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Evaluating Some Selected Soil Physical Characteristics Influencing the Infiltration Rate Of Basin Irrigation Fields At Lower Anambra Irrigation Project(Laip) In Anambra State

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ABSTRACT : *Pertinent information on the soil physical characterization of a surface irrigated field, gives an insight on the level of infiltration rate of the soil. This study was centered on assessing some selected physical soil characteristics influencing the soil infiltration rate of basin irrigation fields at lower Anambra irrigation project(LAIP). Four fields cultivated with rice were randomly selected for the study. The soil texture was clay loam with aspect ratio ranging from 0.35 to 0.67 while the surface area was between 216 and 504 m^2. The mean soil moisture, volumetric moisture, bulk density, field capacity, permanent wilting point and the total available water taken at different depth profiles of 0 - 15, 15 - 30 and 30 - 45 cm were 23.4 %, 28.6 %, 1.28 g/cm^3, 35.26 % v/v, 21.77 % v/v, and 2.84 mm/m, respectively. The soil infiltration rate after 160 min was 0.12 mm/min, while the maximum cumulative infiltration was 62 mm at 220 min. It is recommended that the basin irrigation fields can be more effective when the information on the soil physical characterization and the infiltration rate are employed in irrigation design.*

KEYWORDS: *Basin Irrigation, Infiltrometer, Infiltration Rate, Soil Physical Characteristics, Surface Irrigation.*

I. INTRODUCTION

Background of Study : In the International Food Policy Research Institute (IFPRI) Discussion Paper 00894 by [1] on measuring irrigation performance in Africa, it was stated explicitly that the continued concern over food security in Africa and a persistent agricultural productivity lag behind other regions have refocused attention on the importance of key investments in the African agricultural sector. They noted that irrigation is an investment that has been promoted persistently by donors, research analysts, and scientists within the international agricultural development community to address that lag. Irrigation is only one of the productivity-improving capital investments and technological inputs that are deficient in Africa. They however stated that irrigation stands out strongly among others. This is mainly because of its role in stabilizing yields in the face of climatic variability, which has increased notably in recent times and is projected to increase further under almost all future climate change scenarios. In addition, much of Africa is expected to experience reduced annual precipitation, which would, along with higher temperatures, enhance the potential productivity-enhancing effects of irrigation. The important soil characteristics in irrigated agriculture filed according to [2] include the following: soil texture, bulk density, soil moisture content, volumetric moisture content, field capacity, permanent wilting point, and Total Available Water (TAW) were determined at various depths. The performance of a farm irrigation system is determined by the efficiency with which water is diverted, conveyed and applied, and by the adequacy and uniformity of application in each field on the farm [3]. The soil characteristics also affect the infiltration rate, which in turn determines the performance of an irrigation scheme in an area. This work is targeted to evaluating the level of infiltration rate of soil at basin irrigation fields of Lower Anambra Irrigation Project(LAIP) as influenced by the soil physical characteristics.

II. MATERIALS AND METHODS

Study Area : The experimental field for the study was located at the Lower Anambra Irrigation Project (LAIP) situated at Omor, Anambra state, south eastern
Nigeria with geographic coordinates: Latitude 05° 45' and 06° 46' N and Longitude 06° 31' and 07° 03' and covered an estimated surface area of about 7200km^2 and an average elevation above sea level of 2200 m.
The climate is characterized by an average annual evaporation of about 2,000 mm, with rainy and dry seasons starting from April to November, and December to March, respectively. Average annual precipitation is about 419.8 mm; average annual reference evapotranspiration (ET_o) is around 1,490 mm and average temperature ranges from 18 to 28 °C. LAIP has a number of basin fields, ranging from 20 - 38 m in length and 10 - 25 m in width, with each basin cultivated with rice. The soil type of the field was clay loam, appropriate for rice cultivation. The fields were irrigated via earthen canals whose source of water was the Anambra River. Four randomly selected basins were evaluated in the study and were denoted as basins A, B, C and D. The irrigation parameters evaluated in the study were based on a limited selection found to be useful in field evaluation of surface irrigation systems. The performance evaluation included the determination of infiltration rate. The appraisal was based on a combination of field inspections for evaluating physical system and operations, interviews with the operators and evaluation of service indicators and physical characteristics[4].

Soil Physical Characterization

Soil and volumetric moisture content : One of the most important effects of irrigated agriculture is to fully satisfy the soil moisture in the root zone of the crop. The soil water content should be measured periodically to determine when to apply the next irrigation and how much water should be applied. The soil moisture content was measured after an irrigation event to the depths of 0-15, 15-30 and 30-45 cm [5]. The gravimetric method was used to determine the soil moisture content.

