# ASSESSING THE SUITABILITY OF RICE CULTIVATION IN MUVUMBA P-8 MARSHLAND OF RWANDA USING SOIL PROPERTIES

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## Abstract

This paper deals with the estimation of different soil properties of Muvumba P-8 marshland in Rwanda to assess the soil for its suitability for rice cultivation. The objective of the research is to determine the soil properties. Properties like texture, bulk density, total available water, infiltration rate, hydraulic conductivity and permeability were determined. Soil properties were estimated for different soil depths of 0-15, 15-30, 30-45 and 45-60 cm. It was found that the layer of the soil with 0-15, 15-30 and 30-45 cm is having the soil texture of sandy clay loam and the depth of 45-60 cm is having the texture of clay loam. The soil of the plots with depths like 0-15, 15-30, 30-45 and 45-60 cm are having the clay content of 21, 25, 26 and 38% respectively and are having the bulk densities of 1.38, 1.29, 1.33 and 1.12 $gm/cm^3$. It shows that clay content increases as the depth of the soil increases. The average total available water for three different depths mentioned are 8.5, 11.2, 15.5 and 16.5 mm and it varies from 4.5 mm to 26.4 mm. The data were analysed by using GENISTAT in order to get the difference of variation. The average infiltration rate of the field at Muvumba P-8 marshland was 12.8 mm/hour. It means that a water layer of 12.8 mm on the soil surface will take one hour to infiltrate. The experimental plot at Muvumba P-8 marshland was found to be moderately slow infiltration rate but it has rapid permeability. It indicates that there is slow entry of water in top soil surface but the percolation will be faster due rapid permeability. It is good for rice cultivation.

**Keywords**: Soil properties-weather parameters-marshland-assessment-rice cultivation

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## Introduction

Rwanda is a land locked agriculture based country. Agriculture employs 78.8% of the active population (EICV2 data) and contributes 36% [of which 90% is by livestock production] of the GDP of the country. Rwanda is classified among countries of "Low Human Development" index with a GDP per capita of USD 370 and it is vital to move it from this level. Though small in size, it has several agro-climatic zones that potentially produce diverse range of crops. According to (FAO Aquastat, 2005), Rwanda has water resources in the form of natural lakes, rivers, groundwater, marshlands and runoff. Rwanda has internal renewable water resources of $31.9 \times 10^9$ $m^3$/year and potential irrigable area of 580,000 ha as per Irrigation Master Plan of Rwanda, less than 2% of the available water resource is being exploited. The agriculture production system in Rwanda is characterized by small arable lands, with a familiar exploitation of 0.8 hectares per household.

(MINAGRI,2012) in its Farm land use consolidation report stated that the total area under land use consolidation has increased by 18-fold from 28,016 Ha in 2008 to 502,916.55 Ha in 2011. The consolidated production of priority crops under Crop Intensification Program has also brought significant increases in food production – maize by 5-fold; wheat and cassava by about 3 fold; Irish potato, soybean and beans by about 2-fold; rice by 30%. The area of rice cultivation is 12000 ha in 2008 and it is increasing every year due to reclamation of marshlands. The total marshland available in Rwanda is 219,791 ha as per Rwanda Irrigation Master Plan. The area of the experimental plot was 21.8 ha. Hence, there is more scope to produce rice in marshland. According to (MINAGRI, 2013), marshland irrigation schemes have been developed by improving swamp area. Marshlands are public owned lands where farmers have allocated plots on lease. The surface irrigation systems used in the marshlands are stream diversions by gravity or from valley dams through a canal networks for flooding with rice fields. The land holding in a marshland scheme is on average 0.1 to 1.0 ha per farmer. Farmers in the marshland share common irrigation infrastructure. The area under marshlands is currently 21,775ha.

(Md Abiar Rahman et al., 2017) stated that the normal climatic parameters at a given station at any scale can be assumed to be the mean of over a 30-year period. Inconsistency in climate regimes of rainfall and temperature is a source of biotic and abiotic stresses in agricultural systems worldwide. Several studies from Bangladesh report that this variability is a cause of poor yield potential and crop failure. He reported that the data recorded were with few missing values and some over estimations. The available observed station data should show consistency with the regular data set. (Rathnayake et al.,2016) stated that climatic suitability analysis is a prerequisite to achieve optimum utilization of the available resources in rain fed rice cultivation. Therefore, a study was conducted to assess the climatic factors and to map their suitability for rain fed paddy farming in Mahananeriya, Ibbagamuwa and Alawwa ASC regions representing dry, intermediate and wet areas of Kurunegala District of Srilanka in Yala and Maha seasons using Geo-Informatics.

