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REVIEW ARTICLE

THE PLACE OF SUPPLEMENTARY IRRIGATION: AGRICULTURE AND SUSTAINABLE RURAL TRANSFORMATION STRATEGY IN A CHANGING CLIMATE: A REVIEW

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ABSTRACT

Farmer productivity has been experiencing some decline for some decades now. There is some evidence that internal push factors such as conflicts, policy failure have affected productivity, Climate change impacts have contributed greatly to the decline in yield making rural farmers the most affected. Climate Smart Agriculture however presents nouvelle community-based approaches for farmers to adapt and mitigate these impacts of climate change on their production whiles improving their incomes. This review paper models a supplementary irrigation system as a solution to the crop water stress caused by climate change. The system provided the required water to the crops resulting in optimal development and improved yields of the rice farm it was modelled for. The paper used data from Tungan Macheri community in Kebbi state, Nigeria and climate data of 1987 to model the supplementary irrigation system for a 0.5 hector rice farm. CLIMWAT and CROPWAT tools from FAO were used to obtain some climatic parameters in relation to farming, generate the various developmental stages of the rice crop and their corresponding crop factor (kc) values. The Blaney-Criddle approach was used to calculate the water requirements of the crop. A 13.41m^3 surface reservoir will be sufficient to provide the right amount of water to the 0.5 hector rice farm for optimum productivity. This reservoir will be supplied from rainfall runoff from a watershed area of 14,184.41m^2.

KEYWORDS

Supplementary irrigation, Blaney-Criddle Approach, Crop water needs, Climate Smart Agriculture

1. INTRODUCTION

Rice is one of the most cultivated cereal staples that feed over half of the world's population (Dogara and Jumare, 2014). This translates to about 3.5 billion people worldwide who regard rice as their staple (Lanessa 2017). Mainland China alone produced 141,310,620 tons of the 505 million metric tons of milled rice in 2020. In the same 2020, 25,272,498 of rice was produced in Africa with Nigeria being the leading producer of 5.4 million tons (FAOSTAT, 2022). Sub-Saharan Africa remains a major market for rice from China and India partly because of the production deficits experienced in the region. West Africa accounts for 52% of the 25 million tons produced in Africa. Rice is very much patronised and produced in almost all African countries (Imolehin and Wada, 2000). Landlocked countries like Burkina Faso and Niger are gradually increasing their rice production quantities through irrigation from facilities like the Bagri dam, 'Fleuve Niger' and other irrigation scheme.

Rice production has contributed to the development of many communities in Nigeria. High production capacities have improved farmer's incomes whiles the many culinary uses have also generated varied incomes for small medium and large businesses. The volatility of rice production in Nigeria resulting from climatic and systemic factors have often led to declining food/rice sufficiency, culminating to increased market prices and other forms of inequalities (Oludare, 2014). These shocks may be contributing to the negative production quantities. For instance, in 2017, production quantities of 3.7 million tons as against the 6.4 million tons demanded was recorded in Nigeria with a 4.7% growth in per capita consumption (Erhie et al., 2018). Rice imports also saw a marginal 22% increase in 2016. Some researchers have recommended that increasing agriculture mechanisation would increase the 57% or 3.7 million tons of domestic rice production to 7.2 million tons over the next 5 years (Pricewaterhouse Coopers, 2018).

Climate Change impacts is resulting freshwater scarcity globally with Sub-Saharan Africa and the Sahel regions being the worse affected. Agriculture remains the largest user of freshwater accounting for about 70% of the global freshwater stock (D'Odorico et al., 2020). A reduction in water availability will lead to significant effects on agriculture. There is therefore the need to adopt Climate Smart Agricultural strategies that will ensure effective water management and constant water supply to increase productivity amidst the unfavourable climatic impacts. For instance, the Savannas and tropics are experiencing unprecedented droughts with declining rain volumes resulting in a reduction in an estimated 25% of upland crop production (Mohammed et al., 2015; Jeong et al., 2010). Ironically, higher yields are often recorded in the dry seasons than in the raining seasons drawing from national statistics. For instance, an average of 3.05 tons per hector was recorded during the dry season as against an average of 1.85 tons per hector in the raining season in Nigeria. This could be attributed to intensive irrigation by (Udemezue, 2018).

This review paper will design a model supplementary irrigation system for rice production in Tungan Macheri, Kebbi state, Nigeria. It is a major

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'*rice basket'* of the country. The Kebbi state has about 70,000 farmers engaged in rice production. Some civil servants and other white-collar workers engage in rice farming to generate additional income. The project will provide supplementary irrigation as a sustainable solution to increasing production amidst impacts of the changing climate. This will provide water when the soil water content is below 7mm during the crop's life cycle. Climate data of 1987 was used as a basis for modelling the irrigation system. Important data such as precipitation, minimum and maximum temperatures, and evapotranspiration was used to ascertain the water need for rice using the crop coefficient. The model irrigation system is designed for a rice field with an area of 0.5 hector. A soil water content level of less than 7mm (<7mm) was used as a reference point for irrigating the field.

2. Project Area

The project is implemented in Tungan Macheri, Kebbi state, Nigeria. Its geographical coordinates are lat. 11°15'00.0"N and long. 5°45'00.0E. This territory is found within a State where 36.46% of its 37,699km^2 of its landmass comprises farmlands, and $^1/_3$ of it risks being desert due to drought impacts (Kebbi State Government).

2.1 Biophysical Characteristics

The section focuses on describing the biophysical characteristics of the project area. Agriculture/crop production largely depends on the biophysical environment and therefore, understanding the characteristics can give an idea of crop needs, farm planning, cultural practices and yield maximization strategies. The project will focus on two biophysical variables whose knowledge and monitoring are crucial to crop irrigation arrangements.

