panels required was determined by dividing total PV wattage by PV rating. However, the PVs are assumed to be of 250W rating. The power bank sizing was determined using equation 14:

$$B_c = \frac{T_L * D_a}{B_L * D_d * NB_V} \qquad 14$$

Where, B_c is the battery capacity in (Ah), T_L is the total load on the system in (Whr), D_a is the days of autonomy in (days), B_L is the battery losses (%), D_d is the depth of discharge in (%), and NB_V is the nominal battery voltage in (V). The charge controller sizing was determined by first dividing the PV wattage by its voltages and multiplying by the total number of PVs in parallel (Emmanuel, 2009). This was as presented in equation 15. The battery specifications and charge controller size determined were noted and included as the design requested.

$$CC_S = \frac{P_{Wt}}{P_V} * NP_p \qquad 15$$

Where, CC_S is charge controller size in (A), P_{Wt} is panel wattage rating in (W), P_V is panel voltage rating in (V), and NP_p is number of panels to be connected in parallel. For this study, the panels are rated 250W, 24V and all 8 panels are expected to be connected in parallel.

3. Result and Discussions

3.1 Result of Agronomic Design

The preliminary soil test indicated that samples obtained from points A and B, as well as their composite contain clay in higher proportion compared to other fractions of sand and silt, and therefore are classified as clay loam soils based on textural triangle. The dry bulk densities of the three (3) samples were found to be 1.48gcm^{-3}, 1.51gcm^{-3} and 1.46gcm^{-3} respectively. Gravimetric moisture content at saturation was 0.39gg^{-1} and by implication, every 1g of the soil sample has a void of 0.39% to be occupied by air or water when dry and wet respectively. This was in line with the submissions of Palada *et al.* (2011) that all soils culturally have an average of 55% solid composition and 45% space for either air at dry states or water when saturated.

The result of the infiltration rate indicates an infinitesimal intake rate in both points A and B, even as the test was carried out in late December. This also authenticates the result of the soil classification test which confirmed the soil to be clay loam. The rates of infiltration in the two (2) points are as low as 0.75cm/min and 1.0cm/min respectively as in Figures 3.1a and 3.1b. These low infiltration rates give an idea of selection of drippers with very low discharge that fits the soil water intake rate, in order to avoid runoff. The chart also indicates that after 40minutes, the water intake was almost zero. That is, there was stagnancy in water movement into the soil after this time, and any continues application will lead to wastage.

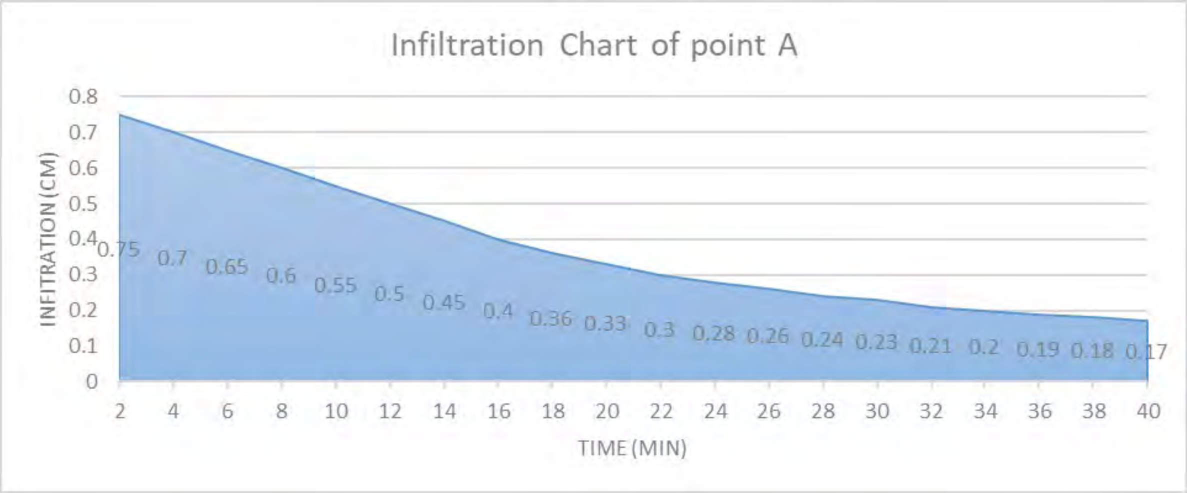

Fig. 2: Infiltration in (cm) by time (min)

