Guidelines for Irrigation with Saline and Alkali Waters

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FOREWORD

Though India is well endowed with natural resources, the challenge to produce more food to feed the burgeoning population will remain as great and compelling as ever. In this context, the importance of irrigated agriculture can hardly be over emphasised as the country will continue to depend on irrigation as the most reliable means of increasing production on a sustainable basis. Unfortunately, with increasing competition from other sectors of the economy, good quality water supplies to agriculture are going to stabilize if not diminish in future. Agriculture will have to cope with this situation by increasing the utilization of marginal quality waters. However, sustained use of poor quality waters in the absence of proper soil-water-crop management practices adversely affects the soil health and surrounding environment. For devising means of using poor quality waters in technically sound, economically viable and environmentally non-degrading ways, scientific investigations have been actively pursued at various research centres located in different agro-ecological regions of the country. Such efforts of CSSRI, AICRP-Saline Water and the State Agricultural Universities have yielded experimentally verifiable information for assessing water quality hazards and concepts on their use to raise crops. This document, where the current status of water, soil and crop management techniques have been analyzed, fulfills the long felt need to promote technologies of tackling the problems related to use of poor quality waters. It is hoped that this publication will be found useful by all those concerned with the management of saline waters for crop production in a sustainable manner.

(G.B. Singh)

Contents

Executive Summary

Presently, agriculture is the major user (89%) of the country's water resources but the estimates show that the growing demands from municipalities, industry and energy generation will claim about 22 % (24.3 m ha-m/year) of the total water resources (105 m ha-m/year) by 2025 AD. Consequently the marginal waters will have to be increasingly utilised to raise agricultural crops. Recent surveys on ground water quality rate 32-84 per cent of the presently 'running' wells as of poor quality (PQW) because their long term utilization leads to salinity, sodicity and toxicity problems. The saline ground waters exist mainly in arid areas of Rajasthan and western parts of Haryana and Punjab while the ground waters are usually sodic in the semi-arid parts of north-west regions of India. Thus for ensuring long term sustainability in agricultural production, water resources in the region are required to be managed with minimal economic and environmental costs.

With scientific advances, the basic principles of soil-water-plant system are now well understood for the efficient managemnt of saline water but need appropriate tailoring for the monsoonal climate in the Indian sub-continent e.g. providing for leaching requirement does not pay off when growing season of post-monsoon winter crops starts with surface leached soil profile, except to increase the salt load. In fact, higher salinities during initial stages prove more harmful. Further, if benefits from frequent saline irrigations are to be accrued, water applied per irrigation need to be reduced which is not possible with most widely practiced surface irrigation methods but with sprinkler and drip methods. However, the technical and economic feasibilities of such systems on larger scale are awaited. The goal is to simultaneously induce utilisation of carried over rainwater in the soil profile/ shallow water-tables.

Tolerance limits of crops to the use of saline waters as developed under different agro-ecological regions, have been observed to vary with soil type, rainfall and anionic/cationic constituents of salinity. Multi-location trials on conjunctive use of saline and non-saline waters reveal the benefits of irrigating with non-saline canal waters during initial stages including pre-sowing irrigation/ cyclic modes over mixing of two supplies. Monsoon induced salt leaching decreases with clay content, SARw and is enhanced with the dominance of chloride salinity. Additional doses of phosphorous to alleviate the effects of chloride toxicity and use of organic materials to enhance the efficiency of applied nitrogen are recommended under saline irrigated conditions.

Contrary to the general belief that high-SAR saline water irrigated soils may regain infiltration capacity when electrolytic concentration of ingoing water is more than flocculation value, irreversible reductions are induced under cyclic saline-rain water infiltration where sub-soil layers ingressed with clays control steady intake rates. Thus the use of gypsum is advocated for soils irrigated with saline waters with SARw > 20, Mg:Ca ratio > 3 and rich in silica. Other cultural practices like furrow planting, increasing populations and post seeding irrigation in crops like mustard also prove useful. Too conservative water quality standards have been replaced with site specific guidelines where factors like soil texture, rainfall and crop tolerance have been given due consideration.

Introduction

Large scale development of surface and ground water resources during the post-independence period has reduced the susceptibility of Indian agriculture to the vagaries of monsoons. Recent estimates show that nearly 64 million ha out of total cropped area of 184 M-ha has provisions for supplemental irrigation facility, particularly in arid and semiarid regions. Increased water availability along with high yielding fertilizer responsive varieties led to ushering in of 'Green Revolution' in seventies particularly with the increased production of rice and wheat from areas endowed with better water quality resources. Nevertheless, the development of water resources has proved to be mixed blessing. Though the country has spent more than Rs. 25000 crores on major and medium irrigation projects, 15-20 % of their command areas have become afflicted with the menace of salinity and waterlogging. These areas are mostly underlain with marginal and poor quality underground waters. At the same time, water levels are receding at alarming rates due to excessive withdrawl of water in regions underlain by good quality ground waters. Unfortunately, water quality in 32-84 % of the aquifers surveyed in different states have been observed to be of poor quality (Table 1). In many such areas the good quality surface water supplies are either inadequate or are not available at all and the farmers are left with no option but to use brackish underground waters for irrigation purposes. Sustained use of these poor quality waters in absence of proper soil-water-crop management practices pose grave risks to soil health and environment. Experimental evidences under the aegis of AICRP-Saline Waters and elsewhere in the country have shown that salinity/ sodicity build up in soils irrigated with brackish waters can be controlled by following specific system of management. This compilation has been developed to describe some of the useful options and guidelines to sustain crop yields with the use of poor quality waters for irrigation.

2.0 Parameters for Water Quality Assessment

2.1 Salinity Hazard

The most important criterion for evaluating a given water is its total salt concentration. The quantity of salts dissolved in irrigation water are usually expressed in terms of electrical conductivity (EC), mg/L (ppm) or me/L. The former is the most popular because of ease and precision of its measurement. The determination of EC involves measurement of resistance of the solution with "Solu bridge" when a known electrical potential difference is created between two electrodes of known dimension and then values are converted to the reciprocal of resistance i.e. conductance to get the parameter which increases with salt concentration. The EC values are usually expressed as mmhos/cm or in SI units as dS/m at 25 °C for waters and soil solutions generally encountered in irrigated agriculture. But for rain water or solutions of very low electrolyte concentration, units can be μmhos/cm. The conversion of EC to total dissolved salts (TDS) and osmotic potential of waters (ψ_p) can be approximated by the following equations:

$$TDS(mg/L) = 640\ EC$$
$$\psi_p\ (M\ Pa) = -0.036\ EC$$

For an example, wheat crop receiving 5 irrigations (each 7 cm) with saline water of ECw 4 dS/m will result in addition of about 9 tons salt/ hectare. EC values can also be used for inferring the salt concentrations expressed in milli equivalents per liter and such relation for mixed soil solutions having EC upto 5 dS/m is represented by: Total ions (me/L) = EC (dS/m) x 10. The waters are categorised on the basis of their salt content (TDS) into following classes:

Fresh water	=	< 500 mg/L
Marginal water	=	500-1,500 mg/L
Brackish water	=	1,500-5,000 mg/L
Saline water	=	> 5,000 mg/L
Brine water	=	35,000 mg/L
Bittern water	=	> 350,000 mg/L

Mostly cations like Na^+, Ca^{2+} and Mg^{2+} and anions like Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-} are the major salt constituents contained in saline water. Plant growth is adversely affected with saline irrigation primarily through the effects of excessive salts on osmotic pressures of the soil solution resulting in reduced availability of water. The excessive concentration and absorption of individual ions e.g. Na, Cl, B etc. may also prove toxic to plants and/or retard the absorption of other essential plant nutrients. The reduced water availability at high salinity thus causes water deficits for plants and the plant growth gets inhibited when soil solution concentration reaches a critical concentration value often referred to as threshold salinity (ECt). Under the field situations, first reaction of plants to the use of saline waters is reduction in the germination but the most conspicuous effect is the growth retardation of crops. A general conclusion can be that the detrimental effects of salinity include reduced initial growth resulting in smaller plants. These smaller plants with lesser LAI (leaf area index) in turn to produce

Table 1. **Water resources and their quality and yield statistics of North-west states of India.**

Characeristic	Punjab	Haryana	U.P.	Rajasthan
Geographical area (Mha)	5.0	4.4	29.4	34.2
Net sown area	4.2	3.5	17.2	16.1
Arid area(%)	26.8	29.3	Nil	57.4
Semi-arid area(%)	60.2	59.7	70	36.7
Mean annual rainfall(mm)	611	556	836(W)	700(W),300(E)
Net irrigated area(%)	94	73	59	29
Canals	38.3	48.9	30.1	35.1
Wells	61.6	50.8	65.5	23
Ground water resources (Mha-m/yr)				
Utilizable	1.31	0.88	9.27	1.83
Net draught	0.93	0.61	2.68	0.46
Potential available	0.36	0.27	6.59	1.37
Use of poor quality waters	0.38	0.38	1.28	0.39
Rating of ground water quality				
Good(%)	59	33	37	16
Marginal(%)	22	8	20	16
Poor(%)	19	55	43	68
Characteristic featuos of poor quality waters				
Saline(%)	22	24	NA	16
Sodic(%)	54	30	NA	35
Saline sodic(%)	24	46	NA	49

lesser assimilates for their bio-conversion to seeds. In other terms, a complementary development of vegetative and reproductive phases is necessary for higher yields as translocation of assimilates once developed may remain unaffected by salinity, provided the environmental factors remain favourable during flowering. Experimental evidences indicate that an interplay of number of factors like nature and content of soluble salts in irrigation water, soil type, rainfall, water-table conditions, nature of crops grown and the water management practices followed, govern the resultant salinity build up vis-a-vis crop performance from the long term use of saline waters.

2.2 Sodicity Hazard

Some of the irrigation waters when used for irrigation of crops have a tendency to produce alkalinity/sodicity hazards depending upon the absolute and relative concentrations of specific cations and anions contained in them. The parameters which are generally analyzed for knowing the potential of irrigation waters to create sodicity/alkalinity hazards are discussed as follows.

2.2.1 Sodium Adsorption Ratio (SAR)

SAR is determined by using the relation

$$SAR = \frac{[Na+]}{\sqrt{[(Ca+Mg)/2]}}$$

where all concentrations are expressed in me/L. It has been found to be useful in determining the exchangeable sodium to exchangeable calcium plus magnesium ratio (exchangeable sodium ratio, ESR) of soil exchange sites and the governing relation is given as:

$$ESR = -0.0126 + 0.01475\ SAR \qquad r = 0.92$$

$$ESP = 100\ ESR\ /\ (1 + ESR)$$

where ESP denotes exchangeable sodium percentage.

2.2.2 Residual Sodium Carbonate (RSC)

RSC is another empirical approach used to assess the sodicity hazard of carbonate and bicarbonate rich waters. Presence of such anions in irrigation waters result in precipitation of calcium and magnesium of the soil and thus increase sodicity hazard of waters. The RSC is expressed as:

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

where all concentrations are expressed in me/L. The complete precipitation of CO_3^{2-} and HCO_3^- as is the basis of this concept may not hold good for field situations. The proportion precipitating has been shown to be related to the fraction of applied water passing beyond the root zone (leaching fraction), release of inherent calcium and Pco_2 of the root zone. Also CO_3^{2-} precipitates more rapidly and has been shown to be more dangerous.

2.2.3 Adjusted SAR (adj.SAR)

When a given water is used for irrigating the crops, it concentrates in the soil because pure water being sieved for evapo-transpirational the crop roots. If no precipitation of salts takes place then $SAR_{(soil\ water)}$ which is in equilibrium with the exchange, is expected to increase by a factor 1.4 (√2) and vice versa. Since in soils, precipitation and dissolution reactions (mainly involving Ca^{2+} ions) do occur and SAR alone can not be used accurately to predict ESP build up in soils. Therefore, the concept of SAR was modified to account for the effects of mineral weathering, leaching fraction, solution composition and Pco_2 in the root zone. The proposed derivation for better prediction of SAR_{dw} and in turn ESP is:

$$SAR_{dw} = \frac{Na_{iw}/LF}{\sqrt{[Mg_{iw}/LF + X(Pco_2)^{1/3}]}}$$

The 'X' represents the Ca in applied water modified due to salinity (ionic strength) and HCO_3^-/Ca^{2+} ratio (concentration in me/L at the estimated Pco_2 of $7x10^4$ MPa in surface few millimeters of soil). The values of 'X' can be read from Table 2. The modified value of Ca (Ca_x) is then used to correct calcium concentration vis-a-vis the SAR of waters in terms of adj.R_{Na}.

$$adj.R_{Na} = \frac{Na}{\sqrt{[(Ca_x + Mg)/2]}}$$

Example : Calculations of various sodicity indices of water

Given: Different ionic constituents of water are as follows

Ca^{2+} = 0.6 me/L, Mg^{2+} = 0.8 me/L , Na^+ = 13.2 me/L
CO_3^{2-} = 1.4 me/L, HCO_3^- = 10.0 me/L, Cl = 2.8 me/L
ECiw = 1.4 dS/m. The water is to be used by maintaining LF = 0.3

Calculations:

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}} = \frac{13.2}{\sqrt{(0.6+0.8)/2}} = 15.8 \ (m\ mol/L)^{1/2}$$

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$
$$= (10.0 + 1.4) - (0.6 + 0.8) = 10.0 \ me/L$$

$$ajd.R_{Na} = \frac{Na}{\sqrt{(CaX+Mg)/2}} = \frac{13.2}{\sqrt{(0.29+0.8)/2}} = 17.9 \ (m\ mol/L)^{1/2}$$

$$SAR.dw = \frac{Na/LF}{\sqrt{(CaX+Mg/LF)/2}} = \frac{13.2/0.3}{\sqrt{(0.29+0.8/0.3)/2}} = 36.2 \ (m\ mol/L)^{1/2}$$

Irrigation with sodic waters containing high Na^+ relative to Ca^{2+} and Mg^{2+} and high carbonates (CO_3^{2-} and HCO_3^-) leads to an increase in alkalinity and sodium saturation in soils. The increase in exchangeable sodium percentage (ESP) adversely affects soil physical properties including water infiltration and soil aeration. On drying soils become very hard and on wetting soil particles get dispersed and clog the pores that affects root respiration and development. Due to poor respiration, young plants of arable crops e.g wheat show yellowish appearance after first irrigation. The waters with low calcium (Ca^{2+} < 2 me/L) and high amounts of carbonates result in specific toxicity symptoms on plants particularly scorching and leaf burning at the early seedling development stage of crops.