(Nirote Sinnarong, 2015) stated that Climate change poses a significant threat to agriculture and global food supply. The purpose of this study was to evaluate the potential impacts of weather on rain-fed rice production and agro-adaptation measure to mitigate its impacts in Northern Thailand. Based on the rice production and weather data from 17 provinces during 1989-2012, the unit root tests and feasible generalized least squares involving a panel data model are explored to obtain reliable estimates. Stochastic production function in the context of current observed productions was applied and then simulated the impact of altered planting dates on mean and variance of rice production. It was shown that weather variables had a major impact on rice production. Increase in temperature decrease mean rice production and increased its variance. ousef et al., (2018) stated that irrigation regime and soil clay content had significant effects on growth, yield and water productivity of rice. However, their combination showed no significant impact on panicles number, root biomass, harvest index and irrigation water productivity. Higher soil clay content results in increase in growth, yield, and water productivity of rice.

A better use, distribution and management of water in marshland will help in satisfying future food demands, for this reason a study was conducted in Muvumba P-8 marshland. This research lead to the proper soil and water conservation with sustainable use of Muvumba P-8 marshland. The overall objective of this paper is to estimate and analyse different soil properties of Muvumba P-8 marshland and test its suitability for optimum rice cultivation.

## Research Methodology

The marshland of Muvumba P 8- site is located in Eastern Province of Nyagatare District and exactly lies in both Tabagwe and Rwempasha sectors. It has cultivable area of 1750 ha alongside Umuvumba River, starting at Gitengure Cell in Tabagwe Sector to Kazaza Cell in Rwempasha Sector, which is near the border of Republic of Uganda. The marshland has been developed since 2011 in order to increase the agricultural productivity. The rice has been selected as the crop to be grown in the developed marshland for the first time because of water availability. The coordinates of Nyagatare marshland is :1° 18' S latitude and 30° 19'E longitude. The geographical map is shown below.


Figure 1. Map of Nyagatare District showing the location of the study area

The following methods are used to find out the soil properties of the experimental plots.

***Soil texture:*** A sample of soil from the field was taken for estimating the percentage of sand, silt and clay. The USDA texture triangle is used to classify the soil into twelve major soil texture classifications like sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. The USDA texture triangle chart was used to find out the soil texture of the experimental field based on the percentage of sand, silt and clay estimated in the laboratory.

Experiment was conducted in the rice field of the marshland. Three plots were chosen for the experiment. Experiment was conducted in each plot by taking soil samples at four different depths viz: 1) 0 to 15 cm 2) 15 to 30 cm 3) 30 to 45 cm and 4) 45 to 60 cm. The soil texture analysis involves with 3 plots x 4 depths giving 12 experiments. The details are shown below.

Soil samples were taken from three rice plots at the soil depth of 0-15, 15-30, 30-45 and 45-60 cm. The soil samples were analyzed using sieve analysis. ***Bulk density:*** A sample of soil is taken from the field. Its weight was measured using electronic balance. Its volume was measured using a graduated jar. The bulk density was computed by finding the ratio of the weight of soil divided by the total volume. It is expressed in $gm/cm^3$. Experiment was conducted in the rice field of the marshland. Three plots were chosen for the experiment. Experiment was conducted in each plot by taking soil samples at four different depths viz: 1) 0-15 cm 2) 15-30 cm 3) 30-45 cm and 4) 45-60 cm. The soil weight and volume were recorded. Soil samples were taken from three rice plots at the soil depth of 0-15, 15-30, 30-45 and 45-60 cm. The weight of the soil samples were measured in an electronic balance. The volume of the soil samples were found out using measurement jar. The bulk density was found out by dividing.

***Total Available Water:*** The total available soil water is the amount of soil moisture available to plants. It is the difference between the moisture content at field capacity to moisture content at the permanent wilting point. It is expressed as follows.

$$TAW = 1000(\theta_{FC} - \theta_{WP}) Z_r \quad \text{eq.(1)}$$

Where

TAW is the total available soil water in the root zone, mm

$\theta_{FC}$ is the water content at field capacity, $m^3 m^{-3}$

$\theta_{WP}$ is the water content at wilting point, $m^3 m^{-3}$

$Z_r$ is the rooting depth, m

***Infiltration rate of the soil:*** The infiltration rate is the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm or cm) of the water layer that can enter the soil in one hour. The infiltration rate of the study area has been determined experimentally by the use of double ring infiltrometer. It consists of pouring water and put it at a level of 15 cm, which is the initial height of water. The water level after 10 to 15 min was recorded. After recording the final level of water, the ring is refilled to the initial level of 15 cm and the process continues like that until the constant change in water level is obtained. The constant water depletion obtained is called the infiltration rate.