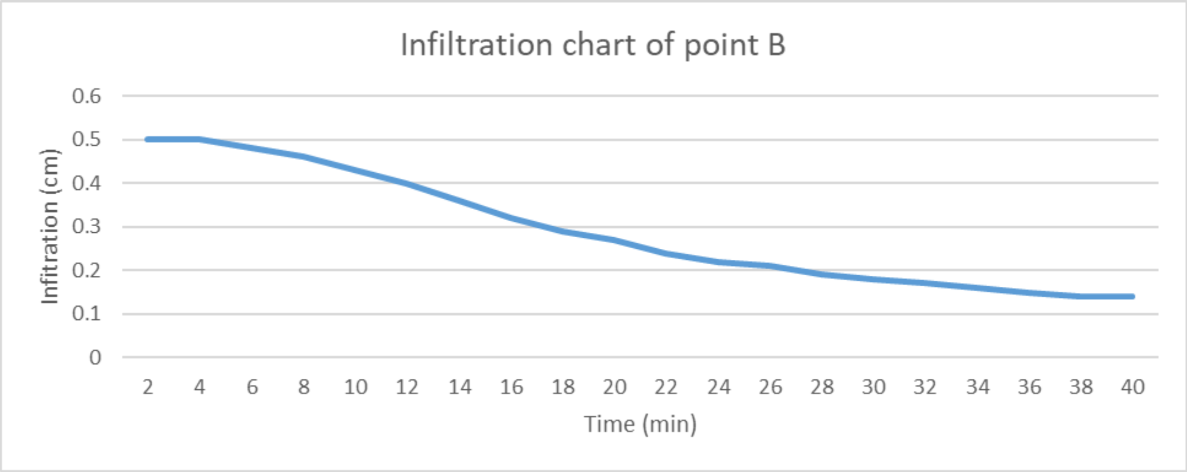

Fig. 3: Infiltration rate (cm) by time (min)

The soil pH was found to be 6.9, which is just slightly (about 0.1) above the recommended pH (between 5.5 and 6.8) for tomato and eggplant as in (NRC, 2006). Also, the concentration of available phosphorus was found to be 10.3mgg^{-1}; while concentrations of sodium, potassium, magnesium and calcium are 0.16, 0.13, 2.3 and 4.0 cmolkg^{-1} respectively. The average wetted perimeter and wetted depth are 37cm and 26cm respectively, this result also confirmed the fact that the soil in the area is a clay, as horizontal movements of water into clay soils in a given time intervals are always more than the vertical movements (Michael and Ojha, 2006).

3.1.2 *Result of crop water requirement*

The crop water requirement was for the intended growing periods (109 days) within the dry months of November, December, January and February as presented in Tables 1 and 2. It could be seen from Table 1 that the highest water requirement computed in (mmday^{-1}) for tomato is 6.45 mmday^{-1}, in the month of December, which is the mid-season stage of its growing period. The least is 3.33 mmday^{-1}, which is the harvesting period.

Also, the highest crop water requirement computed for the eggplant is 5.95 mmday^{-1} in the month of December, which was the development stage as presented in Table 2. The minimum water required is in the month of January with the value 3.60 mmday^{-1}. However, the research does not captured crop water requirement at the initial growing stages of both crops because all are expected to be first raise in nurseries and seedlings be transplant after one month (after the emergence of five true leaves). In all, seasonal (total growing period) water requirements for both crops are above 400 mmday^{-1}, this is in line with the work of (Wondatir *et al.*, 2013; Brouwer and Heibloem, 1986), which submits that seasonal water requirement of the crops is between 400 and 800 mm.