In the early stages of sodic irrigation, large amounts of divalent cations are released into the soil solution from exchange sites and minerals. Under the monsoonal climate of India, alternating irrigation with sodic waters and rain water induces cycles of precipitation and dissolution of salts in soils. The sodicity build up in soils is, thus, the outcome of equilibrium between all these processes. Several field observations have shown that though the steady state conditions may not be achieved under the monsoonal climatic conditions but quasi-stable salt balances are attained after 4-5 years of sustained sodic irrigation and that further rise in pH and ESP is very slow. The average ESP build up in the most important surface layer (0-30 cm) get stabilised at values almost equal to adj.RNa of the sodic water used in millet/maize-wheat rotation but the values for rice-wheat the ESP are 2.6 adj.RNa indicating greater soil deterioration in the latter. That is why rice-wheat system is usually not recommended for sodic irrigations.

2.3 Toxicity Hazards

Ground waters having higher toxic ions such as B, F, NO_3, Se, etc. also become problematic for irrigating crops and have consequence of entering human food chain. High accumulation of B in plants causes necrosis and may sometimes reduce leaf size to the extent of significantly reducing photosynthesis. Displacement of boron being very difficult, even small quantities in waters tend to accumulate in soils. Excess of fluoride, usually present in alkali waters, cause serious health hazards such as fluorosis resulting in decay of teeth and weakening of bones and their deformation. Higher uptake of N as a consequence of irrigation with waters containing excessive amounts of NO_3 results in vigorous plant growth, delayed maturity, increased succulence resulting in lodging, poor grain filling and shrivelled grains. Accumulation of organic acids such as malate and oxalate in higher amounts in forages and leafy vegetables may prove toxic to animals and human beings.

3.0 Ground Water Resources and Their Quality

The development of ground water resources through shallow tubewells has played a pivotal role in enhancing the overall agricultural production in the country. For example, the increase in area irrigated through canal irrigation during the last three decades was only about 19% whereas through tubewells it has been of the order of 160 and 196% in Haryana and Punjab, respectively. As a consequence of over-exploitation, the ground water table is declining at alarming rate with threats of being polluted by pesticides and nitrates. According to latest water balance studies, out of 118 blocks in Punjab, 70 blocks are 'dark' (their ground water exploitation is > 85% of the annual recharge) out of which 6 blocks are overexploited. Similarly, out of 16 districts in Haryana, 11 districts (mostly rice-wheat growing area) are showing decline in ground water table.

Ground water surveys have shown (Table 1, Fig. 1) that about 41-84 % of the well waters in the north-west states of India are brackish. Vertical as well as lateral variations in ground water quality are encountered, even at short distances. Higher salinity ground waters are mostly encountered in arid parts of north-west states like Rajasthan, Gujarat and Haryana. The main districts in Rajasthan where highly saline aquifers exist include Jodhpur, Jalore, Pali, Churu, Barmer, Bikaner, Luni and Jaisalmer. Parts of Rohtak, Jind, Hisar, Bhiwani, Sirsa and Mohindergarh in Haryana are also underlain with saline aquifers where as similar conditions exit in parts of Faridkot, Bhatinda and Ferozepur districts of Punjab. The incidence of sodic waters occur mainly in semi-arid parts with annual rainfall of 50-70 cm. High RSC waters are common in central and south west Punjab including parts of Amritsar (Khara Majha), Bhatinda (Mansa and Phul), Ferozepur (Zira and Dharamkot), Moga (Bagha Purana, Nihalsighwala), Ropar (Kharar), Sangrur (Malerkotla and Sangrur) and southren Ludhiana covering about 25% of the total area of the sate. In Haryana, these waters are encountered in Jind (Rajaund, Narwana), Karnal (Nilokheri, Nissang), Kaithal (Gulha Cheeka, Pundari, Dand, Kaithal), Panipat (Assandh), Bhiwani (Dadri), Mahendergarh (Bawal, Narnaul, Pataudi), Gurgaon, Faridabad (Ballabargh, Sohna), Rewari (Broad) and Sirsa covering almost 21% of the total area of the state. Alkali waters are also common in Agra, Mathura, Aligarh, Mainpuri, Etah, Ballia and several other districts of Uttar Pradesh and to the east of Aravalli range in Rajasthan including parts of Jaipur,