To calculate the soil moisture content, equation 3.1 was used.

(2.1)

$$W_i\,(\%) - \left(\frac{W_{ws}\ \ W_{ds}}{W_{ds}}\right)100$$

Where:
W_i = the moisture content (dry weight fraction);
W_{ws} = the weight of wet soil (g); and
W_{ds} is the weight of dry soil (g).
To convert the dry weight soil moisture fraction into volumetric moisture content, □□ the dry weight fraction was multiplied by the bulk density, □ $_b$; and divided by specific weight of water, □ $_w$ which can be assumed to have a value of unity [6]. Thus:

□ = □ $_b$ W/□ $_w$ (2.2)

The water content can be expressed as a depth using the expression [6]:
Depth of Water = □□*Depth of Soil

Field capacity : The most common method of determining field capacity in the laboratory uses a pressure plate to apply a suction of -1/3 atmosphere to a saturated soil sample. When water is no longer leaving the soil sample, the soil moisture in the sample is determined gravimetrically and equated to field capacity. [2] however, suggested a field technique for finding field capacity which involves irrigating a test plot until the soil profile is saturated to a depth of about one metre. Then the plot covered to prevent evaporation. The soil moisture is measured each 24 hours until the changes are very small, at which point the soil moisture content is the estimate of field capacity. The laboratory method was used in this study.

Bulk density : Measurement of bulk density of the soil was carried out by carefully collecting a soil sample of known volume and then drying the sample in an oven to determine the dry weight fraction. Then, the dry weight of the soil, W_b was divided by the known sample volume, V, to determine bulk density, □ $_b$:

□ $_b$ = $\mathbf{W_e / V}$ (2.3)

Bulk density has been reported to vary considerably with depth and over an irrigated field. Thus, it became necessary to repeat the measurement at different points over the field to develop a reliable estimate.

Permanent wilting point : Generally, at the permanent wilting point the soil moisture coefficient is defined as the moisture content corresponding to a pressure of -15 atmospheres from a pressure plate test [6]. Although actual wilting points can be somewhere between -10 and -20 atm, the soil moisture content varies little in this range. Thus, the -15 atm moisture content provides a reasonable estimate of the wilting point.

Total available water (TAW) : The total available water, TAW, for plant use in the root zone is commonly defined as the range of soil moisture held at a negative apparent pressure of 0.1 to 0.33 bar (a soil moisture level called 'field capacity') and 15 bars (called the 'permanent wilting point') [2]. The TAW will vary from 25 cm/m for silty loams to as low as 6 cm/m for sandy soils. Some typical values of TAW, field capacity, permanent wetting point and miscellaneous features have been given in [2].

Determination of System Variables : The following system variables, that is, the length, L and width, W of the basin, the unit inlet flow rate, Q_o, and the infiltration rate were determined based on direct field measurement. L and W represent known physical dimensions of the basins. The flow rate in the field supply channel was measured using a flume built into the head end of the field supply channel. Channel length (L), the length of a basin needs to be known in order to estimate advance and recession over the length of run of the channel and the ultimate distribution of infiltrated water and system performance [7]. Unit inlet flow rate (Q_o) is the discharge diverted into a unit width basin. Inflow rate is one of the key variables that influences the outcome of an irrigation event, it affects the rate of advance to a significant degree and also recession to a lesser but appreciable extent. It has a significant effect on uniformity, efficiency, and adequacy of irrigation[7].

Infiltration rate : Infiltration is the most important process in surface irrigation as it essentially controls the amount of water entering the soil reservoir, as well as the advance and recession of the overland flow[2]. The cylinder infiltrometer as described by [8] which is one of the techniques for measuring infiltration as noted by [2]. was used. A metal cylinder (Figure 3.2) with a diameter of 30 cm or more and a height of about 40 cm was driven into the soil, using a driving plate set on top of the infiltrometer and a heavy hammer. As stated in [9], because infiltration rates vary with conditions, such as soil water content, the test was conducted as close to the time of irrigation as possible and under representative conditions. After the infiltrometer had been installed, the test was conducted in the following manner. The volume of the cylinder above the soil was carefully measured (diameter, depth). A gauge was fixed to the inner wall so that the water level changes that occur can be measured. A pre-measured volume, about 80-90 % of the infiltrometer capacity of water similar to the irrigation water, was added quickly to the infiltrometer. When the water surface was quieted, an initial reading was taken. The infiltration that occurred during the period between the start of the test and this first measurement was the difference between the computed initial level and the first actual reading. Additional measurements were recorded at periodic intervals, 5 to 10 minutes at the start of the tests, expanding to 30 to 60 minute intervals after 3 or 4 readings. Measurements were continued until the intake rate was constant over a 1 to 5 hour period. Analysis of the data was made by plotting the data (cumulative depth, Z, on the vertical axis, cumulative time, t, on the horizontal axis) and the basic infiltration rate determined.

