



ANALYSIS OF FIELD CHARACTERISTICS FOR IRRIGATION SYSTEM DESIGN: A CASE STUDY

U. E. Uche^{1*}, L. K. Soretire¹, I. M. B. Omiogbemi¹, L. I. Iwuoha¹ and W. E. Aserifa²

¹Department of Mechanical Engineering, Air Force Institute of Technology, Kaduna, Nigeria

²Department of Aerospace Engineering, Air Force Institute of Technology, Kaduna.

*Corresponding author's email address: eaumie@gmail.com

ARTICLE INFORMATION

Submitted 1 May 2023
Revised 14 July 2023
Accepted 20 July 2023

Keywords:

Infiltration rate
Permeability
Irrigability
Plasticity
Workability

ABSTRACT

The determination of field characteristics is key to the successful installation of irrigation because the water use efficiency depends on the soil infiltration rate, storage capacity, permeability, and plasticity. The shear strength of the soil was also determined for the purpose of construction of water abstraction systems. The applicability of irrigation for paddy rice cultivation in the Igwu River Basin was assessed as a case study using secondary data from the Igwu River World Bank Rice Project and Abia State Ministry of Agriculture. Primary data was generated by field and laboratory soil tests. The soil survey and project land classification were based on the United State Bureau of Reclamation general land classification standard on limiting factors to irrigation. Field and laboratory tests were used to generate data on the specific gravity of soil particles and the compaction characteristics to determine the dry, moist, saturated, and buoyant unit weight of the soil. Consistency limits, plasticity, shear, and compressive parameters as well as coefficient of permeability, infiltration characteristics and soil storage capacity were also determined. The result showed that the soil profile is well drained to a depth of about 1m and of characteristic agricultural nature, rich in mineral nutrient and having a pH of 6.7. The soil is of good workability, with largely fine to medium texture, characterized by dull orange. (7.5yrs 6/4 dry, brownish black (10yrs 3/2) wet topsoil. The topsoil is made up of sandy loam of weak angular structure, few fibrous roots and, of mixed humous, with few fine and continuous pores. It was further, observed that erosion was minimal because of forest cover and the area holds a high potential for irrigated agriculture. It is therefore the opinion of the authors that the study site is suitable for paddy rice irrigation.

© 2023 Faculty of Engineering, University of Maiduguri, Nigeria. All rights reserved.

1.0 Introduction

The high cost of development of irrigated agriculture requires justification by assessment of the risks and benefits. In fact, the design of the irrigation scheme itself is dependent on detailed knowledge of soils lying within the irrigation area. Hence, a knowledge of the soils within the irrigation area serves as an aid in the location of canals and other irrigation waters, aids in determining the irrigation need, determines the drainage need, controls the overall land leveling need, and limits the size of fields in irrigation projects (Albaji *et al.*, 2022).

According to González-Briones *et al.* (2018), irrigation is described as "the artificial application of water to the soil for the purpose of supplying the water essential to plant growth" with the following three goals: (i) to make up for soil moisture deficiencies; (ii) to improve the environmental conditions of the soil and crop; and (iii) to apply nutrients and plant protectors.

Rice may be grown on many types of soil. Purselove (1975) reported that soil from sandy loamy and shallow laterite to heavy clay may be used if there is adequate water either as rainfall or by irrigation. Because of water requirements, heavy clay is preferred as a means of holding and preserving water for the plant. The water should not be stagnant but free flowing (Appraisal of Rice Project Nigeria, 1974). Rice is adapted to acid soils and will thrive well under pH ranges of 4.5 to 7.5 (Chapman and Carter, 1976). However, the optimum range is a pH of 5.5- 6.5. The purpose of the study is to establish the suitability, and compatibility of the field characteristics of the study site for irrigated paddy rice project as a case study for the design of paddy rice irrigation systems.

2.0 Materials and Methods

2.1 Study area and experimental design

The study site (Figure 1) is in Igberere town which lies at latitude 5°4' N and longitude 7°32' E. in Bende Local Government Area of Abia State of Nigeria (Ofomata, 1975).

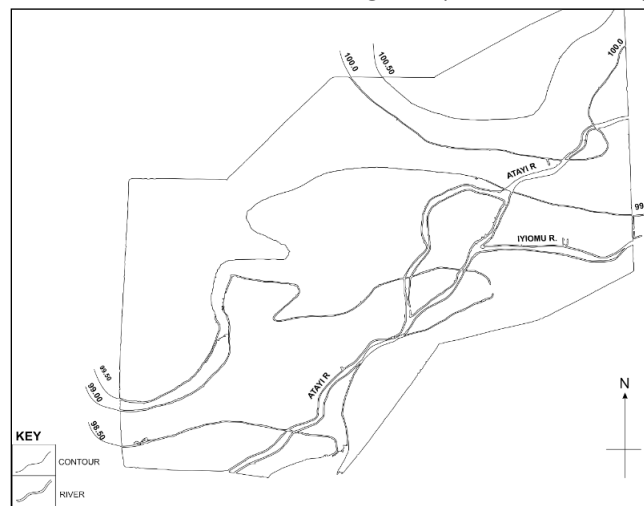


Figure 1: Topographic map of the study site

In the study, both historical data and field tests were explored to characterize the field and elicit irrigation design parameters. A completely randomized block design was employed in obtaining test samples. The randomized block design permits the isolation of smaller areas, each homogenous within itself which are known as blocks as shown in Figure 2.

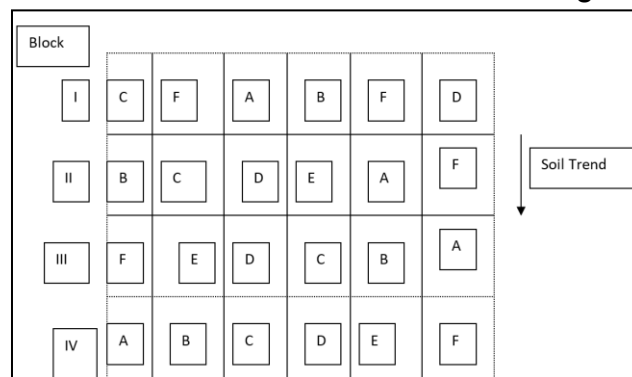


Figure 2: Randomized block experimental sampling design.

The study includes a soil survey, irrigability of the project area, determination of specific gravity of soil particles, consistent limit test, coefficient of permeability and infiltration characteristics tests.

2.2 Soil Survey

A survey of the characteristics of the soil in the project area was conducted by the World Bank Project Team during the feasibility stages of the Igwu Rice Scheme within which the study site is contiguous (Appraisal of Rice Project, Nigeria, 1974). The information is presented in the result section. Further, an augur soil sample from the study site was collected randomly as per figure 2, from different soil depths and analyzed by the Soil Science Department of the University of Nigeria to include the physical and chemical properties of the project soils.

2.3 Irrigability of the Project Area

The evaluation of the project land for irrigation suitability was carried out with reference to the results of the soil physical and chemical tests conducted. As Dent and Young (1981) noted, qualitative evaluation is one in which the suitability of land for a purpose or alternative purpose is expressed in qualitative terms only, such as highly suitable, moderately suitable, or marginally suitable. Qualitative evaluation is adopted for this work because of little or no information on economic and social-cultural factors which are needed for quantitative appraisal. Some of the economic factors include land, labour, and capital input while the socio-cultural elements are land tenure systems and the religious belief attached to the land. In classifying the project land, the USBR general land classification system which sums up the limiting factors – slope, texture, depth of rooting zone, salinity, and flooding risk, has been used (Table 2).