2.1.1 Meteorological Variables

This concerns features of the weather. These include precipitation, relative humidity, radiation from the sun and temperature. Places where agriculture is largely dependent on rainfall and increasingly impacted by climate change, such as the African continent, water stress is almost always imminent creating a need for supplementary irrigation. Average annual rainfall volumes recorded in the Kebbi state differs greatly from the north (733mm) and to the south (1045mm). This project is therefore appropriate for Tungan Macheri, which is situated in the semiarid zone of west Africa. Meteorological data for the project area includes rainfall, maximum and minimum temperatures, evapotranspiration potential (ETP), and evaporation, all drawn from 1987 climate data.

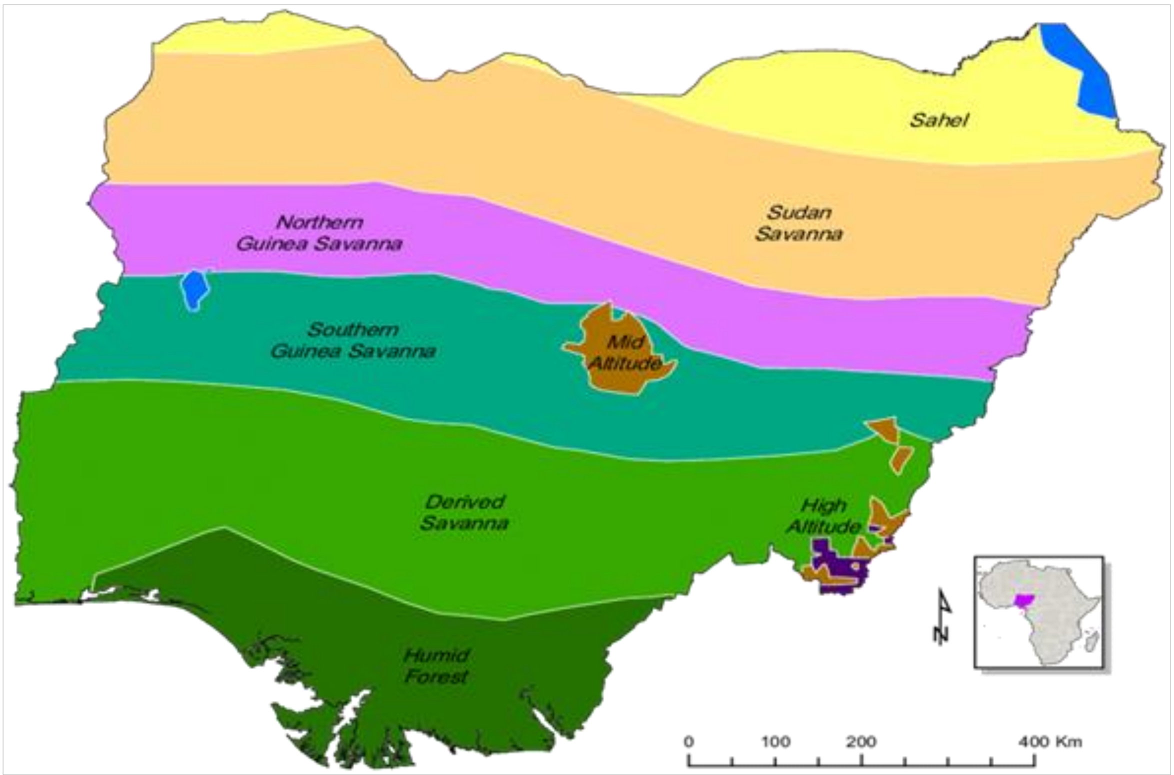

Figure 1: Ecological Zones of Nigeria

Figure 2: Location of Project Area.

2.1.2 Soil Moisture

Soil water retention capacity is very important for crop survival and water needs. This section will give information about the soil types available in the project area and their water retention capabilities. Ordinarily, soils with high water retention capacities tend to be more appropriate than the construction of irrigation systems. Those that are highly porous have less water retention capabilities and so, some form of ground treatments and the introduction of soil binding materials are necessary to improve water retention. Also, knowing the soil characteristics is good for determining soil moisture as it is for determining runoff coefficient. The type of soil also influences the frequency of providing supplementary water. The frequency of providing supplementary water for crops sown on sandy soil or gravel will be higher than crops on loamy or clay soils, given their water retention capacities. The predominant soil type of the project area is ferruginous tropical soils. The main features include a sandy surface horizon underlain by weakly developed clayey, molted and sometimes concreting subsoil. Quality wise, these types of soils are generally considered to be highly natural but very susceptible to erosion. The soil in the project site is, however, clay-loam with high water holding capacity.

2.1.3 Cropping Calendar

In Nigeria, rainfed rice production starts at the onset of rains. By implication, the calendar for the south is different from that of the north. Cultivation usually starts in April and harvest begins in August. There is a high opportunity for farmers in the south to cultivate twice in the year. However, in the north, where the project is located, the rains set in, in June were cultivation begins and harvest begins from October to December, depending on the time of cultivation and method used (transplanting, 150 days or Direct sowing, 120 days). This has been confirmed by the United States department of Agriculture (USDA) and FAO. The earliest to cultivate rice in Tugan Macheri is on the first week of June and harvest from the first week of October if its Direct sowing. The project therefore used this data in its computations to arrive at the various components of the design.