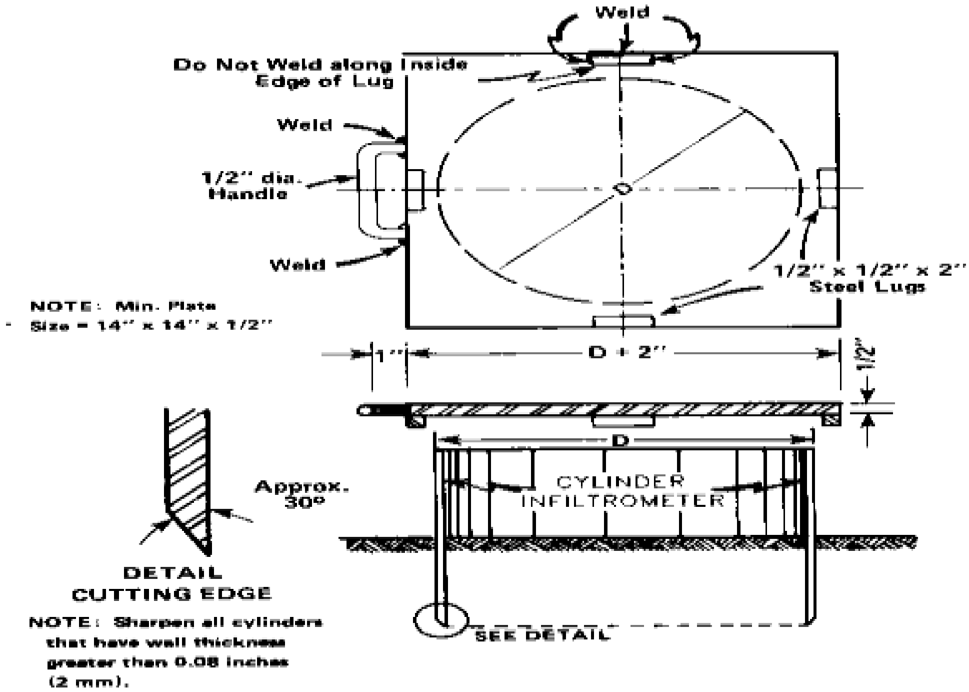

Figure 2.1: A schematic of a ring infiltrometer and driving plate

Source:[8]

III. RESULTS AND DISCUSSION

Hydraulic Network of the Irrigation System : As earlier stated, surface irrigation by flooding is the main irrigation method used at the LAIP. The source of water supply for the basin irrigation at LAIP is the perennial Anambra River. The irrigation water is first delivered to major earthen canals of about 1.8 m in width, which constitute the primary network (Figure 3.1). The water from the primary network channels is diverted into individual irrigation basins/ fields through earthen sub-canals which are termed the secondary network channel (Figure 3.2). The irrigation project was made up of a series of small level basins on which is rice cultivated. The field average dimensions were about 20 – 38 m in length and 12 – 20 m in width. The secondary channels were designed such that irrigation water flows into the basins simultaneously, for as long as there is flow of water in the primary channels. As such a basin does need to be fully saturated before water flows into the next. The basins were allowed to pond until the fields are observed to be saturated before the basin water inflow is cut off. The water distribution system is rather crude in that there were no gated pipes to either open up or close the inflow of water from the major canals. The surrounding soil was usually used to close up the sub-canals through which water flows into the individual basins.