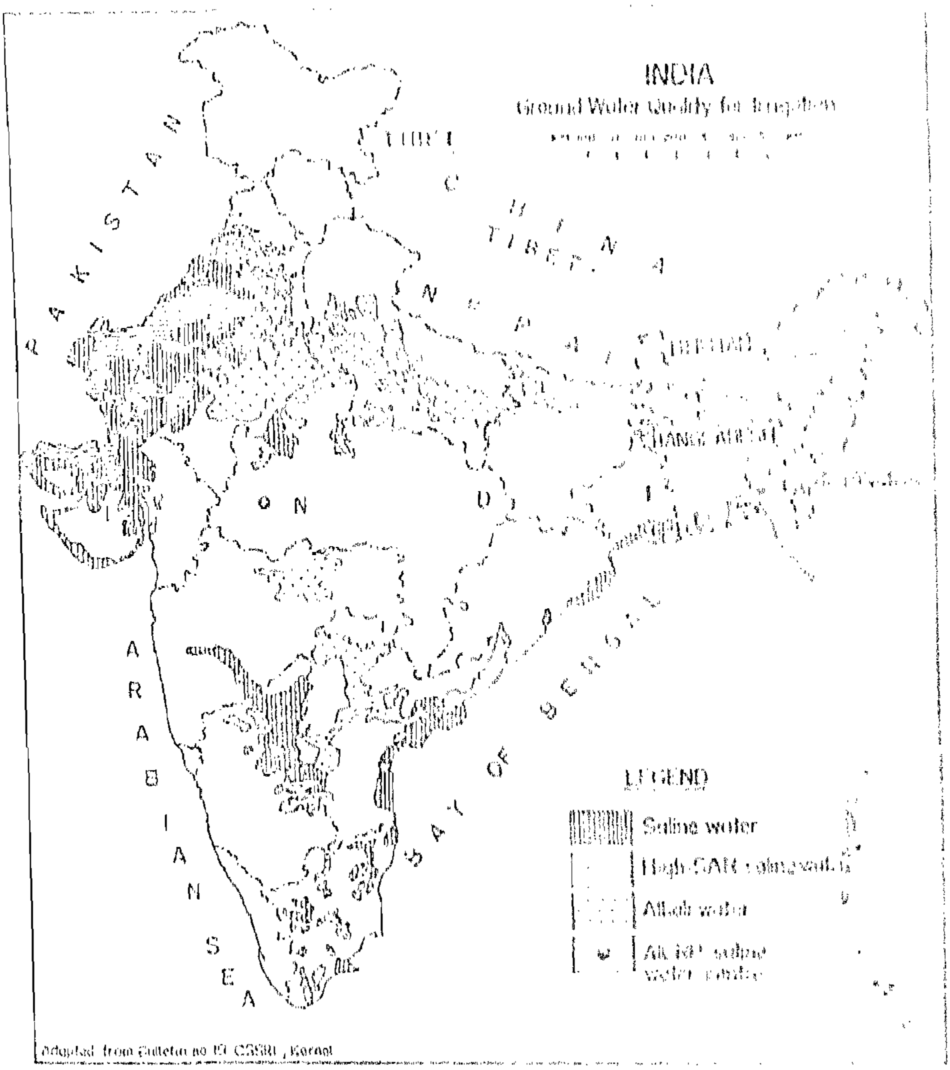


Fig. 1. Ground water quality for irrigation (First Approximation)

Kota, Udaipur, Tonk, Nagaur, Sikar and Jhunjhunu districts. Associated with salinity, ground waters in some pockets especially these may contain toxic levels of B, F, NO_3, Se and Si etc. Boron contents > 5 ppm have been encountered in ground waters of Agra, Hisar and Bhatinda. Similarly, high F (> 4 ppm) has been reported for ground waters of several pockets e.g. Ganganagar, Nagaur, Sirohi, Jalore, Pali, Jodhpur, Bikaner, Jaipur, Bhilawara, Udaipur, Bharatpur, Barmer, Jaisalmer in Rajasthan, Bhatinda, Ferozepur, Sangrur in Punjab, Hisar and Sirsa in Haryana and Unnao, Muradnagar, Modinagar, Muzafarnagar and Meerut in Uttar Pradesh. Several of these districts in Rajasthan have ground waters with toxic levels of nitrates.

Based on the characteristic features of majority of ground waters in use by the farmers in different agro-ecological regions of the country and the above indices which describe the nature of hazards on soils and crops, irrigation waters have been broadly grouped into good, saline and alkali waters. Depending upon the degree of restrictions, the two poor quality water classes have been further grouped each into three homogenous subgroups (Table 2). Since each subgroup needs specific management practices, this classification also serve the purpose of planning their development and management at block / mandal/ tehsil level. A map of ground water quality for irrigation has been prepared on a 1:6 million scale, which has been the first approximation in the country (Fig. 1). Four legends used were; Good water (ECiw < 2 and SAR < 10), Saline water (ECiw > 2 and SAR < 10), High-SAR saline water (ECiw > 4.0 and SAR > 10) and Alkali waters (ECiw variable; SAR variable and RSC > 2.5).

Table 2. Grouping of poor quality ground waters for irrigation

Water Quality	ECiw (dS/m)	SARiw (mmol/L)	RSC (me/L)
A. **Good**	< 2	< 10	< 2.5
B. **Saline**			
i. Marginally Saline	2-4	< 10	< 2.5
ii. Saline	> 4	< 10	< 2.5
iii. High-SAR saline	> 4	> 10	< 2.5
C. **Alkali waters**			
i. Marginally alkali	< 4	< 10	2.5-4.0
ii. Alkali	< 4	< 10	> 4.0
iii. Highly alkali	Variable	> 10	> 4.0

The other features of ground waters in different agro-ecological regions emerged out of analyses are;

i. Majority of natural ground waters have pH between 7.2 and 8.5 and are either in equilibrium or even supersaturated in respect of calcite and dolomite. Waters with pH less than 7.2 seem to be undersaturated in respect of calcite. Water samples having pH more than 8.4 invariably have SAR more than 10. High pH is associated with waters containing residual alkalinity and a high CO_3^{2-} : HCO_3 ratio.

ii. HCO_3-type ground waters have 2 distinct characteristics. Waters having residual alkalinity upto 4 me/L have both a low salinity (< 2.0 dS/m) and low SAR (SAR < 10 mmol/L). When soluble salt content of bicarbonate type waters increases (more than 2.0 dS/m), the residual alkalinity and SAR also increase primarily due to the higher amounts of carbonate and bicarbonates of sodium. In waters with RSC < 4 me/L and DCR > 0.25, the SAR is invariably less than 10. In the other category of bicarbonate types, waters have SAR > 10, RSC > 4 me/L and DCR < 0.25. In absence of canal water supplies and rainfall less than 500 mm, farmers generally face acute problems in managing waters of this category particularly on finer textured soils.

iii. Waters having residual alkalinity contain carbonate and bicarbonate ions in varying proportions depending on the pH. The ratio of carbonate ions in ground waters generally vary between 1:10 and 1:2. Whenever waters have high proportions of CO_3^{2-} ions, DCR is often < 0.25.

iv. Marginally saline waters have low SAR, the usual range being up to 20. Hardly 10-15 percent of the total ground waters have both a high SAR (> 20) and high salinity.

4.0 Management Practices for Sustained Saline Water Use

Consistent efforts have been made at different research centres in the country to devise ways for the safe utilization of saline/sodic waters to raise agricultural crops. With scientific advances, the basic principles of soil-water-plant systems are now fairly well understood and advocate specialized soil, crop and irrigation management practices for preventing the deterioration of soil to levels which limit the crop productivity. Some such measures for controlling salinity/sodicity build up and maintaining the physical and chemical properties of soils irrigated with saline and sodic waters have been discussed in the following sections:

4.1 Leaching for Salinity Control

4.1.1 Monsoon Induced Leaching

One of the fortunate situation with continental monsoon climate of India is the concentration of rains in a short span of 2-3 months (July - September). Thus, if the water penetrating into soils during this period exceeds the ET demands of crops, it induces leaching of salts added through saline irrigations to winter crops or in low rainfall regions, farmers resort to fallows during monsoon rain for achieving salt balances in semiarid parts. In arid parts of Rajasthan, cultivation of lands every alternate year or after two to three years to allow the accumulated salts o leach out by rain before next crop is sown is a common practice. The amount and frequency of rains basically govern the salt leaching during monsoon season but soil texture has been also shown to influence leaching. Predictions show that removal of 80% of the salts accumulated during the period preceding monsoons would require 1.85, 0.95 and 0.76 cm of rainwater per cm soil depth in fine, medium and coarse textured soils. In other words, removal of salt from the surface 30cm of respective soils would require about 55, 29 and 23 cm rainfall to occur during monsoons. Obviously, the lower water holding capacity of coarser soils leads to higher pore volumes of displacing solutions consequent upon similar rainfall. But low infiltration rates of fine textured soils (having high clay content) cause a larger fraction of rainwater either to be wasted as run off or evaporate from stagnated water at the surface/soil which reduces water available for displacing salts.