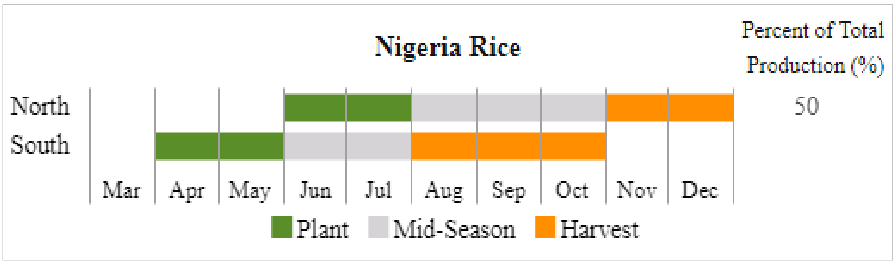

Figure 3: Crop calendar of Nigeria (Source: USDA, 2022)

3. Methods and Materials

The project designed an irrigation system for rice, cultivated on an area of 0.5 hectares. Soil water content of below 7mm was used as a reference for irrigating the rice field. Calculating the water needs of the rice crop is very important to arrive at designing the most suitable irrigation system with the required holding capacity. Climate data of 1987 is used as a basis. An FAO software CLIMWAT was used to get some climatic parameters in relation to farming and then another software, CROPWAT was used to generate the various developmental stages of the rice crop and their corresponding crop factor (kc) values. Two main approaches can be used, the Penman Monteith method and the Blaney-Criddle approach. In calculating the water need for the rice just as other food crops, the Penman-Monteith method is more efficient. This method makes use of exhaustive data and has a high degree of accuracy in its results. Another method, the Blaney-Criddle method, which is simpler makes use of available climate data which is not exhaustive. It is also good for estimation purposes. It was recommended that this method can be used in estimations for projects in places where climate data is limited. This project will therefore adopt the Blaney-Criddle method, since that permits us to make our computations using the available limited climate data of 1987. The project will draw a water budget to know which months supplementary water will be needed for the rice farm within the rainy season.

4. Results and Discussions

4.1 Crop Coefficient

The crop coefficient (Kc) takes into account the crop type and crop development to adjust the evapotranspiration for that specific crop. There may be several crop coefficients used for a single crop throughout an irrigation season depending on the crop's stage of development (Ministry of Agriculture, Food and Fisheries, 2001). Therefore, knowing the crop co-efficient of the food crop to be irrigated is important to designing the most appropriate supplementary irrigation system. This will aid in calculating the crop water needs and other important parameters. Using Food and Agriculture (FAO) software CROPWAT, we were able to determine the duration of the various stages in the life of the rice crop with their corresponding coefficients. The coefficients generated by the software, CROPWAT do not have significant differences from available literature.

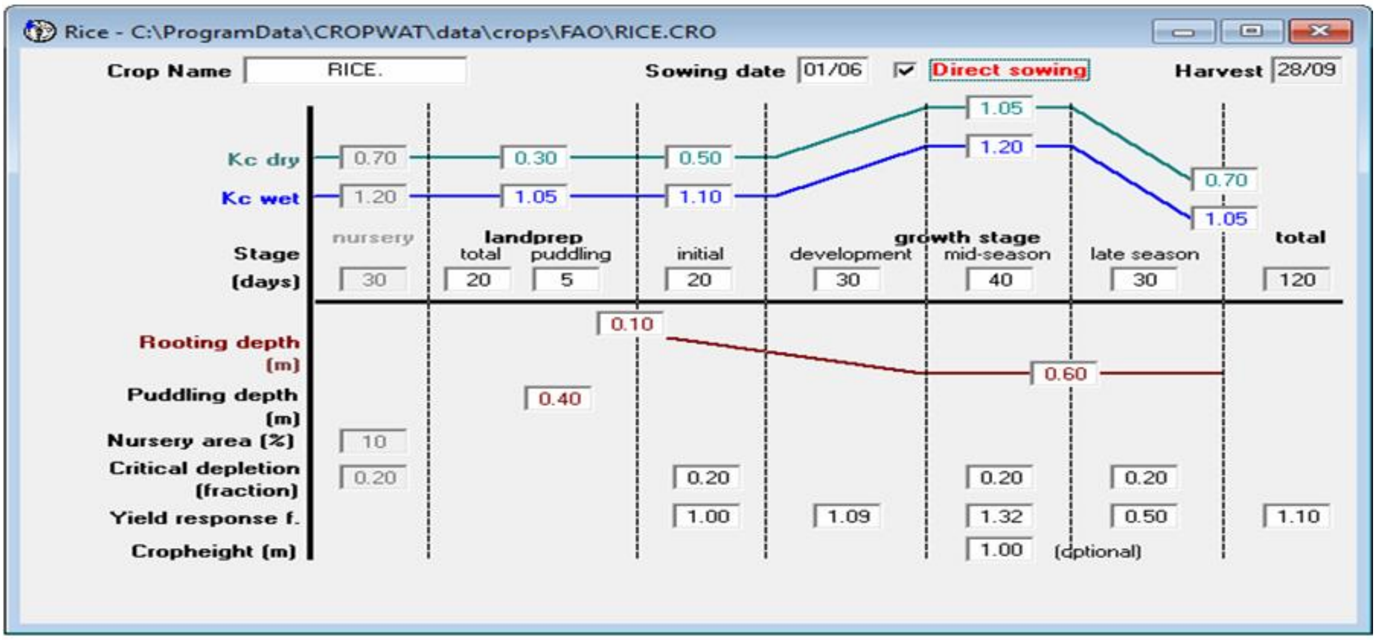

Figure 4: CROPWAT (Source: FAO)

Farmers in the project area practice the direct sowing technique given the large sizes of their farms. For the direct sowing technique, it takes 120 days to harvest. Another technique used is the transplanting technique where the rice seeds are nursed for some days before transplanting onto the rice field. This is mostly practiced on small fields and takes up to 150 days to reach harvest. The project therefore adopts the direct sowing technique since it is the predominant practice. Sowing begins in June and harvesting is done by close of September. The Kc for the initial stage of the crop development is 1.10. The growth stage which lasts about 70 days has a Kc of 1.20 and the late season, that is when its nearing harvest it has a Kc of 1.05. These were generated from FAO's CROPWAT software as can be seen in the figure above.

4.2 Crop Water Need for Rice

As crops grow on a field, it loses some of its water content due to factors such as evapotranspiration. Knowledge of the required amount of water needed to compensate for this water losses can help to determine the irrigation scheduling and irrigation water requirement for the crops (Todorovic, 2005). This amount of water required to compensate for losses equates to the effective irrigation water to ensure optimum crop yields. For the purposes of paper, we calculated the crop water needs for each day of the entire cropping period. This corresponds with argument of Todorovic that this will ensure a higher degree of accuracy (Todorovic, 2005). To determine this, it is necessary to calculate reference evapotranspiration (ETo). The Blaney-Criddle method will be used due to the limited climate data available.