Figure 3.1: Primary network channel at LAIP

Figure 3.2: Secondary distribution channels on two fields at LAIP

Irrigated Basin Soil Characteristics : The following important soil physical characteristics: soil texture, bulk density, moisture, volumetric moisture content, field capacity, permanent wilting point and Total Available Water (TAW) [2] which were determined at various depths for each of the experimental basin irrigation field are shown in Tables 3.1 – 3.4 while the mean data of the experimental plots are shown in Table 3.5. Soil moisture characteristics indicate the capacity of a soil to retain water for plants and irrigation scheduling depends on the amount of water available to plants and schedules are based on the amount of water available in particular soils [10]. The mean moisture content of the fields was recorded as 23.4 %. Bulk density as was noted by [11] provides an estimate of total water storage capacity, texture, infiltration rate, compactness, or aeration condition. It also gives useful information in assessing the potential for leaching of nutrients, erosion, and crop productivity. Furthermore, it affects how easily plant roots can penetrate the soil when the roots propagate. The bulk density of the experimental fields A – D at different soil depths from the ground surface ranged from 1.20 – 1.24 g/cm^3 with a mean value of 1.22 g/cm^3 which represents low density for permanently cultivated irrigated soils as was noted by [12]. The bulk density of a field depends on compactness, hence the bulk density of a cropped soil is not a constant value, but varies from sowing/transplanting to harvest, depending on the irrigation events and other cultural practices [11].

Field capacity may be defined as the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased [11]. It is influenced by organic content and over-burden pressure or compaction. The mean value of 35.3 % v/v was recorded for field capacity of the experimental fields at different depths while it ranged from 34.3 – 36.0 % v/v from field. Most plants wilt permanently (not regaining its original activities) or die when soil moisture tension reaches to 15 bars. The moisture content of the soil at this pressure is called the permanent wilting point. The permanent wilting point recorded for the experimental fields ranged from 21.0 – 22.7 % v/v with the mean value for the fields recorded as 21.77 % v/v (Table 3.5).The total available water available moisture that is easily extractable by the Plant, that is, the water between field capacity and wilting point (storage capacity) within the root zone soil was recorded to range from 2.8 – 2.87 mm/m from the fields A – D while the mean value was recorded as 2.84 mm/m (Table 3.5).

Table 3.1: Soil physical characteristics at the experimental irrigation field A

Parameters	**Soil depth from ground surface (cm)**			**Average**
	0 – 15	**15 – 30**	**30 – 45**	
Soil moisture (%)	25.3	20.9	23.5	23.2
Volumetric moisture content (%)	32.3	24.1	28.5	28.3
Bulk density (g/cm^3)	1.3	1.2	1.2	1.2
Field capacity (% volume)	36.0	37.0	35.0	36.0
Permanent wilting point (% volume)	22.0	23.0	22.0	22.3
Total available water (mm/m)	2.9	2.8	2.9	2.9

Table 3.2: Soil physical characteristics at the experimental irrigation field B

Parameters	Soil depth from ground surface (cm)			Average
	0 – 15	**15 – 30**	**30 – 45**	
Soil moisture (%)	26.3	23.9	22.1	24.1
Volumetric moisture content (%)	34.5	29.4	26.1	30.0
Bulk density (g/cm^3)	1.3	1.2	1.2	1.2
Field capacity (% dry volume)	35.0	38.0	34.0	35.7
Permanent wilting point (% dry vol.)	22.0	24.0	22.0	22.7
Total available water (mm/m)	2.9	2.6	3.0	2.8

Table 3.3: Soil physical characteristics at the experimental irrigation field C

Parameters	Soil depth from ground surface (cm)			Average
	0 – 15	**15 – 30**	**30 – 45**	
Soil moisture (%)	23.9	21.3	24.5	23.2
Volumetric moisture content (%)	28.6	24.2	30.7	27.8
Bulk density (g/cm^3)	1.2	1.1	1.3	1.2
Field capacity (% dry volume)	34.0	36.0	35.0	35.0
Permanent wilting point (% dry vol.)	21.0	24.0	19.0	21.3
Total available water (mm/m)	3.0	2.7	2.8	2.8

Table 3.4: Soil physical characteristics at the experimental irrigation field D

Parameters	Soil depth from ground surface (cm)			Average
	0 – 15	**15 – 30**	**30 – 45**	
Soil moisture (%)	20.1	23.9	24.5	22.8
Volumetric moisture content (%)	23.7	29.1	29.7	27.5
Bulk density (g/cm^3)	1.2	1.2	1.2	1.2
Field capacity (% dry volume)	34.0	36.0	33.0	34.3
Permanent wilting point (% dry vol.)	20.0	20.0	23.0	21.0
Total available water (mm/m)	2.8	2.7	2.9	2.8

Table 3.5: Mean value of the soil physical characteristics of the experimental basins