2.4 Determination of Specific Gravity of Soil Particles

The specific gravity of material is the ratio of the given weight of a given volume of that material to the weight of an equal volume of water. But the weight of an equal volume of water displaced by solids equals to weight of solids in air minus submerged weight of solids. Density bottles together with a stopper were completely dried and weighed (W_1). About 5 to 10 gm of oven dried soil were placed in the density bottles. The soil, bottle, and stopper were weighed (W_2). Distilled water was then added to cover the soil and thoroughly shake to remove air bubbles. More distilled water was added. The stopper fitted and allowed time to settle. After an hour more water was added to fill the density bottle. Time was allowed to eliminate air and the water, soil, stopper, and bottle weighed (W_3) after the exterior of the bottle had been dried. The bottles were finally thoroughly cleaned, filled with distilled water, stoppered, and reweighed (W_4). The specific gravity of the solid soil particles was determined from Equation (1) : (Smith, 1981). It is dimensionless.

$$GS = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \quad (1)$$

where GS = Specific gravity

W_1 = Mass of density bottle and stopper (gm)

W_2 = Mass of density bottle, stopper, and oven dried soil (gm)

W_3 = Mass of density bottle, stopper, oven dried soil and distilled water. (gm)

W_4 = Mass of density bottle, stopper, soil and topped distilled water (gm)

2.5 The Proctor Compaction Test

The proctor compaction test (Smith, 1981) was carried out to determine the various unit weights, optimum moisture content, void ratio, degree of saturation as well as porosity. The test further enabled the choice of appropriate moisture content for the triaxial test using Equation 2.

$$W_n = \frac{W_s \times 100}{MCS} = \frac{(MCO - MCS)}{(100)} \quad (2)$$

where

W_n = Amount of Water to be added

W_s = Mass of sample (g)

MCS = Moisture content of soil (%)

MCO = Optimum moisture content of soil from proctor test (%)

The proctor compaction test involves compacting 3 kg of sample in three approximately equal layers by means of 2.5 kg rammer falling through a height of 30 mm above the soil, 25 times for each layer of the soil placed in 1000 cm³ compaction mould. A sample of the compacted soil was taken and its moisture content was determined gravimetrically. The remainder of the soil specimen was broken up and mixed with the remainder of the sample. 60 cm³ increment of water, representing about 20% (twenty percent) of the sample was added after each breaking and mixing, and the above procedure was repeated (Smith, 1981).

2.6 Consistency Limit Test

The liquid index (LI) which relates the natural moisture content of the soil to both the plastic and liquid limits is given by Equation 3; (Levchich, 1981)

$$LI = \frac{M - PL}{PI} \quad (3)$$

where LI = liquid Index (%)

M = The natural moisture content of the soil (%)

PI = difference between the plastic and liquid limit or (%)
plasticity index

The liquid limit test involved the initial mixing of a soil passing the No. 425m B5 test sieve and of about 200g minimum weight with distilled water to putty like consistency. The soil was then placed in the Casagrande apparatus consisting of a brass cup and leveled off to a depth of 1 cm by means of palette knife. After making a groove in the soil the crank of the apparatus was turned to lift and lower the cup until the two sides of the sample closed at the bottom of the groove. The number of blows was recorded. The water content of the soil sample was determined by drying in oven at 105° for 24 hours and weighed. More distilled water was added to the paste and the procedure repeated three more times. A 'flow curve' of moisture content (as ordinate)

versus number of blows (as abscise) to a logarithmic scale was plotted (Figure 6). The moisture content of the soil sample at the count of 25 blows was determined.

For the plastic limit test the same soil sample passing through the same sieve size but of about 15gm was mixed with distilled water on a glass plate to obtain a plastic material and shaped into ball. The soil was rolled between the palms of the hand and the glass plate to form the soil into a thread of about 3mm diameter. It was then reformed into ball, kneeled, and rolled out. The procedure was repeated until cracks appeared at a rolled was determined. This represents the plastic limit of about 24% for the project soil.

Lastly the linear shrinkage test was conducted by preparing the soil as for the liquid limit test. At a blow of 25, a paste was taken and placed in a brass mould of semicircular cross section and the length noted (14 cm). The sample was air dried, transferred to oven at 105 °C for 24 hours drying after which the length was measured (13 cm) and the linear shrinkage was obtained using Equation 4

$$LS = \frac{1 - \text{length after drying}}{\text{Initial length}} \quad (4)$$

where LS = linear shrinkage cm.

2.7 Determination of Shear Parameters

The unconsolidated undrained, triaxial compression test was used to determine the shear parameters for soil in the project pump station site involving cohesive strength C and Angle of friction ϕ of the soil. To obtain the cohesive strength G and angle of friction ϕ a series of Mohr Circles are drawn (Figure 3). A common tangent through them represents the Coulomb equation. For any desired width and depth of the strip footing foundation for the pump house the net ultimate bearing capacity of the soil can be determined. The ultimate bearing capacity is the value of the gross loading intensity at which the ground fails in shear. The test consisted of preparing a sample of the soil by extruding three soil samples using tubes from a compaction cylinder, pushing them one after the other into split moulds of known dimension and noting the length and weight of specimen as well as the determination of their moisture content. After necessary adjustment of triaxial machine the samples being surrounded by rubber membranes were placed centrally on the pedestal of the triaxial cell and subjected to compressive stresses one after the other. At the maximum (failure) stress the cell was drained of fluid, dismantled and the rubber membrane removed to observe the failure mode.

Calculations involved in the triaxial test are as follows:

- Actual Load: This is necessary because a proving ring is used to measure the load.
Load = load dial reading x proving ring constant
- Area: The area of the specimen normal to its axis at any stage of the test has been computed on the assumption that the specimen deforms as a right-angled cylinder. The area at any strain E is given by Equation 5.

$$A = \frac{AC}{1-E} \quad (5)$$

Where $E =$ percentage strain at the stage of the which it is to be determined

$$= \frac{L_0 - L}{L_0}$$

$L_0 =$ Original length of Specimen (mm)

$L =$ Final length of specimen at the stage test. (mm)

c. Compressive Strength

The principal stress difference $\sigma_1 - \sigma_3$ is determined from compressive strength as given in Equation 6 as;

$$\sigma_1 - \sigma_3 = \frac{\text{Axial Load}}{A} \quad (6)$$

$\sigma_1 =$ Maximum principal stress N/m^2

$\sigma_2 =$ Minimum principal stress N/m^2

To obtain the cohesive strength G and angle of friction ϕ a series of Mohr Circles are drawn. (Figure 3) A common tangent through them represents the Coulomb equation.

