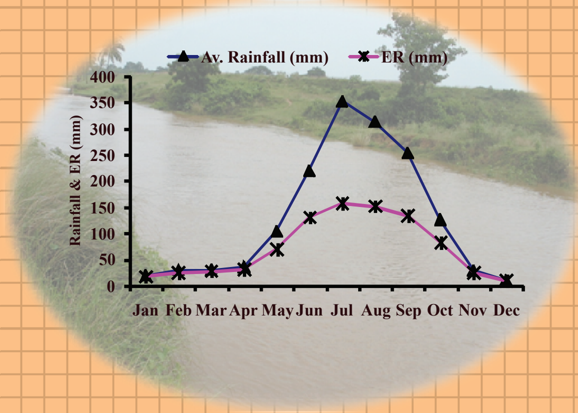
भाकृ अनुप
ICAR

Research Bulletin 57

# Analyses of Rainfall and Soil Characteristics of Kuanria Canal Command for Water Resources Management


K.G. Mandal,
Ashwani Kumar, S. Ghosh,
D.K. Kundu, R.K. Panda, R.K. Mohanty,
M. Raychaudhuri, J. Padhi, P. Majhi and D.K. Sahoo

जल प्रबंधन निदेशालय
D. W. M
DWM

Directorate of Water Management
(Indian Council of Agricultural Research)
Bhubaneswar-751 023, Odisha

2013

भाकृ अनुप
ICAR

Research Bulletin 57

# Analyses of Rainfall and Soil Characteristics of Kuanria Canal Command for Water Resources Management

K.G. Mandal,
Ashwani Kumar, S. Ghosh,
D.K. Kundu, R.K. Panda, R.K. Mohanty,
M. Raychaudhuri, J. Padhi, P. Majhi and D.K. Sahoo

जल प्रबंधन निदेशालय
D. W. M

Directorate of Water Management
(Indian Council of Agricultural Research)
Bhubaneswar – 751 023, Odisha

2013

***Correct citation***

Mandal, K.G., Kumar, Ashwani, Ghosh, S., Kundu, D.K., Panda, R.K., Mohanty, R.K., Raychaudhuri, M., Padhi, J., Majhi, P. and Sahoo, D.K. 2013. Analyses of Rainfall and Soil Characteristics of Kuanria Canal Command for Water Resources Management. Research Bulletin No. 57, Directorate of Water Management (ICAR), Bhubaneswar, Odisha, India, 43p.

***Published by***

Director
Directorate of Water Management
(Indian Council of Agricultural Research)
Bhubaneswar-751 023, Odisha, India
March, 2013



***Printed at***
Space Setter Press & Publicity (P) Ltd.
84, Chandaka Industrial Esate,
In front of KIIT, Patia, Bhubaneswar

# CONTENTS

| Contents | Page No. |
|---|---|

# Preface

Rainfall is the primary source of water for agricultural production systems. The knowledge of the rainfall- its onset, amount, distribution, withdrawal, effective rainfall, the dry and wet spell (s), probability of its distribution and forecasting is an important prerequisite in a canal command for effective management of water and crop planning. There has been an increasing demand for rainfall analysis for its variable applications including planning for its full utilization, monitoring of extreme events and climate analyses. Rainwater harvesting in the on-farm reservoirs or in the secondary reservoirs is the need of the hour. Water shortage has become a problem in almost every area barring a few water logged regions. The problem of scarcity is increasing and will continue to increase in future. This calls for massive water conservation and storage initiatives. In addition, canal delivery schedule needs precise information on the rainfall pattern. This information along with basic soil characteristics help in making appropriate water management decisions.

The understanding on the soil properties is essential for land use planning, for adopting proper water management technique, water harvesting structures, management of soil environment, and overall development of canal command. The basic soil properties viz. pH, salinity, particle size fractions, bulk density, hydraulic properties etc. are very useful for making strategy on soil and water management. Saturated hydraulic conductivity and water retention characteristics of soil are needed to characterize the hydrological response of canal commands. Assessment of available water capacity is also an important step in making water management decisions. Soil organic carbon plays an important role for the functioning of agro-ecosystems. It has significant influence on the environment and the climate. Now-a-days, there is an increasing trend in the concentration of greenhouse gases, and carbon dioxide is the most important one which occurs in greatest concentration. This calls for adoption of measures for carbon sequestration to mitigate the climate change. The soil organic carbon influences the physical structure of the soil, the soil's ability to store water, and form complexes with metal ions and supply nutrients. Loss of soil organic carbon, thus lead to a reduction in soil fertility, increase in land degradation and even desertification.

The rainfall analyses and characterization of the cultivated soils of Kuanria irrigation project command in Nayagarh, Odisha have been done by a multidisciplinary team of scientists including research associates from Directorate of Water Management (ICAR), Bhubaneswar, and is presented in this bulletin. Authors are grateful to Deputy Director General and Assistant Director General of Natural Resources Management Division of the ICAR, New Delhi for their valuable support, suggestions and encouragement in carrying out this research and analyses. We sincerely thank research students, all colleagues and staff members of Directorate of Water Management for their help, cooperation and encouragement.

We hope that this bulletin will be very useful to the researchers, stake holders/ development agencies, water resources departments, water users' associations/ farmers and to all those who will be interested for the management of water and soil resources of the canal command.

**Authors**

# Executive Summary

*Rainfall analyses are essential for proper management of water resources and crop planning even in canal command areas, especially under changing climate. Attempts have been made to collection of rainfall data and analyzing this for Daspalla region in Odisha, eastern India for prediction of monsoon and post-monsoon rainfall by using six different probability distribution functions, forecasting the probable date of onset and withdrawal of monsoon, occurrence of dry spells by using Markov chain model and finally crop planning for the region. Soil parameters viz. particle size distribution, soil pH, bulk density (BD), soil moisture content at field capacity and permanent wilting point, available water capacity (AWC), soil organic carbon storage were assessed; and pedotransfer functions (PTFs) were developed for saturated hydraulic conductivity (Ks), water retention at field capacity (FC, -33 kPa) and permanent wilting point (PWP, -1500 kPa) for different sites under major cropping system in the Kuanria canal command.*

*It is revealed from this analysis that, for prediction of monsoon and post-monsoon rainfall, Log Pearson Type-III and Gumbel distribution, respectively have been found as the best fit probability distribution function. The earliest and delayed most week of onset of rainy season was 20th standard meteorological week (SMW) (14-20th May) and 25th SMW (18-24th June), respectively. Similarly, the earliest and delayed most week of withdrawal of rainy season is 39th SMW (24-30th September) and 47th SMW (19-25th November), respectively. The longest and shortest length of rainy season was 26 and 17 weeks, respectively. The chances of occurrence of dry spells are high from 1st – 22nd SMW and again 42nd SMW to the end of the year. The probability of weeks (23rd-40th SMW) remain wet (PW) varies between 62 to 100% for the region.*

*The study on soil characteristics reveals that the soils are mainly composed of sand and clay with the clay contents ranging from 29.6 to 48.8% depending on the soil depth and cropping system. The BD, which increased with increase in soil depth, ranged from 1.44 to 1.72 Mg $m^{-3}$ irrespective of different sites under rice-based cropping. The Ks decreased significantly with soil depth due to greater clay contents in lower layers; whereas water retention at FC, PWP, and AWC increased significantly with increase in soil depths and was higher under rice-sugarcane crop rotation compared to other cropping systems.*

*Soil organic carbon (SOC) varied from 0.34 to 0.95%; it was the highest in the surface (0-15 cm) layer and then decreased down to the soil profile. SOC storage in the surface layer was higher in rice-sugarcane crop rotation systems (18.90-20.53 Mg $ha^{-1}$) than other sites. The soil enzymes viz. dehydrogenase for surface soil (0-15 cm) for different cropping systems showed a range of 283.52 to 313.31 µg TPF $g^{-1}$soil $24h^{-1}$ with the coefficient of variation (CV) ranged from 8.36 to 9.22%. Soil phosphatase activity ranged from 280.58 to 480.28 µg phenol $g^{-1}$soil $h^{-1}$ with the CV of 9.24 to 11.93% and soil urease activity ranged from 38.36 to 67.75 µg $NH_4^+$-N $g^{-1}$soil $2h^{-1}$ with CV of 9.73 to 11.08% irrespective of different sites and cropping systems.*

*The PTFs were best represented as the power functions for prediction of Ks with clay content (%) as a predictor variable; whereas the PTFs for water retention at FC and PWP were better represented as the exponential functions using clay content. These are valid with significant values of $R^2$ for every study site. The developed PTFs for different sites under major cropping systems would be very useful in soil and water management strategies for the study area or elsewhere having similar soil and cropping practices.*

# 1. INTRODUCTION

Indian agriculture and water management options are primarily influenced by the rainfall pattern. Increased climate variability has made rainfall patterns more inconsistent and unpredictable in the country increasing the recurrence of drought or draught like situations, even in canal command areas. India ranks first among the countries that practice rainfed agriculture both in terms of extent (86 M ha) and value of production (Sharma et al., 2010). More than 70% of net sown area of eastern Indian ecosystem is rainfed where the yield of rice which is the predominant rainy season crop, is very low as compared to irrigated ecosystem. The most important factor for low rice yield in the whole country is due to the lack of assured water supply (Panigrahi and Panda, 2002). The overall efficiency of the irrigation projects from the head works to the farmers' field has been quite low in India. Current irrigation withdrawals already cause stress in many of the world's major river basins (Molle et al., 2007). The demand of water in other sectors especially to meet the increasing demand due to growing industrialization and urbanization will dwindle the share of water available for agriculture in the future. For this reason, it is also not possible to provide irrigation to all crops in future because of land, soil, drainage and other related problems in addition to higher investment in infrastructural development activities.

Agricultural systems in canal command area needs rainwater as well as canal water management. A more efficient use of water will be essential. Even, the rainfed ecosystem will play a major role in future for increasing food demand and sustainability of the systems. Kothari et al. (2007) opined that on the basis of water harvesting, water can be utilized for saving the crops during severe moisture stress and also to raise the post-monsoon crops thereby enhancing cropping intensity and net returns from the cultivated lands. In order to address the issue, detail knowledge of rainfall distribution can help in deciding the time of different agricultural operations and designing of water harvesting structures to meet out irrigation requirement (Prakash and Rao, 1986; Sharma et al., 1979). For sustainable crop planning, rainfall has been characterized in term of its variability and probability distribution by many researchers (Mohanty et al., 2000; Rana and Thakur, 1998) for different places of India. The onset and withdrawal of monsoon largely determine the success of rainfed agriculture. A prior knowledge of possible onset and withdrawal of effective monsoon is valuable in crop planning. Such knowledge in advance helps in deciding cropping pattern and choice of suitable crop varieties and also to plan comprehensive strategies for proper and efficient rainwater management for improving crop production per unit of available water (Das et al., 1998). However, for a canal command like Kuanria medium irrigation command, the detailed rainfall analysis has not been made so far.

Odisha, an eastern Indian province, is mainly an agrarian state where about 70% of the population is engaged in agricultural activities and 50% of the state's economy comes from agricultural sector (Panigrahi et al., 2010). Agricultural development rests heavily on the management of natural resources which have to be utilized optimally to obtain food, nutrition and environmental security for future generation (Kar and Singh, 2002). Crop planning for an area depends upon number of factors, namely type of crop, cropping intensity, available water resources, climate, crop water requirements, method of irrigation, drainage, efficiency of the irrigation system, soil characteristics, topography and socio-economic conditions etc. However, in rainfed areas it mainly depends upon the magnitude and distribution of rainfall both in space and time (Shetty et al., 2000).

In order to stabilize the crop production at certain level, it is essential to plan agriculture on a scientific basis in terms of making best use of rainfall pattern of an area. This necessitates studying the sequences of dry and wet spells of an area so that necessary step can be taken up to prepare crop plan in rainfed regions. Scientific prediction of wet and dry spell analysis may prove useful to farmers for improving productivity and cropping intensity and in turn their economic returns. Dry and wet spells could be used for analyzing rainfall data to obtain specific information needed for crop planning and also for carrying out agricultural operations. Markov chain probability model has been used for finding out the long term frequency behaviour of wet and dry spells (Victor and Sastry, 1979) as well as for computation of probability of occurrence of daily precipitation (Stern, 1982). Previous researchers have used Markov chain model to study the probability of dry and wet spell in terms of shortest period like week and also demonstrated its practical utility in the agricultural planning (Pandarinath, 1991; Dash and Senapati, 1992). On a region basis, the dry spell analyses would help in formulation of contingency plan against drought. Another aspect is forward and backward accumulation of rainfall to determine the onset and withdrawal of monsoon. Pre-monsoon showers help in land preparation and sowing of rainy season crops. Late onset of monsoon delays sowing of crops leading to poor yields. Similarly, early withdrawal of rains affects the yield due to severe moisture stress especially when the rainy season crops are at critical growth stages of grain formation and grain development (Dixit et al., 2005). The annual and seasonal analysis of rainfall will give general idea about the rainfall pattern of the region, whereas the weekly analysis of rainfall will be of much use as far agricultural planning is concerned.

The knowledge on soil properties viz. particle size distribution, bulk density, hydraulic properties, water retention characteristics is essential for land use planning, water resources management (Singh, 2000; Kaur et al., 2001; Saikia and Singh, 2003) and also for development of water harvesting structures in a canal irrigated commands. Assessment of soil water regime is an important step in making water management decisions (Ungaro et al., 2005). Soil organic carbon (SOC) plays an important role for the functioning of agro-ecosystems. It influences the physical structure of the soil, the soil's ability to store water, and form complexes with metal ions and supply nutrients for crop production, and overall soil sustainability (Bauer and Black, 1994; Lal et al., 1997). The amount of SOC storage depends on soil texture, climate, vegetation and historical and current land use/ management (Mandal et al., 2012). This has more relevance in soils of the tropical and subtropical parts of the globe, including the Indian sub-continent (Bhattacharyya et al., 2000). Recently, the matter of carbon concentration in both soil and the atmosphere draws attention of researchers and policy makers because it has direct and indirect impacts on the phenomenon of global warming (Milne and Heimsath, 2009). Soil enzymes play the key biochemical functions in the overall process of organic matter decomposition in soil system (Burns, 1983; Sinsabaugh et al., 1991). They are important in catalyzing several important reactions necessary for the life processes of micro-organisms in soils and the stabilization of soil structure, the decomposition of organic matter and nutrient cycling (Dick et al., 1994). These enzymes are constantly being synthesized, accumulated, inactivated and/or decomposed in the soil, hence playing an important role in agriculture and particularly in nutrients cycling (Tabatabai, 1994). The enzyme levels in soil systems may vary in amounts primarily due to the soil type and cropping effects that need to be investigated for every region. A better understanding of these soil enzymes would provide the basis in maintaining soil health, and potentially provide a unique opportunity for an integrated biological assessment of soils.

The pedotransfer functions (PTFs) allow translation of textural information into estimation of or prediction of hydrologic properties (Bouma, 1989; Bouma and Finke, 1993). As the direct measurement of hydraulic properties at multiple locations even within an agricultural field is time-consuming and costly (Romano and Palladino, 2002), the indirect estimation of soil hydraulic properties using the PTFs is very useful for soil and water management in a command area (Larson and Pierce, 1991; Manrique et al., 1991). The research on soil properties and development of models or PTFs has increased rapidly in recent years to improve the understanding of important soil processes, evaluating agricultural and environmental problems. The first attempt to use PTF came from the study of Briggs and McLane (1907), which was later refined by Briggs and Shantz (1912). They determined the wilting coefficient as a function of particle size. Veihmeyer and Hendrikson (1927) attempted to correlate particle-size distribution, bulk density and organic matter content with water content at field capacity (FC, -33 kPa), permanent wilting point (PWP, -1500 kPa), and available water content (AWC). In North Queensland, Australia, Stirk (1957) suggested an estimate of water content at -1500 kPa for soil containing up to 60% clay. Nielsen and Shaw (1958) presented a parabolic relationship between clay content and PWP for Iowa soils. In 1960s, Salter and Williams (1965, 1967), and Salter et al. (1966) explored the relationships between texture classes and available water capacity. In 1970s, Hall et al. (1977) established field capacity, permanent wilting point, available water content, and air capacity as a function of textural class for soils of England and Wales. In USA, Clapp and Hornberger (1978) derived average values for the parameters of a power function for the water retention curve, sorptivity and saturated hydraulic conductivity (Ks) for different texture classes. Bouma (1989) for the first time, called these transfer functions as pedotransfer functions. Since then, the development of PTFs has been a continuous effort in US and Europe. Results of such research have been reported widely, which were conducted in USA (Rawls et al., 1982), UK (Mayr and Jarvis, 1999), the Netherlands (Wösten et al., 1995), Germany (Scheinost et al., 1997), Qingdao soils of China (Liao et al., 2011) and southern Tehran in Iran (Abbasi et al., 2011). Efforts are continuing for determination of soil water retention properties from soil textural data using van Genuchten model parameter (Ghanbarian-Alavijeh et al., 2010).

In India, researchers have developed the relationships or PTFs for prediction of FC, PWP, Ks for some sites under Indo-Gangetic Plains using sand, silt, clay, organic carbon and bulk density (Abrol et al., 1968; Bhavanarayana et al., 1986; Singh, 2000; Saikia and Singh, 2003; Kaur et al., 2001). For a few other selected sites, attempts have been made recently by the researchers (Adhikary et al., 2008; Chakraborty et al., 2011; Patil et al., 2012). These PTFs are not always applicable to every soil and crop production system. In eastern Indian conditions, attempts have only been made for the western catchment of the Chilika Lake, Odisha state for Ks, water retention (Santra and Das, 2008). But these studies have not considered a specific area or a canal command where site-specific water resource management receives the most attention. Moreover, for a canal command, for example Kuanria Irrigation Project (KIP) as our study area, no attempt has been made so far for characterizing the soil properties and development of PTFs. Therefore, the site-specific characterization of soils and development of relationships are essential for proper land use planning and management of water in agricultural production systems.

