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Design and Selection of Best Pump Capacity for a Solar-Powered Smart Drip Irrigation System for Tomato (*Lycopersicum esculentum*) in Mokwa, Nigeria

Jibril, I[1]., Adeoye, P. A[2]., Olorunsogo, S. T[2]., Zubair, S[3]. and Adesiji, A. R[4].

[1]Department of Agricultural Technology, Niger State College of Agriculture, P. M. B. 109, Mokwa, Nigeria; abbatee2007@gmail.com
[2]Department of Agricultural and Bioresources Engineering, Federal University of Technology, P. M. B. 65, Minna, Niger State, Nigeria; peter.adeoye@futminna.edu.ng
[2]Department of Agricultural and Bioresources Engineering, Federal University of Technology, P. M. B. 65, Minna, Niger State, Nigeria; olorunsogosam@yahoo.com
[3]Department of Telecommunication Engineering, Federal University of Technology, P. M. B. 65, Minna, Niger State, Nigeria; zubairman@futminna.edu.ng
[4]Department of Civil Engineering, Federal University of Technology, P. M. B. 65, Minna, Niger State, Nigeria; ade.richard@futminna.edu.ng
Corresponding Author: *abbatee2007@gmail.com*

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ABSTRACT

The trend in the advancement of irrigation system in both developed and developing nations of the world is amazingly progressing. It has gone beyond only applying water to plants, but applying good quality water, right quantity and at the right time. This can only be achieved when proper pump design and selection is prioritized. This research paper focuses on the design and selection of best pump capacity for a solar-powered smart drip irrigation system for tomato in Mokwa, Nigeria. The preliminary result obtained indicated that the soil of the area is loamy sand, with gravimetric moisture content of 0.39gg^{-1} for every 1g at saturation. Time of irrigation and irrigation frequency obtained are 90minutes and 3days respectively. Total volume of water required by plants to attain maturity stage is computed to be 4,260 litres. Based on the total volume of water obtained, two reservoir tanks of 5,000 and 2,500 litres capacities, to serve as ground and overhead respectively was suggested for the work. The conveyance pipe diameter was determined as 0.027m, velocity of water through the conveyance pipe was determined as 1.35m/s, the overall dynamic head was determined as 4.57m and pump capacity in kilowatt was computed as 0.046kW, which is approximately 0.1kW. The pump is designed to lift water into the overhead tank only, which will fall by gravity by action of the automatic valves through lateral lines as at when needed by the plants. However, the smallest commercial solar-powered pump for irrigation available was about 0.37kW (0.5HP), and therefore it is selected for the experiment. It is recommended that design specifications are obeyed during installations.

1. INTRODUCTION

Throughout the history of the earth, climates (global, regional, and local) have never been static. The non-static natures are in various magnitudes ranging from variability through fluctuations, trends, and abrupt to gradual changes. Analyses of proxy data from tidal waves, and changing sea and lake levels have shown that climatic changes have been dramatic on time scales of 10,000 years or more (Adakayi, 2012). This has been linked to

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non-uniform rainfall throughout the world, coupled with increasing human population and their anthropogenic activities, consequently leading to food shortage. The increase in human population forced man to think of alternative means of all year round farming, which finally gave birth to irrigation (Jibril, 2006). As important as it is, irrigation has its own bad sides if not practice in accordance with the norms governing its theory and practice.

According to Shinde and Wandre (2015), irrigation is a well-established procedure on many farms and is practiced on various levels around the world. It allows diversification of crops, while increasing crop yields. However, typical irrigation systems consume a great amount of conventional energy through the use of electric motors and generators powered by fossil fuel, most especially when proper system design and execution is not respected. Proper design of an irrigation system requires that the pumping system be precisely matched to the irrigation distribution system. Then the pressure and flow rate required can be efficiently provided by the pumping system (Haman and Zazueta, 2014).