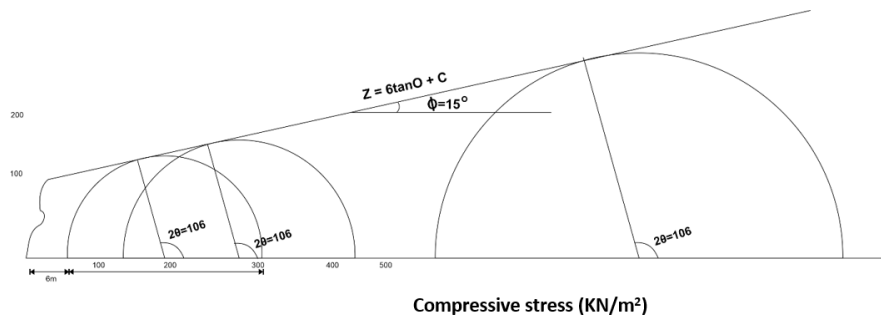


Figure 3: Mohr Circle for Principal Stress and Mohr Envelope

The shear strength of the soil can be given by Equation 8 as;

$$Z = C + C \tan \phi \quad (7)$$

Where $Z =$ Shear strength of the soil

$C =$ Cohesive strength of soil (point of intersection)

$\phi =$ Angle of friction.

For any desired width and depth of the strip footing foundation for the pump house the net ultimate bearing capacity of the soil can be determined from the expression in Equation 8 as;

$$q_n = C N_c + r Z (N_q - 1) + 0.5 r B N_r \quad (8)$$

Where $q_n =$ net ultimate bearing capacity of the soil (KN/m^2)

N_c, N_q and $N_r =$ bearing capacity factors

$C =$ Cohesion (KN/m^2)

$r =$ Unit weight of soil (KN/m^3)

$z =$ foundation depth (m)

$B =$ width of foundation (m)

From the Mohr circle the shear at failure is given by Equation 9;

$$Z_f = \frac{1}{2} (\sigma_1 - \sigma_3) \sin 2\phi \quad (9)$$

For the samples

$$\begin{aligned}
 (1) Z_f &= \frac{1}{2} (26.3) \sin 106 \\
 &= 12.64 \text{ N/cm}^3 \\
 &= 126.4 \text{ KW/m}^2 \\
 (2) Z_f &= \frac{1}{2} (32.7) \sin 109 \\
 &= 15.46 \text{ N/cm}^2 \\
 &= 154.59 \text{ KW/m}^2 \\
 (3) Z &= \frac{1}{2} (66.2) \sin 106 \\
 &= 3.82 \text{ N/cm}^2 \\
 &= 3.17 \text{ KW/m}^2
 \end{aligned}$$

Average shear strength of soil

$$\begin{aligned}
 &= \frac{154.59 + 126.41 + 318.17}{3} \\
 &= 199.22 \text{ KW/m}^2 \\
 &= 200 \text{ KN/m}^2 \\
 C &= 85 \text{ KN/m}^2 \\
 \phi &= 15^\circ
 \end{aligned}$$

2.8 Determination of the Co-Efficient of Permeability

The test consists of a constant head permeameter cylinder containing a disturbed sample of the soil, through which water was allowed to percolate under a constant head of pressure. The quantity of water Q passing through the sample in the time t was collected in the measuring cylinder while manometers tapped into the side of the cylinder gave the loss of head H over a length of sample L .

the downward movement of water (V_y) is given by Equation 20;

$$V_y = \frac{I_f}{ns} \quad (20)$$

Where:

$$\begin{aligned}
 V_y &= \text{rate of flow through the soil (cm/s)} \\
 I_f &= \text{soil permeability (cm/s)} \\
 n &= \text{pore space} \\
 s &= \text{Degree of saturation} \\
 V_y &= \frac{1.43 \times 10^{-5}}{0.38 \times 0.8} \\
 &= 4.7 \times 10^{-5} \text{ cm/s} \\
 &= 0.169 \text{ cm/hr}
 \end{aligned}$$

2.9 Determination of Infiltration Characteristics

The test involved the use of concentric cylinders of 30 cm and 60 cm diameters installed about 10cm deep in the soil and the ponding of water in the inner and outer cylinders. The second hand of a wristwatch was used to observe the rate at which water level descended in the inner

cylinders. After each reading at specified time intervals (Table 13) the water surface in the cylinder rings was returned to the original level and the process was repeated.

The functional relationship between the cumulative intake F and the time t was determined based on the equation.

$$F = at^b + c \quad (21)$$

Where F = Cumulative intake (mm)
 t = time water is in contact with the soil
 a,b,c = constant unique to the soil and hence the intake family

to determine the constants a, b and c, the method of average suggested by Michael (1978) was used. The results of the analysis are:

$$\begin{aligned} a &= 0.064 \\ b &= 1.14 \\ c &= 0.2 \end{aligned}$$

Hence the infiltration rate at any instant t was obtained as follows (Equation 22):

$$\begin{aligned} F &= at^b + C \\ \frac{dF}{dt} &= abt^{b-1} = I \end{aligned} \quad (22)$$

Where I = Infiltration rate mm/min.
 At t = 435min
 $I = 0.064 \times 1.14 \times (435)^{-1.4}$
 $= 0.17 \text{ mm/min}$

2.10 Soil Storage Capacity

The range of water available to the plant is that between the field capacity (FC) and the wilting point (WP). The readily available moisture which is that portion of the available moisture that is most easily extracted by plants is taken as 75% of the available moisture (Israelsen and Hansen, 1962). The available moisture is given by Equation (23):

$$Ma = FC - WP \quad (23)$$

Where Ma = available moisture (%)
 FC = field capacity (moisture content of the fields soil after drainage has become negligible (%))
 WP = wilting point (soil water content below which plant growing in that soil remains wilted even when transpiration is nearly eliminated (%))

In determining the permanent wilting point a field capacity of 2.3 times the wilting point was assumed considering the silty nature of the field soil (Israelsen and Hansen, 1962).

Therefore, the available moisture is given by Equation 24.

$$Ma = FC - \frac{FC}{2.3} \quad (24)$$

The field capacity was estimated by weighing after drying in oven, samples scooped at various depths and locations of the field (under cover) two days after thorough wetting.

The depth of available moisture was obtained using equation 25:

$$da = \frac{Ma As Dr}{100} \quad (25)$$

Where
 da = depth of available moisture in the roof zone
 As = Apparent specific gravity
 Dr = Rice rooting depth

The unit weights of the soil were obtained by determining the respective densities and multiplying by acceleration due to gravity (g)

2.10.1 The bulk density, S_m . of compacted soil at any given moisture content is given by equation 26:

$$S_m = \frac{M_2 - M_1}{1000} \quad (\text{kg/m}^3) \quad (26)$$

Where
 M_1 = Mass of mould in gm
 M_2 = Mass of mould + soil (in gm)

2.10.2 The soil dry densities

S_d in kg/m^3 is given by equation 27:

$$S_d = \frac{S_m}{1+m} \quad (27)$$

S_m = bulk density in kg/m^3
 m = Moisture content (dry basis).

The dry density gives the state or compaction of the soil.

2.10.3 Optimum moisture content and maximum dry density.

These are obtained by plotting a curve of dry density versus moisture content from which the optimum moisture content and maximum dry density can be read off. Figure 4 shows that for all densities except the one which gives optimum moisture content (OMC). There are two moisture contents that gave the same density. Also using more than 25 blows a greater density can be obtained and the optimum moisture will be less.