Parameters	Soil depth from ground surface (cm)			Average
	0 – 15	**15 – 30**	**30 – 45**	
Soil moisture (%)	23.9	22.6	23.6	23.4
Volumetric moisture content (%)	29.8	27.4	28.7	28.6
Bulk density (g/cm^3)	1.2	1.2	1.2	1.3
Field capacity (% volume)	34.8	36.4	34.7	35.3
Permanent wilting point (% volume)	21.3	22.5	21.6	21.8
Total available water (mm/m)	2.9	2.7	2.9	2.8

INFILTRATION RATE : An infiltrometer was used to determine the infiltration rate of the irrigation basins which describes the capacity of a soil to absorb water (Figure 3.3). The infiltration curves that is, the graph of infiltration rate (mm/min) against time as well the cumulative infiltration curve as plotted from table 3.6, are shown in Figures 3.4 and 3.5, respectively. It could be seen from Figure 3.4 that the initial infiltration rate was high and decreased rapidly over time.

The final infiltration rate, otherwise known as the basic infiltration rate was 0.12 mm/min attained after 160 min. for the clay loam soil sample of the rice irrigated field basins. The infiltration curves showed a monotonical decline which tend to approach an asymptotic steady state known as the final infiltrability or basic/equilibrium infiltration rate [13,14,15]. A low infiltration rate soil often exhibit low rates of movement of water through the soil profile referred to as percolation. The implication of the infiltration rate is that if the application of water continued at rates higher than it can infiltrate, then it will run off. Since effective infiltration is a key aspect of good irrigation, strategies such as the 'cycle and soak' technique, where irrigation water is delivered in a number of smaller applications over an extended period of time is sometimes adopted [16].

The infiltration rate was higher than that reported by [14] for sandy clay loam soil which was 0.05 mm/min. It should be noted that some soil and water characteristics such as the initial moisture content, condition of the surface, hydraulic conductivity of the soil profile, texture, porosity, degree of swelling of soil colloids, organic matter, vegetative cover, duration of irrigation or rainfall and soil texture all affect soil infiltration rate [17, 18]. The low infiltration rate and cumulative infiltration recorded for the clay loam soil was expected due to the high clay content which may be responsible for the swelling and dispersion of clay particles causing the sealing of the soil pores leading to low infiltration rate and cumulative infiltration [14,15]. From the infiltration curves, it is possible to determine how long it will take to infiltrate a certain amount of water which has implications for irrigation scheduling and flood control