A pressurize irrigation system like the drip cannot do without water pump, because a certain force is required to raise and drive specific volume of water at a time from its source to point of discharge. According to Egharevba (2009), irrigation requires that water be raised from a source to the field surface where it can be used by the plants using an irrigation pump, which perhaps could be placed closed to the water source itself. Several literatures have shown that a quite number of pumps exist, which are used for both irrigation and drainage. Among the readily available are the propeller, centrifugal and the reciprocating or the piston types (Egharevba, 2009). Most importantly, in the selection of pump for a specific irrigation system, relationship between head and pump capacity at different speeds must be put into considerations, as well as efficiency of the pump. For an efficient result, the selection of pump for any irrigation activity should be based on careful analysis of the prevailing discharge and head combinations under which the pump is to operate in relation to its characteristics.

Egharevba (2009) maintained that pumping requirements for irrigation vary considerably depending upon certain factors such as water source, method of irrigation as well as the size of area under irrigation command. By implication, if pump selection for irrigation is not based on these three factors itemized, there will be likely no better result. This has been the practice of our local farmers that practices dry season farming all over Nigeria, and has been the major source of soil nutrient loss, with consequent effect on yield. This research paper therefore, look at design of an irrigation pump, select actual pump capacity and test to ascertain the efficiency of the locally designed drip system.

2. METHODOLOGY

Description of Study Area

The research took place at the Orchard of the Niger State College of agriculture Mokwa. Mokwa Local Government Area of Niger State is an agrarian domain, occupying a strategic land area with maximum potential for all year round crop farming. The potentials in the study area had been observed long before now, which led to the citation of a good number of agricultural institutions, owned by government at all levels, as well as some non-governmental agencies (i.e. Ahmadu Bello University Farms, National Cereal Research Institute, International Institute of Tropical Agriculture, Golden Penny Farms, Ultra-Modern Abattoir, Cattle Ranch e.t.c). Mokwa town is on the trunk A1 highway in the west of the State. The long southern border of the local government area is formed by the Niger River from Lake Jebba in the west beyond the confluence of the Kaduna River in the east (Figure 1).

The study area falls under the Southern 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 April-May and terminates around October-November, an average annual rainfall amount of 1229mm, with highest amount (260mm) mostly in September, and the least amount (0.1mm) in January. Average maximum and minimum monthly temperatures are 34 and 27 ^oC respectively, and an average daily sunshine hours of 7.0. It has a total land area of approximately 4,338km^2 (1,675 sq mi) and an estimated human population of 244, 937 (NPC, 2006), predominantly Nupe speaking people. Geographically, it is on the north and east hemisphere, stationed on Latitude 9^o 17' 41.35" N and Longitude 5^o 03' 14.83" E., politically it is a local government area in the Zone A senatorial district (Wikiwand, 2021).