***Hydraulic conductivity of the soil:*** Hydraulic conductivity is a soil property that describes the ease with which the soil pores permit water movement. It depends on soil type, porosity and configuration of the soil pores. A hole is made in the soil and is filled with water. The size of the hole is 60 cm diameter and 80 cm depth. The water level goes down as time increases. The reduction in depth of water is recorded for every 300 seconds. In every water level, calculate the hydraulic conductivity as per the formula given below. The formula used to calculate the hydraulic conductivity is:

$$K = 1.15 \times r \frac{[\log(h_o + r/2) - (\log(h_t + r/2)]}{\Delta t} \quad \text{eq.(2)}$$

Where

K is the hydraulic conductivity, cm/min or cm/hour

r is the radius of the hole, cm

$h_o$ is the initial height of water in the hole, cm

$h_t$ is the final height of water in the hole, cm

$\Delta t$ is the time interval in minutes

***Permeability of the soil:*** Hydraulic conductivity of the soil is used to find out the permeability of the soil. According to the Smith and Browning (1975), there is a table showing the permeability classes of the soil for every range of hydraulic conductivity of the soil. It was used in this experiment and the permeability class was determined.

## Results and Discussion

Data were collected and analyzed in Muvumba-P-8 marshland based on the methodology adopted. It includes soil characteristics of the marshland like soil texture, bulk density, comparison of soil texture and soil bulk density.

#### Analysis of weather and soil characteristics of marshland

This section deals about the weather and soil characteristics like temperature, rainfall, sunshine hours and the relative humidity of the region. It also deals with the soil texture, bulk density, total available water, total available water, infiltration rate, hydraulic conductivity and permeability of soil. infiltration rate and hydraulic conductivity of soil. These soil characteristics play an important role in the assessment of water use efficiency in Muvumba-P8 marshland. The details of the soil characteristics are shown below.

### Weather report of the Nyagatare region

The weather data collection and analysis pertaining to the Muvumba-P8 marshland was carried out and are given herewith. It was found that the average minimum temperature fluctuates between 15.7 °C to 13.7 °C in the month of March and July respectively. The highest average maximum temperature of 29.2 °C is found for the months of December followed by January with 29.1°C. The highest rainfall of 94.6 mm was received during the month of October followed by 93.3 mm during April. The lowest rainfall of 21.6 mm was found in the month of July. The highest wind speed of 7.0 to 7.7 km/hour was experienced from July to October. There was the lowest wind speed of

5.8 to 6.2 km/hour for the months of December to April. km/hour. It was found that the highest sunshine duration is
between 6.1 to 6.7 hours during the months of July to October. There was lowest sunshine duration of 5.0 to 5.4 hours for the months of January to April.

**Soil texture**

The average monthly wind speeds was found to be 6.5

Soil texture is one of the important characteristics of soil. It is a physical property needed to be studied for assessing the water use efficiency. It describes the mixtures of sand, silt and clay particles. The results are shown below.

Table 1. Soil texture of the experimental field at different depths

| Crop | Plots | Soil depth, cm | clay % | silt % | sand% | Soil texture based on Textural Triangle |
|---|---|---|---|---|---|---|
| Rice | Plot 1 | 0-15 | 9 | 16 | 75 | Loamy sand |
| Rice | Plot 2 | 0-15 | 20 | 19 | 61 | Sandy clay loam |
| Rice | Plot 3 | 0-15 | 35 | 16 | 59 | Sandy clay loam |
| Average | | 0-15 | 21 | 17 | 65 | Sandy clay loam |
| Rice | Plot 1 | 15-30 | 15 | 14 | 71 | Sandy loam |
| Rice | Plot 2 | 15-30 | 22 | 19 | 59 | Sandy clay loam |
| Rice | Plot 3 | 15-30 | 37 | 14 | 69 | Sandy clay loam |
| Average | | 15-30 | 25 | 16 | 66 | Sandy clay loam |
| Rice | Plot 1 | 30-45 | 23 | 20 | 57 | Sandy clay loam |
| Rice | Plot 2 | 30-45 | 22 | 23 | 55 | Sandy clay loam |
| Rice | Plot 3 | 30-45 | 33 | 12 | 55 | Sandy clay loam |
| Average | | 30-45 | 26 | 18 | 56 | Sandy clay loam |
| Rice | Plot 1 | 45-60 | 25 | 20 | 55 | Sandy clay Loam |
| Rice | Plot 2 | 45-60 | 36 | 21 | 43 | Clay loam |
| Rice | Plot 3 | 45-60 | 52 | 16 | 32 | Clay |
| Average | | 45-60 | 38 | 19 | 43 | Clay loam |

Table 1 show that the top layer of the soil between 0-15 cm depths is having the texture of sandy clay loam to loamy sand. It has high sand followed by silt and less quantity of clay content. The average value of sand, silt and clay among the three plots were 65, 17 and 21% respectively. The texture triangle for the averages of three plots shows that the soil texture is sandy clay loam. The layer of the soil of 15-30 cm depth is having the texture of sandy loam to sandy clay loam form plots 1 to 3. It has high sand followed by clay and less quantity of silt content. The average value of sand, silt and clay among the three plots were 66, 16 and 25% respectively. The texture triangle for the averages of three plots shows that the soil texture is sandy clay loam

The layer of the soil of 30-45 cm depths is having the texture of sandy clay loam form plots 1 to 3. It has high sand followed by clay and less quantity of silt content. The average value of sand, silt and clay among the three plots were 56, 18 and 26% respectively. The texture triangle for the averages of three plots shows that the soil texture is sandy clay loam. The layer of the soil of 45 to 60 cm depth is having the texture of sandy clay loam for plot 1, clay loam for plot 2 and clay for plot 3. The average value of sand, silt and clay among the three plots were 43, 19 and 38% respectively. The texture triangle for the averages of three plots shows that the soil texture is clay loam.