4.2.1 Application of the Blanney-Criddle Method

The formula for this approach is ETo = p (0.46 T mean + 8), where ETo is reference evapotranspiration, the p stands for mean daily percentage (p) of annual daytime hours for different latitudes or p value, whereas the Tmean refers to mean temperature. Geographical coordinates are needed to plot the p values for different months using the table below.

The geographical coordinates for the project area are lat. 11°15'00.0"N and long. 5°45'00.0E.

Latitude	North	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	South	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
60°		.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
55		.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
50		.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
45		.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
40		.22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35		.23	.25	.27	.29	.31	.32	.32	.30	.28	.25	.23	.22
30		.24	.25	.27	.29	.31	.32	.31	.30	.28	.26	.24	.23
25		.24	.26	.27	.29	.30	.31	.31	.29	.28	.26	.25	.24
20		.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25
15		.26	.26	.27	.28	.29	.29	.29	.28	.28	.27	.26	.25
10		.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5		.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0		.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

The linear interpolation method is applied to find the **p value** of the project area's latitude 11°15'00.0"N.

Using the linear interpolation method, the p value for coordinate 11° N for each month is obtained by applying the formula:

(y1-y2)/(x2-x1)=(y-y2)/(x2-x).

Where;

x1=5° from the table above

y1=0.28, the corresponding value for x1 for the month of sowing (June)

x2=10° from the table above

y2=0.29, the corresponding value for x2 for the month of sowing (June)

y=???? the corresponding value for the 11° N to be found

x= the 11° N.

(y1-y2)/(x2-x1)=(y-y2)/(x2-x)

(y1-y2)*(x2-x)/(x2-x1)=y-y2

y2+(y1-y2)*(x2-x)/(x2-x1)=y

y=y2+(y1-y2)*(x2-x)/(x2-x1)

we input the values into the formula

y=0.29+(0.28-0.29)*(10-11)/(10-5)

y=0.29

Therefore, p value for June is 0.29.

This same formula is used to calculate the p values for July = 0.29, August=0.28, September=0.28 and October=0.27. These p values are in the attached excel sheet.

The **Tmean** is obtained by calculating the average of maximum and minimum daily temperatures. The following formula was applied, $\frac{Tmax+Tmin}{2}$. Where

Tmax is maximum daily temperature.

Tmin is minimum daily temperature.

After finding the value of ETo, the result is multiplied by crop coefficient (Kc) to obtain the crop water need (ET crop). The daily water need for the crop is finally determined by adding ET crop to the expected loss of water through soil evaporation. Calculations were made on daily basis for the purpose of irrigation scheduling.

The estimated crop water needs of rice for the entire cropping season is 822.42mm. Crop water need is the amount of water required by the crop during its cycle, from sowing to harvesting. These can be found in the attached excel sheet.

4.3 Volume of Water Needed for Rice Production (Vw)

The volume of water needed for the rice crop takes into account the surface area to be cultivated and the water requirement of the rice crop. Water volume required = $\sum ETcrop * S * 10^{-3}$, where, $\sum ETcrop$ is the water requirement of rice, S is the surface area to be cultivated 0.5 hectares (5000 m^2 converted), and 10^{-3} is the conversion factor from mm to m.

Therefore, the volume of water needed for the rice farm

$Vw=822.42 * 5000\ m^2 * 10^{-3} = 4112.1m^3$

Therefore, the volume of water needed to cultivate rice on an area of 0.5 ha for the entire growing season is $4112.1m^3$

4.4 Irrigation Scheduling

A crop producer has to take the decision on when to irrigate the field and how often within a given time. Knowledge of variables such as the crop water needs of the crops among other will equally help in deciding how much water should be applied on the field per irrigation session (Ministry of Agriculture, 2015). Irrigation scheduling is therefore an effective agriculture water management strategy that can increase the viability farms. It ensures water efficiency in food production. Optimal crop development can be achieved when there is aeration and the required balance of water in the roots of the crop. This buttresses the argument of water sensitivity at some critical stages of plant development (McMullen, 2000).

Climatic conditions and soil characteristics are key to the practicability of irrigation design and operation. These mainly help to estimate what quantity of water should be pumped to the field, how long it will take to drain, evaporate and how soon the field should be irrigated again. Knowledge of factors like how much water a crop can tolerate at each stage of growth, its response to water deficits and the need to achieve optimal water efficiency in the production process are of import to developing a schedule for irrigation. Broner argues that scheduling irrigation and deciding on the quantity of water to apply depends on the irrigator's goal (Broner, 2005).

The two common goals for irrigation are; irrigation to maximize yields or irrigation to maximize net returns. For the former, the irrigator does not have an economic perspective of the action and therefore focuses on applying enough water to ensure optimal development. The later, considers the economic value of the amount of water to be applied. The cost of water is factored into the cost of production. The irrigator is therefore meticulous about the right quantity of water to apply, thereby minimizing the cost of water applied. This will ensure that he makes much returns from his farm due to the water saving strategy.

In developing the irrigation schedule, two factors are basic. First, how much water is in the soil at the given time and second, how much water is needed by the crop (FAO, 2007). Therefore, in coherence with the developed schedule for irrigation and computations, the field is only irrigated if effective rainfall - (Evapotranspiration + Soil evaporation) is less than 7mm (< 7mm). However, if the result is greater than the 7mm reference point, no irrigation is required (see excel for more details). In this project, out of the total period of 120 days (Direct sowing), there are 105 days of supplementary irrigation and 15 days of no irrigation with varying water needs of the crop.