The porosity (n) of the soil, void ratio, and degree of saturation were determined as follows:

(i) Porosity is determined from the expression (equation 28 and 28)

$$d = Gs \left(\frac{n}{100} \right) \quad (28)$$

$$n = 100 \left(1 - \frac{Sd}{Gs} \right) \quad (29)$$

where

n = Porosity % (Ratio of volume and pores to total soil volume)
 S_d = dry bulk density g/cm

Average dry density of the sample.

$$\begin{aligned} S_d &= \frac{1534+1598+1639+155+1525+1458}{6} \\ &= 1551.5 \text{ kg/m}^3 \\ &= 1.5515 \text{ g/cm}^3 \end{aligned}$$

$$G_s = 2.51$$

Therefore Porosity

$$\begin{aligned} n &= 100 \left(1 - \frac{1.55}{2.51} \right) \\ &= 0.38 \times 100 \\ &= 38\% \end{aligned}$$

(ii) Void ratio

This is the quantity expressing the ratio or volume of pores to the volume of solids (equation 30)

$$\begin{aligned} e &= \frac{V_r}{V_s} \\ &= \frac{n}{1-n} \end{aligned} \quad (30)$$

where

$$V_r = \text{Volume of void}$$

$$V_s = \text{Volume of Solid}$$

This index is important because the total soil volume changes with volume change of voids and hence a knowledge of the dynamics of pore due to external load is possible with the information or void ratio.

$$e = 0.38 / (1 - 0.38) = 0.61$$

(iii) Degree of Saturation: This is the ratio of volume of water to volume of voids and it refers to the volume of water present in the total pore volume.

$$S = V_w / V_v \quad (31)$$

S = Degree of Saturation

V_w = volume of water

V_v = volume of void.

It can also be shown that

$$S = \frac{0.154 \times 2.51}{0.61} \times 100$$

$$S = \frac{MGS}{e} \times 100$$

$$S = 43.4$$

(a) **Determination of Saturated Density and Buoyant Density of Soil.**

$$W_n = S_w n \quad (32)$$

W_n = water contained in pores when saturated (kg/m^3)

S_w = Density of water kg/m^3

n = Porosity.

$$W_n = 1000 \times 0.30 \quad (380 \text{ kg/m}^3)$$

Saturated density of soil

S_s = saturated density kg/m^3

S_d = Dry density

$$S_s = 1551.5 + 380 = 1931.5 \text{ kg/m}^3$$

Buoyant density of soil

$$S_b = S_s - S_w$$

$$S_b = \text{buoyant density kg/m}^3$$

$$S_b = 1931.2 - 1000$$

$$= 931.5 \text{ kg/m}^3$$

- (b) **Dry unit weight:** To obtain the dry unit weights of the soil N/m^3 , the various dry densities are multiplied by acceleration due to gravity. Assuming $g = 10\text{m/s}$

- (i) Dry unit weight

$$W_d = gS_d$$

$$= 10 \times 1551.5$$

$$= 15515 \text{ N/m}^3$$

- (ii) Bulk moisture unit weight

$$W_m = gS_m$$

where

$$S_m = S_d (1 + m)$$

$$= 1551.5 (1 + .126)$$

$$= 1746.99 \text{ kg/m}^3$$

0.126 for moisture content m is obtained from the graph – Figure 6

$$W_n = 10 \times 1747$$

$$= 17470 \text{ N/m}^3$$

- (iv) Saturated unit weight

$$W_s = S_s$$

$$= 1931.5 \times 10$$

$$= 19315 \text{ N/m}^3$$

- (iv) Buoyant Unit weight W_b

$$W_b = gS_d = 10 \times 931.5 = 9515 \text{ N/m}^3$$

). The available moisture is given by Equation 33,34 and 35 respectively.

$$Ma = FC - WP \tag{33}$$

Where

Ma = available moisture (%)

FC = field capacity (moisture content of the fields soil after drainage has become negligible (%))

WP = wilting point (soil water content below which plant growing in that soil remain wilted even when transpiration is nearly eliminated (%))

In determining the permanent wilting point a field capacity of 2.3 times the wilting point was assumed considering the silty nature of the field soil (Israelsen and Hansen, 1962).

Therefore,

$$Ma = FC - \frac{FC}{2.3} \tag{34}$$

The field capacity was estimated by weighing after drying in oven, samples scooped at various depths and locations of the field (under cover) two days after thorough wetting. A value of 28% for the field capacity was obtained.

Therefore

$$\begin{aligned} Ma &= 28 - \frac{28}{2.3} \\ &= 15.83\% \end{aligned}$$

The depth of available moisture was obtained using:

$$da = \frac{Ma \ As \ Dr}{100} \quad (35)$$

where

da = depth of available moisture in the roof zone

$$\begin{aligned} da &= \frac{15.83 \times 1.5 \times 40}{100} \\ &= 9.498\text{cm} \\ &= 9.5\text{cm} \end{aligned}$$

The readily available moisture da is then given as

$$\begin{aligned} Dra &= \frac{75 \times 9.5}{100} \\ &= 7.125 \text{ cm} \end{aligned}$$

3. Results and Discussion

3.1 Soil Survey

Historically, the soil in the project area is generally waterlogged seasonally because of heavy clay dominance and the impervious sub-strata of shales. Reyment 1965 the soil is classified under the hydromorphic soils of Eastern Nigeria. According to the soil survey, which details the soil profile of the Igwu Rice Scheme, the soil is 6.7 pH, well-drained to a depth of around 1 m, and has a typical agricultural nature. The project further described the soil as being of good workability, with largely fine to medium texture, characterized by dull orange. (7.5 YR 6/4 dry, brownish black (10 YR 3/2) wet topsoil. The topsoil is made up of sandy loam of weak angular structure, few fibrous roots and of mixed humous, few fine and continuous pores. In conclusion the report noted that erosion was minimal because of forest cover and the area holds a high potential for irrigated agriculture. The result of the study (Table I) is closely related to the World Bank Appraisal Report of the Igwu Irrigation Scheme (Appraisal of Rice Project, Nigeria 1974). The table indicates good soil of sandy loam with high carbon content (.6%) extending over a depth of 34cm. However, the decrease in carbon and nitrogen content down the soil shows a progressive decrease in plant nutrient, thereby limiting the extent of soil removal during leveling. The test further shows that the predominate cation involved in exchange is calcium (6.2) which generally promotes good tilth while sodium is found in lesser amount.

Table 1: Physical and chemical properties of study site soil

Mechanical Analysis			Chemical Analysis																					
Depth (cm)	% Clay	% Silt	% Fine Sand	% Coarse Sand	Textural Class	% Gravel in kg Soil	pH 1:2:5	Organic Matter	Na/100g/Soil															
0-54	12	10	72	6	sandy loam	0	5.20	4.10	0.60	0.03	0.06	9.70	0.29	0.32	6.20	0.60	7.41	1.20	0.40	74.00	9.01	10.00	2.00	4.48
54-86	50	9	34	7	clay	0.50	6.70	5.60	0.15	0.26	0.03	5.50	0.46	0.49	25.30	2.10	28.35	0.80	4.80	97.80	33.95	29.00	8.00	17.92
86-170	60	10	22	8	clay	0	6.00	4.50	0.10	0.17	0.02	4.30	0.39	0.40	23.00	1.70	25.50	0.60	0.60	90.10	26.70	28.10	4.00	8.96

In classifying the project land, the USBR general land classification system which sums up the limiting factors – slope, texture, depth of rooting zone, salinity, all salinity and flooding risk. Table 2 has been used.

Table 2: Land classification of Limiting factors.