It was found that the soil texture from 0-45 cm was same as sandy clay loam. When the depth soil increases after 45 cm, then the soil texture changed to clay loam. It means that the clay content is increased from 21% at top soil to 38% at the depth of 45 to 60 cm.

FAO (2008) stated that the maximum depth of root of the rice crop varies from 0.5 m to 1.0 m. It was found out from the experiment that the soil texture at the experimental plot has increasing trend of clay content like 21% clay at top soil up to 15 cm depth, 25% clay at 15-30 cm depth, 26% clay from 30-45 cm depth and 38% clay from 45-60m depth. The clay content is in increasing trend. It may also increase from 60-100 cm. Hence, the soil of the experimental can hold more moisture because of clay content which is a basic need for the rice crop. Fugen Dou, (2016) stated that soil textures like clay and sandy loam are the suitable for rice cultivation. Soil properties were estimated for different soil depths of 0-15, 15-30, 30-45 and 45-60 cm. It was found that the layer of the soil with 0-15, 15-30 and 30-45 cm are having the soil texture of sandy clay loam but the soil having the depth of 45-60 cm is having the texture of clay loam. Hence, it is also concluded that the Muvumba P-8 marshland suits very well for rice cultivation due to its sandy clay loam and clay loam according to (Yousef Alhaj Hamoud et al., 2018) statement of the irrigation regime and soil clay content had significant effects on growth, yield and water productivity of rice.

**Bulk density of soil**

Soil bulk density is a measure of how compact or dense a soil is. . It is affected by both the nature of solids and the volume of pores. If there is high pore space then there is low bulk density and vice versa. The results are shown in Table 2.

Table 2. Bulk density of soil samples taken at different depth

| S.No | Plots | Depth (cm) | Oven dry weight, gm | Volume, cm³ | BD, gm/cm³ |
|---|---|---|---|---|---|
| 1 | Plot 1 | 0-15 cm | 132.94 | 88.62 | 1.50 |
| 2 | Plot 2 | 0-15 cm | 108.42 | 88.62 | 1.30 |
| 3 | Plot 3 | 0-15 cm | 112.12 | 90.47 | 1.33 |
| Average | | 0-15 cm | 117.83 | 89.24 | 1.38 |
| 1 | Plot 1 | 15-30 | 102.75 | 90.43 | 1.25 |
| 2 | Plot 2 | 15-30 | 114.30 | 90.47 | 1.34 |
| 3 | Plot 3 | 15-30 | 106.75 | 88.62 | 1.28 |
| Average | | 15-30 | 107.93 | 89.84 | 1.29 |
| 1 | Plot 1 | 30-45 | 113.23 | 92.35 | 1.34 |
| 2 | Plot 2 | 30-45 | 110.30 | 94.24 | 1.31 |
| 3 | Plot 3 | 30-45 | 113.67 | 90.47 | 1.35 |
| Average | | | 112.40 | 92.35 | 1.33 |
| 1 | Plot 1 | 45-60 | 112.19 | 92.35 | 1.35 |
| 2 | Plot 2 | 45-60 | 92.07 | 88.62 | 1.10 |
| 3 | Plot 3 | 45-60 | 77.13 | 88.60 | 0.90 |
| Average | | | 93.80 | 89.86 | 1.12 |

Table 2 shows that the layer of the soil between 0-15 cm depths is having the average bulk density of 1.38 gm/cm³ for plots 1 to 3. It varies from 1.30 to 1.50 gm/cm³. The layer of the soil of 15-30 cm depth is having the average bulk density of 1.29 gm/cm³ for plots 1 to 3. It varies from 1.25 to 1.34 gm/cm³. The layer of the soil of 30-45 cm depth is having the average bulk density of 1.33 gm/cm³ form plots 1 to 3. It varies from 1.31 to 1.35 gm/cm³. The layer of the soil between 45-60 cm depth is having the average bulk density of 1.12 gm/cm³ for plots 1 to 3. It varies from 0.90 to 1.35 gm/cm³.