Table 1: Water requirement of tomato for the entire growing period in Minna

S/no	**Months**	**ETo determined**	**ETc for Tomato**	**Growth Period**	**Monthly ETc**
01	November	5.17 mmday^{-1}	4.40 mmday^{-1}	Development	131.84
02	December	4.96 mmday^{-1}	6.45 mmday^{-1}	Mid-season	193.50
03	January	4.50 mmday^{-1}	4.50 mmday^{-1}	Late season	135
04	February	5.12 mmday^{-1}	3.33 mmday^{-1}	Harvest	-
TOTAL					460.34mm

Table 2: Water requirement of eggplant for the entire growing period in Minna

S/no	**Months**	**ETo determined**	**ETc for Tomato**	**Growth Period**	**Monthly ETc**

01	November	5.17 mmday^{-1}	4.13 mmday^{-1}	Development	124.08
02	December	4.96 mmday^{-1}	5.95 mmday^{-1}	Mid-season	178.5
03	January	4.50 mmday^{-1}	3.60 mmday^{-1}	Late season	108
04	February	5.12 mmday^{-1}	-	Harvest	-
TOTAL					410.58mm

3.1.3 *Result of irrigation scheduling*

Result obtained as shown in Tables 3 and 4. The clay soil in the sample occupies more than 15cm of the total sample, and its readily available water (RAW) of 30mm was multiplied by the depth (26cm) in accordance with (Palada *et al.*, 2011), which gives a value of 7.8mm. This value was then multiplied by the wetted perimeter to obtain 3.36litres as volume of water held at the root zone of plant. The time of irrigation was about 45 minutes. Irrigation frequencies in days for tomato are computed to be 6days, 4days and 5days at the development, mid-season and late season stages respectively. Table 4 also showed similar outcome except for the irrigation frequencies. Unlike for the tomato, irrigation frequencies for eggplant are computed to be 7days, 5days and 7days at the development, mid-season and late season stages respectively. However, the average irrigation frequencies computed for tomato and eggplant are 5days and 6days respectively. This outcome was in line with the findings of (Dewidar, Ben Abdallah, Al-Fuhaid and Essafi, 2015).

Table 3: Irrigation Scheduling for Tomato throughout the growing season

Crop	**Soil Type**	**Depth of Water**	**Readily Available Water (litres)**	**Time of Irrigation (hours)**	**Irrigation Frequency**		
					Dev. Stage	Mid Stage	Late Stage
Tomato	Clay Loam	26cm	3.36L	40min	6days	4days	5days

Table 4: Irrigation Scheduling for Eggplant throughout the growing season

Crop	**Soil Type**	**Depth of Water**	**Readily Available Water (litres)**	**Time of Irrigation (hours)**	**Irrigation Frequency**		
					Dev. Stage	Mid Stage	Late Stage
Eggplant	Clay Loam	26cm	3.36L	40min	7days	5days	7days

3.1.4 *Result of hydraulic design*

Considering the slow water intake rate of the soil, a pressure compensating dripper was selected for the experiment. The dripper has an orifice of 0.0018mm, and a manufacturer's design discharge of 2litres/hour. Based on this discharge, a dripper is expected to discharge at most, approximately one litre of water at the base of a plant after every elapse time. For each lateral length of 7m, a total of six drippers was computed, thus making a total volume of 6litres ($6.0 \times 10^{-3} m^3$) per lateral line. Lateral line, submain line and mainline internal diameters were computed as 0.40cm, 1.50cm and 1.70cm respectively.

3.1.5 *Result of pump design*

For the pump capacity, it was assumed that diameter of pipe through which water will be lifted by the pump equals the selected mainline diameter (i.e., 0.022m). The Lea formula for determination of most economic diameter of pumping mains was utilized to determine the discharge as contained in Punmia *et al.*, (2002). Then the velocity of water was determined as 1.35m/s. Friction head losses through the pipe length and other fittings was computed as 0.57m, and the overall dynamic head was determined as 4.57m. The pump capacity in kilowatt was computed as 0.046kW, which is approximately 0.1kW. However, the smallest commercial electric powered pump for irrigation available was about 0.37kW (0.5HP), and therefore it is selected for the study.

3.1.6 *Result of system power requirement*

Table 5 presents the hardware used in the research, their power rating and total load on the entire system. The power requirement of the system was determined based on the total load of the system hardware in accordance with Geofrey *et al.* (2015). The load by the pump, by the Arduino board and the solenoid valves are 185Whr, 9600Whr and 100Whr respectively. The total load on the entire system was determined to be 9,885Whr/day.