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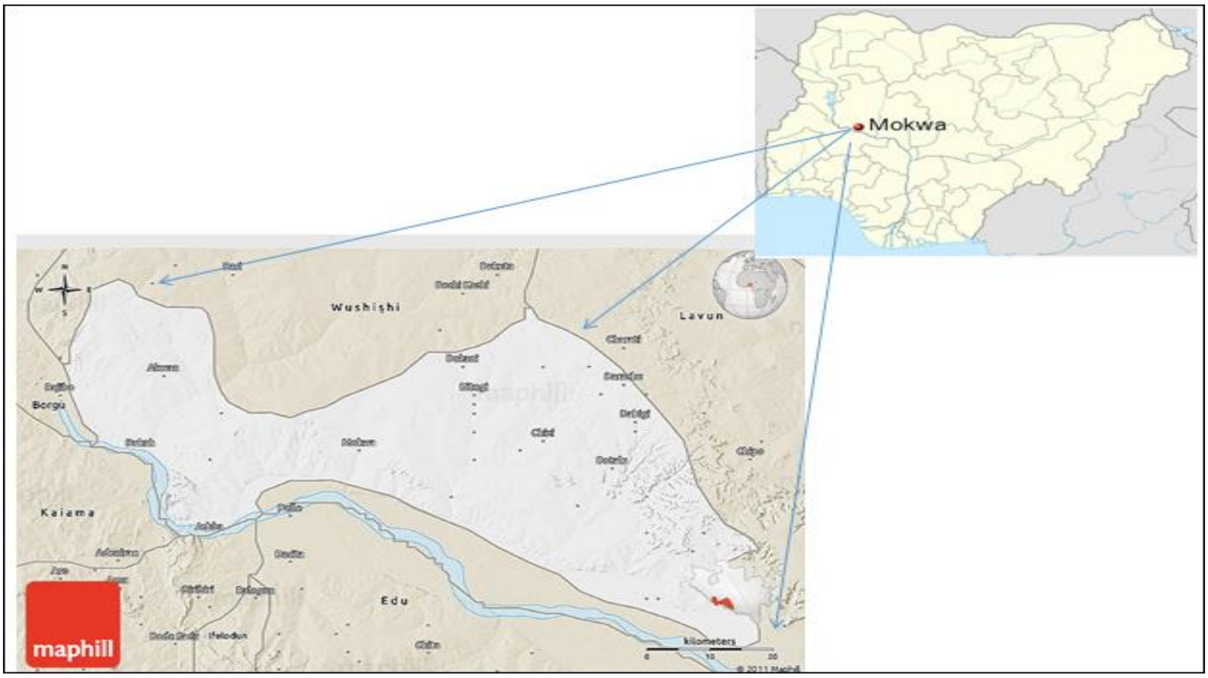

Figure 1: Map of Nigeria showing the location of the Study Area. (Source: www.wikiwand.com)

Materials

In order to determine the best pump capacity for the system, important parameters were considered, which include; climatic condition of the study area, soil type and its infiltration capacity, land topography, type of plant to be irrigated and its water requirement, irrigation scheduling, reservoir capacity and its height above the ground, type of drippers and their discharge rates.

Procedures

A reconnaissance survey was conducted to determine the slope of the land, to know the appropriate direction or position for placing the reservoir tank as specified in (Egharevba, 2009). Soil samples were collected from the field using soil auger at two (2) different points, placed in polythene bags, labeled appropriately before laboratory tests. Preliminary tests conducted include the soil water infiltration test, soil textural class determination, wetted perimeter test and soil chemical properties. The land was measured 15m x 10m, land clearing and bed making was prepared manually using local farming tools. Beds of length, breadth and height of 10m x 0.5m x 0.3m was prepared respectively.

Irrigation Design Procedure

Net Irrigation Water Requirement (NIWR)

Net Irrigation Water Requirement (NIWR) is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity. The net depth of irrigation in this research was determined from Readily Available Moisture (RAW) using Equation 1 in accordance with (Edoga and Edoga, 2006):

$$RAW = (MAD)AW \qquad 1$$

Where; RAW is readily available water (mm), MAD is maximum allowable deficiency, and AW is available water. It can be expanded as in Equation 2:

$$RAW = \frac{(MAD)(D_{rz})(FC - PWP)(P)}{100} \qquad 2$$

MAD for most plants is culturally 0.5, the average effective rooting depth (D_{rz}) of tomato (*solanum spp*) is 70cm; P = area wetted as a percent of the total area, and it is estimated to be 80%. Result obtained was noted and tabulated.

Gross Irrigation Water Requirement (GIWR)

The gross irrigation requirement is the total amount of water applied throughout irrigation. The gross irrigation water requirement for this research was determined as the net irrigation depth divided by the application efficiency in accordance with (Alebachew, 2017) Equation 3:

$$GIWR = \frac{NIWR}{E_a} \quad 3$$

Where; E_a is the irrigation application efficiency, and other parameters are as earlier defined. Since the system is the drip type (i.e. with an application efficiency of between 85-90%), 85% is used as the system application efficiency.