Most of the chloride salts being highly soluble are leached easily while SO_4^{2-} may be held back because it precipitates as salts of sulphate in soils e.g. relatively insoluble gypsum, which continue to dissolve with the rainfall events. The clays in soils irrigated with high SAR-saline /sodic waters become vulnerable to dispersion and movement upon leaching especially with low electrolytic rain water. Thus, salts are held back and such soils have been shown to require almost double the quantity of water compared with the structurally stable saline soils. So the addition of gypsum to prevent surface sealing and enhance infiltrability of rain water is advocated for such situations.

Conclusion: Monsoon induced leaching is of immense value for maintaining salt balances. Incorporate gypsum @ 1-2 t/ha before monsoons if permeability problems are envisaged.

4.1.2 Leaching requirement for salt balances

The traditional salinity management approach assumes the steady state conditions to exist in the long run which implies that the economic way for controlling soil salinity is to ensure net downward flow of water through the root zone. Therefore, leaching requirement has been defined as the minimal fraction of the total water applied that must pass through the root zone to prevent reductions in crop yield below the acceptable level. The leaching requirements for any acceptable yield (Ya) can be calculated using the general salt tolerance equation as

$$RY = Ya/Ymax = 1 - S\,(ECa - ECt)$$
$$ECa = ECt + (1 - Ya/Ymax)/S)$$
$$LR = ECiw/ECdw$$
$$\text{For } LF > 0.3 \quad ECa = ECdw/2.5 \quad \text{or} \quad LR = ECiw/2.5\,ECa$$

where 'ECt' is threshold salinity where yield just begin to decline and 'S' is the rate of yield decline with increasing salinity. The concept of leaching requirement is mainly of practical importance for the situations of no or very low rains where nearly the steady state can be achieved. However, under continental monsoonal climate as in India, concentration of rains in a short span of 2-3 months is the most uncontrolled factor causing non-steady state salinity. It leaches down the salts when infiltrating down the soil, gets stored in the soil profile to be carried over until either it gets mixed with the applied saline irrigation water or consumed by winter crops. Experiments have shown that the practice of providing for leaching requirements to crops do not benefit much. Rather such a practice that demands for the quantity of applied water in excess of the irrigation needs of crops pushes the carried over good quality rain water beyond root zone which otherwise would have been utilised by the crops. Moreover, with equal salt inputs, those increase salinisation rates during later stages, although result in higher salinity, but are less toxic than the higher salinisation rates but lesser final salinities. Similarly with sodic irrigation, sodicity build up and pH could not be controlled by providing for higher leaching fractions and was rather related to the quantity of sodic irrigation under the different crop rotations.

Conclusion: Maintaining leaching requirements do not pay off well under the monsoonal climate and rather it increases salt load into soils

4.2 Farm Irrigation Management

4.2.1 Irrigation interval

Under saline conditions, irrigation should meet both the water requirements of crops and leaching requirements to maintain a favourable salt balance in the root zone. During the intervening periods between the irrigation cycles, evapo-transpiration by crops reduces the soil water contents which in turn decreases the matric as well as solute potentials. The rate of ET and soil-water characteristic curve [$\Psi = f(\theta)$] determine the rate of fall of the two components of total soil water potentials but as a consequence the water uptake by crops and hence the yields are expected to suffer. Therefore, it is usually opined that irrigations in saline soils should be more frequent because it reduces the cumulative water deficits (both matric and osmotic) between the irrigation cycles.

But such an opinion is still controversial as small irrigation intervals subsequently induce water uptake from shallow soil layers, increase unproductive evaporative losses from soil surface and with saline irrigations, increase the salt load of soils. Moreover, the non-saline soil water carried over from the monsoons rains may also be displaced beyond the reach of plant roots by the added saline solutions. Soil solution concentrations adjacent to growing roots in saline soils are 1.5 to 2 fold higher than the bulk soil. Wetter the soil and higher the transpiration rate, larger are the differences indicating that keeping soil wet by decreased irrigation intervals may rather enhance the effects of salinity. The extended irrigation intervals, on the other hand, usually result in deeper roots and larger proportions of water extractions from deeper zones. Reductions in water uptake and thus evapotranspiration losses occur under saline conditions. These in turn mean higher salinity soils will retain more water than the low salinity ones in between the irrigations and such a situation should moderate the total water stress and thus reduce the inhibitory effects of increase in solution concentration on growth. Nevertheless, the net results of above counteracting processes still awaits further experimentation but evidences are that depth of applied water should be simultaneously reduced if benefits from small intervals of irrigations are to be accrued. Because the infiltration rate controls the application depths, it is difficult to apply < 25 mm water with surface methods and too frequent irrigations may in fact lead to aeration problems. This points out towards the following of micro-irrigation systems where scheduling is typically at very high frequency with small applications. This aspect has been discussed in a later section on "method of irrigation".

Conclusion: To maximise the benefit from frequent saline irrigation, attempts should be simultaneously made to minimise the water applied for each irrigation.

4.2.2 Pre-irrigation

Primary objectives of presowing irrigation include the creation of optimal soil moisture conditions to facilitate tillage, seed bed preparation and to recharge the projected root zone with water for germination and later ET needs of crops. In saline soils, these should further include the leaching of soluble salts below the seeding zone as the germination and seedling establishment are most critical and any failures at this stage can not be rectified later. Plants are also known to tolerate the salinity better with aging. Experiments show that crops can tolerate higher salinity once the non-saline water was substituted for presowing irrigation to leach salts out of seeding zone. This substitution enhances germination, crop growth and yields markedly and results in better utilisation of soil water even from the lower soil layers. The presowing irrigation assumes a still more critical role for the success of summer crops.

Conclusion: Use of fresh water for presowing irrigation to leach the salts of seeding zone allows for the utilisation of higher salinity waters at later growth stages.

4.2.3 Multiquality irrigation practices

Under most saline situations in India, canal water supplies are either unassured or in short supply forcing farmers to pump saline ground/ drainage waters to meet the crop water requirements. These waters from the two sources can be applied either separately or mixed together. Mixing of waters to acceptable quality for crops also results in improving stream size and thus enhance the uniformity in irrigation especially for the surface method practiced on sandy soils. The fractions (F) for mixing can be worked out depending upon quality (EC or RSC) of tubewell water (Qtw), canal water (Qcw) and that desired for mixed water (Qmw) with the following equations.

$$Qmw = [Qcw \times Fcw] + [Qtw \times Ftw]$$

However, the SAR of mixed water (SARmw) is calculated as:

$$SARmw = \frac{[Nacw \times Fcw + Natw \times Ftw]}{[((Ca+Mg)cw \times Fcw + (Ca+Mg)tw \times Ftw)/2]^{1/2}}$$

Example: Calculate EC, RSC and SAR of mixed water when a canal water (EC 0.26 dS/m, Ca^{2+} 1.2, Mg^{2+} 1.3, Na^{+} 0.6, Cl^{-} 0.6 and HCO_3^{-} 2.2 me/L) and a tubewell water (EC 2.9 dS/m, Ca^{2+} 0.6, Mg^{2+} 1.1, Na^{+} 27.5, Cl^{-} 19.2 and HCO_3^{-} 10.7 me/L, RSC 9.0, SAR 29.8) are mixed in the ratio of 3:7.