Factors and Symbol	Meaning	Highest class in which classifiable
Drainage W	Minor drainage difficulties	II
	Medium drainage difficulties	III
	Major drainage difficulties	IV
Available Moisture Am	Moderate – 10% - 13%	II
	Low - 6% - 10%	III
	Very low - under 6%	IV
Salinity S	Saturated extract conductivity 4-6 mmhos/ cm at 25 ^o c	II
	Saturated extract conductivity 4- 16 mmhos/ cm at 25 ^o c	III or IV
	Saturated extract conductivity over 16 mmhos/ cm at 25 ^o c	V or VI
Alkalinity A	Na/T = 10 % - 15%	II
	Na/T = 15 % - 20%	III
	Na/T = 20% - 30%	IV
	Na/T over 30%	V or VI
Flooding F	Only exceptional flooding	II
	Major floods every two or three years, or for short periods each year	III
	Major floods each year	IV or V
Depth D	Deep = 0.75 m - 1.5 m	II
	Moderately deep = 0.25 m - 0.75 m	III

Erosion E	Shallow = 0.25 m	IV or V
	Medium to slight erosion	II
	Severe erosion	III
	Very severe erosion	IV or V
Slope T	3% - 6%	II
	6% - 8%	III
	8% - 25%	IV
	Over 25%	V or VI
Micro Relief M	Scattered holes and ditches up to 60 cm in depth.	II
	More densely distributed deeper holes and ditches	III

The system employs six capability classes ranging from class I to 6 with class I having the least limitations and class 6 the greatest limitation.

3.2 Irrigability of the Project Area

Figure I in 2.1 shows detailed topographic map of the project site that characterized the field. The field is divided into four land patches by the Atayi and Iyoma streams. Each land unit has a terrain sloping towards the stream bordering it. Hence the entire field drains into the stream. The extreme western section of the field is more or less a high land with a general slope of about 6% and ranges in elevation from 102.25 m to 105.66 m. It is, therefore, proposed that this portion of the field be used for the farmstead. The central portion of the field surrounded by both streams is relatively flat and rises about 4m above the surrounding stream beds. Presently it is marshy but a mechanical analysis of soil from the area indicated a preponderance of fine sand (Table 3). With good drainage, a central location, and an area of about 0.5ha this area is considered suitable for siting the pump station. A shear stress analysis of the underlying soil showed good load bearing capacity. The other portions of the field are gently sloping (0.6 %) and of general sandy loam topsoil to an average depth of 60 cm, well-drained but badly fragmented by the streams. Overall, a total land area of 10.15 ha is considered irrigable out of the 16-ha project land. Table 3 summarizes the attributes of the study site for irrigation.

Table 3: Project land classification

Factor considered	Site Attribute	Possible Class
Drainage	Medium drainage Difficulties	III
Available moisture	15%	I
Salinity	0.25 Mm ho/cm	I
Flooding	Major flood for short period each year	III
Depth Erosion	0.5m moderately deep	III
Erosion	Medium to slight erosion	II
Slope	0.3 to 6%	II
Micro-Relief	Scattered to and ditches to 60cm in depth	II

An average class of II is assigned to the project for irrigation purposes.

3.3 Compaction Test

The value obtained as presented in Tables 4, 5, 6, plotted in Figure 4 and summarized in Table 7 could be seen as reasonable for soil of high organic matter and plant mineral content. It should however be noted that it is impossible to obtain complete saturation as per the compaction test as there must be air void in the compacted soil. Hence the test should be used as a guide to compaction on site (Majumdar 2015)

Table 4: Analysis of data on compaction test

Location	Amayi		
Taken by	Uche Uche		DATE:
Tested by	G. Okey and Uche Uche		
Type of mould	Proctor		
No of blows	25	25	
Wt of mould + Soil gm	5937	6040	
Wt of mould gm	4231	4231	
Wt of soil mould gm	1706	1809	
Bulk density kg/m ³	1706	1809	
W.C. Timing	84	55	10
Wt. Tin + Wet soil	71.8	63.0	58.8
Wt. of Tin	15.9	16.0	
Wt. of water	5.5	4.8	
Wt. of dry soil	50.4	52.2	
Moisture content %	10.9	11.4	
Average MC %	11.2		
Dry Density	1534		

Table 5: Specific gravity test

	DATE:		
	1	2	3
Mass of density bottle	29.1	29	25.2
W ₁ (g) including stopper			
Mass of density bottle + Stopper + oven dried soil	71	73.2	61.5
W ₂ (g)			
Mass of density Bottle + Stopper + oven dried soil	104.4	105.3	97.3
+ Distilled water W ₃ (g)			
Mass of Density Bottle + Stopper + Distilled water	79.21	79.07	75.2
Specific gravity GS =	2.51	2.47	2.56

The Proctor compaction test enabled the choice of appropriate moisture content for the triaxial test. Result is as shown in Table 6.

Table 6: Particle size distribution for the pump station site

BS Sieve Size (mm)	BS Sieve No.	Weight Retained I	Weight Retained II	Percent Retained	Percent Passing
2.50	7	2.5	1.2	0.20	99.80
0.578	14	35.3	27.7	3.46	96.34
0.60	25	126.1	113.3	13.19	83.15
0.45	36	140.1	1.4	14.33	68.82
0.30	52	140.0	138.4	15.35	53.47
-	72	6.3	44	0.59	52.88
0.15	72	200.3	198.0	21.97	15.89
	200			15.89	0
	Passing 200				

An optimum moisture content of 15.4% at 1640 maximum dry density was obtained (Figure. 4)

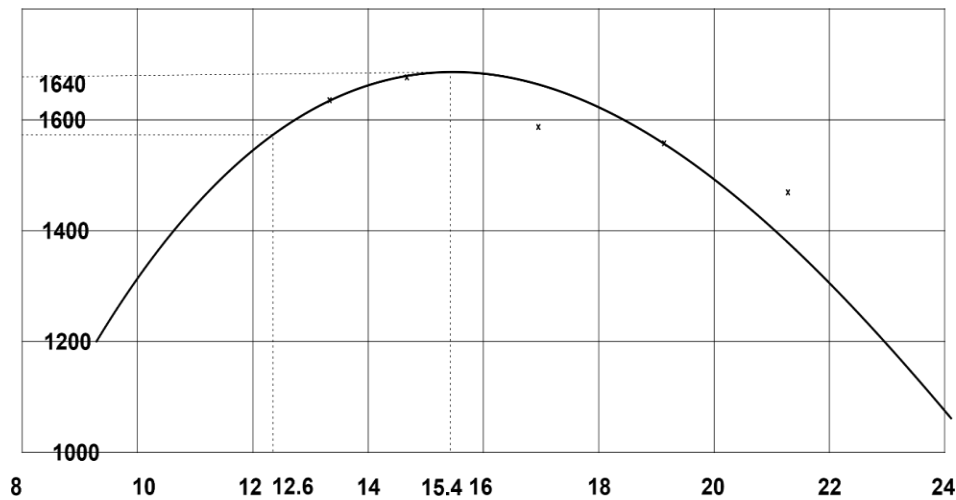


Figure 4: Proctor soil density curve

Result of the dry, moist, saturated, and buoyant unit weight test of the soil is shown in Table 7.

Table 7: Summary of Compaction test results.