The Kuanria irrigation project (KIP) command area spread over two blocks viz. Daspalla and Nuagaon of Nayagarh district in Odisha. Its geographical area is 571.57 and 385.24 km2, respectively. The KIP irrigates about four thousand ha benefiting about forty thousand people living in sixty seven villages. For agricultural development of this vast area, this study was carried out with the following objectives:

i) To analyse rainfall pattern, prediction of monsoon and post-monsoon rainfall using six probability distribution functions, and forecasting of onset and withdrawal of rainy season for water and crop management planning,

ii) To analyze the dry and wet spells i.e., initial, conditional probability and consecutive dry and wet spells by using Markov chain model,

iii) To characterize basic soil properties including soil enzyme activities viz. dehydrogenase, phosphatase and urease for different sites under major cropping systems being followed in the command,

iv) To assess the soil organic carbon (SOC) content, its distribution & storage in soil profile in different sites/ cropping systems,

v) To develop site-specific pedotransfer functions (PTFs) to predict hydraulic conductivity, water retention characteristics of soils of Kuanria medium irrigation command.

# 2. METHODOLOGY

## 2.1 The study site

The study was carried out on the canal commands of Kuanria Irrigation Project (KIP) at Nayagarh district of Odisha (Fig. 1). Nayagarh district has 8 blocks viz. Bhapur, Daspalla, Gania, Khandapara, Nayagarh, Nuagaon, Odagaon, Ranpur. The study area covers the Daspalla and Nuagaon blocks with geographical area of 571.57 and 385.24 $km^2$, respectively. The site comes under Agro-Eco Sub-Region 12.2 (AESR 12.2) according to NBSS&LUP (ICAR) and Agro-Climatic Zone 7 (ACZ 7) according to the classification by Planning Commission, Govt. of India. Kuanria dam from where water is distributed through a network of canals is located at 20° 21′ N latitude and 84° 51′ E longitude at an elevation of 122 m above mean sea level. The command area is intercepted by a river named 'Kuanria' which is a right tributary of a major river in India named Mahanadi and a ditch locally called as 'Khalakhala' by an earth dam form the reservoir of KIP. The KIP has two number of head regulators such as right and left distributaries, which runs for the length of about 18.2 and 16.5 km, respectively. The culturable command area is about 4 thousand ha. The command area has head, mid- and tail reaches along the right and left distributaries.

## 2.2 The data and estimation of effective rainfall

Rainfall data for 16 years (1995-2010) have been collected from meteorological observatory of Kuanria dam, Daspalla, Nayagarh. Rainfall data are categorized into four seasons such as pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-December) and winter (January-February) season. The monthly effective rainfall was calculated using the equations 1 and 2 following USDA Soil Conservation Service method. This method is being widely used in India for calculation of monthly effective rainfall (Sharma et al., 2010) and also used by All India Coordinated Research Project for estimation of effective rainfall at different locations (AICRP, 2009).

$$P_e = P_t / 125\ (125 - 0.2\ P_t)\ (\text{when } P_t < 250 \text{ mm}) \qquad \text{(Eq.1)}$$

$$P_e = 125 + 0.1\ P_t\ (\text{when } P_t > 250 \text{ mm}) \qquad \text{(Eq.2)}$$

where, $P_e$ = monthly effective rainfall (mm) and $P_t$ = total monthly rainfall (mm).

## 2.3 Prediction of rainfall using probability distribution functions

In this study, rainfall were predicted by six probability distribution functions (PDF) i.e. Normal, 2-Parameter Log Normal, 3-Parameter Log Normal, Pearson Type III, Log Pearson Type III and Gumbel distribution by using DISTRIB 2.13 component of SMADA 6.43 (Storm Water Management and Design Aid) software. Different probability distribution functions (Chow, 1964) are given as follows:

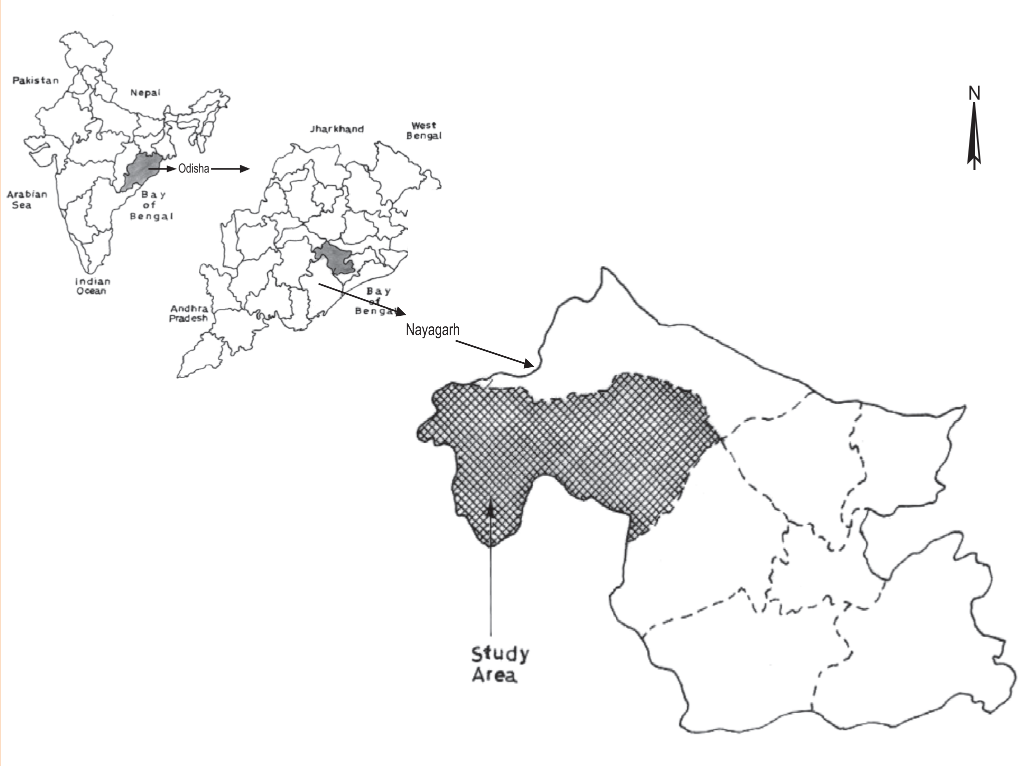



Fig. 1. The study area, Daspalla region of Nayagarh district in Odisha, an eastern Indian state

***2.3.1 Normal distribution***

$$p_x(x) = \frac{1}{\sigma\sqrt{2\pi}} e\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] \qquad \text{(Eq.3)}$$

where, $\mu$ = mean of the population of x and $\sigma$ = variance of the population of x.

***2.3.2 Two-Parameter Log Normal distribution***

$$p_x(y) = \frac{1}{\sigma_y\sqrt{2\pi}} e\left[-\frac{(y-\mu_y)^2}{2\sigma_y^2}\right] \qquad \text{(Eq.4)}$$

where, y = ln(x), $\mu_y$ = mean of the population of y and $\sigma_y$ = variance of the population of y.

***2.3.3 Three-Parameter Log Normal distribution***

$$px(y) = \frac{1}{\sigma_y\sqrt{2\pi}} e\left[-\frac{(y-\mu_y)^2}{2\sigma_y^2}\right] \qquad \text{(Eq.5)}$$

where, y = ln(x-a), $\mu_y$ = mean of the population of y and $\sigma_y$ = variance of the population of y.

#### *2.3.4 Pearson Type III distribution*

$$p_x(x) = p_o(1+x/\alpha)^{\alpha/\delta} e^{-x/\delta} \quad \text{(Eq.6)}$$

where, δ = difference between mean and mode ($\delta = \mu - X_m$), $X_m$ = mode of population x, α = scale parameter of distribution, and $p_o$ = value of $p_x(x)$ at mode.

#### *2.3.5 Log Pearson Type III distribution*

$$p_x(y) = p_{yo}(1+y/\alpha)^{\alpha/\delta y} e^{-y/\delta y} \quad \text{(Eq.7)}$$

where, $\delta y$ = difference between mean and mode ($\delta_y = \mu_y - Y_m$), $Y_m$ = mode of population y, α = scale parameter of distribution and $p_{yo}$ = value of $p_x(y)$ at mode.

#### *2.3.6 Gumbel distribution*

This is also referred to as Fisher-Tippett Type I, Double Exponential, Gumbel Type I and Gumbel extremal distribution. It is characterized by the probability density function of the following type,

$$p_x(x) = \frac{\alpha}{\beta-\gamma}\left(\frac{x-\gamma}{\beta-\gamma}\right)^{\alpha-1} e\left[\frac{x-\gamma}{\beta-\gamma}\right]^{\alpha} \quad \text{(Eq.8)}$$

where, $\alpha$ = scale parameter of distribution, and $\beta$ = location parameter of the distribution.

All six PDFs were compared by Chi-Square test for goodness of fit as given in the following equation (Eq.9).

$$\chi^2 = \sum \frac{(O-E)^2}{E} \quad \text{(Eq.9)}$$

where, O is the observed value obtained by Weibul's method and E is the estimated value by probability distribution functions. Chi-square test was performed to obtain the best PDF following the standard method and the model having least Chi-square value was selected as best fit PDF.

### 2.4 Computation method for onset and withdrawal of rainy season

The onset and withdrawal of rainy season was computed from weekly rainfall data by forward and backward accumulation methods as per the procedure suggested by Dash and Senapati (1992). Each year was divided into 52 standard meteorological weeks (SMW). The first SMW of any year starts from 1-7th January and 52nd SMW is from 24-31st December. Weekly rainfall was summed by forward accumulation (20+21+ --- +52 weeks) method until 75 mm of rainfall was accumulated. This 75 mm of rainfall has been considered as the onset time for sowing of rainfed crops (Panigrahi and Panda, 2002). The withdrawal of rainy season was determined by backward accumulation of rainfall (48+47+46+...+30 weeks) data. Twenty millimetres of rainfall accumulation was chosen for the withdrawal of the rainy season, which is sufficient for ploughing of fields after harvesting of the crops (Babu and Lakshminarayana, 1997; Srinivasareddy et al., 2008).

The percent probability (P) of each rank was calculated by arranging them in ascending order and by selecting highest rank allotted for particular week. The following Weibull's formula has been used for calculating percent probability.

$$P = (m/N+1) \times 100 \quad \text{(Eq.10)}$$

where, m is the rank number and N is the number of years of data used.

## 2.5 Markov chain probability model for dry and wet spell analyses

In this study, weekly rainfall values have been computed from daily values and were used for initial, conditional and consecutive dry and wet spell analysis based on Markov chain probability model as described by Pandarinath (1991). In this method, 20 mm or more rainfall in a week is considered as wet week otherwise dry as the previous researchers (Pandarinath, 1991; Dash and Senapati, 1992) also used 20 mm as the threshold value. Initial, conditional and consecutive dry and wet spell analysis for 52 SMWs are made by using equations from 11-20.

### *2.5.1 Initial probability*

$$P(D) = F(D)/N \quad \text{(Eq.11)}$$

$$P(W) = F(W)/N \quad \text{(Eq.12)}$$

where, P(D) = probability of the week being dry, F(D) = frequency of dry weeks, P(W) = probability of the week being wet, F(W) = frequency of wet weeks, and N = total number of years of data being used.

### *2.5.2 Conditional probabilities*

$$P(DD) = F(DD)/F(D) \quad \text{(Eq.13)}$$

$$P(WW) = F(WW)/F(W) \quad \text{(Eq.14)}$$

$$P(WD) = 1\text{-}P(DD) \quad \text{(Eq.15)}$$

$$P(DW) = 1\text{-}P(WW) \quad \text{(Eq.16)}$$

where, P(DD) = probability of a week being dry preceded by another dry week, F(DD) = frequency of dry week preceded by another dry week, P(WW) = probability of a week being wet preceded by another wet week, F(WW) = frequency of a wet week preceded by another wet week, P(WD) = probability of a wet week preceded by a dry week, and P(DW) = probability of a dry week preceded by a wet week.

### *2.5.3 Consecutive dry and wet week probabilities*

$$P(2D) = P(DW1) \times P(DDW2) \quad \text{(Eq.17)}$$

$$P(3D) = P(DW1) \times P(DDW2) \times P(DDW3) \quad \text{(Eq.18)}$$

$$P(2W) = P(WW1) \times P(WWW2) \quad \text{(Eq.19)}$$

$$P(3W) = P(WW1) \times P(WWW2) \times P(WWW3) \quad \text{(Eq.20)}$$

where, P(2D) = probability of 2 consecutive dry weeks starting with the week, P(DW1) = probability of the first week being dry, P(DDW2) = probability of the second week being dry, given the preceding week being dry, P(3D) = probability of 3 consecutive dry weeks starting with the week, P(DDW3) = probability of the third week being dry, given the preceding week dry, P(2W) = probability of 2 consecutive dry weeks starting with the week, P(WW1) = probability of the first week being wet, P(WWW2) = probability of the second week being wet, given the preceding week being wet, P(3W) = probability of 3 consecutive wet weeks starting with the week and P(WWW3) = probability of the third week being wet, given the preceding week wet.

## 2.6 Collection of soil samples and analyses

Soil samples were collected from different sites of head, mid- and tail reaches, and two sites of each of rice-fallow, rice-sugarcane and rice-mung bean cropping system. The exact location of different plots with respect to their latitude and longitude were measured with a GPS meter (model, Garmin eTrex Vista, Germany) (Table 1). Soil samples were collected during dry periods of the year 2010-11 and 2011-12. Samples were collected with the help of auger and down to the profile depth up to 90 cm from 5 different locations within one representative in a zig-zag pattern and also from four depth increments (i.e. 0-15, 15-30, 30-60 and 60-90 cm) from the soil profile to study the soil properties. After collection of soil samples during dry periods during the year 2010-11 and 2011-12, soil samples were processed properly for analyses.

Table 1. Location (with respect to latitude & longitude) of each represented site from where soil samples were collected for different cropping systems

| Site no. | Cropping system | Latitude | Longitude |
|---|---|---|---|
| 1 | Rice-fallow | 20° 18' 52.42'' N | 84° 55' 59.56'' E |
| 2 | Rice-fallow | 20° 21' 13.22'' N | 84° 53' 48.96'' E |
| 3 | Rice-sugarcane | 20° 20' 14.80'' N | 84° 54' 43.63'' E |
| 4 | Rice-sugarcane | 20° 20' 34.80'' N | 84° 54' 59.56'' E |
| 5 | Rice-mung bean | 20° 20' 11.57'' N | 84° 52' 33.77'' E |
| 6 | Rice-mung bean | 20° 20' 17.85'' N | 84° 52' 18.55'' E |

### *2.6.1 Methods of analyses of soil samples for different soil properties*

Soil particle size distribution was determined by the hydrometer method (Bouyoucous, 1951) and soil texture class was determined by following the procedure of USDA classification. Soil pH was measured with the help of a digital pH meter (pHTestr30, Malaysia). Field capacity and permanent wilting point were determined by a pressure plate apparatus (Eijkelkamp, Model 505). The available water capacity (AWC, $cm^3$ $cm^{-3}$) of soils, expressed as volume of water per unit volume of soil, was estimated as the difference between field capacity (FC) and permanent wilting point (PWP). Saturated hydraulic conductivity (Ks) was measured by constant head method. Five replicates of bulk density (BD, expressed as Mg $m^{-3}$) samples down to the profile depth up to 90 cm was also collected using soil cores and core samplers (Eijkelkemp Agrisearch Equipment) from four different layers and carried to laboratory.

#### *2.6.2 Assay for determining soil enzymes*

Soil enzymes dehydrogenase, phosphatase and urease were assayed using the procedure of Tabatabai (1982). Twenty g of air-dried soil (<2 mm) was mixed thoroughly and 2 g of $CaCO_3$ and placed 6 g of this mixture in each test tube. The procedure was adopted as per the above-mentioned method as applicable to triphenyl formazan (TPF) method. The amount of triphenyl formazan (TPF) produced was calculated by a reference calibration graph prepared from TPF standards. Soil phosphatase activity was measured by disodium phenyl phosphate method. The absorbance of color in the solution was measured at 660 nm. Urease activity was assayed using tris (hydoxymethyl) aminomethane (THAM) buffer and $NH_4^+$-N was determined through distillation method as outlined by Tabatabai (1982).

#### *2.6.3 Determination of soil organic carbon*

Organic carbon was determined by wet digestion method (Walkley and Black, 1934). SOC storage was calculated by using soil organic carbon content (SOC), bulk density (BD), thickness of soil layer and the area. SOC storage was thus calculated using the following equation (Eq. 21):

$$\text{SOC storage (Mg ha}^{-1}) = [\text{SOC (g g}^{-1}) \times \text{BD (Mg m}^{-3}) \times \text{area (ha)} \times \text{soil depth (m)}] \quad \text{(Eq.21)}$$

### 2.7 Major cropping systems

The principal crop is rice, which is cultivated in the command in about 90.4% of the total area. Hence, the cropping system is predominantly rice-based. Rice is being grown during rainy season and green gram (10.6% of the total area) is mostly grown during post-monsoon season. Sugarcane is a major cash crop in the region. Pigeon pea is also grown in upland areas. Among vegetables, brinjal is leading; however, the cultivation of vegetables in the command is very less compared to rice. Rice, brinjal and mung bean (also known as green gram, *Vigna radiata* (L.) Wilczek, a pulse crop) occupy about 90.4, 8.8 and 10.6% of the total command area, respectively. The major cropping systems are presented with detailed information on varieties of crops and management practices (Table 2).