As a farmer may strive to achieve optimum yields through the right scheduling of irrigation, he/she should not be oblivious of the fact that the crops can suffer from undue water deficits or over watering during peak periods or periods of minimum water demand respectively. Therefore, determining what volume of water is required during each scheduled irrigation session to ensure that the water does not only stay at the top but reaches the root regions of the crop (net irrigation depth) and the intervals is important. This ensures that the water that has been collected into the reservoir is able to supply the field for the entire cropping season (Ibrahim and Ibrahim, 2020). Important factors to consider in scheduling the irrigation of the rice farm include the following.

4.4.1 Irrigation Water Requirement

The net irrigation requirements of the crops (**In**) are calculated using the water balance of the field. Therefore, crop evapotranspiration (ETcrop), soil evaporation and effective rainfall (Pe) will be used to get the net daily irrigation requirements. **In** = Pe - (ETcrop+soil evaporation). The irrigation water requirements of crops can be calculated on seasonal, monthly or at any given time based on the purpose. The project seeks a certain high degree of accuracy and will therefore determine this on a daily basis to arrive at an applicable daily irrigation schedule. The total irrigation water required for the rice cropping season is 456.48mm. (refer to excel sheet).

4.4.2 Gross Daily Irrigation Water Requirement (Ig)

This takes into account the net daily irrigation water requirement in relation to the application efficiency (Ea) and conveyance efficiency (Ec). Thus, $Ig=\frac{Ir}{Ea*Ec}$.

4.4.3 Effective Root Depth

This is the soil depth from which the plants draw most of its water and nutrients that is usually the part of the soil where the plant's roots are closely packed. The rooting depths is influenced by factors such as plant physiology, soil, and available water (FAO, 2007). During mid to late growth season of rice, (FAO CROPWAT 8.0) estimates 0.60m as the maximum root depth.

4.4.4 Total Available Water (TAW)

The water retention capacity of a soil for plants to benefit from. Typically, after it rains or a large volume of water is applied to a soil, the soil drains the water usually to its sub compartments or runoff while retaining what is within its capacity (Ibrahim and Ibrahim, 2020). The phenomenon of Field capacity or water retention with the soil's capacity is best explained by considering the amount of water the soil holds against gravitation that causes increased vertical seepage. In the case of irrigation or rains, the retention of the capacity of the soil presents a favorable condition to plants as they are able to easily absorb close of 70% of the moisture available in the soil. Clay loam soils have an estimated average of 164mm in total available soil water (McMullen, 2000).

4.4.5 Depletion of Soil Available Water

When water is applied to the field, the estimates maximum of 70% of the soil's retained water (Sa) that is easily absorbed by plants is termed 'Readily available water'. The readily available water is obtained when the water held in the soil (Sa) is multiplied by the ***P*** value which represents the moisture. Prevailing climate, the plant types, root formation and absorption rate and type of irrigation/amount of water applied within a given time can influence the p value (FAO, 2007). The FAO CROPWAT (8.0) software estimates the maximum critical depletion fraction of rice at 0.20 with 0.20 at late season, 0.20 at mid-season and 0.20 at the initial stages. This critical depletion fraction is obtained by calculating the average of the depletion fractions at the various stages of growth of the rice crop.

4.4.6 Net Depth of Irrigation Application (NDI)

This implies the quantity of water that is applied to a field during an irrigation session to restore the soil's water balance for crop needs. Shallow or deep-rooted plants and the soil type determines the NDI (Ibrahim and Ibrahim, 2020). In drawing from Pujara, Net depth of irrigation application can be calculated with the formula (NDI) (mm) = (Sa × p) D; (Pujara, 2016)

where Sa is the available water,

p is the permissible depletion (fraction) and

D is the root depth.

Hence the net depth of irrigation application (NDI)= 164 mm/m x 0.20 x 0.6 = 20mm

($20 \text{ mm} \times 5000 \text{ m}^2 \times 10^{-3} = 100 \text{ m}^3$)

4.4.7 Irrigation Interval or Frequency

This is the period usually days between the previous and the next irrigation session. It is thus, how many days will it take to apply the next irrigation after the previous one. Lack of water and excess water at certain stages of a crop's growth could have a more negative effect on the crop. Take for instance capsicum, lack of water during the flowering stage could result in abortion of flowers and fruits. Excess water helps in developing the roots of the plant it however contributes to abortion given that the overly moist soil does not provide the conditions its needs for optimal growth (Lima et al., 2018). It is therefore obtained by dividing the net depth irrigation application (NDI) by the daily evapotranspiration of the crop which is in millimetres (FAO, 2007).

Simply put, calculating the water that is lost each day through evaporation and transpiration and dividing by how much water has been applied to restore soil water balance will help to control, know what the optimal irrigation is and exactly when to irrigate next (Gordin et al., 2019). By implication, the varied crop water needs at the different growth stages, it is expected that the intervals for irrigating may be closer at the growth stage when there is more need for water by crops, and wider when the growth stage demands relatively lesser water need. The amount and frequency of effective rainfall between these periods will have an influence on the intervals (Ibrahim and Ibrahim, 2020). Hence, when the soil cumulative water deficit is less than 7 mm, 19.68 mm of irrigation is applied. The irrigation interval is less during periods of peak demand and high during periods of low water demand.

4.4.8 The Number of Irrigation Applications Over the Total Growing Season

To determine the number of times the field should be irrigated, the total water that has been estimated for irrigating the field over the cropping season should be divided by the net depth irrigation per application. In the case of our 0.5 hector rice field, the irrigation water need is 456.48 mm and the net irrigation application depth is 19.68 mm (rounded to 20mm). So, the number of irrigation applications is approximately 23 times over the cropping season.

4.4.9 System Flow

To ensure effectiveness of the supplementary irrigation system, its design should allow for its flow to meet the peak water demand of the field even at its minimum (FAO, 2007). The system flow is obtained by:

$$Q = 10 * A * \frac{dg}{it}$$

where ***Q*** is the system flow in cubic metres per hour,

A is the area in hectares,

dg is the gross irrigation application depth (irrigation dose) in m³,

i is the interval in days between two irrigations at peak demand,

t is the operating hours per day and

10 is a constant.