Time of Irrigation

This is the time taken for the soil voids (within plants root zone depth) at different point of the experimental site to be filled with water after irrigation. This was determined according to (Khalifa, 2012) as presented in Equation 4:

$$T_i = \frac{V_w}{Q_e} \quad 4$$

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

Considering a single ridge; Length of ridge = 5m, width of ridge = 0.4m, area of ridge = 2.0m^2. Amount of water required in the plot is given by:

$$A_w = A_r \times L_r \times G_d \quad 5$$

Where; A_w is amount of water needed in plot (L), A_r is the area of a ridge in a plot (m^2), L_r is the total number of ridge in a plot = 6, G_d is the gross irrigation depth = 0.011866m. The amount of water needed to wet a single ridge to a required gross irrigation depth was determined. On every ridge, a total of 15 tomato stand is expected, therefore each stand is expected to receive certain quantity of water, which was determined and tabulated.

Irrigation Interval

This simply described how frequent will the irrigation be, that is at what interval of hours or days will the next irrigation take place. Knowing the depth of water to apply in the soil root zone, the irrigation interval or frequency was determined as (Doorenbos and Pruitt, 1977; Richard *et al.*, 2006, Michael and Ojha, 2006) using Equation 6:

$$I = \frac{N_d}{ET_c} \quad 6$$

Where; N_d is net irrigation application depth (mm) at a defined time, ET_c is the crop water requirement of the specific plant under study; and I is the interval or irrigation frequency of irrigation.

Now, the net irrigation depth is determined using Equation 7 as contained in (Edoga and Edoga, 2006):

$$RAW = (MAD) \times (D_{rz}) \times (F_c - PWP) \times {}^{(P)}/_{100} \quad 7$$

Where, RAW is the soil readily available water, D_{rz} is effective rooting depth (established as 0.7m), P is the allowable depletion which is culturally 50%, and $(F_c - PWP)$ gives the difference between field capacity and permanent wilting point.

Pump Capacity Design Procedure

On the design of pump capacity, the power needed by pump to drive water from a surface water source to an overhead point is determine in accordance with (Punmia, *et al.*, 1995) using Equation 8:

$$P_e = 9.81 \times {}^{HQ}/_{\mu} \quad 8$$

Where; P_e is Power of pump, Q is Total discharge, H is Total maximum head, and μ is pump efficiency.

Determination of the total maximum head

The total maximum head H, against which the pump is required to operate is given by Equation 9:

$$H = H_s + H_L + H_V \qquad 9$$

Where: H is total maximum head in meters, H_s is total suction head (or lift), H_L is total head loss (including losses through valves, bends and other pipe fittings) through the suction and delivery pipe., H_V is velocity head at all discharge points.

But $H_L = h_f + {KV^2}/{2g}$ 10

$$\text{And, } h_f = {flV^2}/{2gd} \qquad 11$$

Where: h_f is Friction head loss, f is Friction factor along length of pipes, V is Velocity of flow, g is acceleration due to gravity, d is diameter of pipes and K is friction factors due to pipe fittings.

Also, from $Q = AV$ 12

$$V = {Q}/{A} \qquad 12a$$

$$V = {4Q}/{\pi D^2} \qquad 12b$$

Where: Q, A and D are discharge from pipe (m^3/s), area of pipe (m^2) and diameter of pipe (m) respectively. The volume (Q) of water that must be lifted in a given time is determined using Leah Formula presented as Equation 13:

$$D = a\sqrt{Q} \qquad 13$$

Where: D is conveyance pipe diameter (m), and a, is constant which ranges between 0.97 and 1.22. The types and number of fittings to be use for installations are presented in Table 1, while system reservoir set-up is as presented in Figure 2. Water will be lifted automatically from the surface to the overhead reservoir by action of the micro-controller, and be allow to fall by gravity to the field when needed.