### 2.8 Statistical analyses

The analysis of variance (ANOVA) technique was carried out on the data for each parameter as applicable to completely randomized design (Gomez and Gomez, 1984). The significance of the treatment effect was determined using F-test at 5% level. The mean differences were compared using the least significant difference (LSD) and the ordering of treatments was done by using Duncan's multiple range test (DMRT) at 5% level of probability. Root mean square error (RMSE), standard error of estimate (SE), correlations, and pedotransfer functions were developed using standard methods.

Table 2. Major cropping systems- their location and crop management information

| Cropping systems, location | Cropping period | Crop variety, duration & spacing | Land preparation/ tillage operations | Manure and fertilizer application | Irrigation | Average yield |
|---|---|---|---|---|---|---|
| Rice-fallow system (20° 18' to 20° 21' N, 84° 53' to 84° 55' E) | Rice (mid-Jun to end of Oct) in rainy season | Rice var. 'Pratikshya (125 d) with 20x10 cm, 'MTU 1001' (120 d) with 20x10 cm | One summer ploughing and puddling before transplanting of rice | Farmyard manure (FYM) @ 3-5 t $ha^{-1}$ $yr^{-1}$, $N-P_2O_5-K_2O$ @ 60-30-30 kg $ha^{-1}$ | Supplemental irrigation 2-3 times during dry spells | 2.8-3.2 t $ha^{-1}$ |
| Rice-sugarcane-2 years rotation (20° 20' N, 84° 54' E) | Rice (Jul-Nov) in rainy season; sugarcane (mid April-Feb/Mar) | Rice var. 'Pratikshya (125 d), 'Swarna' (140-145 d), 'MTU 1001' (120 d) with 20 x 10 cm & sugarcane var. 'Co 87044 (Uttara) Co 86249 (Bhavani) with 60-75 cm | One summer ploughing and puddling before transplanting of rice; ploughing and trenching while planting of sugarcane | FYM @ 3-5 t $ha^{-1}$; $N-P_2O_5-K_2O$ @ 80-40-40 kg $ha^{-1}$; FYM @ 5-7 t $ha^{-1}$; $N-P_2O_5-K_2O$ @ 200-80-60 kg $ha^{-1}$ in splits for sugarcane | Supplemental irrigation 4-5 times to rice; need periodical based irrigation to sugarcane | Rice yield 3-4.5 t $ha^{-1}$ & sugarcane 80-100 t $ha^{-1}$ |
| Rice-mung bean system (20° 20' N, 84°52' E) | Rice (Jul-Oct/Nov) in rainy & green gram (second fortnight of Nov-early Feb) | Rice var. Pratikshya (125 d), 'Swarna' (140-145 d), 'MTU 1001' (120 d) with 20 x 10 cm and mung bean var. 'Sujata' (65-70 d), 'Samrat' (75-80 d) with broadcasting | One summer ploughing and puddling before transplanting of rice, one ploughing for mung bean | FYM @ 3-5 t $ha^{-1}$ for rice; $N-P_2O_5-K_2O$ @ 60-30-30 kg $ha^{-1}$ for rice and 20-40-20 kg $ha^{-1}$ for mung bean | Supplemental irrigation 3-4 times to rice and residual moisture or one irrigation to mung bean | Rice yield 3.0-3.5 t $ha^{-1}$ & mung bean 0.5-0.7 t $ha^{-1}$ |

# 3 RESEARCH FINDINGS

## 3.1 Long-term annual rainfall, effective rainfall and distribution over seasons

Total annual rainfall in Daspalla region ranged between 993.5 to 1901.8 mm with an average of 1509.2 mm and the coefficient of variation (CV) was 14.8%. If rainfall received in a year was equal to or more than the average rainfall plus one standard deviation for 16 years of rainfall (i.e. 1509.2+223.8=1733 mm), it was considered as excess rainfall year (Sharma and Kumar, 2003). On four occasions (1995, 2001, 2003 and 2008), this region had received rainfall of more than 1733 mm; these years were considered as excess rainfall years. Only 25% of total years of analyses under this study had received rainfall of more than 1733 mm for this region. It is also observed that 44% of the total years of rainfall were below average (1509.2 mm) which were considered as the deficit rainfall years.

Monthly average and effective rainfall of Daspalla region for 16 years are presented in Fig. 2. It is revealed that, mean rainfall of July was 351.4 mm, which was the highest and its contribution was 23.3% to the average annual rainfall (i.e. 1509.2 mm). August rainfall was slightly lower than July rainfall (i.e. 20.6% of annual average rainfall). Average rainfall was lowest in the month of December. Total annual effective rainfall (ER) is 858.2 mm which is 56.9 percent of the total annual rainfall. Therefore, 651 mm of rainfall water is lost in the form of surface runoff, deep percolation and evaporation.

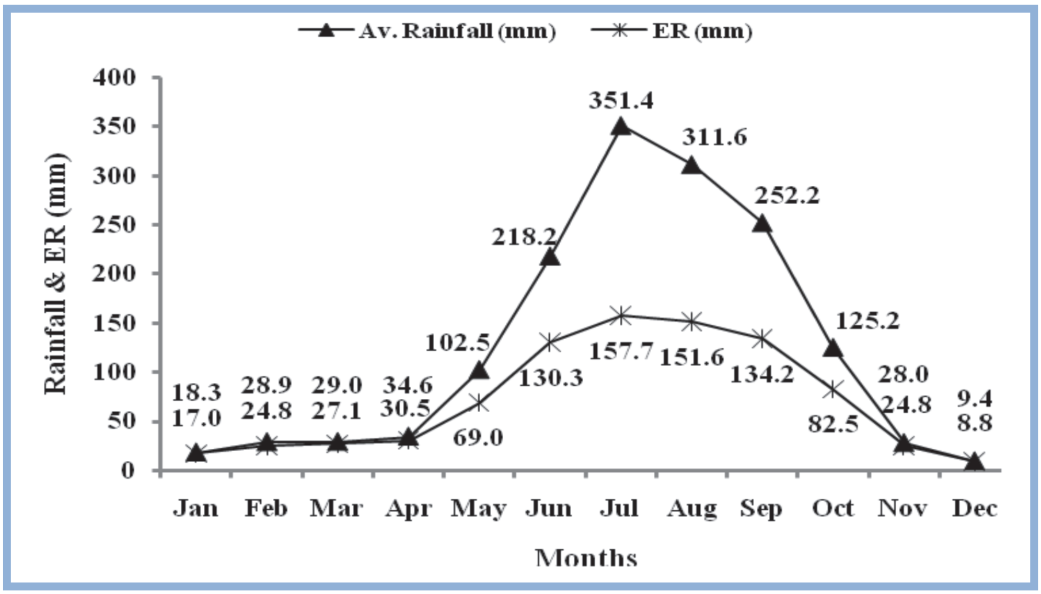



Fig. 2. Long-term average monthly rainfall and effective rainfall for study area, Daspalla; ER is the effective rainfall

The distribution of rainfall for different seasons from 1995-2010 is shown in Table 3. The normal southwest monsoon, which delivers about 75.7% of annual rainfall, extends from June to September. This is also the main season (rainy season) for cultivation of rainfed crops. The monsoon rainfall (1133.3 mm) is spread over a few rainy days with fewer rain events of high intensity. It causes surface runoff and temporary water stagnation in agricultural fields. Winter season contributes only 3.1% of the total annual rainfall; 10.8 and 10.4% of the total annual rainfall occurred during pre- and post-monsoon season, respectively.

Table 3. Rainfall distribution in Daspalla region over different seasons

| Seasons | Average rainfall (mm) | Percentage of total rainfall |
|---|---|---|
| Pre -monsoon (March -May) | 166.1 | 10.8 |
| Monsoon (June-September) | 1133.3 | 75.7 |
| Post -monsoon (October -December) | 162.6 | 10.4 |
| Winter (January-February) | 47.2 | 3.1 |

## 3.2 Prediction of rainfall using probability distribution functions

Annual rainfall for the region was predicted by using DISTRIB 2.13 component of SMADA 6.43 for 6 different probability distribution functions. Six predicted annual rainfall values were obtained from 6 PDFs by running DISTRIB 2.13. After that Chi-square value for each PDF was estimated by using equation 9. Chi-square values varied from 29.2 to 58.8 for 6 PDFs. Least Chi-square values were observed in Log Pearson Type III distribution for prediction of annual rainfall in Daspalla. Therefore, for this region, Log Pearson Type III considered as best fit PDF for prediction of annual rainfall. In this region, about 86% of the total annual rainfall occurs during monsoon and post-monsoon season and agriculture is totally dependent on the performance of south-west monsoon. Therefore, prediction of monsoon and post-monsoon rainfall is more important than annual rainfall for raising crops successfully with high and stable yields. For this reason, monsoon and post monsoon rainfall were predicted and results are presented in Fig. 3 & 4.

It is revealed from analyses that, during monsoon season, the observed monsoon rainfall was 1049.6 mm at 70% probability level and all the probability distribution functions predicted almost comparable rainfall. With regard to the post-monsoon rainfall, lowest Chi-square value was obtained in case of Gumbel distribution (Fig. 4). In this study, for prediction of monsoon and post-monsoon rainfall, Log Pearson Type III and Gumbel distribution are found as best fit PDFs. Observed rainfall at different probability levels for monsoon and post-monsoon months were determined by using Weibul's formula and presented in Table 4.

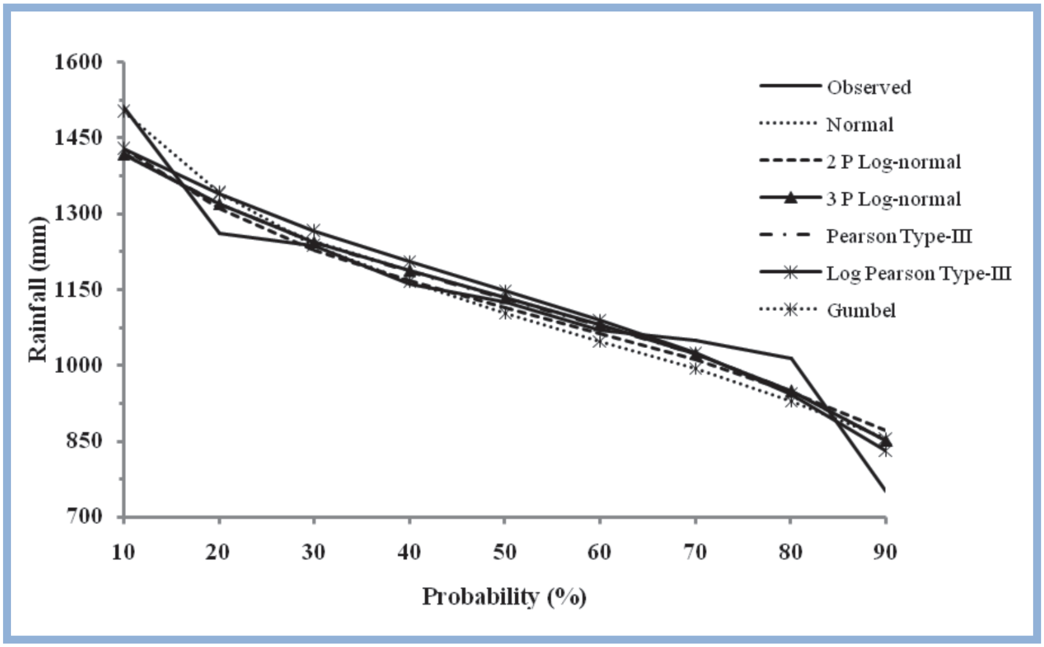



Fig. 3. Observed and predicted rainfall (mm) at different probability levels for the monsoon season

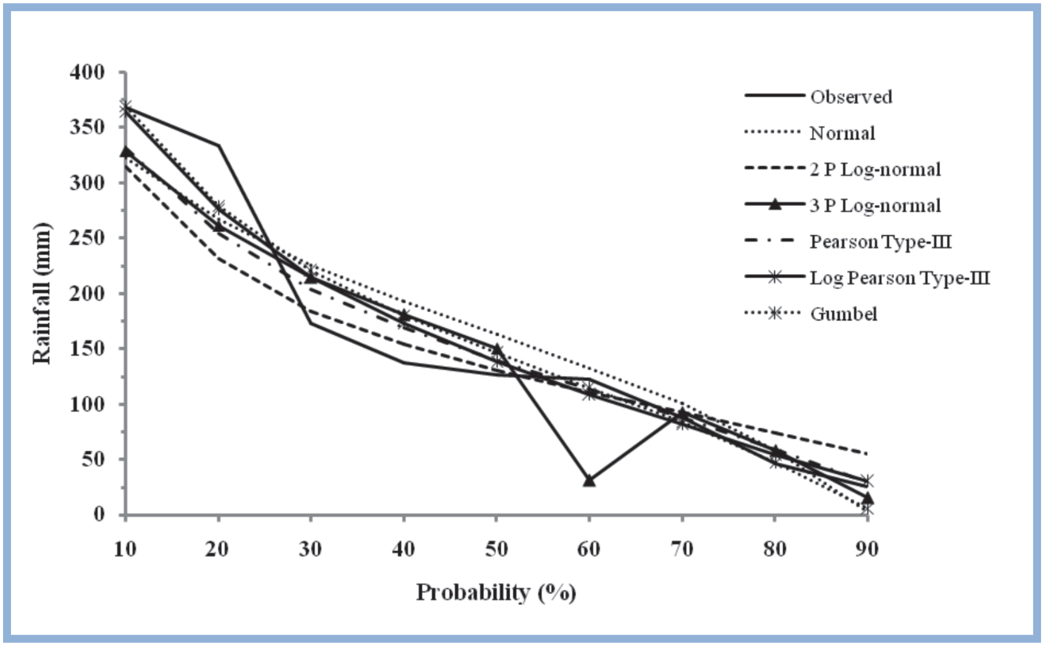



Fig. 4. Observed and predicted rainfall (mm) at different probability levels for post-monsoon season in the study area

Table 4. Observed rainfall at different probability levels for monsoon and post- monsoon months

| Probability (%) | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|
| 10 | 415.2 | 724.0 | 523.3 | 450.0 | 322.0 | 105.5 | 47.6 |
| 20 | 333.3 | 469.8 | 413.1 | 381.5 | 274.1 | 47.7 | 29.7 |
| 30 | 217.0 | 365.8 | 356.5 | 354.0 | 123.1 | 29.7 | 2.8 |
| 40 | 196.6 | 337.5 | 321.1 | 301.3 | 116.2 | 20.9 | 0.3 |
| 50 | 194.8 | 282.8 | 299.7 | 227.4 | 87.5 | 14.8 | - |
| 60 | 182.8 | 270.0 | 275.2 | 177.8 | 77.4 | 11.8 | - |
| 70 | 158.0 | 244.4 | 274.2 | 164.9 | 57.9 | 6.2 | - |
| 80 | 132.4 | 217.3 | 180.6 | 141.6 | 28.0 | 1.0 | - |
| 90 | 105.9 | 181.9 | 164.5 | 75.4 | 16.9 | - | - |

### 3.3 Analyses of rainfall for onset and withdrawal of monsoon season

The data on onset, withdrawal and duration of the rainy season (difference between onset and withdrawal time) and its variability in Daspalla region are presented in Table 5. Weekly rainfall data indicated that the monsoon starts effectively from 23rd SMW (4-10th June) and remains active up to 43rd SMW (22-28th October). Therefore, mean length of rainy season was found to be 21 weeks (147 days). The earliest and delayed week of onset of rainy season was 20th SMW (14-20th May) and 25th SMW (18-24th June), respectively. Similarly, the earliest and delayed week of cessation of rainy season was 39th SMW (24-30th September) and 47th SMW (19-25th November), respectively. The longest and shortest length of rainy season was coincided with 26th and 17th weeks, respectively. The probabilities of onset and withdrawal of rainy season was calculated by using Weibull's formula and results are presented in Table 6. The results reveal that there is a 94% chance that the onset and withdrawal of rainy season will occur during 25th and 47th SMW, respectively.

### 3.4 Markov chain model

Results of initial and conditional probabilities of dry and wet weeks are presented in Table 7 for the 52 standard meteorological weeks. The results reveal that, the probability of occurrence of dry week is high until the end of 22nd SMW. The range of probability of occurrence of dry week from 1st to 22nd SMW is between 56 to 100%. The probability of occurrence of dry week preceded by another dry week (PDD) and that of dry week preceded by another wet week (PDW) vary from 54 to 100% and 28 to 100%, respectively during 1st-22nd SMW periods. However, from 23rd to 40th SMW the probability of both PD and PDD are low. The probability that these weeks (23rd-40th SMW) remain wet (PW) varies between 62 to 100%. The conditional probability of wet week preceded by another wet week (PWW) varies between 30 to 100%. The chances of occurrence of dry spells are again high from 42nd SMW to the end of the year.