If 1 day is allowed to cater for repair works when the system is damaged or down, ***t*** the minimum flow which allows for the completion of irrigation at least a day before the ensuing irrigation session. Given the above condition, ***i*** will be reduced by 1 day. From our data, demand for supplementary water is at its peak in June with an average irrigation interval of 3 days. The system operates for 7 hours per irrigation session.

Therefore,

$$Q = 10 * 0.5 * \frac{100}{(3days - 1day) * 7hrs}$$

The rate of flow for the system $(Q) = 35.14m3/hr$

The system's poerating time per irrigation session is determined by:

$$T = 10 * A * \frac{dg}{Q} / I$$

$$T = 10 * 0.5 * \frac{98.4}{35.14} / 2$$

$$T = 7hrs$$

4.4.10 Cumulative Soil Water Deficit

The project will calculate the cumulative soil water deficit in order to understand in real terms the need to irrigate the farm. the cumulative soil water deficit makes it possible to understand if the water content in the soil on a particular day is sufficient to supply the soil water needs of that day alone or it can also satisfy soil water needs of the coming days. It also helps to know the amount of water that is at current available in the soil and how much water is needed to be supplied to satisfy the coming days. It is therefore useful in managing the amount of water the system should apply to the farm, prevent wastage of water and also design the supplementary irrigation system.

4.5 Reservoir Design and Monitoring

Reservoirs are water holding facilities designed to hold water and to ensure constant or uninterrupted supply of water. The usually have a water supply source that feeds it with the required volumes of water which it then holds for controlled use. In most cases, they are artificially made and serve as a collection and storage point for run-off water to ensure water availability for productive activities (Zhang and Gao, 2020). Reservoirs are more common in either water scarce locations to ensure water security and constant supply or in water excess locations to control and manage inundations. They are able to hold water for irrigation or other domestic and potable uses (Ibrahim and Ibrahim, 2020). The dimensions of the reservoir for harvesting water for irrigation is dependent on the maximum volume of water that can be harvested within the cropping season. But of course, this comes with cost implications.

The project will therefore design an irrigation system that should be able to contain a volume of water more than the total crop water needs and soil evaporation of the rice farm for the season. The excess water in the system will cater for the inevitable evaporation due to climatic factors. The irrigation water requirement is 456.48 mm (456.48 mm x 5000 m² x 10^{-3} = 2,282.4 m³). The loss of water to soil evaporation and crop evapotranspiration during the growing season is estimated at 949.2 mm (949.2 mm x 5000 m² x 10^{-3} = 4,746 m³). Therefore, a reservoir of a minimum of 7,028.4m³ (2282.4 m³ + 4746 m³) in volumetric capacity is adequate to hold enough water to irrigate the field during the season. From the above computations, a system with a minimum water volume of 7,028.4m³ may be costly even though it is ideal.

Alternatively, the project can consider sizing the reservoir to hold the volume for irrigation and water losses caused by seepage and evaporation during the peak demand period as the minimum volume. The net depth irrigation application during the peak demand (June and first week of July) is 260mm (1,300m³). The daily seepage losses for the soil type (Clay loam) will average 8.75mm/day or 0.00875m (from 2.50 to 15mm/day), (Coche, 1986). Therefore, the estimated water seepage losses for the peak period (32 days) is obtained by multiplying the daily average seepage by the surface area of the reservoir and then multiply by the number of days.

That is 0.00875m*119.07m²=1.04m³ per day. The total water seepage for the 32 days will be 32*1.04=33.34m³ or 6.67mm. The surface evaporation for the peak period is 215.6mm (1,078m³). The minimum volume of water in the reservoir has to also compensate for the above water seepage. Hence, a system volume of 2,411.34 m³ (260mm +6.67mm +215.6 = 482.27mm) will be able to hold enough water for irrigation during periods that water demand is at its peak and the growing season through controlled supply of water from rainfall runoff.

4.6 Water Harvest

It is of outmost importance to determine the daily water harvest of the supplementary irrigation system the project seeks to design. That is how much water should be harvested daily by the system to ensure its optimal functionality of supplying the required quantities to the cultivated field. It will also help in sizing the system. Water will be harvested from runoff of rainwater into the system from a watershed. It is therefore important to determine the catchment area or size of the watershed. Since the system will be fed by runoff water, it is paramount to determine the runoff coefficient of the area. The runoff coefficient (μ) relates to how much runoff is obtained or measured from the rainfall received. Consequently, in areas where the soil has a slower water absorption rate, most of the water on the surface experiences a horizontal displacement or runoff. Runoffs are also faster in areas that less porous and have steep gradients. However, areas with good vegetative cover, relatively flat and having porous soils experience very little runoffs in most case (State Water Resources Control Board, 2011).

The area of a watershed is needed to calculate the volume of water from a runoff ***V***. Hence, multiplying the area of the designated watershed ***A*** that will feed the reservoir by the effective rainfall ***Pe*** and a runoff coefficient ***μ***, (***V = μ *Pe * A* 10***$^{-3}$). The project area characterized by ferruginous tropical soils. Whose main features include a clay loam surface. These types of soils have high water holding capacity. The area also has some trees and grasslands. Given the permeability of the sandy soils, shrubs and some grasslands, the runoff coefficient is expected to be high. A runoff coefficient for the purpose of this project which will be implemented on a new site (bare land) is 0.50. This is chosen from the recommended range of 0.30-0.60 given the steepness and land surface. The table below shows the recommended runoff coefficients of different circumstances.

To obtain the ideal size of the watershed from which the runoff will feed the system, we employ the formula,

$$A = \frac{V}{\mu * Pe * 0.001}$$

where A is size of watershed

μ is the runoff coefficient=0.50

Pe is effective rainfall during peak demand=68

V is minimum volume of water to be harvested in the reservoir=482.27

Conversion factor (10^{-3}) is =0.001

$$A = \frac{482.27}{0.50 * 68 * 0.001}$$

A=14,184.41m²

Rain water will be harvested on the first day of sowing. From the weather data, the rainfall on the first day would also introduce some moisture into the soil. Subsequently, water will be harvested after every rain on a cumulative basis until the minimum volume is reached. The inlet of the system will be locked to prevent more runoff getting into the system. The inlet will be opened again when the water level is sufficient enough for a day's irrigation so that more rainwater can be harvested. The table below shows that weekly climate data, weekly irrigation needs, irrigation scheduling and rain water harvesting schedule.