Table 1: Type and Number of Pipe Fittings to be use

S/no	Types of fittings	Number of fittings	K-value for each fittings	Total loss by group of fittings
1	Elbow connector	4	0.5	0.108m
2	Union connectors	2	1.5	0.717m
3	Sockets	4	0.3	0.144m
4	Nipples	4	0.3	0.144m
5	Union	3	0.3	0.144m
6	Gate valve	2	0.3	0.144m

3. RESULTS AND DISCUSSION

The preliminary result obtained indicated that the soil is loamy sand. Gravimetric moisture content of 1g of the composite sample 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 outcome was in line with the submissions of Palada *et al.*, (2011) in which it was stressed that soil samples have basically about 55% solid components. As contained in Table 2, the average wetted diameter obtained was 23.2cm, average point of shrinkage was 20cm and the average depth was 8.5cm. This means that, soil moisture sensing device should not be placed beyond the average wetted diameter around the plant, and should be within the average depth.

On the system design, expected depth of water applied in (litres), readily available water in the soil root zone, time of application in (hours) and irrigation frequency in (days) are determined, and the result are as presented in Tables 3 and 4. From Table 3, the length and width of ridge considered are 5000mm and 400mm respectively. This gave a net irrigation depth of 10.08mm and gross irrigation depth of 11.86mm. Each plot is expected to have six (6) ridge with ten (10) plants on each, thus making a total of sixty (60) plant stands per plot. Total volume of water in liters required to give a plot an effective wetting pattern was determined as 142litres.

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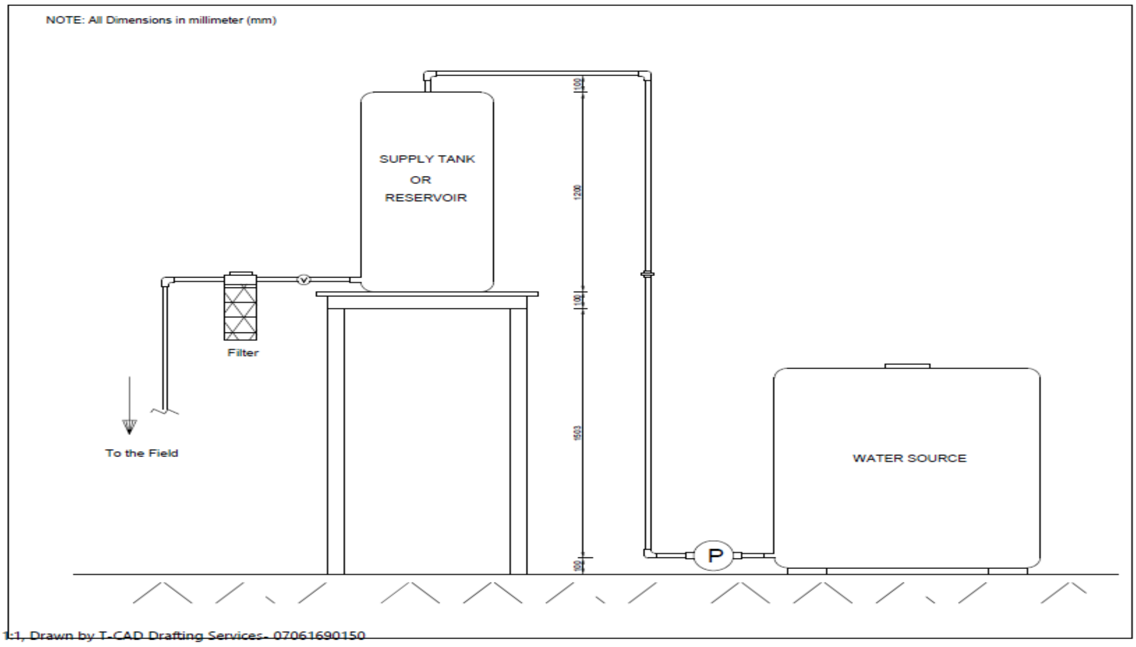