$$ECmw = (0.3x0.26) + (0.7x2.9) = 2.1 \text{ dS/m}$$

$$RSCmw = (0.3x2.2 + 0.7x10.7) - (0.3x2.5 + 0.7x1.7) = 7.2 \text{ me/L}$$

$$SARmw = \frac{(0.3x0.6 + 0.7x27.5)}{\sqrt{(0.3x2.5 + 0.7x1.7)/2}} = 19.7 \text{ (m mol/L)}^{1/2}$$

Application of the two waters separately, if available on demand, can be done either to different fields, seasons or crop growth stages so that higher salinity water is not applied to sensitive crops/growth stages. As pointed out earlier, germination and seedling establishment has been identified as the most sensitive stage in most crops. Therefore, better quality water should be utilised for presowing irrigation and early stages of crop growth. Then switch over to poor quality waters later when the crops can tolerate higher salinity. In the seasonal cyclic use, often referred to as 'Dual Rotation' strategy by US workers, non-saline water is used for salt sensitive crops/ initial stages of tolerant crops to leach out the accumulated salts from irrigations with salty waters to previously grown tolerant crops. Such a management strategy may work better for arid climates with very low rainfall but it is of natural occurrence under the semiarid parts of India. Thus the options of utilising multiquality waters have to be either mixing or stage dependent cyclic use that too mainly during the growth of winter crops. If it is presumed that the prerequisite facilities for blending exist and different qualities of waters are simultaneously available on demand, then the question arises as to which option should be followed. Analysis of a large number of multi-locational trials with different crops conducted under AICRP Saline Water has favoured the cyclic use over mixing with the advantage following the order; (2C : 1S) > (1C : 1S) > (1C : 2S) ; canal: saline water irrigations. Therefore, use canal waters at early stages and the use of saline waters should be delayed to later stages. Benefits of cyclic use modes in sustaining crop yields have been also demonstrated under sodic irrigation.

Conclusion: Cyclic uses have both operational and performance advantages over mixing. Therefore, resort to the use of canal water supplies during initial stages and use of saline waters should be delayed to later stages of crop growth.

4.2.4 Method of irrigation

The distribution of water and salts in soils vary with the method of irrigation. The surface irrigation methods including the border strips, check basins and furrows are the oldest and most commonly practiced in most parts of India. These irrigation methods even after following the best design criteria generally result in excessive irrigation and non-uniformity in water application. Consequently the on-farm irrigation efficiency is low (60-70 %). However, properly designed and operated surface irrigation methods can maintain the salt balance and minimise salinity hazards. To meet these twin objectives, land needs to be properly levelled to ensure even distribution of water. Parameters such as the length of the water run, stream size, slope of the soil and cut off ratio which influence the uniformity and the depth of water application for a given soil type, should be as per the desired specifications.

High energy pressurized irrigation methods such as sprinkler and drip are typically more efficient as the quantity of water to be applied can be adequately controlled but the initial investment and maintenance costs of such systems are high. Water use efficiency improves considerably when saline water is applied using the sprinkler than by surface method to winter crops (wheat and barley). Sprinklers also ensure uniform distribution of water even on undulating and sandy terrains. Leaching efficiency is also better under sprinkler method as of lower pore water velocity and the water contents at which water moves reduces the preferential flow. Saline water use through sprinklers, however, may cause leaf burning and toxicity when used on some sensitive crops. Some of the burning effects of saline water can be avoided by operating the sprinklers during the twilight/ night time when evaporation rates are lower.

The use of irrigation waters through drip system has revolutionised the production of some high value crops and orchards in countries like Israel and elsewhere especially when using saline waters. Though drip irrigation system is still in its infancy in India but the system has a great potential in the arid and semiarid regions particularly for the light textured soils. As regular and frequent water supply is possible with drip system of irrigating crops, it has been observed to enhance the threshold limits of their salt tolerance by modifying the patterns of salt distribution and maintenance of constantly higher matric potentials. Due to enhanced leaching and accumulation of salts at the wetting front and the soil between the drip laterals, the salt accumulation below the drippers remain very low where as the water contents are maintained at higher levels at the latter sites. As the crop roots are known to follow the path of least resistance, most roots are found below the surface drippers. Hence the drip system seems to be the best method of saline water application as it avoids leaf injury to plants as with sprinklers and maintains optimum conditions for water uptake by plant roots. A major drawback of irrigation with drippers is the high salt concentration that develops at the wetting front. Accumulated salts cause difficulties in the planting of subsequent crops because effective leaching of salts would require the use of flood or sprinklers irrigation. Another problem is clogging of drippers due to precipitation of salts. Some of the indigenous alternative to drips tried on micro-scale are the use of pitchers and specially designed earthen cups but their feasibility on larger field scale remain untested.

Conclusion: A shift towards micro-irrigation systems, where a better control on salt and water distributions can be achieved, holds promise for enhancing the use of saline waters especially for high value crops.

4.2.5 Shallow water-table management

To minimise the salinity hazards under high water table conditions, salts are usually leached down and waterlogging problems are alleviated by the installation of sub-surface drainage system. Since the drainage waters contain considerable amounts of salts and sometimes toxic elements also, their disposal to the natural outlets often create problems. Several reports have indicated that substantial contributions to the seasonal evapotranspiration can come from the shallow water tables. Optimum yields of wheat have been obtained with only one irrigation under non-saline shallow (1.2m) water table condition. Similarly, crops have been observed to meet much of their water requirements (upto 50-70%) from the shallow saline water tables. Therefore, a potential solution for reducing drainage volumes could be to promote exploitation of water-table for meeting a part of crop water use. Though, maximising the crop water use from shallow ground waters can reduce the volume of drainage effluents but often it is thought that such a practice would simultaneously lead to salt accumulations in root zone. However, experimental evidences indicate that the salts left in the rooting profile during the post-monsoon period are more or less similar because of leaching during monsoon rains.

Conclusion: Strategies of inducing consumptive use from shallow water-table can play an important role in solving problems related to disposal of drainage effluent.

In addition to tapping of saline water by inducing uptake by crop roots in the inland salinity zones, a system of skimming called "Dorouv" is in vogue in coastal areas since long. To illustrate, a unique feature of ground water, depth varying between 0.5 to 3.0 m, of narrow sandy belt along the sea coasts is the formation of fresh water layer by rain infiltrated water floats over saline water intruded from the sea. For this farmers have been digging pits and excavating small quantities of fresh water. To improve fresh water yields, this technology has been refined by installing tile lines radially along the pumping units and water is used for raising nurseries / crops through sprinklers.

Conclusion: Improved 'Dorouv' technology has been amply demonstrated for the efficient utilisaton of fresh water floating over the brine water intruded from the sea and needs to adapted on a large scale.