Properties	Value
Optimum moisture content	15.4%
Maximum dry density	1640 kg/m ³
Porosity	38%
Void ratio	0.61
Degree of saturation	63.4%
Saturated density	1931.5 kg/m ³
Buoyant density	931.5 kg/m ³
Dry unit weight	15515 N/m ³
Bulk moist unit weight	17470 N/m ³

It should also be noted that climatic condition should be taken into account as well as the ability to accurately control moisture content on site. Relative compaction is therefore recommended in using the proctor soil density curve result.

3.4 Consistent limit test

The design of foundations especially under saturated soil conditions as is often the case in the project area during the high flood season and the selection of irrigation canal lining material are influenced by the Atterberg limits: Liquid limits (LL), Plastic limit (PL) and Shrinkage limit (SL) as shown in Figure 5.

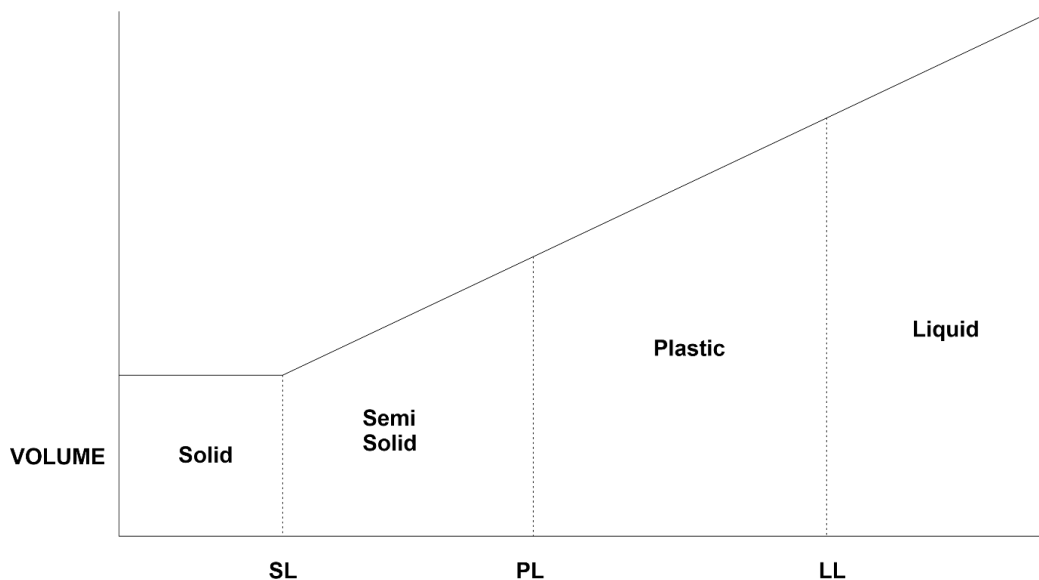


Figure 5: Soil Consistency Limit

The result of the test is as shown in Table 8 which is plotted and read from Figure 6 to obtain the liquid limit of 29%, plastic limit of 5% and plastic index of 24%.

Table 8: Determination of the liquid and Plastic Limits of the soil

Type of Test	Liquid Limit				Plastic Limit		
	1	2	4	5			
Test No.							
Moisture Content Tin No.	51	23	20	4	45	74	199
Mass of Wet Soil + Tin $w(g)$	29.25	20	29.8	33.85	30.25	21.8	33.5
Mass of Dry Soil + Tin $W_D (g)$	26.1	26.7	26.5	29.7	27.00	20.8	32.6
Mass of Tin $W_T (g)$	15.8	15.6	15.5	15.6	15.5	15.4	27.9
Mass of Water $W_w = W - W_D (g)$	3.15	3.3	3.3	4.15	3.25	1.0	0.9
Moisture Content $M \% = \frac{W_w}{W_s} \times 100$	30.6	29.7	30.28	29.4	28.3	18.5	19.2
Number of blows: N	13	17	29	34	48	5.05	5%

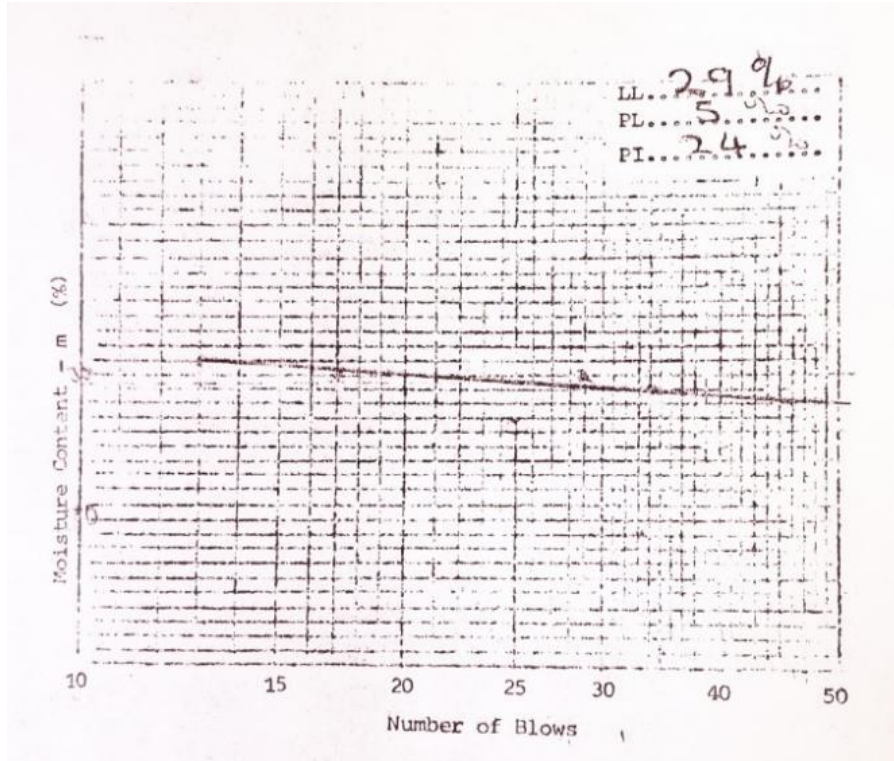


Figure 6: Liquid Limit Test.

Using the Plasticity Chart for Soil Classification shown in Figure 7, the project soil falls within the inorganic clay of low plasticity (29, 24) (Smith, 1981).

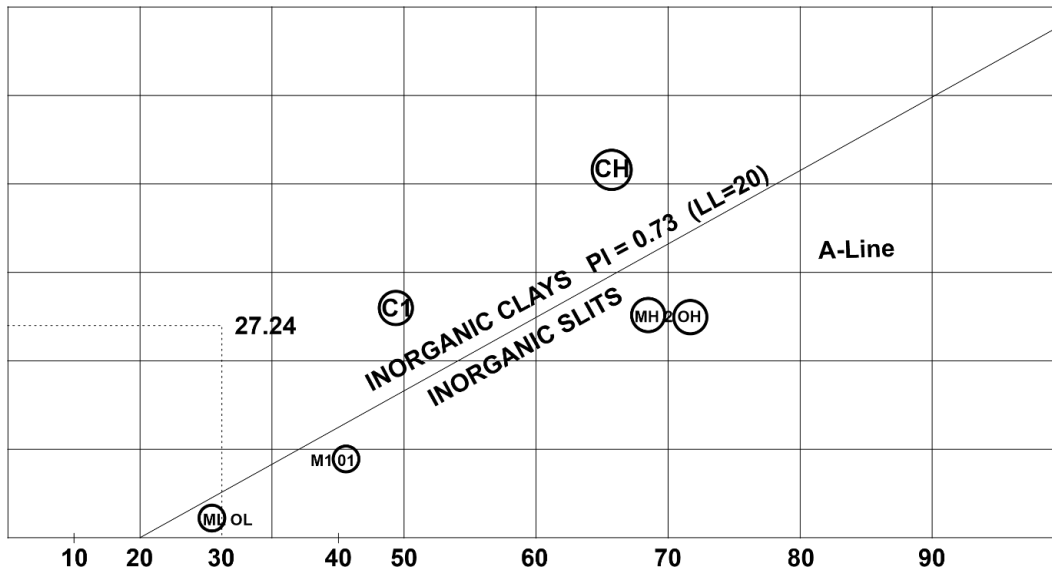


Figure 7: Plasticity Chart for Soil Classification

Lastly, the linear shrinkage test was conducted with a length of 14cm to obtain 13cm on drying, to obtain 7.14%.