Table 5. Characterization of rainy season at the study site, Daspalla

| Particulars | Week No. | Date |
|---|---|---|
| Mean week of onset of rainy season | 23 | 4-10 June |
| Earliest week of onset of rainy season | 20 | 14-20 May |
| Delayed week of onset of rainy season | 25 | 18-24 June |
| Mean week of withdrawal of rainy season | 43 | 22-28 October |
| Earliest week of withdrawal of rainy season | 39 | 24-30 September |
| Delayed week of withdrawal of rainy season | 47 | 19-25 November |

Table 6. Probability of onset and withdrawal of rainy season at the study site, Daspalla

| Probability of onset and withdrawal | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Onset* | | | | | | | | | |
| SMW | 20 | 21 | 22 | 23 | 24 | 25 | | | |
| P (%) | 17.6 | 29.4 | 35.3 | 64.7 | 82.4 | 94.1 | | | |
| *Withdrawal* | | | | | | | | | |
| SMW | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| P (%) | 5.9 | 11.8 | 23.5 | 41.2 | 47.1 | 64.7 | 76.5 | 88.2 | 94.1 |

SMW – Standard Meteorological Week, P – Probability in percentage

The analyses of consecutive dry and wet spells (Table 8) reveal that there are 31 to 100% chances that 2 consecutive dry weeks (P2D) will occur within the first 22 weeks of the year. Similarly, the probabilities of occurrence of 3 consecutive dry weeks (P3D) are also very high (15-86%) in the first 22 weeks of the year. The corresponding values of 2 and 3 consecutive wet weeks (i.e. P2W and P3W) from 1st to 22nd SMW are very low with values ranging from 0 to 31% and 0 to 13%, respectively. From 23rd to 40th SMW, the chances of occurrence of 2 and 3 consecutive dry weeks are only within 0 to 19% and 0 to 15%, respectively. Conversely, there are chances of 36 to 100% and 28 to 87% the weeks from 23rd to 40th SMW will be getting sufficient rain with 2 and 3 consecutive wet weeks, respectively. This study reveals that the last 12 weeks of the year (41 to 52th weeks) may remain under stress on an average, as there are 75% chances of occurrence of 2 consecutive dry weeks. The corresponding value for 3 consecutive dry weeks during the period is 67%.

Table 7. Initial and conditional probabilities of dry and wet spells of rainfall at the study site, Daspalla region.

| SMW | Initial probabilities (%) | | Conditional probabilities (%) | | | |
|---|---|---|---|---|---|---|
| | $P_D$ | $P_W$ | $P_{DD}$ | $P_{WD}$ | $P_{WW}$ | $P_{DW}$ |
| 1 | 100.0 | 0.0 | - | - | - | - |
| 2 | 87.5 | 12.5 | 100.0 | 0.0 | 0.0 | 100.0 |
| 3 | 87.5 | 12.5 | 85.7 | 14.3 | 0.0 | 100.0 |
| 4 | 93.8 | 6.2 | 86.7 | 13.3 | 0.0 | 100.0 |
| 5 | 93.8 | 6.2 | 93.3 | 6.7 | 0.0 | 100.0 |
| 6 | 93.8 | 6.2 | 100.0 | 0.0 | 100.0 | 0.0 |
| 7 | 87.5 | 12.5 | 92.9 | 7.1 | 0.0 | 100.0 |
| 8 | 87.5 | 12.5 | 92.9 | 7.1 | 50.0 | 50.0 |
| 9 | 81.3 | 18.7 | 92.3 | 7.7 | 33.3 | 66.7 |
| 10 | 81.3 | 18.7 | 84.6 | 15.4 | 33.3 | 66.7 |
| 11 | 87.5 | 12.5 | 78.6 | 21.4 | 0.0 | 100.0 |
| 12 | 93.8 | 6.2 | 86.7 | 13.3 | 0.0 | 100.0 |
| 13 | 87.5 | 12.5 | 92.9 | 7.1 | 0.0 | 100.0 |
| 14 | 87.5 | 12.5 | 85.7 | 14.3 | 0.0 | 100.0 |
| 15 | 93.8 | 6.2 | 86.7 | 13.3 | 0.0 | 100.0 |
| 16 | 93.8 | 6.2 | 93.3 | 6.7 | 0.0 | 100.0 |
| 17 | 81.3 | 18.7 | 100.0 | 0.0 | 33.3 | 66.7 |
| 18 | 93.8 | 6.2 | 80.0 | 20.0 | 0.0 | 100.0 |
| 19 | 68.8 | 31.2 | 100.0 | 0.0 | 20.0 | 80.0 |
| 20 | 56.3 | 43.7 | 66.7 | 33.3 | 28.6 | 71.4 |
| 21 | 56.3 | 43.7 | 77.8 | 22.2 | 71.4 | 28.6 |
| 22 | 68.8 | 31.2 | 54.5 | 45.5 | 40.0 | 60.0 |
| 23 | 18.7 | 81.3 | 66.7 | 33.3 | 30.8 | 69.2 |
| 24 | 37.5 | 62.5 | 33.3 | 66.7 | 90.0 | 10.0 |
| 25 | 25.0 | 75.0 | 50.0 | 50.0 | 66.7 | 33.3 |
| 26 | 18.7 | 81.3 | 66.7 | 33.3 | 84.6 | 15.4 |
| 27 | 18.7 | 81.3 | 33.3 | 66.7 | 84.6 | 15.4 |
| 28 | 31.2 | 68.8 | 20.0 | 80.0 | 81.8 | 18.2 |
| 29 | 0.0 | 100.0 | 0.0 | 100.0 | 68.8 | 31.2 |
| 30 | 12.5 | 87.5 | 0.0 | 100.0 | 100.0 | 0.0 |
| 31 | 6.2 | 93.8 | 0.0 | 100.0 | 86.7 | 13.3 |
| 32 | 12.5 | 87.5 | 0.0 | 100.0 | 92.9 | 7.1 |
| 33 | 18.7 | 81.3 | 0.0 | 100.0 | 84.6 | 15.4 |
| 34 | 0.0 | 100.0 | 0.0 | 100.0 | 81.3 | 18.7 |
| 35 | 12.5 | 87.5 | 0.0 | 100.0 | 100.0 | 0.0 |
| 36 | 12.5 | 87.5 | 0.0 | 100.0 | 85.7 | 14.3 |
| 37 | 37.5 | 62.5 | 0.0 | 100.0 | 80.0 | 20.0 |
| 38 | 18.7 | 81.3 | 66.7 | 33.3 | 69.2 | 30.8 |
| 39 | 31.2 | 68.8 | 40.0 | 60.0 | 90.9 | 9.1 |
| 40 | 37.5 | 62.5 | 33.3 | 66.7 | 70.0 | 30.0 |
| 41 | 56.3 | 43.7 | 44.4 | 55.6 | 57.1 | 42.9 |
| 42 | 56.3 | 43.7 | 88.9 | 11.1 | 85.7 | 14.3 |
| 43 | 81.3 | 18.7 | 69.2 | 30.8 | 100.0 | 0.0 |
| 44 | 75.0 | 25.0 | 91.7 | 8.3 | 50.0 | 50.0 |
| 45 | 81.3 | 18.7 | 76.9 | 23.1 | 33.3 | 66.7 |
| 46 | 93.8 | 6.2 | 86.7 | 13.3 | 100.0 | 0.0 |
| 47 | 93.8 | 6.2 | 93.3 | 6.7 | 0.0 | 100.0 |
| 48 | 100.0 | 0.0 | 93.8 | 6.2 | 0.0 | 100.0 |
| 49 | 93.8 | 6.2 | 100.0 | 0.0 | 0.0 | 100.0 |
| 50 | 87.5 | 12.5 | 100.0 | 0.0 | 50.0 | 50.0 |
| 51 | 93.8 | 6.2 | 86.7 | 13.3 | 0.0 | 100.0 |
| 52 | 100 | 0.0 | 93.8 | 6.2 | 0.0 | 100.0 |

Probabilities are mentioned under materials and methods

Table 8. Analyses of consecutive dry and wet week probabilities of rainfall at the study site

| SMW | Consecutive dry week probabilities (%) | | Consecutive wet week probabilities (%) | |
|---|---|---|---|---|
| | $P_{2D}$ | $P_{3D}$ | $P_{2W}$ | $P_{3W}$ |
| 1 | 100.0 | 85.7 | 0.0 | 0.0 |
| 2 | 75.0 | 65.0 | 0.0 | 0.0 |
| 3 | 75.8 | 70.8 | 0.0 | 0.0 |
| 4 | 87.5 | 87.5 | 0.0 | 0.0 |
| 5 | 93.8 | 87.1 | 6.3 | 0.0 |
| 6 | 87.1 | 80.8 | 0.0 | 0.0 |
| 7 | 81.3 | 75.0 | 6.3 | 2.1 |
| 8 | 80.8 | 68.3 | 4.2 | 1.4 |
| 9 | 68.8 | 54.0 | 6.3 | 0.0 |
| 10 | 63.8 | 55.3 | 0.0 | 0.0 |
| 11 | 75.8 | 70.4 | 0.0 | 0.0 |
| 12 | 87.1 | 74.6 | 0.0 | 0.0 |
| 13 | 75.0 | 65.0 | 0.0 | 0.0 |
| 14 | 75.8 | 70.8 | 0.0 | 0.0 |
| 15 | 87.5 | 87.5 | 0.0 | 0.0 |
| 16 | 93.8 | 75.0 | 2.1 | 0.0 |
| 17 | 65.0 | 65.0 | 0.0 | 0.0 |
| 18 | 93.8 | 62.5 | 1.3 | 0.4 |
| 19 | 45.8 | 35.6 | 8.9 | 6.4 |
| 20 | 43.8 | 23.9 | 31.3 | 12.5 |
| 21 | 30.7 | 20.5 | 17.5 | 5.4 |
| 22 | 45.8 | 15.3 | 9.6 | 8.7 |
| 23 | 6.3 | 3.1 | 73.1 | 48.8 |
| 24 | 18.8 | 12.5 | 41.7 | 35.3 |
| 25 | 16.7 | 5.6 | 63.5 | 53.7 |
| 26 | 6.3 | 1.3 | 68.8 | 56.3 |
| 27 | 3.8 | 0.0 | 66.5 | 45.7 |
| 28 | 0.0 | 0.0 | 47.3 | 47.3 |
| 29 | 0.0 | 0.0 | 100.0 | 86.7 |
| 30 | 0.0 | 0.0 | 75.8 | 70.4 |
| 31 | 0.0 | 0.0 | 87.1 | 73.7 |
| 32 | 0.0 | 0.0 | 74.0 | 60.2 |
| 33 | 0.0 | 0.0 | 66.0 | 66.0 |
| 34 | 0.0 | 0.0 | 100.0 | 85.7 |
| 35 | 0.0 | 0.0 | 75.0 | 60.0 |
| 36 | 0.0 | 0.0 | 70.0 | 48.5 |
| 37 | 25.0 | 10.0 | 43.3 | 39.3 |
| 38 | 7.5 | 2.5 | 73.9 | 51.7 |
| 39 | 10.4 | 4.6 | 48.1 | 27.5 |
| 40 | 16.7 | 14.8 | 35.7 | 30.6 |
| 41 | 50.0 | 34.6 | 37.5 | 37.5 |
| 42 | 38.9 | 35.7 | 43.8 | 21.9 |
| 43 | 74.5 | 57.3 | 9.4 | 3.1 |
| 44 | 57.7 | 50.0 | 8.3 | 8.3 |
| 45 | 70.4 | 65.7 | 18.8 | 0.0 |
| 46 | 87.5 | 82.0 | 0.0 | 0.0 |
| 47 | 87.9 | 87.9 | 0.0 | 0.0 |
| 48 | 100.0 | 100.0 | 0.0 | 0.0 |
| 49 | 93.8 | 81.3 | 3.1 | 0.0 |
| 50 | 75.8 | 71.1 | 0.0 | 0.0 |
| 51 | 87.9 | - | 0.0 | - |
| 52 | - | - | - | - |

Probabilities are mentioned under materials and methods

## 3.5 Soil characteristics in the command-head, mid and tail-reaches

### *3.5.1 Particle size distribution and soil pH*

Particle size fractions of soil i.e. sand, silt and clay differed in different sites, and in different soil depths (Table 9). The soils are mainly composed of sand and clay and textural class was classified as sandy clay loam in the surface layer, clayey or sandy clay in the lower layers except that in site 4, where surface soils are clay loam. In general, sand contents ranged from 34.0 to 56.2%, clay from 29.6 to 48.8% depending on the soil depths and cropping systems. Depth-wise distribution showed a significantly decreasing trend in sand content towards lower soil layers in every cropping system; whereas clay contents increased gradually towards lower soil depths. Clay fractions were comparatively higher in the study site 3 and 4 under rice-sugarcane crop rotations than other sites. Silt contents in these soils were low. The pH of the soil varied from 6.5 to 7.5. The surface soils of site 1, 2 and 5 were slightly acidic as evident from the values (i.e. <7.0). In the study sites 2, 3 and 6 under rice-sugarcane crop rotation and rice-mung bean system, soil pH in the depths up to 90 cm were above 7.0. With the increase in soil depth, pH increased and tended to be in the range of neutral or slightly alkaline.

### *3.5.2 Soil bulk density and saturated hydraulic conductivity*

The bulk density (BD) of soils in different soil depth was generally near or greater than 1.5 Mg $m^{-3}$ and it ranged from 1.44 to 1.72 Mg $m^{-3}$, irrespective of different sites under major rice-based cropping in the command and soil depths (Fig. 5). There was a slight difference in the bulk density in different cropping systems and sites in the upper soil layers. It indicated a comparatively lower in the sites 3, 4 with rice-sugarcane rotation and in site 5 rice-mung bean cropping systems relative to other sites and systems. For every site, BD increased with soil depth; however, this increase was higher in rice-fallow system in site 1. Overall, the soils of rice-fallow systems in site 1 and 2 showed greater BD in every soil depth than other systems and study sites. The saturated hydraulic conductivity (Ks) of soils (Table 10) decreased significantly towards greater depths in the soil profile for each site under different cropping systems. This decrease was related to the greater clay contents in lower depths of soils. Among sites, Ks values were lower in the sites 3 and 4 where rice-sugarcane crop rotation is a prevalent system when compared to other sites. In sites 3 and 4, higher clay contents were also observed.

### *3.5.3 Water retention and available water capacity of soils*

The water retention at field capacity (FC, -33 kPa) and permanent wilting point (PWP, -1500 kPa) was slightly higher in sites 3 and 4 under rice-sugarcane crop rotation compared to other sites and cropping systems (Table 11). In general, FC ranged from 0.228 to 0.465 $cm^3$ $cm^{-3}$ irrespective depth and site. Depth-wise water retention at FC showed a significantly greater retention with the increase in soil depth; and this trend was similar in every site and cropping system.

Table 9. Particle size fractions i.e. sand, silt and clay contents of the profile soil and textural classes under different sites and major cropping systems in the command

| Site/ cropping system | Soil depth (cm) | Particle size distribution | | | Textural class |
|---|---|---|---|---|---|
| | | Sand (%) | Silt (%) | Clay (%) | |
| Site-1 (Rice-fallow cropping) | 0-15 | 50.1a | 15.9a | 34.0c | scl |
| | 15-30 | 42.7b | 16.1a | 41.2b | c |
| | 30-60 | 39.0b | 12.8a | 48.2a | c |
| | 60-90 | 38.7b | 12.5a | 48.8a | c |
| | $LSD_{5\%}$ | 6.1 | 4.1 | 4.2 | |
| Site-2 (Rice-fallow cropping) | 0-15 | 51.9a | 13.5ab | 34.6d | scl |
| | 15-30 | 48.4b | 13.9ab | 37.7c | sl |
| | 30-60 | 45.7c | 14.5a | 39.8b | sc |
| | 60-90 | 44.8c | 10.4b | 44.8a | c |
| | $LSD_{5\%}$ | 2.4 | 3.4 | 1.9 | |
| Site-3 (Rice-sugarcane crop rotation) | 0-15 | 50.5a | 15.9a | 33.6c | scl |
| | 15-30 | 43.3b | 15.9a | 40.7b | c |
| | 30-60 | 38.8b | 13.6ab | 47.6a | c |
| | 60-90 | 38.3b | 11.0b | 50.7a | c |
| | LSD5% | 5.5 | 3.9 | 4.1 | |
| Site-4 (Rice-sugarcane crop rotation) | 0-15 | 42.6a | 18.4a | 39.0c | cl |
| | 15-30 | 38.9b | 15.7ab | 45.4b | c |
| | 30-60 | 37.4bc | 13.8ab | 48.8b | c |
| | 60-90 | 34.0c | 12.7b | 53.3a | c |
| | $LSD_{5\%}$ | 3.6 | 3.8 | 3.6 | |
| Site-5 (Rice-mung bean cropping) | 0-15 | 54.6a | 15.8a | 29.6c | scl |
| | 15-30 | 48.6a | 14.6a | 36.8b | sc |
| | 30-60 | 43.3ab | 13.1a | 43.6a | c |
| | 60-90 | 41.8bc | 13.1a | 45.2a | c |
| | $LSD_{5\%}$ | 6.1 | 3.8 | 4.3 | |
| Site-6 (Rice-mung bean cropping) | 0-15 | 56.2a | 12.2a | 31.6d | scl |
| | 15-30 | 50.8b | 14.7a | 34.5c | scl |
| | 30-60 | 48.5bc | 14.0a | 37.5b | sc |
| | 60-90 | 46.6c | 11.3a | 42.2a | sc |
| | $LSD_{5\%}$ | 3.1 | 3.9 | 2.9 | |

Mean values with the same letter within a column under any site are not significantly different according to DMRT at $P < 0.05$