4.3 Crop Management

4.3.1 Crop salt tolerance

Crop tolerance to salinity and sodicity vary a great deal, almost 10 fold, amongst the crop plants and to a lesser extent amongst their genotypes. These inter and intragenic variations in salt tolerances of plants can be exploited for selecting crops/cultivars those produce satisfactorily under a given root zone salinity (Fig. 2). Information generated on the crop tolerance to the use of saline waters in different agro-climatic zone of India has been included in Table 3. Similarly, the sodicity tolerance of crops has been given in table 4. However, it may be pointed that the cultivation of high water requiring crops like sugarcane and rice should be avoided with brackish waters as these aggrevate the salinity problems. Salinity tolerance of specific crop may be modified by several factors as discussed in the following sections.

Conclusion: Salt tolerance and the water requirements should be the deciding factors in crop selection for saline irrigation.

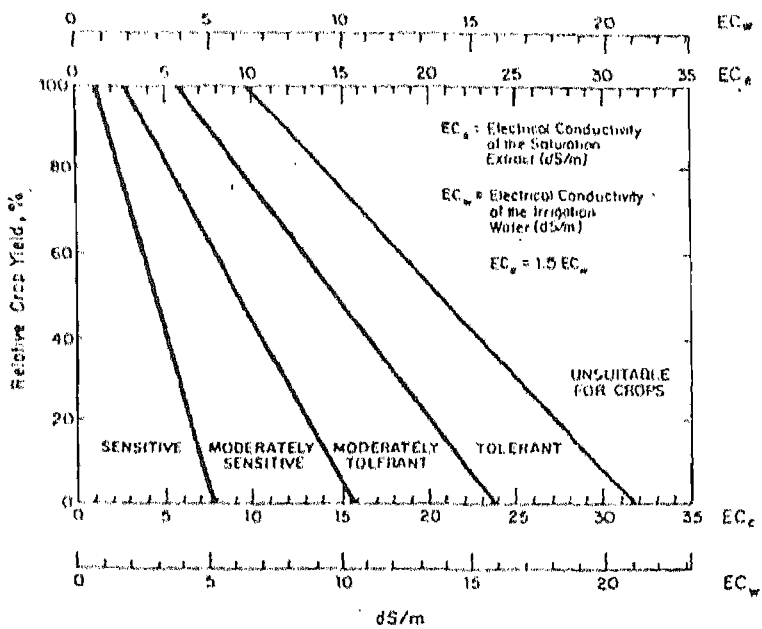


Fig. 2 Salt tolerance rating of crops

Table 3. Salinity limits of irrigation waters for agricultural crops

Crop/ Location	Soil type	No.of years	Previous crop	ECiw(dS/m) for relative yield 90%	75%	50%
			CEREALS			
Wheat						
Agra	sl	6	Bajra	6.6	10.4	16.8
"(late sown)		2	Toria	4.3	6.6	11.0
Dharwad	scl	5	Sorghum	3.4	7.0	12.9
Hisar	sl	5	"/fallow	6.1	8.7	13.0
Indore	cl	8	Maize	4.7	8.7	15.2
Jobner	ls	4	Fallow	8.3	11.7	17.5
Jodhpur	scl	2	Fallow	8.3	10.2	13.4
Karnal	sl	5	Fallow	9.1	10.8	13.7
"	s	5	Fallow	14.0	16.1	19.5
Sampla	sl	5	Fallow	9.5	17.9	—
Barley						
Agra	sl	2	Fallow	7.2	11.3	18.0
Jobner	ls	5	Fallow	13.0	21.1	—
Rice						
Agra	sl	1	Berseem	2.3	4.6	8.6
Bapatla	scl	6	Kh.Rice	2.2	3.9	6.8
		3	Ra.Rice	1.8	2.9	4.8
Maize						
Dharwad	scl	5	Sorghum	3.7	7.8	14.5
Indore	cl	7	Wheat	2.2	4.7	8.8
Pearl-millet						
Agra	sl	4	Wheat	5.4	9.0	15.0
Jobner	ls	5	Methi	11.9	22.7	—
Italian-millet						
Bapatla	s	5	Kh.Sunflower	2.4	4.6	8.2
		4	Ra.Ita.millet	2.5	4.9	8.7
Sorgum						
Agra	sl	3	Mustard	7.0	11.2	18.1
"(fodder)	sl	2	Berseem	5.2	10.2	18.4
Hisar(")	sl	2	Wheat	2.5	5.7	11.0
Dharwad	scl	6	Wheat	2.6	5.1	9.2
			OILSEEDS			
Mustard						
Agra	sl	6	Sorghum	6.6	8.8	12.3
Bapatla	scl	5	Soyabean	3.8	7.9	14.7
Jobner	ls	2	Guar	6.6	13.5	—
Toria						
Agra	sl	1	Wheat	4.7	5.1	5.9
Safflower						
Dharwad	scl	5	Maize	3.3	6.8	12.6
Sunflower						
Bapatla	sl	3	Mustard	3.5	7.2	13.4
Hisar	sl	1	Kh.Wheat	2.5	5.7	11.0
Groundnut						
Bapatla	s	5	It.millet	1.8	3.1	5.3
Soyabean						
Bapatla	scl	3	Mustard	2.0	3.1	5.0

Crop/ Location	Soil type	No.of years	Previous crop	ECiw(dS/m) for relative yield 90%	75%	50%
			PULSES/LEGUMES			
Pigeonpea						
Agra sl	sl	6	Onion	1.3	2.3	3.9
Clusterbeans						
Bapatla	sl	3	Variable	3.2	4.5	6.8
Jobner	ls	2	Mustard	3.9	6.6	11.1
Cowpea						
Jobner	ls	2	Variable	8.1	13.2	—
Berseem						
Agra	sl	5	Rice/sorghum	2.5	3.2	4.4
			VEGETABLES			
Onion						
Agra	sl	5	Pigeonpea	1.8	2.3	3.3
Bapatla	s	5	Variable	5.1	6.0	7.5
Potato						
Agra	sl	5	Okra	2.1	4.3	7.8
Tomato						
Bapatla	s	3	Variable	2.4	4.1	6.9
Okra						
Agra	sl	5	Potato	2.7	5.6	10.5
Bapatla	s	2	Variable	2.1	3.9	6.7
Brinjal						
Bapatla	s	2	Variable	2.3	4.1	7.1
Fenugreek						
Jobner	ls	3	Pearl-millet	3.1	4.8	7.6
Chillies						
Bapatla	s	2	Variable	1.8	2.9	4.9
Jobner	ls	2	"	4.5	7.5	12.5
Coriander						
Bapatla	s	3	"	2.9	5.8	10.7
Jobner	sl	2	"	9.8	15.4	—
Bitter gourd						
Bapatla	s	3	"	2.0	3.4	5.8
Bottle gourd						
Bapatla	s	3	"	3.2	4.5	6.8

Annual rainfall at Agra, Bapatla, Dharwad and Jobner is 660, 803, 778, 750 and 500 mm, respectively.

Table 4. Relative tolerance to alkalinity /sodicity of soils.

ESP Range*	Crops
10-15	Safflower,mash,peas,lentil,pigeon-pea,urd bean
16-20	Bengal gram,soyabean
20-25	Ground nut,cowpea,onion,Pearl-millet
25-30	Linseed,garlic,guar
30-50	Raya,wheat,sunflower
50-60	Barley,sesbania
60-70	Rice

*Relative crop yields are only 50 % of the potential in respective sodicity ranges.