3.5 Determination of Sheer Parameters

The result of the coefficient of Permeability test (Table 9 and 10), indicates that the project soil has a permeability coefficient of the order of 10.4 mm/s. The unconsolidated undrained, triaxial compression test result was used to determine the shear parameters (Cohesive strength C and Angle of friction ϕ) of the soil for the project pump station site.

Length = 7.64 m = 764cm
 Net weight of specimen = 167.2gmb =
 162.8gm
 N/C = 12.3%
 Moving ring No = 4582
 Ring Constant = 0.53
 Diameter 3.8cm
 Time of strain = 1.08 min

Table 9: Triaxial test reading

Weight/Pressure			TEST 1 63 = 7			TEST 2 63 = 14			TEST 3 63 = 21		
Strain Dial Reading	Strain %	Area of Specimen (cm ²)	Stress Dial Reading	Force (N)	61 -63 (N/cm ²)	Stress Dial Reading	Force (N)	61 -63 (N/cm ²)	Stress Dial Reading	Force (N)	61 -63 (N/cm ²)
30	1	11.46	175	92.8	8.1	21	11.1	1	4	2.12	0.2
60	2	11.57	240	127.2	11	95	50.4	4.4	245	129.9	11.2
90	3	11.7	289	153.2	13.1	186	98.6	8.4	428	226.8	19.4
120	4	11.82	325	172.3	14.6	265	140.5	11.9	583	209	26.1
150	5	11.94	355	188.2	15.8	323	171.2	14.3	710	376.3	31.5
180	6	12.07	382	202.5	18.8	370	196.1	16.3	918	486.5	40.3
210	7	12.2	430	227.9	18.7	414	219.4	18	1020	540.6	44.3
240	8	12.33	480	254.4	20.6	460	243.8	19.8	1034	525.1	42.6
270	9	12.4				508	269.2	21.6	1165	617.5	49.6
300	10	12.6	515	273	21.7	551	295.6	23.5	1235	654.6	52
330	11	12.74	540	286.2	22.5	586	310.6	24.4	1305	691.7	54.3

Average shear strength of soil is 199.22 KN/m² (200 KN/m²). Hence for any desired width and depth of strip foundation for the pump house the net ultimate bearing capacity of the soil can be determined. The ultimate bearing capacity is the value of the gross loading intensity at which the ground fails in shear.

3.6 Permeability Test

A permeability test was carried out using a constant head permeameter as detailed by Smith (1981). The test indicated a disturbed clay sample permeability coefficient of 1.43×10^{-d} mm/s; if the final intake rate (I_f) of the soil is assumed equal to permeability of the soil at 80% saturation (Israelsen and Hansen, 1962).

Hence it will take about ten days for water to set through the rooting zone of 40cm depth assuming a uniform clay soil down the root depth. But the topsoil test indicated a 54cm deep sandy loam. Intermittent water submergence permitting drying of soil during irrigation interval and puddling (Wang and Hagan, 1981) as proposed for the project will further reduce deep percolation losses. Based on the above information a deep percolation loss of 15 per cent of the water applied has been assumed. This enables a plot efficiency of 80% (eighty per cent) to be adopted. In the determination of the co-efficient of permeability the Dar 'cy' s equation was deployed and the result obtained from the testis as shown in Table 10. This result indicates that the project soil has a permeability co-efficient of the order of 10.4 mm/s which if compared with Table 11 could be considered of drainage status.

Table 10: Constant Head Permeameter Test

Qty of water flowing through sample (Q)	Time for flow (t)	Difference standpipe level (h)	Difference between tapping points (L)	Cross Sectional Area of Sample (A)	$K = \frac{QL}{Aht}$	Average (K)
(cm ³)	(min)	(cm)	(cm)	(cm ²)	(cm/s)	(cm/s)
8.5	30	75	10	45.36	1.39×10^{-5}	
7.0	30	60	10	45.36	1.42×10^{-5}	1.43×10^{-5}
9.5	30	80	10	45.36	1.45×10^{-5}	0.515mm/hr.

Table 11: Permeability by Soil Types (Smith, 1981)

Soil Type	Value of Permeability(mm/s)	Drainage Properties
Gravel	1000 - 10	Good
Sand	$10 - 10^{-2}$	Good
Silt (Fine/red clay)	$10^{-2} - 10^{-5}$	Poor
Clay	$\gt 10^{-5}$	Impervious

Table 12 further confirms the behavior of the soil as expected from the textural analysis. It could therefore be considered as slightly pervious. Based on Table 11, the soil can be grouped under class I soil.

Table 12: Soil Class Based on Permeability (Kinori and Mavorach, 1984).

Class	Seepage	Hydraulic ₅ conductivity (10 - cm/s)
1	Very slow	3
2	Slow	3 – 15
3	Medium slow	15 – 60
4	Medium	60 – 170
5	Medium guide	170 – 350
6	Quick	350 – 700
7	Very Quick	700

3.6 Field Infiltration

Measurement of infiltration rate was at three different locations. The result of the first location was ignored due to error. It was therefore not considered in the final estimation. Result of the infiltration test of the study site is as shown in Table 13.

Table 13: Infiltration Test

Cylinder No 1						Cylinder No 2						
Distance of Water Surface from Reference Point		Infiltration During Period				Distance of Water Surface from Reference Point		Infiltration During Period			Average infiltration Rate	Average Accumulated Infiltration
Elapsed Time (min)	Before Filling (cm)	After Filling (cm)	Depth	Average Rate (cm/uc)	Accum. In Filling (cm)	Before Filling (cm)	After Filling (cm)	Depth	Average Rate (cm/uc)	Accum. In Filling	cm/hr	cm
		22					22					
5	21.5	22	0.5	6	0.5	21.4	22	0.6	7.2	0.6	6.6	0.6
10	21.4	22	0.6	3.6	1.1	21.6	22	0.4	2.4	1	3	1.1
15	21.2	22	0.8	3.2	1.9	21.4	22	0.6	2.3	1.6	2.8	1.8
25	21.4	22	0.6	1.4	2.5	21.1	22	0.9	2.2	2.5	1.8	2.5
45	21	22	1.1	1.4	3.6	20.7	22	1.3	1.7	3.8	1.6	3.7
60	20.7	22	1.3	1.3	4.9	20.4	22	1.6	1.6	5.4	1.5	5.2
75	20.4	22	1.6	1.3	6.5	20.1	22	1.9	1.5	7.3	1.4	6.9
90	20.2	22	1.8	1.2	8.3	19.8	22	2.2	1.5	9.5	1.4	8.9
110	19.8	22	2.2	1.2	10.5	19.6	22	2.4	1.3	11.9	1.3	11.2
120						19.4	22	2.6	1.3	14.5		