4.7 Eservoir Dimensions

The reservoir will be designed in a square shape. This implies L=B=H. With a reservoir with a volume of 2411.34m³, the dimensions will be obtained with a simple formula: $\sqrt[3]{2411.34}$

Therefore, Length of reservoir will be 13.41m

Breadth of reservoir will be 13.41m, and

Height of reservoir will be 13.41m

The minimum measurement for the design of a square shaped reservoir should be 13.41 m × 13.41 m × 13.41 m, adequate to hold the water to provide supplementary water for the rice farm.

Table 1: Runoff Coefficient Table.

Land Use	C	Land Use	C
Business:		***Lawns:***	
Downtown areas	0.70 - 0.95	Sandy soil, flat, 2%	0.05 - 0.10
Neighborhood areas	0.50 - 0.70	Sandy soil, avg., 2-7%	0.10 - 0.15
		Sandy soil, steep, 7%	0.15 - 0.20
		Heavy soil, flat, 2%	0.13 - 0.17
		Heavy soil, avg., 2-7%	0.18 - 0.22
		Heavy soil, steep, 7%	0.25 - 0.35
Residential:		***Agricultural land:***	
Single-family areas	0.30 - 0.50	*Bare packed soil*	
Multi units, detached	0.40 - 0.60	*Smooth	0.30 - 0.60
Munti units, attached	0.60 - 0.75	*Rough	0.20 - 0.50
Suburban	0.25 - 0.40	*Cultivated rows*	
		*Heavy soil, no crop	0.30 - 0.60
		*Heavy soil, with crop	0.20 - 0.50
		*Sandy soil, no crop	0.20 - 0.40
		*Sandy soil, with crop	0.10 - 0.25
		Pasture	
		*Heavy soil	0.15 - 0.45
		*Sandy soil	0.05 - 0.25
		Woodlands	0.05 - 0.25

The Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment State Water Resources Control Board 5.1.3 FS-(RC) 2011

Table 2: Weekly Data and Irrigation Schedule

Date (D/M)	Rainfall	ETP	Evap	ET crop	Soil Evaporation	Eff. rainfall	Net weekly Irrigation needs	Scheduling	Cumulative Soil Water Deficit	TAW after irrigation	Net depth irrig applic	Water harvesting schedule
7-Jun	5,3	4,675	6,2	6,62	1,14	0	-7,76	Irrigate	-14,66	20	20	Harvest rain water
14-Jun	0	8,470	6,8	6,91	2,4	0	-9,31	Irrigate	-66,29	20	20	
21-Jun	0	5,395	4,1	7,99	1,18	3,76	-5,41	Irrigate	-113,71	20	20	
28-Jun	0	7,188	6,7	7,48	1,52	0	-9,00	Irrigate	-161,66	20	20	
5-Jul	0	6,523	8,4	7,39	1,22	30,16	21,55	no irrigation	-193,31	41,55	0	
12-Jul	0	4,169	6,6	7,57	1,54	0	-9,11	Irrigate	-215,76	19,09	0	
19-Jul	0	5,985	5,6	6,93	1,1	18,24	10,21	No irrigation	-243,52	30,21	0	
26-Jul	23	5,051	2,5	7,27	0,98	9,6	1,35	Irrigate	-247,62	26,11	0	
2-Aug	0	4,784	2,2	6,79	0,68	0	-7,47	Irrigate	-284,55	20	20	
9-Aug	45	5,355	3,3	6,67	0,86	25,36	17,83	No irrigation	-251,69	68,38	0	
16-Aug	0	4,552	4,4	6,85	0,82	0	-7,67	Irrigate	-285,50	34,57	0	No rain water harvesting
23-Aug	0	5,615	6,2	7,05	0,32	21,36	13,99	No irrigation	-303,73	33,99	0	
30-Aug	18	5,481	4,9	7,02	1,04	0,64	-7,42	Irrigate	-325,85	11,87	0	
6-Sep	0	5,362	3,6	6,38	0,2	0	-6,58	Irrigate	-362,47	7,00	0	
13-Sep	0	5,500	6,2	5,92	1,5	0	-7,42	Irrigate	-394,86	20	20	Harvest rain water
20-Sep	2,8	5,920	2,6	5,99	0,72	22,88	16,17	No irrigation	-401,74	42,98	0	No rain water harvesting
27-Sep	9,2	2,381	3,0	6,21	0,8	0	-7,01	Irrigate	-441,93	20	20	
29-Sep	0	5,252	4,0	6,27	0,86	0	-7,13	Irrigate	-456,48	20	20	
TOTALS				822,4	126,78	492,7	-456,48				600	