Table 5: The hardware used in the research, their power rating and total load

Items	Quantity	Power rating (W)	Total power rating (W)	Time of Usage (hrs)	Energy Required (Whr)	Total Load (Whr/day)
Arduino Board	40	10	400	24	9600	
Pump	01	370	370	0.5	185	
Solenoid Valves	40	5	200	0.5	100	
Total Load						9,885 Whr/day

The total PV energy needed was determined as 12,850.5Whr/day, total PV wattage needed is 1,835.79W, and number of PV panels needed was determined to be 7.34 at a rating of 250W. Based on the solar energy best practices (Al-Shamani *et al.*, 2017), a total of 8 panels is selected for this research work. The battery bank size was determined as 807.60Ah, and the number of batteries needed to power the entire system were 4.04 (approximately 4 batteries). Based on this result, the four (4) batteries needed should be rated 808Ah, 12V in order to properly take care of the 12 hours (0.5day) day of autonomy. More so, since the panels are rated 250W, 24V, all the 8 panels must be connected in parallel, this will make expected current passing through as 10.42A. Based on these specifications therefore, the size of solar charge controller required for this research work is rated 83.33A.

4. Conclusion and Recommendations

The study concentrated on design of a solar-powered smart drip irrigation system to irrigate garden egg and tomato in Minna. Study showed that soil in the study area have higher composition of clay particles, and are therefore classified as clay soil. This was also confirmed by its slow intake rate. The plant water requirements were approximately 4 mmday^{-1}, time of irrigation is around 40minutes with an average irrigation interval of 5days. The drip laterals, submain and mainline were designed as 0.40 cm, 1.50 cm and 1.70 cm respectively. The pump capacity in kilowatt was computed as 0.046 kW, which is approximately 0.1 kW. The system is designed to be powered by 4 deep cycle batteries of 808Ah rating that will be charged by 8 mono-crystalline solar panel of 250W rating and a charge controller of 83.33A.

References

Alebachew, K. (2017). Evaluation of Deficit Irrigation and Mulching on Water Productivity of Tomato (*lycopersicon esculentum mill*) under Drip Irrigation System at Kallu Woreda, South Wollo, Ethiopia. A Thesis Submitted to the Postgraduate Program Directorate through the School of Water Resource and Environmental Engineering, Haramaya University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Irrigation Engineering.

Allen, R. G. Pereira, L. S. Raes, D. and Smith, M. (2006). Crop Evapotranspiration: guidelines for Computing Crop Water Requirements. FAO-56, Rome.

Al-Shamani, A. N. Othman, M. Y. Mat, S. Ruslan, M. H. Abed, A. M. and Sopian, K. (2017). Design and Sizing of Stand-alone Solar Power Systems A house Iraq. Recent Advances in Renewable Energy Sources, 145-150.

Awe, G. O. Abegunrin, T. P. Ojediran, J. O. and Oyetoro, O. O. (2017). Performance Evaluation and Characterization of Wetted Soil Parameters of Improvised Mediemitters Installed in a Drip Irrigation Tomato field. *International Journal of Environment, Agriculture and Biotechnology (IJEAB) Vol-2(1):* 319-328. http://dx.doi.org/10.22161/ijeab/2.1.41.

Bracy, R. P. Parish, R. L. and Rosendale, R. M. (2003). Fertigation Uniformity Affected by Injector Type. Hort. Technology, Vol. 13(1): 103-105.

Doorenbos, J. and Pruitt, W. O. (1977). Guidelines for Predicting Crop Water Requirements. FAO Paper 24. Rome.

Dukes, M. (2012). Smart Irrigation Controllers: What Makes an Irrigation Controller Smart?" In Institute of Food and Agricultural Sciences, University of Florida.

Dhanne, B. S. Kedare, S. and Dhanne, S. S. (2014). Modern Solar Powered Irrigation System by using Arm. International Journal of Research in Engineering and Technology, Vol. 3(3): 20-25.

Egharevba, A. N., (2009). Irrigation and Drainage Engineering: Principles, Design and Practices. Second Edition, Jos University Press, Nigeria.