**Table 3. Statistical Analysis of the data**

**Table 3.a: Analysis of variance of oven dry weight**

| Source of variation | Degree of freedom | Sum of square | Mean square | Variance | F.Probability |
|---|---|---|---|---|---|
| Depth | 3 | 953.00 | 317.70 | 2.43 | 0.14 |
| Residual | 8 | 1044.1 | 130.5 | | |
| Total | 11 | 1997.0 | | | |

**Table 3.b: Analysis of variance of volume of core cylinder**

| Source of variation | Degree of freedom | Sum of square | Mean square | Variance | F.Probability |
|---|---|---|---|---|---|
| Depth | 3 | 17.259 | 5.753 | 2.20 | 0.17 |
| Residual | 8 | 20.95 | 2.618 | | |
| Total | 11 | 38.21 | | | |

**Table 3.c: Analysis of variance of bulk density**

| Source of variation | Degree of freedom | Sum of square | Mean square | Variance | F.Probability |
|---|---|---|---|---|---|
| Depth | 3 | 0.117 | 0.039 | 2.40 | 0.144 |
| Residual | 8 | 0.13 | 0.016 | | |
| Total | 11 | 0.247 | | | |

The statistical analysis shows that there is significant difference between soil different soil depth ($p = 0.144$) at 5% level for all soil samples. This means that the soil is suitable for rice growth since plant roots will penetrate easily into the soil profile.

**Comparison of soil texture and soil bulk density as per the USDA-NRCS guidelines**

The Soil Quality Kit guidelines given by the USDA, Natural Resources Conservation Services was used to compare the soil texture of the experimental plots and the soil bulk densities computed for different depth of soils of the experimental plots. The comparisons are given in Table 4.

**Table 4. Comparison of soil texture and soil bulk density as per the USDA-NRCS guidelines**

| Soil Depth Cm | Soil texture | Bulk Density (BD) of experimental plots, gm/cm$^3$. | | USDA-NRCS guidelines Bulk Density (BD) in , gm/cm$^3$ and soil texture | | | Decision taken while comparison of actual bulk density and soil texture of experimental plots |
|---|---|---|---|---|---|---|---|
| | | Range of Soil Bulk density | Average Bulk density | Ideal BD for plant growth | BD that affect root growth. | BD that restrict root growth | |
| 0–15 | Sandy clay loam | 1.30 to 1.50 | 1.38 | < 1.40 | 1.63 | >1.80 | Bulk density of 1.38 gm/cm$^3$ is ideal for plant growth |
| 15-30 | Sandy clay loam | 1.25 to 1.34 | 1.29 | < 1.40 | 1.60 | >1.75 | Bulk density of 1.29 gm/cm$^3$ is ideal for plant growth |
| 30-45 | Sandy clay loam | 1.31 to 1.35 | 1.33 | < 1.40 | 1.60 | >1.75 | Bulk density of 1.33 gm/cm$^3$ is ideal for plant growth |
| 45-60 | Clay loam | 0.90 to 1.35 | 1.12 | < 1.10 | 1.49 | 1.58 | BD of 1.12 and 1.10 are in the same range. Hence, it is also ideal for rice growth |

Table 4 shows that the comparison of soil texture and soil bulk density as per the USDA-NRCS guidelines. It was found that the experimental plots from 0 to 60 cm depth are ideal for plant growth because their bulk densities are always lesser or almost equal compared to the prescribed bulk densities for ideal plant growth and the soil texture varies from sandy loam to clay loam. Wei Zhou (2014) indicated that the soil with the bulk density range of 1.1 to 1.8 gm/cm$^3$ are ideal for rice production. It was found that the soil with depths of 0-15, 15-30, 30-45 and 45-60 cm are having the bulk densities of 1.38, 1.29, 1.33 and 1.12 gm/cm³, which is within the range for rice cultivation.

**Total available water (TAW)**

The total available soil water is the amount of soil moisture available to plants. It is the difference between the moisture content at field capacity to moisture content at the permanent wilting point. It varies based the texture of the soil. It is used that 1% volumetric water content is equivalent to 1 mm depth of water for a layer of 10 cm depth. The soil depth considered in this experiment is 15 cm. Hence, 1% volumetric water content is equivalent to 1.5 mm depth of water for a soil layer of 15 cm depth.

The total available water was computed with the soil depth of 0-15, 15-30, 30-45 and 45-60 cm. The difference between the field capacity and wilting point provides the total available water in percentage. The depth of water in mm for 15 cm depth was computed by multiplying 1.5 mm and the total available water in percentage. The total available water at different depths are given in Table 4.