Figure 2: System Reservoir Set-up

Table 2: Parameters of wetted perimeter test

S/No	D (cm)	d (cm)	Z (cm)	h (cm)
1	19.50	24	8.9	5.40
2	20.20	22.6	8.1	4.90
3	20.50	23	8.5	4.20
Average	20.0	23.20	8.50	4.83

Also, for ten plant stands per ridge as presented in Table 4, the volume of water needed by each plant on every irrigation period is 2.4 litres. By this, a total of 24 litres is needed to give a ridge an effective wetting pattern. Total volume of water required by plants to attain maturity stage is computed to be 4,260 litres. Based on the total volume of water obtained, two reservoir tanks of 5,000 and 2,500 litres capacities, to serve as ground and overhead respectively was suggested for the work. The rate of transpiration at different growing stages also differs. At the earlier growing stage when the plant cover is about 20%, the daily average transpiration rate was 1.78mm. This was different with those at mid and late growing stages which are 4.14mm and 7.10mm respectively.

This outcome was in line with the submission of (Palada *et al.,* 2011) which maintained that the lesser the plant cover, the lesser the transpiration rate of the plants. So also the more the plant cover, the more the transpiration rate. It should be noted however that, the sum of evaporation and transpiration (evapotranspiration) makes up the plant consumptive use. But since water use for plant metabolism is less than one percent (< 1%) (Michael and Ojha, 2006), consumptive use or crop water required is almost exactly that amount of vapour that escaped from both plants and their surrounding surfaces.

The time of irrigation, otherwise known as irrigation duration was supposed to be the time at which soil water intake during infiltration test was almost constant. This phenomenon was attained in a time interval of 40 to 45minutes during the field test. But in the calculation, it was obtained as approximately one and a half hour (that is, 90 minutes), which is in conformity with the wetted perimeter test.

The irrigation frequency determined was 3days. The result is almost similar with the outcome of Edoga and Edoga (2006) in which irrigation interval was determined to be 4days in Minna, a neighboring town to the study area. In all, since transpiration rate determined is not uniform, it signifies non-uniformity of water consumption by crop at different growing stages. This outcome was in line with the findings of (Dewidar *et al.*, 2015), in which it was maintained that crops require more water in their development stage than any other stages of growth.

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. 0.027m). 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 through the delivery pipe 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 experiment.

4. CONCLUSION

The research paper concentrated on the design and selection of the best pump capacity of a solar-powered smart drip irrigation system for tomato in Mokwa, Nigeria. Results for preliminary study were obtained. Based on the total volume of water determined for the plants to grow until maturity, two reservoir tanks of 5,000 and 2,500 litres capacities are recommended. The overall dynamic head was determined as 4.57m and pump capacity in kilowatt was computed as 0.046kW, which is approximately 0.1kW. The pump is designed to lift water into the overhead tank only, which will be release to the field by the action of automatic valves as at when needed by the plants. However, the smallest commercial solar-powered pump for irrigation available was about 0.37kW (0.5HP), and therefore it is selected for the experiment. It is therefore recommended that all design specifications be followed during installations.

Acknowledgment

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Table 3: Values of Irrigation Scheduling (I)

Length of Ridge	Width of Ridge	Net Irrig. Depth	Gross Irrig. Depth	No. of Ridge per Plot	Vol. of Water per Plot
5000mm	400mm	10.08mm	11.86mm	6	0.142 m^3
5m	0.4m	0.01008m	0.01186m		142L

Table 4: Values of Irrigation Scheduling (II)

Vol. of Water per Plant Stand	Number of Plant per Ridge	Time of Irrig. (hours)	Irrig. Interval (days)	Average Transpiration at 20, 50 and 80% Cover		
2.4L	10	1.48 (≈ 1.5)	3.1	1.78mm	4.41mm	7.1mm

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