Figure 3.3: An infiltrometer installed in the field

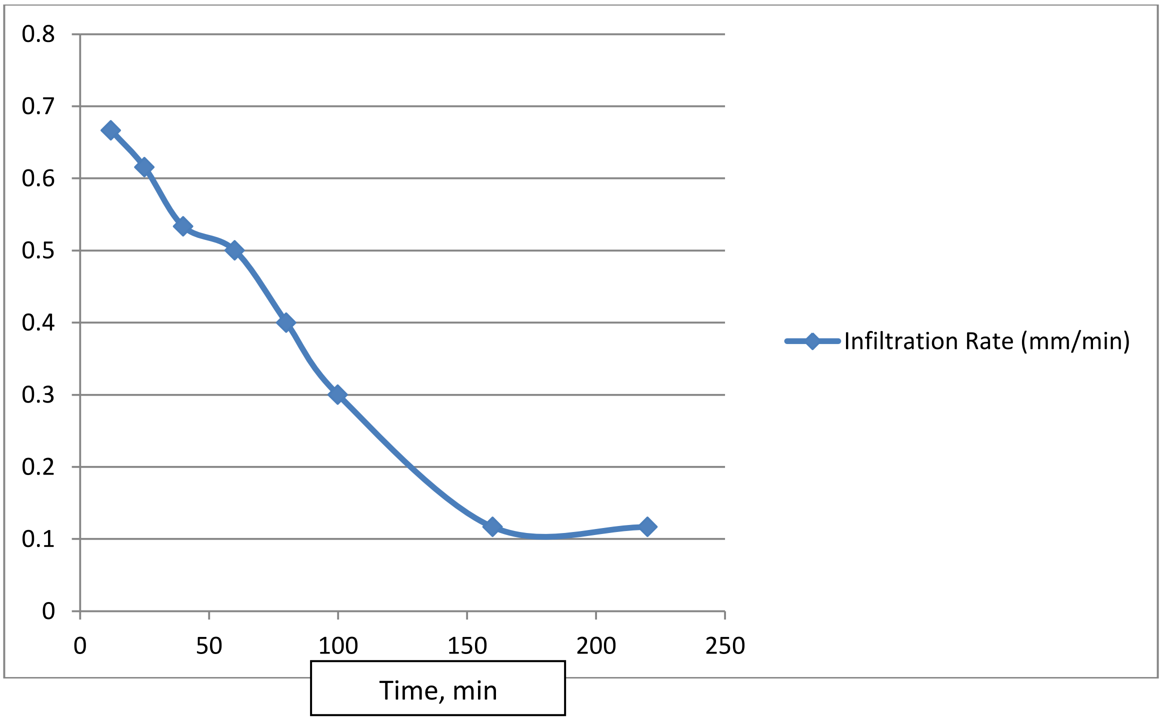

Figure 3.4: A graph of infiltration rate against time

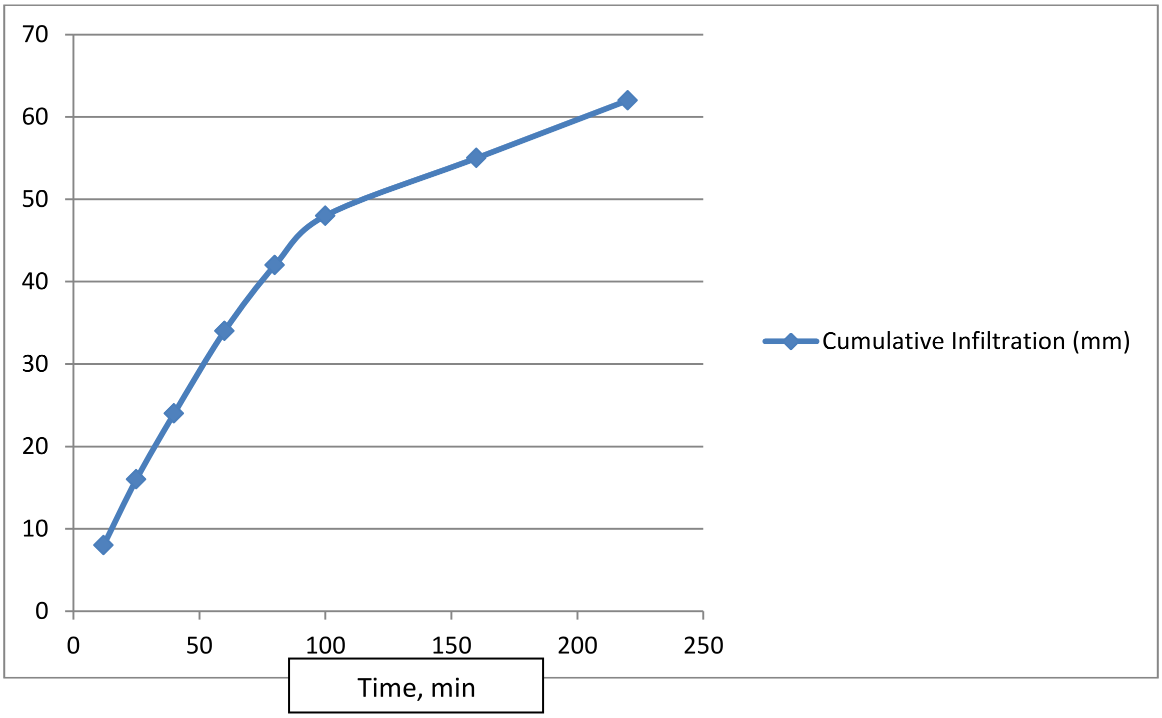

Figure 3.5: A graph of cumulative infiltration against time

Table 3.6- Determination of Infiltration Rate for Different Basins at LAIP.

Time Dif (min)	Cum. Time (min)	Infiltration (mm)	Infiltration Rate (mm/min.)	Cummulative. Infiltration (mm)
12	12	8	0.666666667	8
13	25	8	0.615384615	16
15	40	8	0.533333333	24
20	60	10	0.5	34
20	80	8	0.4	42
20	100	6	0.3	48
60	160	7	0.116666667	55
60	220	7	0.116666667	62

IV. CONCLUSION

Soil physical characteristics influenced the infiltration rate of irrigation soils at Lower Anambra Irrigation Project(LAIP) in Anambra State. The implication of the infiltration rate is that if the application of water continued at rates higher than it can infiltrate, then it will run off. This was so because of the high clay content of the irrigation basin field as unraveled from the result of the fields studied. More efficient water application can be achieved when the design parameters match actual field conditions. Hence, it is recommended that the results of this work be applied in the design of the irrigation schemes of field basins.

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