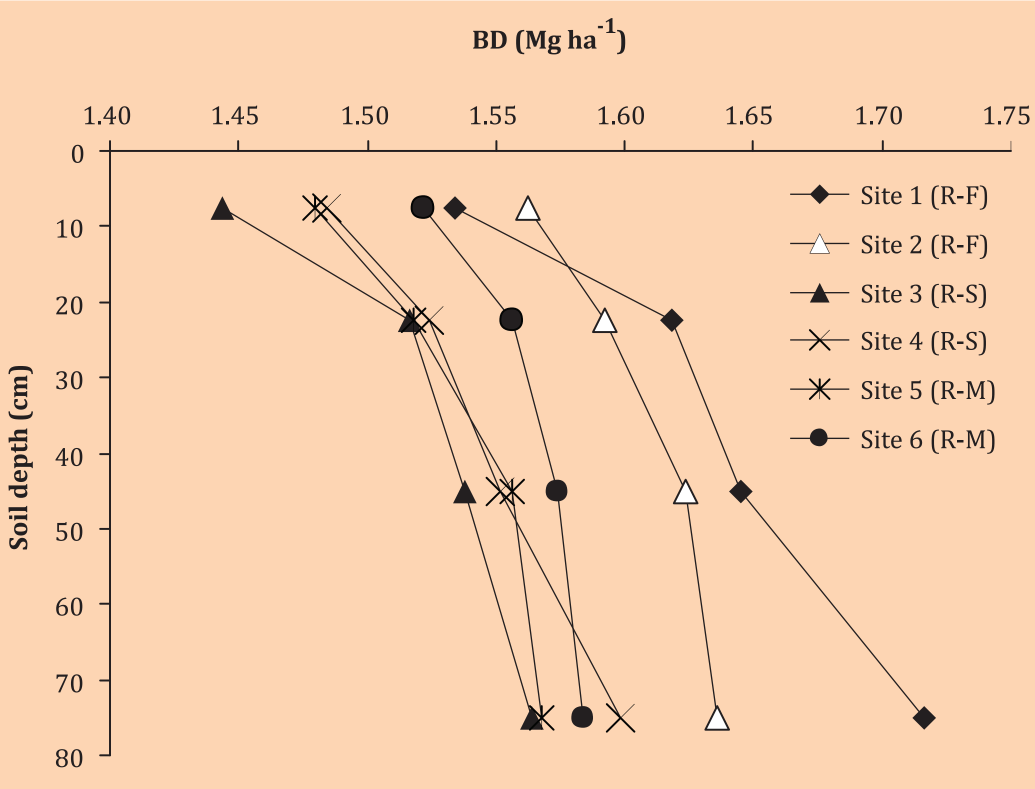



Fig. 5. Bulk density of soils in depth increments under different sites; R-F indicates rice-fallow, R-S rice-sugarcane rotation and R-M is rice-mung bean cropping

Table 10. Saturated hydraulic conductivity (Ks) of soils in different sites under major cropping systems in the command area

| Soil depth (cm) | Saturated hydraulic conductivity (Ks) (cm $h^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Site-1 (Rice-fallow cropping) | Site-2 (Rice-fallow cropping) | Site-3 (Rice-sugarcane crop rotation) | Site-4 (Rice-sugarcane crop rotation) | Site-5 (Rice-mung bean cropping) | Site-6 (Rice-mung bean cropping) |
| 0-15 | 0.22a | 0.22a | 0.21a | 0.17a | 0.27a | 0.24a |
| 15-30 | 0.14b | 0.17b | 0.15b | 0.14b | 0.18b | 0.21b |
| 30-60 | 0.11b | 0.15c | 0.12b | 0.12bc | 0.13c | 0.17c |
| 60-90 | 0.11b | 0.13d | 0.11b | 0.11c | 0.12c | 0.13d |
| $LSD_{5\%}$ | 0.05 | 0.01 | 0.04 | 0.03 | 0.04 | 0.02 |

Mean values with the same letter within a column under a site are not significantly different according to DMRT at $P < 0.05$.

Table 11. Field capacity and permanent wilting point of soils in different depths at different sites/ cropping systems under the Kuanria command area

| Soil depth (cm) | Site-1 (Rice-fallow cropping) | Site-2 (Rice-fallow cropping) | Site-3 (Rice-sugarcane crop rotation) | Site-4 (Rice-sugarcane crop rotation) | Site-5 (Rice-mung bean cropping) | Site-6 (Rice-mung bean cropping) |
|---|---|---|---|---|---|---|
| *Field capacity (at -33 kPa) ($cm^3$ $cm^{-3}$)* | | | | | | |
| 0-15 | 0.228b | 0.236c | 0.331c | 0.286c | 0.255d | 0.231c |
| 15-30 | 0.278b | 0.348b | 0.368b | 0.370b | 0.300c | 0.297b |
| 30-60 | 0.403a | 0.393ab | 0.406a | 0.449a | 0.339b | 0.374a |
| 60-90 | 0.464a | 0.409a | 0.423a | 0.465a | 0.371a | 0.392a |
| $LSD_{5\%}$ | 0.077 | 0.057 | 0.220 | 0.033 | 0.023 | 0.028 |
| *Permanent wilting point (-1500 kPa) ($cm^3$ $cm^{-3}$)* | | | | | | |
| 0-15 | 0.161c | 0.158c | 0.222d | 0.198c | 0.163d | 0.169c |
| 15-30 | 0.211b | 0.239b | 0.257c | 0.245b | 0.194c | 0.192b |
| 30-60 | 0.285a | 0.270a | 0.272b | 0.289a | 0.227b | 0.229a |
| 60-90 | 0.308a | 0.272a | 0.279a | 0.302a | 0.254a | 0.236a |
| $LSD_{5\%}$ | 0.026 | 0.018 | 0.007 | 0.025 | 0.023 | 0.010 |

Mean values with the same letter within a column under any study site are not significantly different according to DMRT at $P < 0.05$.

The range of PWP, irrespective of sites, was 0.161-0.308, 0.158-0.272, 0.222-0.279, 0.198-0.302, 0.163-0.254 and 0.169-0.236 $cm^3$ $cm^{-3}$ in sites 1 through 6, respectively (Table 11). Similar to the trends in FC values, PWP increased significantly with the increase in soil depth for every site. The average values of PWP were greater in site 3 and 4 under rice-sugarcane crop rotation that other sites. The AWC was slightly greater in the soils of site 3, 4 in the rice-sugarcane system than other systems; it showed higher values in the deeper soil layers (Fig. 6). The difference in available water capacity (AWC) was governed by the difference in FC and PWP values; and basically, it is the clay fractions in the soils of different sites which determined the higher FC, and in turn the higher AWC of soils.

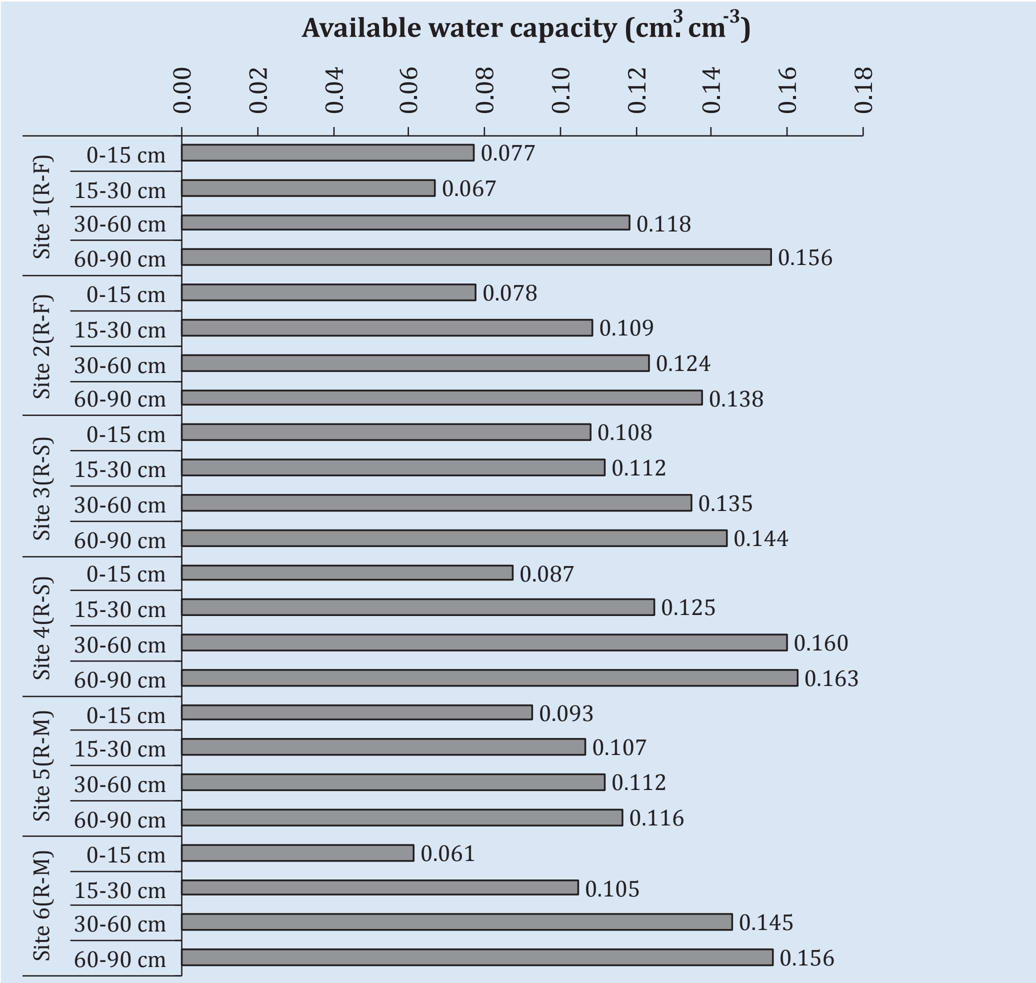



Fig. 6. Available water capacity (AWC) of soils in depth increments under different sites; R-F indicates rice-fallow system, R-S rice-sugarcane rotation and R-M is rice-mung bean cropping.

## 3.6 Soil organic carbon (SOC)

### *3.6.1 Soil organic carbon content and storage*

Soil organic carbon (SOC) content varied from 0.34 to 0.95% depending upon the cropping systems/ sites and the soil layer (Fig. 7). The SOC was highest in surface (0-15 cm) layer and then decreased down to the soil profile in every site. There was no sharp difference of SOC due to difference in cropping systems for every soil depths. However, one trend was clearly emerged out of the results that is, soils of site 3 and 4 under rice-sugarcane crop rotation had greater SOC content compared to other rice-based systems.

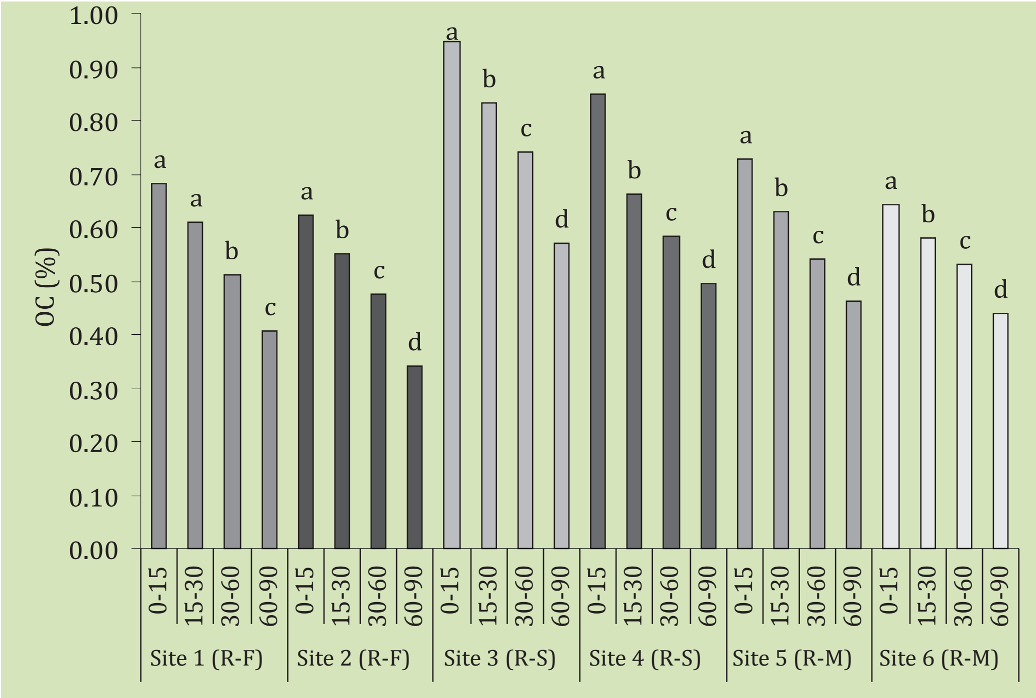



Fig. 7. Organic carbon content of soils in different depths under different sites; R-F indicates rice-fallow, R-S rice-sugarcane rotation and R-M is rice-mung bean cropping; vertical bars with same letter are not significant at $p<0.05$ in a site as per DMRT.

### *3.6.2 Soil organic carbon (SOC) storage in the surface layer and in the profile*

The organic carbon in the surface soil i.e., 0-15 cm is more susceptible to be released into the environment through CO2. Hence, its quantification was made with the help of bulk density, depth, area and organic carbon content data (Fig. 8). It was estimated that SOC storage was higher in rice-sugarcane crop rotation systems, 18.90 and 20.53 Mg $ha^{-1}$ in the sites 3 and 4, respectively. However, other sites also had the organic carbon storage to amount of 14.68, 16.16, 14.58 and 15.70 Mg $ha^{-1}$ in the site 1 (rice-fallow) and site 2 (rice-fallow), site 5 (rice-mung bean) and site 6 (rice-mung bean), respectively.

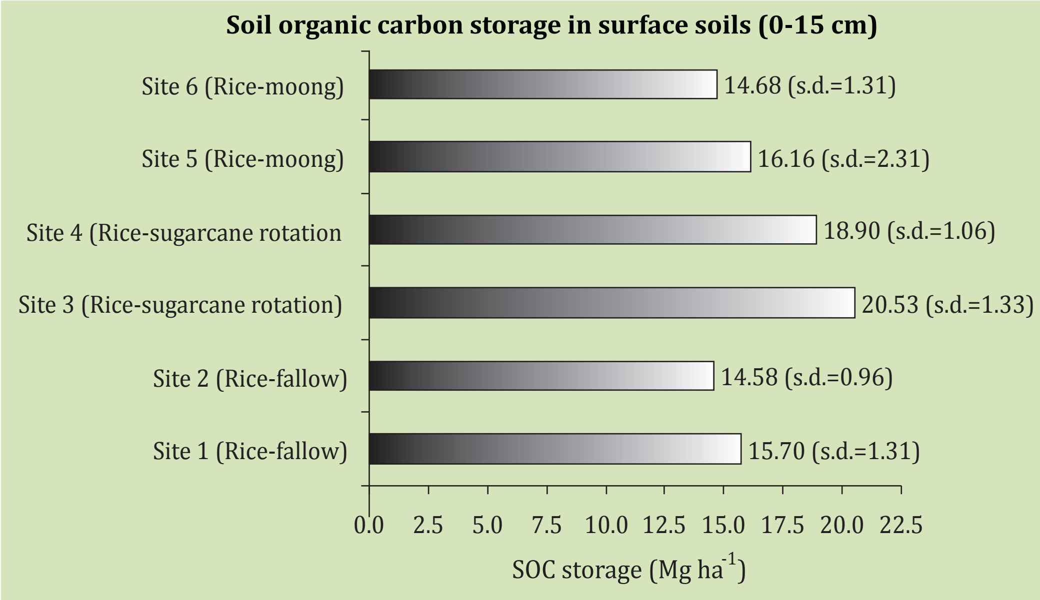



Fig. 8. Soil organic carbon (SOC) storage in surface soil (0-15 cm depth) in different soil sites/ cropping systems; mean values with standard deviation (s.d.) are presented against each horizontal bar

Depth-wise soil organic carbon (SOC) storage shows highest in the first 30 cm soil depth (0-30 cm) and gradually decreased significantly with depth increments in each site (Fig. 9). In the 0-30 cm soil layer, SOC storage ranged from 27.77 Mg ha$^{-1}$ under rice-fallow system in site 2 to 39.44 Mg ha$^{-1}$ under rice-sugarcane in site 3. In the 30-60 cm soil layer, SOC storage ranged from 23.06 Mg ha$^{-1}$ under rice-fallow system in site 2 to 34.15 Mg ha$^{-1}$ under rice-sugarcane in site 3. In the 60-90 cm soil layer, SOC storage ranged from 16.67 Mg ha$^{-1}$ under rice-fallow system in site 2 to 26.83 Mg ha$^{-1}$ under rice-sugarcane in site 3. The SOC storage significantly decreased towards greater depth of soils as evident from estimated values. The SOC storage in the profile (0-90 cm) varied from 67.51 Mg ha$^{-1}$ under rice-fallow system in site 2 to 100.43 Mg ha$^{-1}$ under rice-sugarcane in site 3 (Fig. 10). Rice-sugarcane system has greater SOC storage in the profile.

### 3.7 Activities of soil enzymes

Studies on activities of soil enzymes viz. dehydrogenase, phosphatase and urease were made for surface soil (0-15 cm) for five sites/ cropping systems (Table 12, 13 & 14). Results on dehydrogenase activity showed a range of 283.52 to 313.31 µg TPF g$^{-1}$ soil 24h$^{-1}$ with the coefficient of variation (CV) ranged from 8.36 to 9.22%; the highest value was obtained at site 5 under rice-mung bean cropping system and the lowest at site 2 under rice-fallow system. Soil phosphatase activity ranged from 280.58 to 480.28 µg phenol g$^{-1}$soil h$^{-1}$ with the CV ranged from 9.24 to 11.93%; the highest value was obtained at site 5 under rice-mung bean cropping system and the lowest at site 6 under another rice-mung bean system. Soil urease activity ranged from 38.36 to 67.75 µg $NH4^{+}$-N $g^{-1}$soil $2h^{-1}$ with the CV ranged from 9.73 to 11.08%; the highest value was obtained at site 1 under rice-fallow system and the lowest at site 6 under rice-mung bean cropping system.