Geoffrey, G., de Dieu, M. J., Pierre, N. J., and Aimable, T., (2015). Design of Automatic Irrigation System for Small Farmers in Rwanda. *Journal of Agricultural Sciences.* 6, 291-294. http://dx.doi.org/10.4236/as.2015.63029.

Igbadun, H. E. (2012). Estimation of Crop Water Use of Rain-Fed Maize and Groundnut Using Mini-Lysimeters. *The Pacific Journal of Science and Technology, Vol. 13(1): 527-535.*

Jibril, I. (2005). Design and Construction of Drip Irrigation System for Bosso Estate Mosque Orchard, Minna, Niger State. Thesis Submitted to the Department of Agricultural Engineering, in Partial Fulfilment of the Requirement for the Award of Bachelor Degree in Engineering. School of Engineering and Engineering Technology, Federal University of Technology, Minna, Niger State.

Khalifa, A. B. A. (2012). Comparison of Surface and Drip Irrigation Regimes for Banana (Musa AAA) cv. Grand Nain in Gezira, Sudan. A Thesis Submitted to the Sudan Academy of Sciences in Fulfillment of the Requirements for Degree of Master of Science in Agriculture (Soil and Water Sciences). University of Khartoum, Sudan.

Khan, G. D. Ali, A. and Akbar, F. (2014). Assessment of Coefficient of Variation of Emitters Flow Rate with Respect to Design, Manufacturers and Plugging in Installed Drip Irrigation Systems at Selected Sites of Peshawar valley. Adv. Life Sci. Tech., 19: 27-32.

Ko, J. H. Piccinni, G. and Steglich, E. (2009). Using EPIC Model to Manage Irrigated Cotton and Maize. Agricultural Water Management, Vol. 96(9): 1323-1331.

Michael, M. A. and Ojha, T. P. (2006). Agricultural Engineering, 5th Edition, Volume II. Jain Brothers, New Delhi, India.

Molden, D., Frenken, K., Barker, R., de Fraiture, C., Mati, B., Svendsen, M., Sadoff, C., Finlayson, C.M., Attapatu, S., Giordano, M., Inocencio, A., Lannerstad, M., Manning, N., Molle, F., Smedema, B., Vallée, D., (2007). Trends in water and agricultural development. A Comprehensive Assessment of Water Management in Agriculture: 1-18. Earthscan. London, United Kingdom and International Water Management Institute (IWMI). Colombo, Sri Lanka.

Palada, M. Bhattarai, S. Wu, D. Roberts, M. Bhattarai, M. Kimsan, R. and Midmore, D. (2011). More Crop Per Drop. Using Simple Drip Irrigation Systems for Small-scale Vegetable Production. AVRDC – The World Vegetable Center, Shanhua, Taiwan. AVRDC Publication No. 09-723. 83p.

Punmia, B. C., Ashok, J., and Arun, J., (1995). Water Supply Engineering I. 2nd Edition, Laxmi Publications Limited, New Delhi.

Richard, G. A. (1998). Crop evapotranspiration: guidelines for computing crop water requirements. FAO, Rome. ISBN 92-5-104219-5.

Thakur, S. Pyasi, S. K. Yadav, B. K. Shrivastava, R. N. Sharma, S. K. and Singh, R. B. (2018). Hydraulic Performance of Drip Irrigation in Tomato - A Review. *International Journal of Current Microbiology and Applied Sciences*, Volume 7(5). https://doi.org/10.20546/ijcmas.2018.705.246.

Wondatir, S. Belay, Z. and Desta, G. (2013). Effect of Drip Lateral Spacing and Irrigation Regime on Yield, Irrigation Water use Efficiency and Net Return of Tomato and Onion Production in the Kobo Girrana Valley of Ethiopia. Proceedings of the Nile Basin Development Challenge Science Meeting, Addis Ababa, 9 –10 July 2013.

Wu, G. Liu, Y. and Wang, T. (2007). Methods and Strategy for Modeling Daily Global Solar Radiation with Measured Meteorological Data – A Case Study in Nanchang Station, China. Energy Conversion and Management 48: 2447-2452.