**Table 5. Total available water at different depths**

| Expt. Plots (1) | Soil depth, cm and texture (2) | Moisture content at Field capacity, % (3) | Moisture content at Permanent wilting point, % (4) | Total available water % (5) | Depth of water in mm (for 15 cm soil depth) is column(5)x1.5mm |
|---|---|---|---|---|---|
| Plot 1 | 0 - 15 | 21.9 | 18.9 | 3.0 | 4.5 |
| Plot 2 | 0 - 15 | 25.5 | 18.7 | 6.8 | 10.2 |
| Plot 3 | 0 - 15 | 26.8 | 19.6 | 7.2 | 10.8 |
| Average | 0 - 15 | 24.7 | 19.1 | 5.7 | 8.5 |
| Plot 1 | 15 - 30 | 21.4 | 16.3 | 5.1 | 7.7 |
| Plot 2 | 15 - 30 | 19.2 | 7.3 | 11.9 | 17.9 |
| Plot 3 | 15 - 30 | 24.1 | 18.7 | 5.4 | 8.1 |
| Average | 15 - 30 | 21.6 | 14.1 | 7.5 | 11.2 |
| Plot 1 | 30 – 45 | 15.9 | 11.4 | 4.5 | 6.8 |
| Plot 2 | 30 – 45 | 25.8 | 8.2 | 17.6 | 26.4 |
| Plot 3 | 30 – 45 | 24.1 | 15.2 | 8.9 | 13.4 |
| Average | 30 – 45 | 21.9 | 11.6 | 10.3 | 15.5 |
| Plot 1 | 45 – 60 | 17.8 | 8.0 | 9.8 | 14.7 |
| Plot 2 | 45 – 60 | 20.6 | 8.8 | 11.8 | 17.7 |
| Plot 3 | 45 – 60 | 23.8 | 12.4 | 11.4 | 17.1 |
| Average | 45 – 60 | 20.7 | 9.7 | 11.0 | 16.5 |

Table 5 shows that the average total available water for 0-15 cm depth of soil is 8.5 mm and it varies from 4.5 mm to 10.8 mm. This variation is mainly due to soil texture. It was found that the soil texture between 0 -15 cm is sandy clay loam and the bulk density varies from 1.30 to 1.50 gm/cm³.

The average total available water for 15-30 cm depth of soil is 11.2 mm and it varies from 7.7 mm to 17.9 mm. This variation is mainly due to soil texture. It was found that the soil texture of 15-30 cm depth of soil is sandy clay loam and the bulk density varies from 1.25 to 1.34 gm/cm³. The average total available water for 30-45 cm depth of soil is 15.5 mm and it varies from 6.8 mm to 26.4 mm. This variation is mainly due to soil texture. It was found that the soil texture of 30-45 cm depth of soil is sandy clay loam and the bulk density varies from 1.31 to 1.35 gm/cm³. The average total available water for 45-60 cm depth of soil is 16.5 mm and it varies from 14.7 mm to 17.7 mm. This variation is mainly due to soil texture. It was found that the soil texture of 45-60 cm is clay loam and the bulk density varies from 0.90 to 1.35gm/cm³.

**Table 6. Statistical analysis of total available water**

**Table 6.a. Analysis of variance of moisture at field capacity**

| Source of variation | Degree of freedom | Sum of square | Mean square | Variance | F.Probability |
|---|---|---|---|---|---|
| Soil depth | 3 | 27.10 | 9.03 | 0.73 | 0.562 |
| Residual | 8 | 99.01 | 12.38 | | |

| | | |
|---|---|---|
| Total | 11 | 126.11 |

**Table 6.b. Analysis of variance of total available water**

| Source of variation | Degree of freedom | Sum of square | Mean square | Variance | F.Probability |
|---|---|---|---|---|---|
| Soil depth | 3 | 55.96 | 18.65 | 1.14 | 0.391 |
| Residual | 8 | 131.40 | 16.43 | | |
| Total | 11 | 187.36 | | | |

**Table 6.c. Analysis of variance of depth of water**

| Source of variation | Degree of freedom | Sum of square | Mean square | Variance | F.Probability |
|---|---|---|---|---|---|
| Soil depth | 3 | 126.08 | 42.03 | 1.14 | 0.390 |
| Residual | 8 | 294.87 | 36.86 | | |
| Total | 11 | 420.95 | | | |

The statistical analysis shows that the soil moisture at field capacity is significantly different in different soil depth and soil texture (Table 6.a) at 5% level. The difference is also significantly different as well for total available water (table 6.b) as for depth of water. Therefore, the soil is suited for crop water requirement since the total available water will be in contact with plant root.

**Infiltration rate of soil**

The infiltration rate was experimentally found as discussed in methodology.. The table 6 shows the results obtained during the experiment.