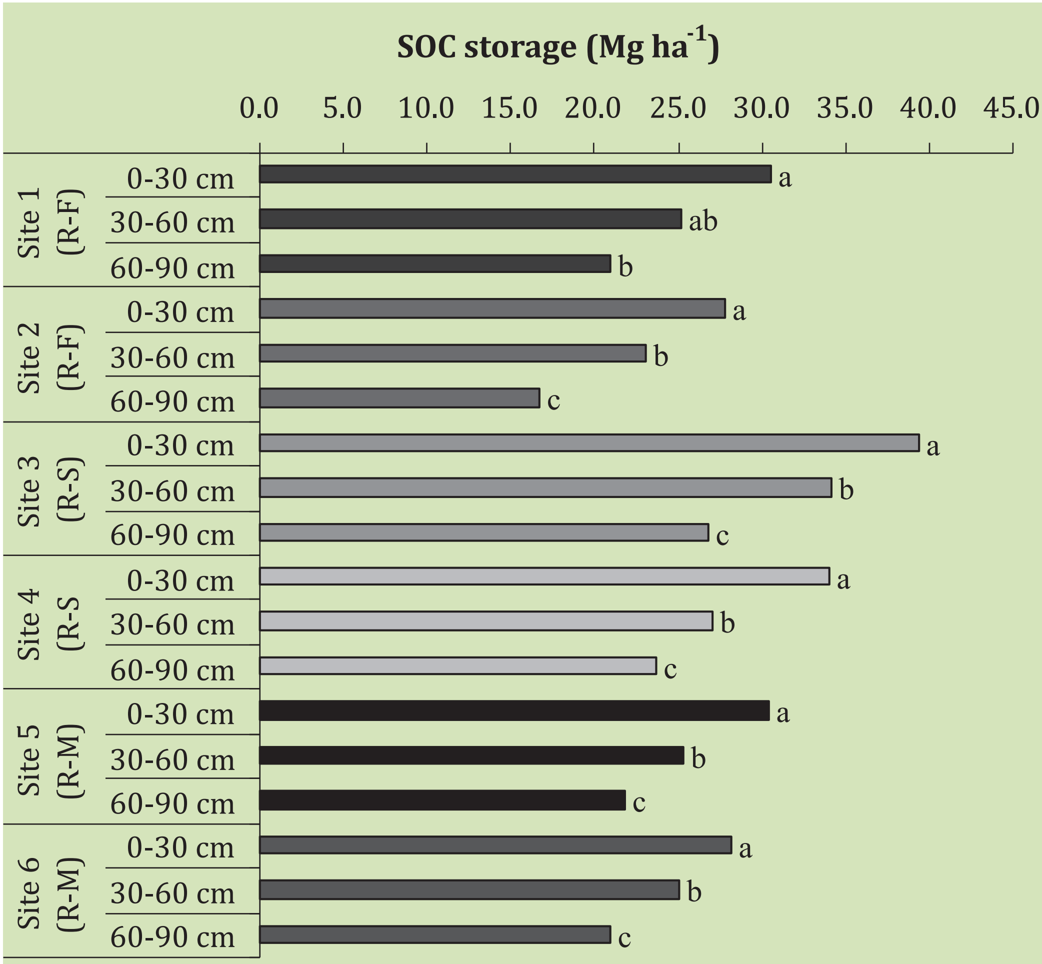



Fig. 9. Soil organic carbon (SOC) storage in different depths under different sites; R-F indicates rice-fallow, R-S rice-sugarcane rotation and R-M is rice-mung bean cropping; vertical bars with same letter are not significant at $p<0.05$ in a site as per DMRT.

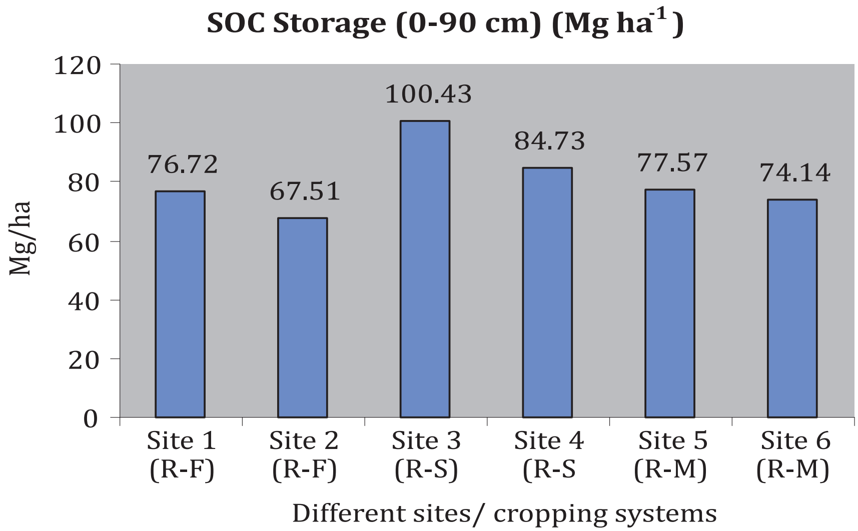



Fig. 10. Total soil organic carbon storage (Mg $ha^{-1}$) in soil profile under different sites; R-F is the rice-fallow cropping, R-S is rice-sugarcane crop rotation and R-M is the rice-mung bean cropping system

Table 12. Soil dehydrogenase activity in the surface soils in different sites/ cropping systems

| Site/ Cropping system | Dehydrogenase activity (µg TPF.$g^{-1}$ soil. $24h^{-1}$) | | |
|---|---|---|---|
| | Mean | s.d. | c.v. (%) |
| Site -1 (Rice -fallow cropping) | 343.73 | 31.68 | 9.22 |
| Site -2 (Rice -fallow cropping) | 283.52 | 23.91 | 8.43 |
| Site -3 (Rice -sugarcane rotation) | 302.68 | 27.09 | 8.95 |
| Site -4 (Rice -sugarcane rotation) | 311.24 | 24.23 | 8.42 |
| Site -5 (Rice -mung bean cropping) | 313.31 | 27.36 | 8.73 |
| Site -6 (Rice -mung bean cropping ) | 300.18 | 25.08 | 8.36 |

Table 13. Soil phosphatase activity in the surface soils in different sites/ cropping systems

| Site/ Cropping system | Phosphatase activity (µg phenol $g^{-1}$soil $h^{-1}$) | | |
|---|---|---|---|
| | Mean | s.d. | c.v. (%) |
| Site -1 (Rice -fallow cropping) | 413.08 | 44.50 | 10.77 |
| Site -2 (Rice -fallow cropping) | 315.64 | 32.89 | 10.42 |
| Site -3 (Rice -sugarcane rotation) | 441.94 | 40.84 | 9.24 |
| Site -4 (Rice -sugarcane rotation) | 452.35 | 42.51 | 10.16 |
| Site -5 (Rice -mung bean cropping) | 480.28 | 57.28 | 11.93 |
| Site -6 (Rice -mung bean cropping) | 280.58 | 30.50 | 10.87 |

Table 14. Soil urease activity in the surface soils in different sites/ cropping systems

| Site/ Cropping system | Urease activity ($\mu g\ NH_4^+$-N $g^{-1}$soil $2h^{-1}$) | | |
|---|---|---|---|
| | Mean | s.d. | c.v. (%) |
| Site -1 (Rice -fallow cropping) | 67.75 | 7.02 | 10.36 |
| Site -2 (Rice -fallow croppi ng) | 42.66 | 4.15 | 9.73 |
| Site -3 (Rice -sugarcane rotation) | 56.95 | 5.85 | 10.27 |
| Site -4 (Rice -sugarcane rotation) | 54.47 | 5.13 | 10.23 |
| Site -5 (Rice -mung bean cropping) | 64.21 | 6.88 | 10.71 |
| Site -6 (Rice -mung bean cropping) | 38.36 | 4.25 | 11.08 |

### 3.8 Development of pedotransfer functions (PTFs)

Pedotransfer functions (PTFs) were developed for saturated hydraulic conductivity (Ks) and water retention at FC (-33 kPa) and PWP (-1500 kPa) using the data set of textural values viz. clay (%), sand fractions (%) and clay+silt (%). Prediction results revealed that the clay (%) was much better predictor variable than sand (%) or clay+silt (%) for prediction of Ks, FC and PWP. The PTFs for Ks were best represented by the power functions with considerably higher and significant values of $R^2$ at $P<0.05$ for every site and cropping system (Fig. 11). The RMSE for six PTFs were also low indicating a stronger relationship. A significantly ($P < 0.01$) strong and negative correlation was obtained between Ks and clay (%) as indicated by the correlation coefficient (r) of -0.93** for site 1, -0.78** for site 2, -0.91** for site 3, -0.83** for site 4, -0.95** for site 5 and -0.94** for site 6. The PTFs for water retention at FC and PWP (Fig. 12 and 13) were found to be exponential functions using clay content (%) with significant $R^2$ ($P < 0.05$) for every study site. A strong positive and significant ($P < 0.01$) was found between clay content and FC or PWP for every site as evident from r values ranging from 0.68* ($P < 0.05$) to 0.89** ($P < 0.01$) and from 0.71* ($P < 0.05$) to 0.90** ($P < 0.01$) for FC and PWP, respectively depending upon sites and cropping systems.

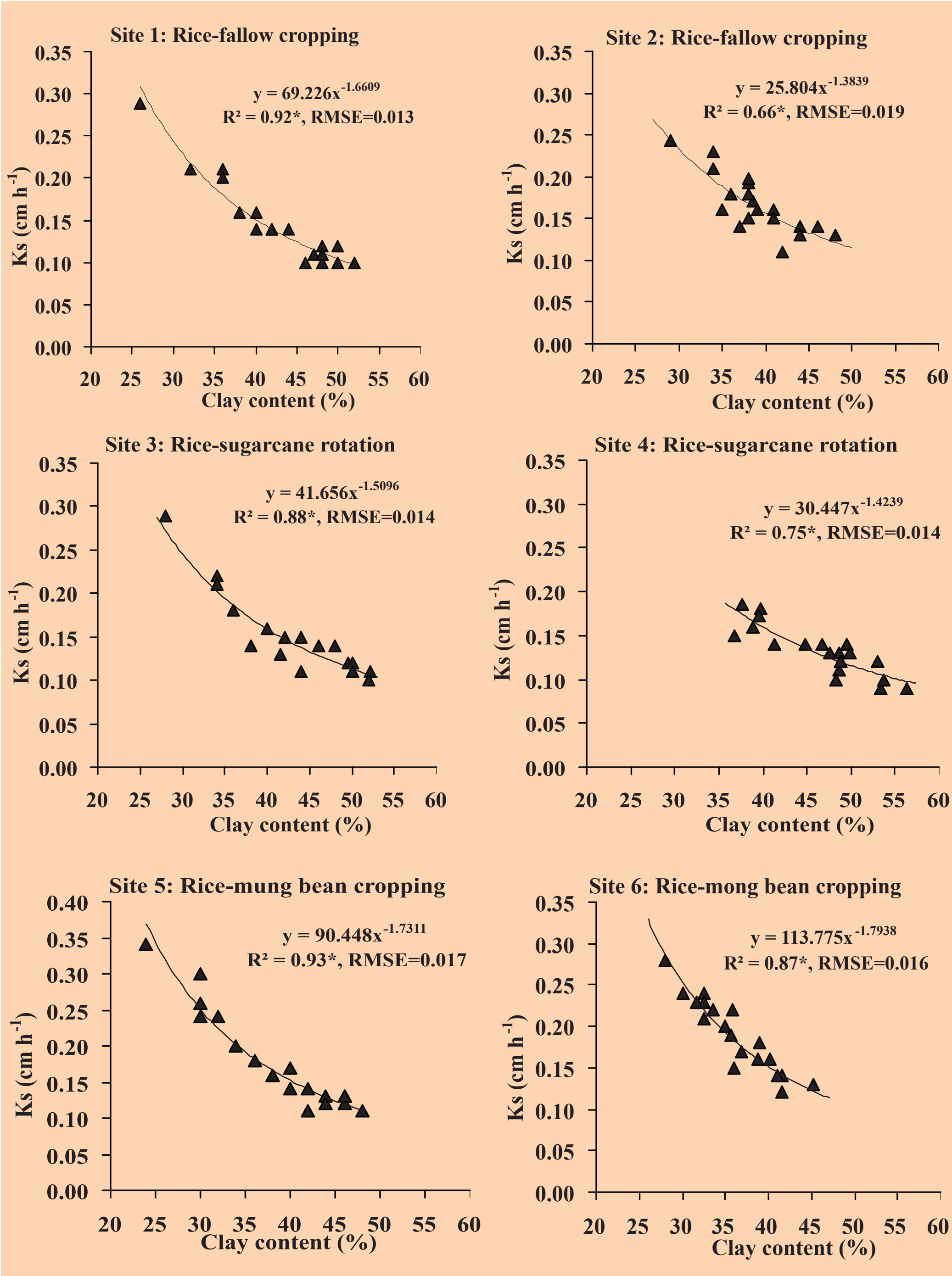



Fig. 11. Pedotransfer functions (PTFs) for determination of saturated hydraulic conductivity (Ks) using clay content of soils from different sites under major cropping systems in the command area; $R^2$, coefficient of determination; RMSE, root mean square error.

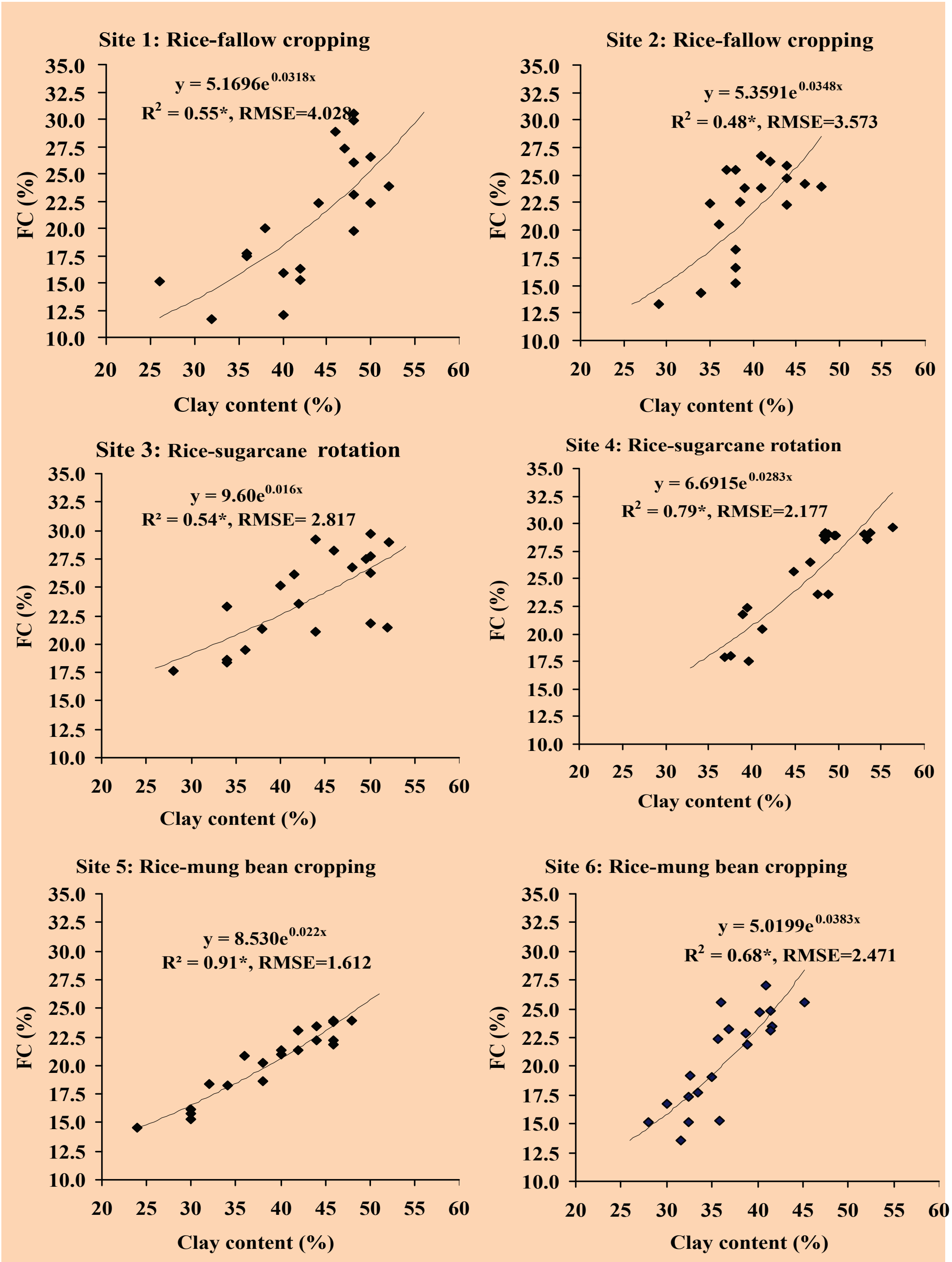



Fig. 12. Pedotransfer functions (PTFs) for water retention at field capacity (FC, -33 kPa) using clay content of soils from different sites under major cropping systems in the command area; $R^2$, coefficient of determination; RMSE, root mean square error.