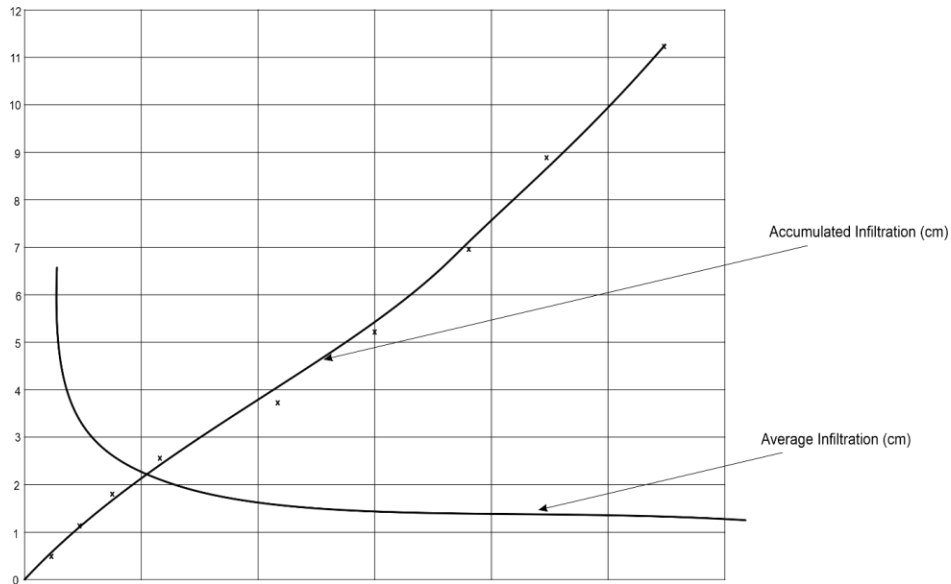


Figure 8: Plot of Accumulated Infiltration and Infiltration Rate against Elapsed Time

From the infiltration rate curve Figure 8, a constant infiltration rate of 1.5cm/hr. after 160 min was obtained. Using the curves, the functional relationship between the cumulative intake F and the time t was determined to be 0.17 mm/min. It is to be noted however, that the cumulative infiltration curve does not strictly agree with the theoretical plots due probably to error in measurement arising from the crude infiltrometer used for the test and possible lateral water movement from the inner cylinder. Finally, it should be borne in mind that ring tests generally overestimate infiltration due to lateral spreading of water applied to a small area only Akhil, 2022 Hence values obtained are subject to field experience of infiltration characteristics over the project life.

3.7 Soil Storage Capacity

The range of water available to the plant is that between the field capacity (FC) and the wilting point. The readily available moisture which is that portion of the available moisture that is most easily extracted by plants is taken as 75% of the available moisture (Israelsen and Hansen, 1962). The apparent specific gravity of 1.5 was estimated from the dry bulk density (Table 7) since the two terms have equal numerical value (Michael, 1978). The Igwu Rice Scheme with similar site conditions as the study area indicated an average rice rooting depth of 40 cm. If a condition of uniform soil is assumed then depth of available moisture (d_a) is 9.5cm and readily available moisture is 7.125 cm

4. Conclusion

Successful use of water for irrigation agriculture involves a highly complex undertaking such as engineering planning, design and construction in addition to. agricultural and other supporting activities. This underscores the essence of the analysis of field characteristics aspect of irrigation project at the preliminary design stage. In this study the soil parameters were determined starting

with soil survey (good soil of sandy loam with high carbon content (.6%) extending over a depth of 34cm) and irrigability of the field (an average class of II, 10.15 out of the 16-ha considered irrigable). The study then proceeded with the determination of the soil compaction strength (17470 N/m³), average shear strength (199.22 KN/m²) and soil consistency test (inorganic clay of low plasticity (29, 24)). The coefficient of permeability of the project soil is 1.43×10^{-4} mm/s with cumulative water intake of 0.17 mm/mi. Under the condition of uniform soil depth, the available moisture (da) is 9.5cm and readily available moisture is 7.125 cm. These are the field characteristics that determine the agronomic water needs of the envisaged crop- rice and therefore the irrigation stream size and subsequent canal hydraulic design. The study, therefore, assessed the field characteristic of Igwu River basin as a case study for installation of irrigation system to produce paddy rice. The results of the analysis recommend the study site suitable for paddy rice irrigation on the aspect of field characteristics.

Reference.

Akhil AK. 2022. Measurement of Infiltration Rate of Soil -Ring Infiltrometer Method, Smart Service, London.

Albaji, M., Eslamian, S., Naseri, AA. and Eslamian, F. 2022. Handbook of Irrigation System Selection for Semi-arid Regions. CRC Press, Boca Raton, Florida City in Florida, USA.

Appraisal of Rice Project Nigeria, 1974. International Bank for Reconstruction and Development, International Development Association, <https://documents1.worldbank.org/curated/en/842751468096580653/pdf/multi-page.pdf>.

Accessed on 14th January, 2023.

Chapman, SR and Carter, LP. 1976. Crop Production Principles and Practices. W. H. Freeman and Co., San Francisco, Publishers, Proceeding 41:250 – 253.

Dent, D. and Young, A. 1981. Soil Survey and Land Evaluation. George Allen and Unwin Publishers London.

González-Briones, A., Castellanos-Garzón, JA., Mezquita-Martín, Y., Prieto, J., Corchado, JM. 2018. A Framework for Knowledge Discovery from Wireless Sensor Networks in Rural Environments: A Crop Irrigation Systems Case Study. Wireless Communications and Mobile Computing., Vol. 2018, Issue 2018, pp.1-14, Hindawi Publishing Corporation.

Israelsen, OW. and Hansen, VE. 1962. Irrigation Principles and Practices. 3rd Edition, Wiley International Edition, New York.

Kinori, B. and Mavorach, J. 1984. Manual of Surface Drainage Engineering Vol. 2, Elsevier Pub. Co., Amsterdam.

Levchich V. 1981, Soil Mechanics in Civil Engineering, Abic Publishers Onitsha, Nigeria

Majumdar DK. 2015. Irrigation Water Management Principles and Practice. PHI Learning Private Limited, Delhi, India.

Michael, AM. 1978. Irrigation theory and practice. Vikas Publishing House, New Delhi. p. 801.

Ofofata, GE. 1975. Nigeria in Maps: Eastern States. Ethiope Publishing House, Benin City.

Purseglove, JW. 1975. Tropical Crops Monocotyledons, John Wiley and Sons New York.

Reyment, RA. 1965. Aspects of the geology of Nigeria. The Stratigraphy of the Cretaceous and Cenozoic deposits. Ibadan University Press. 23-73.

Smith, MJ. 1981. Soil Mechanics Longman Scientific and Technical, Civil -- General. Publisher. England: Longman. Wang, J. and Hagan, R. 1981. Irrigated Rice Production Systems: Design Procedures 1981: 172. <https://books.google.com.ng/book>

Wang, J. and Hagan, R. (1981). Irrigated Rice Production Systems: Design Procedures 1981: 172. <https://books.google.com.ng/book>