**Table 7. Infiltration rate of soil in experimental plots**

| Time, min | Infiltration test in plot 1 | | | | Infiltration test in plot 2 | | | | Infiltration test in plot 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Water level in cm | | | Infiltration rate | Water level in cm | | | Infiltration rate | Water level in cm | | | Infiltration rate |
| | Before filling | After filling | Depth of water | cm/hour | Before filling | After filling | Depth of water | cm/hour | Before filling | After filling | Depth of water | cm/hour |
| 0 | - | 15.00 | | | - | 15.00 | | | - | 15.00 | | |
| 10 | 7.30 | 15.00 | 7.70 | 46.20 | 11.50 | 15.00 | 3.50 | 21.00 | 12.20 | 15.00 | 2.80 | 16.80 |
| 20 | 8.60 | 15.00 | 6.40 | 19.20 | 12.00 | 15.00 | 3.00 | 9.00 | 12.70 | 15.00 | 2.30 | 6.90 |
| 30 | 9.20 | 15.00 | 5.80 | 11.60 | 11.40 | 15.00 | 3.60 | 7.20 | 12.10 | 15.00 | 2.90 | 5.80 |
| 45 | 9.30 | 15.00 | 5.70 | 7.60 | 10.95 | 15.00 | 4.05 | 5.40 | 11.65 | 15.00 | 3.35 | 4.47 |
| 60 | 10.00 | 15.00 | 5.00 | 5.00 | 11.00 | 15.00 | 4.00 | 4.00 | 11.70 | 15.00 | 3.30 | 3.30 |
| 75 | 10.50 | 15.00 | 4.50 | 3.60 | 10.50 | 15.00 | 4.50 | 3.60 | 11.20 | 15.00 | 3.80 | 3.04 |
| 90 | 11.00 | 15.00 | 4.00 | 2.67 | 12.00 | 15.00 | 3.00 | 2.00 | 12.70 | 15.00 | 2.30 | 1.53 |
| 100 | 11.30 | 15.00 | 3.70 | 2.22 | 13.00 | 15.00 | 2.00 | 1.20 | 13.45 | 15.00 | 1.55 | 0.93 |
| 120 | 10.00 | 15.00 | 500 | 2.25 | 13.20 | 15.00 | 1.80 | 0.90 | 13.63 | 15.00 | 1.37 | 0.69 |
| 150 | 9.38 | 15.00 | 5.62 | 2.25 | 12.75 | 15.00 | 2.25 | 0.90 | 13.25 | 15.00 | 1.75 | 0.70 |
| 180 | 8.25 | 15.00 | 6.75 | **2.25** | 12.30 | 15.00 | 2.70 | **0.90** | 12.90 | 15.00 | 2.10 | **0.70** |

Table 7 shows that the infiltration rate of the plot 1, plot and plot 3 are 2.25, 0.90 and 0.70 cm/hour respectively.

The average infiltration rate of the experimental field at Muvumba P-8 marshland was found to be 1.28 cm/hour or 12.8 mm/hour. It means that a water layer of 12.8 mm on the soil surface will take one hour to infiltrate. The class of infiltration of the experimental plot will be obtained from the following data of (Majumdar, 2000) as table 6.

**Table 8 Classification of infiltration rates according to (Majumdar, 2000)**

| S.No | Infiltration rate, cm/hour | Classes of infiltration of soil |
|---|---|---|
| 1 | > 25.4 | Very rapid |
| 2 | 12.7- 25.4 | Rapid |
| 3 | 6.3- 12.7 | Moderately rapid |
| 4 | 2- 6.3 | Moderate |
| 5 | 0.5- 2.0 | Moderately slow |
| 6 | 0.1- 0.5 | Slow |
| 7 | < 0.1 | Very slow |

Table 8 shows that the average infiltration rate of the experimental field at Muvumba P-8 marshland was found to be 1.28 cm/hour. As per (Majumdar, 2000) classification of infiltration rate of the soil, the experimental plot at Muvumba P-8 marshland was found to be moderately slow infiltration rate. This indicates that the percolation loss of water will be minimum.

**Hydraulic conductivity of the soil in the experimental plot**

Hydraulic conductivity of the soil was estimated using the methodology discussed. The data collected and the hydraulic conductivity computed are shown in Table 7.

**Table 9. Testing the hydraulic conductivity of the soil in marshland**

| S.No | Height of water in hole, cm | | Time interval | Hydraulic conductivity, K |
|---|---|---|---|---|
| | Initial filling | Final water level | Sec | cm/sec |
| **Hydraulic conductivity in Plot 1** | | | | |
| 1 | 80.00 | 73.00 | 300 | 0.003823 |
| 2 | 73.00 | 69.00 | 300 | 0.002323 |
| 3 | 69.00 | 66.75 | 300 | 0.001356 |
| 4 | 66.75 | 65.45 | 300 | 0.000801 |
| 5 | 65.45 | 64.00 | 300 | 0.000908 |
| 6 | 64.00 | 63.70 | 300 | 0.000190 |
| Average | | | 300 | 0.001567 |
| **Hydraulic conductivity in Plot 2** | | | | |
| 1 | 55.00 | 46.00 | 300 | 0.006873 |
| 2 | 46.00 | 42.00 | 300 | 0.003387 |
| 3 | 42.00 | 40.00 | 300 | 0.001784 |
| 4 | 40.00 | 39.00 | 300 | 0.000916 |
| 5 | 39.00 | 38.50 | 300 | 0.000465 |
| 6 | 38.50 | 38.50 | 300 | 0.000000 |
| Average | | | 300 | 0.002238 |
| **Hydraulic conductivity in Plot 3** | | | | |
| 1 | 80.00 | 75.00 | 300 | 0.002700 |
| 2 | 75.00 | 71.00 | 300 | 0.002271 |
| 3 | 71.00 | 68.75 | 300 | 0.001324 |
| 4 | 68.75 | 67.45 | 300 | 0.000781 |
| 5 | 67.45 | 66.00 | 300 | 0.000886 |
| 6 | 66.00 | 64.70 | 300 | 0.000808 |
| Average | | | 300 | 0.001462 |