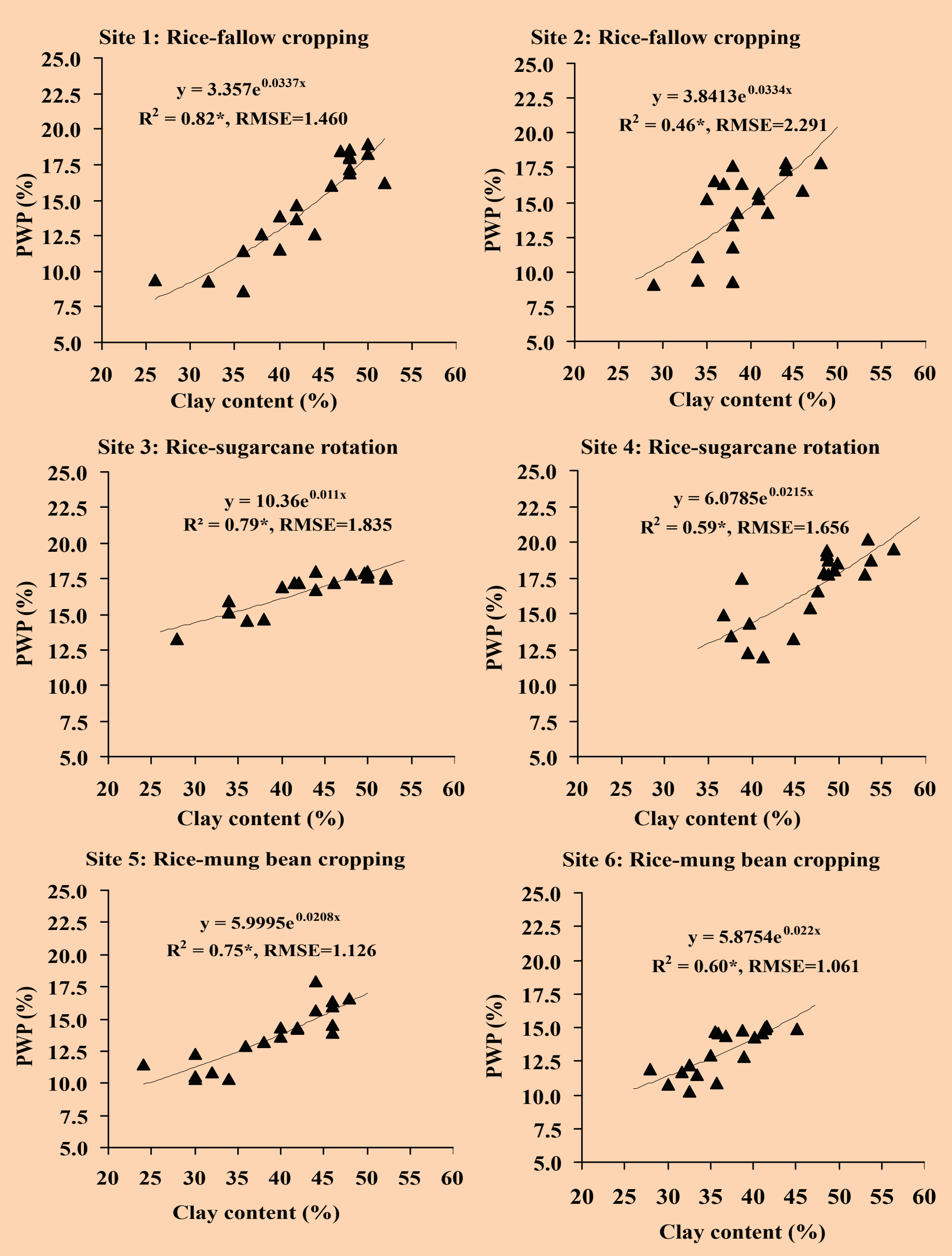



Fig. 13. Pedotransfer functions (PTFs) for water retention at permanent wilting point (PWP, -1500 kPa) using clay content of soils from different sites under major cropping systems in the command area; $R^2$, coefficient of determination; RMSE, root mean square error.

# 4 Discussion: water and crop management strategies

## 4.1 Rainfall analyses

Effective rainfall is that fraction of total rainfall received on the ground which enters into the root zone and remains there for utilization by crops (i.e., the soil moisture in the root zone). Around 86% (i.e. 559 mm) of the total rainfall is lost during monsoon months due to surface runoff, deep percolation and evaporation. In case of rainfall of high intensity, only a part of the rain enters and is stored in the root zone and the quantity of effective rainfall is low. The amount of runoff during monsoon period was quite high because of two reasons. Firstly, runoff occurs when the rainfall intensity exceeds the infiltration capacity of soil or the soil profile is completely saturated. Secondly, surface runoff occurs due to very high intensity of rainfall during monsoon seasons. Because of the impact of high intensity rainfall on the surface layer of the soil, the pore spaces in the soil are blocked after few hours of rainfall; as a result of which surface runoff occurs even if the soil profile is not fully saturated. Except monsoon season, the runoff amount is quite low for winter, pre- and post-monsoon seasons because of the situation that infiltration capacity of the soils exceeded the rainfall intensity most of the times. Consequently, the soil profile is not completely saturated.

In this region, most of the farmers keep their lands fallow after harvesting of rainy season rice because only 162.6 mm of rainfall takes place during post-monsoon season which is not sufficient to grow another crop in post-monsoon season. Rainfall is quite less during winter and pre-monsoon season that is for about 5 months. Therefore, it is essential that every farm entity to have a rain/ runoff water storage reservoir so that farmer can store water in the pond. This may be used as a source for multiple-purposes. Zimmerman (1966) has also opined for the service reservoir for effective and efficient use of water.

The option to go for harvesting rainfall is useful. Harvesting a small fraction of the excess rainfall and utilizing the same for supplemental irrigation to mitigate the impacts of dry spells offer a good opportunity (Rockstrom, 2001 & 2003). Based on experiences from watershed management research and large-scale development efforts, practical harvesting of runoff is possible only when the harvestable amount is more than 50 mm or greater than 10% of the seasonal rainfall (CRIDA, 2001). In this study area, as runoff amount was more than 10% of the seasonal rainfall, practical harvesting of runoff is possible. Therefore, it is essential to construct water harvesting structures (WHS) for conservation of rainfall and runoff water to ensure water availability and dependability to all farmers.

The harvested water in the WHSs during monsoon season should effectively be used as multi-source water for irrigation, domestic use, fish culture and duckery, growing of crops like papaya, banana, coconut etc. along the banks. This could be a unit with a pond-based integrated faming system. This stored water can be used as supplemental or life saving irrigation to post-monsoon crops. The objective of supplemental irrigation is to adequately recharge the upper dry soil and connect it with the moist profile prevailing in the deeper soil layers, to provide continuity to the flow process. Of course, crop selection can be made based on the availability of stored water in the reservoir.

A rainfall of 105.9 mm was observed in the month of June at 90% probability level. Therefore, rainy season crops can be sown and rice nurseries can be prepared in the month of June with the commencement of southwest monsoon. In the month of July at 90% probability level the observed rainfall was 181.9 mm. Rice transplanting can be performed by utilizing this high amount of rainfall during this month. The transplanting of rice in the first week of July will have additional advantages of assured irrigation through rain during the growing periods of rice in the months of August and September. To increase the rain water use efficiency and productivity, paddy can be substituted with other low water requiring high value crops through sole or intercropping. For example, in vertisols soybean/maize and soybean/pigeon pea is proved to beneficial (Mandal et al., 2013). In these intercropping practices under upland situations, water does not stagnate in the field. Thus, weed management should be appropriate for a clean crop stand. Since the rainfall after October is uncertain and erratic, sowing of high value crops without supplementary irrigation is not advisable.

Since the probability of occurrence of wet week is more than 30% during 19th–21st SMW (7-27th May) and average weekly rainfall ranges from 24.1 to 40.7 mm, the pre-monsoon rain can be utilized for summer ploughing and seed bed preparations. The mean onset of rainy season is 23rd SMW. Thus, sowing operations can be done during 22nd SMW (28th May–3rd June) because of the probability of wet week is more than 31% and average weekly rainfall is more than 15 mm. Sowing operations performed on 22nd SMW favours good germination of seeds and also helps in avoiding moisture stress for germination period during 24–26th SMW. In the event of delayed onset of rainy season, the sowing operations can be taken up latest by 27th SMW (2–8th July) and further delay in sowing may cause very low productivity and even crop failure. Since, mean length of rainy season is observed to be 21 weeks (147 days), therefore rice variety of about 130-140 days duration can easily be grown with little fear of drought; and the rice can be harvested before the withdrawal of the monsoon and so the chance of reduction of rice yield due to water stress is reduced. Moreover, the residual soil moisture after the harvest of rice can be effectively utilized for raising another short duration crop in post-monsoon season. The potential benefits of irrigation and nutrient interaction can be explored for saving of limited irrigation water as was successful in central Indian condition (Mandal et al., 2005; Mandal et al., 2006). On the other hand, long duration rice has every chance to undergo a period of drought or water stress situation and hence yields reduction because the critical growth stage of rice that includes the reproductive phase may fall during the receding phase of monsoon. In case of delayed onset and earlier withdrawal of monsoon season, short duration rice variety of 100 days can be grown.

Instead of growing rice, short duration and low water-requiring crops like groundnut, maize, sorghum, green gram, soybean, sunflower, field bean, cowpea which have high return value can be grown during monsoon season. Pigeon pea is a very good crop for growing in this area under upland situation and on the bunds separated by rice fields. Another advantage of growing short duration cereals, pulses and oilseeds in the first fort-night of June is that these can be harvested by the end of September (39th SMW) and short duration post-monsoon crops can be sown during 40–43rd SMW (1–28th October). Since, post-monsoon rainfall is more uncertain and erratic than southwest monsoon, growing of high value post-monsoon crops without supplementary irrigation would be very risky. The significant contribution of weekly rainfall (>46 mm) during 36–40th SMW and high consecutive wet week probability during 36–40th SMW, there is a potential for harvesting excess runoff water for supplemental irrigations. Similarly, greater probabilities of consecutive dry weeks after 44th SMW, hints for need of supplementary irrigations and moisture conservation practices to be taken up. Even in the event of mid season dry weeks, mulching and other moisture conservation practices would help in reducing soil evaporation and conserve moisture in the soil.

## 4.2 Soil analyses

An important finding was that the average clay contents especially in the lower soil layers under rice-sugarcane systems in sites 3 and 4 were comparatively greater than the other sites. Sand content decreased towards lower soil layers in every cropping system; whereas clay contents increased gradually towards lower soil depths. Because of high clay content beyond 40%, the soils of lower layers are mostly clayey. Due to heavy rainfall during rainy season and tillage operations for rice cultivation, the clay fractions were greater in the lower layers. This might be due to the clay migration from upper soil layers to the lower layers. The difference in settling of soil particles in the soil layers due to repeated plouging might have attributed to the difference in sand and clay contents in different sites. Agoumé and Birang (2009) also reported similar results for the fields of Ngoungoumou village near Ebolowa in Cameroon. Clay accumulation in the sub-soil could result in reduced porosity, increased water retention and reduced drainage (Agoumé and Birang, 2009). Site specificity and existing cropping systems affected the sand, silt and clay fraction of soils of our study area. Silt contents in these soils were low; however there was no definitive trend of increase or decrease in silt content due to depth variable. Voundi Nkana and Tonye (2003) also did not find that cropping systems affected the silt fraction distribution with a very less silt content.

A comparatively lower bulk density (BD) values as obtained in the sites 3, 4 and 5 under rice-sugarcane and rice-mung bean cropping systems relative to other sites and systems, this difference was not easily explainable but might be ascribed to the compaction of the topsoil due to repeated ploughing for cropping practices (Agoumé and Birang, 2009). In general, higher BD might be ascribed to the higher clay content and compaction due to repeated ploughing and cropping practices for a long time. The significantly decreased in saturated hydraulic conductivity (Ks) values towards greater depths of soil profile for each site under different cropping systems indicated greater clay contents in lower depths of soils. Among all sites, Ks values were lower in sites 3 and 4, where rice-sugarcane crop rotation was practiced. The difference and the trends are in conformity with the sand and clay contents. The results agree with the finding of McBratney et al. (2002); Santra and Das (2008); Rawls et al., (1991) and Wösten et al., (2001). Water retention at field capacity (FC) and permanent wilting point (PWP) increased significantly with the increase in soil depth for every site. The reasons and underlying factors for difference in PWP values were mostly governed by the difference in clay contents. Available water capacity (AWC) was greater at site 3 & 4 in the rice-sugarcane system. Basically, it was the clay fractions in the soils of different sites which determined higher FC, and in turn higher AWC of soils. The available water capacity was also related to the soil organic matter content of soils as was evident from higher SOC values. Our results match with the finding of Gol (2009).

The greater organic carbon content (SOC) in rice-sugarcane was might be due to the continuous cropping with higher rates of fertilizer, year round cropping practice for sugarcane that might have sequestered greater SOC in sites 3 and 4. Moreover, sugarcane crop residues viz. trashes and greater root biomass from a long duration crop might have favoured higher organic carbon content in these soils. The extensive root systems i.e., formation of new roots and decay of old roots added considerable amount of organic matter to the soils. These soils might have attained an equilibrium condition with respect to different process in the carbon cycle (Alberto Carlos et al., 2007). The comparatively greater SOC in the soils of rice-mung bean system might be ascribed to greater soil organic matter in the soil and lesser loss of carbon through CO2 into the atmosphere. Similar results were also reported by previous researchers, that the SOC content in cropland was strongly correlated with crop and soil management practices (Hao et al., 2002; Mandal et al., 2012). In fact, long duration cropping like sugarcane exposed previously inaccessible organic matter to microbial attack and accelerated the decomposition and mineralization of organic matter (Sparling et al., 1992; Haynes, 1999). The SOC storage significantly decreased towards greater depth of soils. This was plausibly due to the greater organic carbon content in site 3 and 4 under rice-sugarcane crop rotation systems. The variation in total SOC stock in different site was primarily due to differences in soil organic carbon content and bulk density of soil. Similar results were found by previous researchers (Shibu et al., 2010).

Clay content was positively and significantly correlated with BD, FC and PWP, and negatively correlated Ks. Silt was not very well correlated with other parameters. This trend was mostly similar in every study site. It revealed that organic carbon content, bulk density and clay contents were appeared to be the important soil properties to improve estimation of soil water retention from soil texture. The higher SOC in the soils of site 3 and 4 led to greater water retention and lesser Ks. This might be related to the fact that the structure-forming effect of organic matter positively affected the water retention at FC and PWP. The water retention of organic matter itself is a probable reason of the effect of organic carbon on water retention at -1500 kPa although the organic matter is known to modify the availability of adsorption sites of clay minerals to water (Cristensen, 1996). Clay is inversely related to Ks. It was observed that clay content (%) rather than clay+silt content (%) was better predictor for the response variable Ks with power functions. Of course, the nature of power functions for different sites were different. Therefore, for precise prediction of saturated hydraulic conductivity, clay content values may be used and the PTFs as developed for different sites may be utilized for different models. Hence, FC and PWP could be predicted well with clay content (%) as predictor variable for different study sites/ cropping systems under Kuanria canal command area.

# 5. Conclusions

Total annual rainfall of the command ranged from 993.5 to 1901.8 mm (average of 1995 to 2010 rainfall data) with an average annual average of 1509.2 mm (CV 14.8%). Total annual effective rainfall was estimated as 858.2 mm which is 56.9 percent of the total annual rainfall. The normal southwest monsoon, which delivers about 75.7% of annual rainfall, extends from June to September. This is also the main season (rainy season) for cultivation of rainfed crops; the other seasons viz. pre-monsoon (March-May), post-monsoon (October-December) and winter season (January-February) contributes only 10.8, 10.4 and 3.1% of the total annual rainfall.

Analysis of rainfall data at Daspalla region revealed that 651 mm of rainfall water was lost due to runoff, deep percolation and evaporation. This estimated water loss indicates a large potential to improve crop water use efficiency by mitigating dry spells. This can be achieved through water harvesting structures, where local runoff flow is harvested and stored in reservoirs and used for supplementary irrigation during dry spells. The harvested water can also be used for growing of on-dyke crops, fish culture and duckery during monsoon season. By this strategy the productivity of both crop and water in the rainfed but high rainfall region like Daspalla would be enhanced. It requires concerted water governance and management priorities. This will include efforts involving institutional capacities, policy frameworks, knowledge generation, and investment. By knowing the most probable date of onset and withdrawal of effective monsoon, agricultural operations can be planned in advance and also corrective and contingency measures can be taken up during dry periods to avoid crop loss or reduction in crop yield due to soil moisture stress. Through analyses of rainfall using Markov chain model, we have knowledge of probability of dry and wet week spells in a year. This will form the strategies for mitigation of dry spells. Mulching and other moisture conservation practices will also help in reducing soil evaporation and conserve moisture in top layers of the soil even during the mid season dry weeks.

The present study characterized the soil properties like particle size fractions, bulk density, saturated hydraulic conductivity, soil organic carbon and also pH for the cultivable area under Kuanria command area in Odisha, an eastern Indian state. This information will be useful for soil and water management decisions to be undertaken for the area. The measured soil properties and information would be utilized as input variables for many models for studying the changes in climate, soil hydraulic properties, soil environmental issues, water balance and solute transport etc. The organic carbon storage information would help for future planning on the cropping systems concerning carbon sequestration and policy making process for soil organic carbon restoration and other soil properties especially for the Kuanria command. Soil water retention is a major soil hydraulic property that governs soil functioning in ecosystems and greatly affects soil management.

The information on Ks would be useful for making any decision for construction of water storage structure or open wells where water storage would be possible and better management of water would lead to better cropping practices. The development of different models has increased rapidly in recent years to improve the understanding of important soil processes, water balance studies, evaluating agricultural and environmental problems. These models usually require a large number of parameters to describe the transport phenomenon, and other physical and chemical properties. Pedotransfer functions developed in our study would be useful for getting the values of saturated hydraulic conductivity and water retention with one measured parameter i.e., clay content. As the direct determination of these important soil parameters like saturated hydraulic conductivity and water retention are time consuming and expensive, these PTFs developed for different sites under major cropping systems would be very useful. Even, these PTFs may be utilized for soils of elsewhere having similar situations, rainfall pattern, basic soil characteristics and cropping practices.

## Acknowledgements

Authors acknowledge the help and cooperation of Er. S.C. Sahoo, Kuanria Irrigation Sub-Division Officer, water users associations, and farmers under KIP project, Daspalla, Odisha. Authors are thankful to the INCID, Ministry of Water Resources, Govt. of India for providing financial support in carrying out this research work.

# References


Abbasi, Y., Ghanbarian-Alavijeh, B., Liaghat, A. and Shorafa, M. 2011. Evaluation of pedotransfer functions for estimating soil water retention of saline and saline-alkali soils of Iran. Pedosphere, 21(2): 230-237.