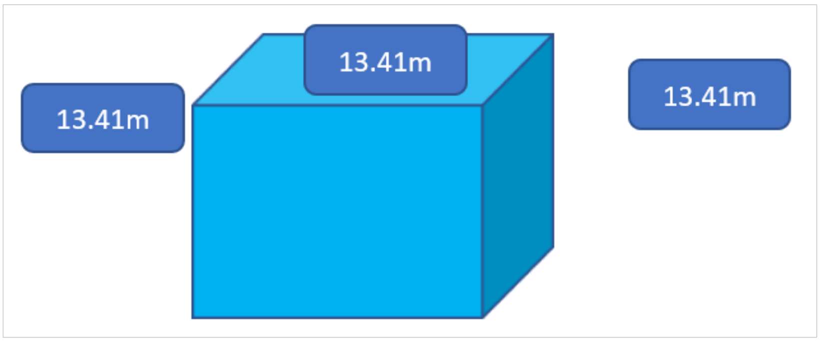

Figure 5: Schematic of Water Reservoir Dimensions

4.8 Supplementary Irrigation Design

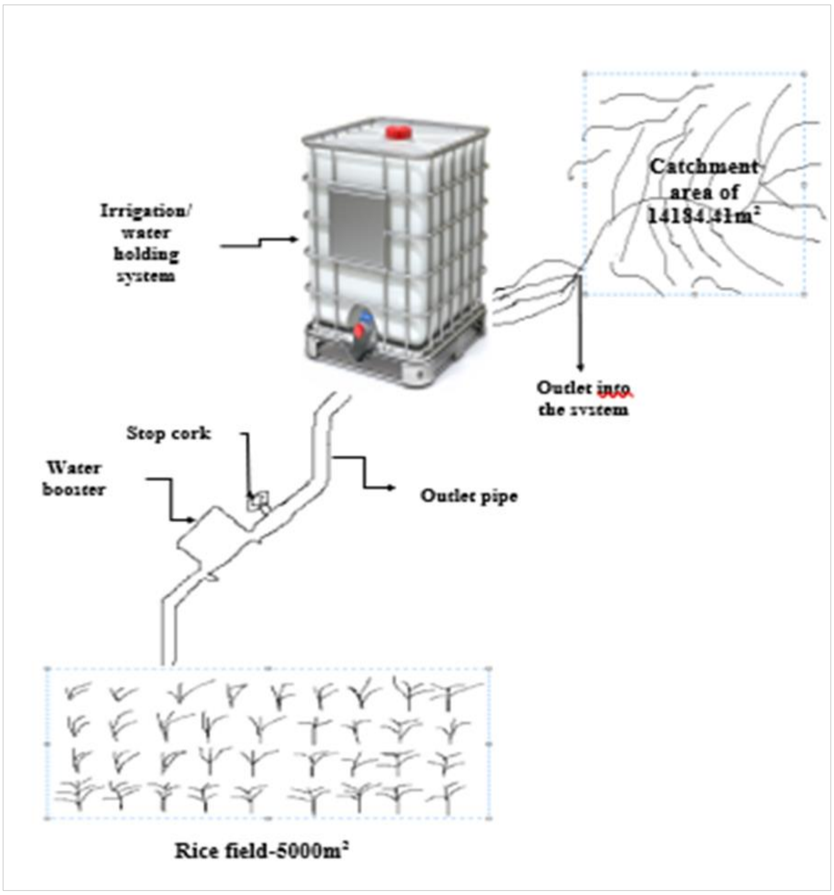

Figure 6: Supplementary Irrigation Scheme (Source: Author's Construct)

4.9 Reservoir Monitoring

Constant monitoring of the entire supplementary irrigation system, especially the water holding component or reservoir is necessary to ensure optimal operationality and water availability to irrigate the field throughout the season. It is strategic to have the reservoir contain a slightly higher volume of water relative to the water needs of the crop. The rationale is to compensate for evaporation from the open reservoir and water seepage. In our case, water seepage contributes to more water lost than evaporation since the period is within the raining season. For dry season farming, the reservoir should hold more water due to a higher possibility of evaporation. Water harvesting started on the first rainfall recorded on the day the crops were sown on the field. The monitoring of the reservoir would ensure that water is always available to be injected into the field to maintain the soil's water balance.

The watershed for harvesting rainwater runoff for the project is 14,184.41m^2. The volume of water that can be harvested on the first day of rainfall (effective rainfall) of 22.48mm is estimated at 159.6mm. From the rain water harvesting schedule (see excel sheet), water will be harvested from the first day, 1st June to 9th August. This water will be sufficient to irrigate the farm at peak demand. Runoff water will not be harvested from 10th August to 6th September. This is because there will be enough water in the reservoir to irrigate the three occasions during this period of no harvest. Water will be harvested again from 7th September to 19th September for irrigating the rice farm to the end of the growing season. No water will be harvested for the remaining days 20th to 29th September.

The harvesting schedule will enhance management of the system and will ensure that the excessive water is not harvested that can pose danger to the system. As mentioned earlier the water held in the reservoir must be higher than water needed to irrigate the field for the duration of the planting season. Part of the difference; the water held and the water needed to irrigate will make up for evaporation and seepage losses. The remaining water which is the net water balance would play an important role of conditioning the reservoir to avoid rapid deterioration after the farming season. It is therefore estimated that, a net balance of 1,440.66m^3 of water will remain in the reservoir after the last irrigation application.

5. Conclusion

Agricultural development is one of the sustainable strategies for rural transformation. There is therefore the need to develop cost effective systems to mitigate the devastating impacts of climate on agriculture which is the main stay of our African Economy. Climate change is further exacerbating freshwater scarcity resulting in increased competition among multi users. The project designs a supplementary irrigation system as a sustainable agriculture and rural transformation strategy taking the case of rice crop in Tungan Macheri. It also demonstrates how scheduling supplementary irrigation can be an efficient water management strategy for agriculture in the light of dwindling freshwater availability. The project area is a typical Sahelian semi-arid zone which highlights the need for the project. The project estimated the plant water requirement of rice as well as the volume of water needed to supplement the water requirements during plants' growth cycle using climate data provided for the year 1987 and some relevant information from literature. Microsoft Excel is employed in calculating the various components that will ensure the successful management of the irrigation system and the availability of water for the crop.

The analysis revealed that, the supplementary irrigation water requirement accounts for about 70% of the water required for rice, a household staple that has the potential of improving food security and increasing farmers' incomes. It is crucial at this age given that the prevailing climatic conditions especially in the Sahel have resulted in low and shorter rainfalls, and prolonged drought affecting soil water content. Supplementary irrigation is one sure strategy farmers can use to mitigate soil moisture stress and increase crop development during critical growth stages. Given that rural livelihoods largely depend on agriculture which in turn depend on the natural environment, which is highly threatened by climate change, supplementary irrigation adoption will enable farmers to mitigate some of the impacts on their farming activities.

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