Table 9 shows that the average hydraulic conductivity of the soil in the plot 1 of Muvumba P-8 marshland was found to be 0.001567 cm/sec or 5.64 cm/hour. The average hydraulic conductivity of the soil in the plot 2 of Muvumba P-8 marshland was found to be 0.002238 cm/sec or 8.06 cm/hour. The average hydraulic conductivity of the soil in the plot 3 of Muvumba P-8 marshland was found to be 0.001462 cm/sec or 5.26 cm/hour.

Hydraulic conductivity of the soil is used to find out the permeability of the soil according to the (Smith and Browning,1975) as given in Table 8.

**Table 10 Permeability classes based on hydraulic conductivity of soil**

| S.No | Hydraulic conductivity of soil, cm/hour | Permeability classes |
|---|---|---|
| 1 | < 0.0025 | Extremely slow |
| 2 | 0.0025 - 0.025 | Very slow |
| 3 | 0.025 - 0.25 | Slow |
| 4 | 0.25 - 2.5 | Moderate |
| 5 | 2.5 - 25.0 | Rapid |
| 6 | >25.0 | Very Rapid |

(Source: Smith and Browning (1975)

According to table 10, it was found that the hydraulic conductivity of the plot 1, 2 and 3 are having rapid permeability. As per (Majumdar, 2000) classification of infiltration rate of the soil), the experimental plot at Muvumba P-8 marshland was found to be moderately slow infiltration rate. Infiltration is the surface entry of water and hence it was found that at the top of soil, the infiltration is slow but downward percolation of water will be high due to rapid permeability.

## Conclusion

Different conclusions drawn from the studies of the soil characteristics of the Muvumba P-8 marshland. It was found that the layer of the soil with 0-15, 15-30 and 30-45 cm are having the soil texture of sandy clay loam but the soil having the depth of 45-60 cm is having the texture of clay loam Muvumba P-8 marshland suits very well for rice cultivation due to its sandy clay loam and clay loam. 1. It was found out from the experiment that the soil texture at the experimental plot has increasing trend of clay content like 21% clay at top soil up to 15 cm depth, 25% clay at 15-30 cm depth, 26% clay from 30-45 cm depth and 38% clay from 45-60 cm depth. The clay content is in increasing trend. It may also increase from 60-100. Hence, the soil of the experimental can hold more moisture because of clay content which is a basic need for the rice crop. 2. It was found that the soil with depths of 0-15, 15-30, 30-45 and 45-60 cm are having the bulk densities of 1.38, 1.29, 1.33 and 1.12 gm/cm$^3$, which is within the range for rice cultivation according to Wei Zhou (2014). 3. It was found that the average total available water for 0-15 cm depth of soil is 8.5 mm and it varies from 4.5 mm to 10.8 mm. It was found that the average total available water for 15-30 cm depth of soil is 11.2 mm and it varies from 7.7 mm to 17.9 mm. It was found that the average total available water for 30-45 cm depth of soil is 15.5 mm and it varies from 6.8 mm to 26.4 mm. It was found that the average total available water for 45-60 cm depth of soil is 16.5 mm and it varies from 14.7 mm to 17.7 mm. 4. It was found that average infiltration rate of the experimental field at Muvumba P-8 marshland was 1.28 cm/hour or 12.8 mm/hour. It means that a water layer of 12.8 mm on the soil surface will take one hour to infiltrate. The experimental plot at Muvumba P-8 marshland is moderately slow infiltration rate. Infiltration is the surface entry of water and hence it was found that at the top of soil, the infiltration is slow but downward percolation of water will be high due to rapid permeability.

The following recommendations are set forth: Rwanda is having undulated topography with mountains and marshlands. There is a need to study the soil and water properties of different marshlands to bring them under rice cultivation. The current agricultural researchers in Rwanda are widely involved in the use of catchment area development for irrigation purposes in the absence of river as the source of water and they have to make a shift to marshland development due to increased need for food safety. There is a need to motivate other researchers to undertake the similar initiatives for adding more researches about similar subjects because it will combat the problem of low rainfall and use of marshland, which will increase the productivity of agricultural outputs.


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