Abrol, I.P., Khosla, B.K. and Bhumbla, D.R. 1968. Relationship of texture to some important soil moisture constant. Geoderma. 2: 33–39.

Adhikary, P.P., Chakraborty, D., Kalra, N., Sachdev, C.B., Patra, A.K., Kumar, S., Tomar, R.K., Chandna, P., Raghav, D., Agrawal, K. and Sehgal, M. 2008. Pedotransfer functions for predicting the hydraulic properties of Indian soils. Aust. J. Soil Res., 46: 476–484.

Agoumé, V. and Birang, A.M. 2009. Impact of land-use systems on some physical and chemical soil properties of an oxisol in the humid forest zone of southern Cameroon. Tropicultura., 27 (1): 15-20.

AICRP, 2009. Annual Report of All India Coordinated Research Project on Water Management, 2008-09. Directorate of Water Management, Indian Council of Agricultural Research (ICAR), Bhubaneswar, India

Alberto Carlos, de C.B., Pedro Luiz, Oliveira de A.M.B., Sílvio Roberto, de L.T., David Vilas Boas, de C. L. de A.C. 2007. Carbon and nitrogen stocks of an Arenosol under irrigated fruit orchards in semiarid Brazil. Scientia Agricola., 64 (2): 169-175.

Babu, P.N., and Lakshminarayana, P. 1997. Rainfall analysis of a dry land watershed-Polkepad: A case study. J. Indian Water Res. Soc., 17:34-38

Bauer, A. and Black, A.L. 1994. Quantification of the effect of soil organic matter content on soil productivity. Soil Sci. Soc. Am. J. 58: 185–193.

Bhattacharyya, T., Pal, D.K., Mandal, C. and Velayutham, M. 2000. Organic carbon stock in Indian soils and their geographical distribution. Curr. Sci., 79 (5): 655–660.

Bhavanarayana, M., Rao, T.V. and Krishnamurthy, G.S.R. 1986. Statistical relationships of water retention and availability with soil matrix and charge properties. Int. Agrophys., 2: 135–144.

Bouma, J. 1989. Using soil survey data for qualitative land evaluation. In: Stewart B. A. (ed.) Advances in Soil Science, Springer Verlag, New York. 9: 177-213.

Bouma, J. and Finke, P. A., 1993. Origin and nature of soil resource variability. In: Robert P.C. et al. (eds.) Proceedings of Soil Specific Crop Management Workshop, Minneapolis, April 14-16, 1992. ASA, Madison, Wl. pp. 3-13.

Bouyoucous, G.J.A. 1951. Recalibration of the hydrometer for making mechanical analysis of soil. Agron. J., 43: 434-438

Briggs, L.J. and McLane, J.W. 1907. The moisture equivalent of soils. USDA Bureau of Soils Bulletin, 45: 1-23.

Briggs, L.J. and Shantz, H.L. 1912. The wilting coefficient and its indirect measurement. Botanical Gazette., 53: 20-37.

Burns, R.G. 1983. Extracellular enzyme-substrate interactions in soil. In: Slater, J.H., Wittenbury, R. and Wimpenny, J.W.T. (Eds) Microbes in Their Natural Environment, Cambridge University Press, London. 249-298.

Chakraborty, D., Mazumdar, S.P., Garg, R.N., Banerjee, S., Santra, P., Singh, R. and Tomar, R.K. 2011. Pedotransfer functions for predicting points on the moisture retention curve of Indian soils. Indian J. Agric. Sci., 81 (11): 1030-1036.

Chow, V.T. 1964. Hand Book of Applied Hydrology. McGraw Hills Book Company, New York.

Clapp, R.B. and Hornberger, G.M. 1978. Empirical equations for some soil hydraulic properties. Water Resources. Res., 14: 601–604.

CRIDA, 2001. Annual Progress Report. Central Research Institute for Dryland Agriculture (ICAR), Hyderabad, India

Cristensen, B.T., 1996. Carbon in primary and secondary organomineral complexes. In: Carter, M.R., Stewart, B.A. (Eds.), Structure and Organic Matter Storage in Agricultural Soils. Lewis Publishers, Boca Raton, pp. 97–165.

Das, H.P., Abhyankar, R.S., Bhagwal, R.S., Nair, A.S. 1998. Fifty years of arid zone research in India. CAZRI, Jodhpur, 417-422

Dash, M.K. and Senapati, P.C. 1992. Forecasting of dry and wet spell at Bhubaneswar for agricultural planning. Indian J. Soil Cons., 20(1&2): 75-82.

Dick, R.P., Sandor, J.A., and Eash, N.S. 1994. Soil enzyme activities after 1500 years of terrace agriculture in the Colca Valley, Peru. Agric. Ecosyst. Environ., 50: 123-131.

Dixit, A.J., Yadav, S.T., Kokate, K.D. 2005. The variability of rainfall in Konkan region. J Agrometeorology, 7: 322-324

Ghanbarian-Alavijeh, B., Liaghat, A., Huang, G.H. and van Genuchten, M.Th. 2010. Estimation of the van Genuchten soil water retention properties from soil textural data. Pedosphere., 20(4): 456–465.

Gol, C. 2009. The effects of land use change on soil properties and organic carbon at Dagdami river catchment in Turkey. J. Environ. Biol., 30(5): 825-830.

Gomez, K.A. and Gomez, A.A. 1984. Statistical Procedures for Agricultural Research- An IRRI book. John Wiley & Sons, New York. pp. 8-20 & 188-194.

Hall, D.G., Reeve, M.J., Thomasson, A.J. and Wright, V.F. 1977. Water retention, porosity and density of field soils. Soil Survey of England and Wales, Harpenden. Technical Monograph No. 9. 75pp.

Hao, Y., Lal, R., Owens, L.B., Izaurralde, R.C. and Post, W.M. 2002. Effect of cropland management and slope position on soil organic carbon pool at the north appalachian experimental watersheds. Soil Till. Res., 68: 133-142

Haynes, R.J. 1999. Size and activity of the soil microbial biomass under grass and arable management. Biol. Fertil. Soils., 30: 210–216.

Kar, G., Singh, R. 2002. Prediction of monsoon and post-monsoon rainfall and soil characterization for sustainable crop planning in upland rainfed rice ecosystem. Indian J. Soil Cons. 30(1): 8-15.

Kaur, R., Kumar, S., Gurung, H.P., Rawat, J.S., Singh, A.K., Prasad, S. and Rawat, G. 2001. Evaluation of pedotransfer functions for predicting field capacity and wilting point soil moisture contents from routinely surveyed soil texture and organic carbon data. J. Indian Soc. Soil Sci., 50 (2): 205–208.

Kothari, A.K., Jat, M.L., and Balyan, J.K. 2007. Water balanced based crop planning for Bhilwara district of Rajasthan. Indian J. Soil Cons., 35(3): 178-183.

Lal, R., Kimble, J. and Follett, R. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Till. Res., 43: 131–167.

Larson, W.E. and Pierce, F.J. 1991. Conservation and enhancement of soil quality. In: Evaluation for Sustainable Land Management in the Developing World. International Board for Soil Research and Management (IBSRAM), Bangkok, Thailand. Technical Paper No. 12(2), pp. 175-204.

Liao, K.H., Xu, S.H., Wu, J. C., Ji, S. H. and Lin, Q. 2011. Assessing soil water retention characteristics and their spatial variability using pedotransfer functions. Pedosphere, 21(4): 413-422.

Mandal, K. G., Hati, K.M., Misra, A.K., Bandyopadhyay, K.K. and Mohanty, M. 2005. Irrigation and nutrient effects on growth and water-yield relationship of wheat (*Triticum aestivum* L.) in central India. J. Agron. & Crop Sci., 191 (6): 416-425.

Mandal, K.G., Baral, U., Padhi, J., Majhi, P., Chakraborty, H. and Kumar, A. 2012. Effects of cropping on soil properties and organic carbon stock in Deras region, India. Reg. Environ. Change, 12 (4): 899-912.

Mandal, K.G., Hati, K.M., Misra, A.K., Bandyopadhyay, K.K. and Mohanty, M. 2006. Assessment of irrigation and nutrient effects on growth, yield and water use efficiency of Indian mustard (*Brassica juncea*) in central India. Agric. Water Manage., 85: 279-286.

Mandal, K.G., Hati, K.M., Misra, A.K., Bandyopadhyay, K.K. and Tripathi, A.K. 2013. Land surface modification and crop diversification for enhancing productivity of a Vertisol. Int. J. Plant Prod., 7 (3): 455-472.

Manrique, L.A., Jones, C.A. and Dyke, P.T. 1991. Predicting soil water retention characteristics from soil physical and chemical properties. Comm. Soil Sci. Plant Anal., 22: 1847-860.

Mayr, T. and Jarvis, N.J. 1999. Pedotransfer functions to estimate soil water retention parameters for a modified Brooks–Corey type model. Geoderma., 91: 1–9

McBratney, A.B., Minasny, B., Cattle, S.R. and Vervoort, R.W. 2002. Pedotransfer functions to soil inference systems. Geoderma., 109: 41-73.

Milne, E., and Heimsath, A. 2009. Soil organic carbon. In: Encyclopedia of Earth. (Eds.) Cutler J Cleveland, Environmental Information Coalition, National Council for Science and the Environment, Washington, D.C.

Mohanty, S., Marathe, R.A., Singh, S. 2000. Probability models for prediction of annual maximum daily rainfall for Nagpur. J. Soil Water Cons., 44 (1&2): 38-40

Molle, F., Wester, P., Hirsch, P., Jensen, J.R., Murray-Rust, H., Paranjpye, S., Zaag, P. van der. 2007. River basin development and management. In: Molden, D. (Ed.), Water for Food Water for Life: A Comprehensive Assessment of Water Management in Agriculture. Earthscan, London, pp. 585–625.

Nielsen, D.R. and Shaw, R.H. 1958. Estimation of the 15-atmosphere moisture percentage from hydrometer data. Soil Sci., 86: 103–105.

Pandarinath, N, 1991. Markov chain model probability of dry and wet weeks during monsoon periods over Andhra Pradesh. Mausam, 42(4): 393-400.

Panigrahi, B,, Panda, S.N. 2002. Dry spell probability by Markov chain model and its application to crop planning in Kharagpur. Indian J. Soil Cons. 30(1): 95-100.

Panigrahi, D., Mohanty, P.K., Acharya, M., Senapati, P.C. 2010. Optimal utilization of natural resources for agricultural sustainability in rainfed hill plateaus of Odisha. Agric. Water Manage., 97: 1006-1016.

Patil, N.G., Pal, D.K., Mandal, C. and Mandal, D.K. 2012. Soil water retention characteristics of Vertisols and pedotransfer functions based on nearest neighbor and neural networks approaches to estimate AWC. J. Irrig. Drainage Engg., 137 (2): 177-184.

Prakash, C., Rao, D.H. 1986. Frequency analysis of rainfall data for crop planning-Kota. Indian J. Soil Cons. 14(2): 23-26.

Rana, R.S., Thakur, D.R. 1998. Rainfall analysis for crop planning in Kulu valley, Himachal Pradesh. Indian J. Soil Cons. 26(2): 144-146.

Rawls, W.J., Brakensiek, D.L. and Saxton, K.E. 1982. Estimation of soil water properties. Trans. ASAE., 25: 1316– 1320, 1328.

Rawls, W.J., Gish, T.J. and Brakensiek, D.L. 1991. Estimating soil water retention from soil physical properties and characteristics. Adv. Soil Sci., 16: 213–234.

Rockstrom, J. 2001. Green water security for the food makers of tomorrow: windows of opportunity in drought-prone savannahs. Water Sci. Tech., 43 (4):71–78

Rockstrom, J. 2003. Water for food and nature in the tropics: vapour shift in rainfed agriculture. Invited Paper to the Special Issue 2003 of Royal Society Transactions Biology, Theme: Water Cycle as Life Support Provider

Romano, N. and Palladino, M. 2002. Prediction of soil water retention using soil physical data and terrain attributes. J. Hydrol., 205: 56–75.

Saikia, U.S. and Singh, A.K. 2003. Development and validation of pedotransfer functions for water retention, saturated hydraulic conductivity and aggregate stability of soils of Banha watershed. J. Indian Soc. Soil Sci., 51: 484–488.

Salter, P.J. and Williams, J.B. 1965. The influence of texture on the moisture characteristics of soils: I. A critical comparison for determining the available water capacity and moisture characteristics curve of a soil. J. Soil Sci., 16: 1–15.

Salter, P.J. and Williams, J.B. 1967. The influence of texture on the moisture characteristics of soils: IV. A method of estimating available water capacities of profiles in the field. J. Soil Sci., 18: 174-181.

Salter, P.J., Berry, G. and Williams, J.B. 1966. The influence of texture on the moisture characteristics of soils: III. Quantitative relationships between particle size, composition and available water capacity. J. Soil Sci., 17: 93– 98.

Santra, P. and Das, B.S. 2008. Pedotransfer functions for soil hydraulic properties developed from a hilly watershed of Eastern India. Geoderma, 146: 439–448.

Scheinost, A.C., Sinowski, W. and Auerswald, K. 1997. Regionalization of soil water retention curves in a highly variable soilscape: I. Developing a new pedotransfer function. Geoderma, 78: 129–143.

Sharma, B.R., Rao, K.V., Vittal, K.P.R., Ramakrishna, Y.S., Amarasinghe, U. 2010. Estimating the potential of rainfed agriculture in India: prospects of water productivity improvements. Agric. Water Manage., 97(1):23-30

Sharma, D., Kumar, V. 2003. Prediction of onset and withdrawal of effective monsoon dates and subsequent dry spells in an arid region of Rajasthan. Indian J. Soil Cons., 31(3): 223-228.

Sharma, H.C., Chauhan, H.S., Sewa, Ram 1979. Probability analysis of rainfall for crop planning. J Agric. Engg., 16(3): 87-94.

Shetty, A.V., Soni, B., Chandrakumar, S. 2000. Planning of crop and water management practices using weekly rainfall. Report National Institute of Hydrology, Roorkee, Uttaranchal, pp. 83

Shibu, M.E., Van Keulen, H., Leffelaar, P. A. and Aggarwal, P. K. 2010. Soil carbon balance of rice-based cropping systems of the Indo-Gangetic Plains. Geoderma, 160: 143-154.

Singh, A.K. 2000. Use of pedotransfer functions in crop growth simulations. J. Water Manage., 8: 18–21.

Singh, S.K., Singh A.K., Sharma, B.K., Tarafdar, J.C. 2007. Carbon stock and organic carbon dynamics in soils of Rajasthan, India; J. Arid Environ., 68: 408-421.

Sinsabaugh, R.L., Antibus, R.K., Linkins, A.E. 1991. An enzymic approach to the analysis of microbial activity during plant litter decomposition. Agric. Ecosyst. Environ., 34: 43-54.

Sparling, G.P., Shepherd, T.G. and Kettles, H.A. 1992. Changes in soil organic C, microbial C and aggregate stability under continuous maize and cereal cropping, and after restoration to pasture in soils from Manawatu region, New Zealand. Soil Till. Res., 24: 141–225.

Srinivasareddy, G.V., Bhaskar, S.R., Purohit, R.C., Chittora, A.K. 2008. Markov chain model probability of dry, wet weeks and statistical analysis of weekly rainfall for agricultural planning at Bangalore. Karnataka J. Agric. Sci., 21(1): 12-16.

Stern, R.D. 1982. Computing a probability distribution for the start of rains from a Markov chain model for precipitation. J. Applied Meteorology, 21(3): 420-423.

Stirk, G.B. 1957. Physical properties of soils of the lower Burdekin valley, North Queensland. Division of Soils, CSIRO, Australia. Divisional Report, pp. 1-57.

Tabatabai, M.A. 1982. Sulphur. In: Methods of Soil Analysis. Part II. Chemical and microbiological Properties (Eds. Page, A.L., Miller, R.H. and Keeney, D.R.). Soil Sci. Soc. Am., Madison., 501-538.

Tabatabai, M.A. 1994. Soil enzymes. In: Weaver, R.W., Angle, J.S., Bottomley, P.S. (Eds.) Methods of Soil Analysis, Part 2. Microbiological and biochemical properties. SSSA Book Series No. 5. Soil Sci. Soc. Am. Madison, Wis., 775-833.

Ungaro, F., Calzolari, C. and Busoni, E. 2005. Development of pedotransfer functions using a group method of data handling for the soil of the Pianura Padano–Veneta region of North Italy: water retention properties. Geoderma, 124: 293–317.

Veihmeyer, F.J., Hendrikson, A.H., 1927. The relation of soil moisture to cultivation and plant growth. In Proc. 1st International Congress on Soil Science. Washington. 3, pp. 498-513.

Victor, U.S., Sastry, P.S.N. 1979. Dry spell probability by Markov chain model and its application to crop development stage. Mausam, 30:479-484

Voundi Nkana, J.C. and Tonye, J. 2003. Assessment of certain soil properties related to different land-use systems in the Kaya watershed of the humid forest zone of Cameroon. Land Degradation Development, 14 (1): 57-67.

Walkley, A. and Black, I.A. 1934. An examination of the method for determining soil organic matter and proposal modification of the chromic acid titration method. Soil Sci. 37:29–38.

Wösten, J.H.M., Finke, P.A. and Jansen, M.J.W. 1995. Comparison of class and continuous pedotransfer functions to generate soil hydraulic characteristics. Geoderma, 66: 227- 237.

Wösten, J.H.M., Pachepsky, Y.A. and Rawls, W.J. 2001. Pedotransfer functions: bridging the gap between available basic soil data and missing soil hydraulic characteristics. J. Hydrol., 251: 123–150.

Zimmerman, J.D. 1966. Irrigation - John Wiley and Sons, New York.

■