4.3.1.1 Growth stages

All crops do not tolerate salinity equally well at different stages of their growth. During the initial stages, the interacting zone of roots is limited to surface few inches where most salts concentrate from the evaporating soils. Hence, germination and early seedling establishment are the most critical stages for most crops to saline irrigation. The other critical period for crops is during the phase change from vegetative to reproductive i.e. heading and flowering to fruit setting. Otherwise the general tolerance of the crops to saline water increases with an advancement of the age of the crops.

> ***Conclusion: Crop establishment is critical under saline irrigation and reproductive phase is the next critical phase.***

4.3.1.2 Crop cultivars

In addition to intergenic variations of crops to tolerate salinity, variation in inherent salt tolerance of the crop cultivars also exist. Generally, there is a negative correlation between tolerance of varieties and their potential yields. Hence, there are not many varieties which are both tolerant to salinity and produce economic yield which is major consideration for most farmers. Some of the cultivars of crops which have been rated better based upon their high yield potential, salt tolerance and stability under saline environment have been included in Table 5.

> ***Conclusion: Cultivation of crop varieties having both high salt tolerance as well as yield potential is recommended in soils irrigated with saline waters.***

4.3.1.3. Soil type and environment

Environmental factors like temperature, evaporativity etc. also markedly influence salt tolerance of crops e.g. when wheat was grown under comparatively cooler climate i.e. low ET demands prevailing during growth period in Northern India at Agra, limits for the use of saline water to achieve particular relative yield when compared with southern parts as in Dharwad (Table 3). Similarly, salinity limits were higher with the presence of shallow water-table. The role of soil texture in describing the limits of saline water usage has also evident from table 3 e.g. compare limits for wheat at Jobner (ls), Agra (sl) and Dharwad (scl). This is obviously due to higher leaching fractions resultant from surface irrigation methods which consequently result in lower salinity build up in coarser soils as well as higher leaching of accumulated salts with monsoon rains. Factors like 1.8, 1.12 and 0.9 for ECe at harvest of rabi crops and ECiw have been given for soils having clay contents of > 20, 10-20 and < 10 percent, respectively.

Table 5. Promising cultivars for saline and alkali environments

Crop	Saline irrigation	Sodic irrigation
Wheat	Raj 2325, 2560, 3077, WH 157	KRL 1-4, Raj 3077, HI1077,WH 157
Pearl Millet	MH 269, 331, 427,HHB-60	MH 269, 280, 427, HHB 392
Mustard	CS 416, CS 330-1, Pusa Bold	CS15, 52, Varuna, DIRA 336
Cotton	DHY 286, CPD 404, G 17060, GA, JK 276-10-5, GDH 9	HY 6, Sarvotam, LRA 5166
Safflower	HUS 305, A-1, Bhima	Manjira, APRR 3, A300
Sorghum	SPV-475, 881, 678,669,CSH 11	SPV 475, 1010, CSH 1, 11, 14
Barley	Ratna, RL 345, RD 103, 137, K169	DL 4, 106, 120, DHS 12
Green gram	LGG 127	
Black gram	LBG 22, 402	
Maize	Vijay, Deccan 103	
Groundnut	KGV 87189, 86309	

Conclusion: With increased fineness of soil texture and harsh environmental conditions of high temperature and low rainfall, tolerance to use of saline waters decreases.

4.3.1.4 Ionic constituents of salinity

In addition to total electrolyte contents, plant responses are also governed by the concentrations of different ions in soil solution. The associated cations and anions of salinity influence to tolerances of crops by : 1) governing effective salinity of soil solution with which the plant roots interact through their control over precipitation and dissolution reactions, leaching and dispersive behaviour of soils etc. and 2) direct toxicity due to excessive accumulation of ions in the plant tissues and thus causing nutritional imbalances. The tolerance to salinity decreased with increase in SAR, pH or Cl contents. It is generally viewed that if soil is saline or if the Ca concentration exceeds about 2 mmol/L, even a high level of SAR will have little nutritional affect on most crops, as distinguishable from salinity and can be ignored. Thus, the major problem with respect to sodium toxicity or calcium nutrition problem, should occur under relatively less saline but sodic and alkaline pH conditions when Na concentration is high and Ca concentration is low and or where the Mg/Ca ratio exceeds 3. Otherwise the prognosis of reduced salt tolerance, therefore, lie with structure deterioration leading to poor physical conditions. Sodicity induced accumulation of salts with the use of high SAR waters has been observed to be the main cause yield reductions for *rabi* crops whereas the yield reductions of *kharif* crops depend on amount of rainfall received. Expectedly increased amount of rainfall reduces the effects of salinity due to dilution and salt leaching but this is upto certain limit that starts affecting *kharif* crops at increased SARiw due to water stagnation problems.

Conclusion: Crops are specifically sensitive to chloride and sodium salts. The tolerance to salinity decreases with an increase in SAR, pH, Cl or Mg/Ca ratio in irrigation waters

4.4 Chemical Management

4.4.1 Fertiliser use

The concept of alleviating salinity stress through enhanced fertility has been evaluated and the results are that such a strategy of additional application of fertiliser nitrogen to reduce/overcome the adverse effect of salts may not pay off well. In general, when salinity is not a yield limiting factor, the applied nitrogenous fertilizers will increase the yields of crops, proportionately more than when the salinity becomes a limiting factor. On the other hand, increasing level of phosphorus over the recommended dose mitigates the adverse affects of salinity especially when chlorides are the dominant anions in saline waters as compared with sulphates. Application of phosphatic fertilisers most likely to improve the threshold limits of crops to the use of chloride dominated saline waters. In addition to structural improvements, incorporation of organic/green manures have added advantages in saline water irrigated soils in following ways: i) because of sensitivity of nitrification process to salinity, the losses through NH_3 volatilisation are aggravated. Thus, it can serve as a temporary bounding agent for ammoniacal pool of nitrogen and reduce its losses. Response to N-fertilisers increases in the presence of organic materials which suggest their role in reducing the volatilisation losses and enhance N-use efficiency.

ii) FYM has a beneficial acidifying effect on soil's sodicity both through the action of organic acids formed during its break down as well as Ca+Mg that FYM contains replaces the Na from the exchange complex. Therefore, addition of organic materials would help in reclamation process by reducing pH and exchangeable sodium in soils irrigated with sodic waters. iii) Because of small and less active microflora in saline soils, mineralisation of organic nutrient fractions is comparatively lower. So the retention of nutrients in organic forms for longer periods also guards against their leaching and other losses.

Conclusion: Additional doses of inorganic N do not materially change salinity tolerance. Response to applied N is rather reduced under saline irrigation but additions of P reduce toxicity of Cl-domonant saline waters. Use of organic materials for improving response to applied N is also recommended.

4.4.2 Need for amendments

Presence of high sodium in relation to calcium contents in soils, increases the pH and ESP which in turn decrease the soil permeability to water and can also cause nutritional imbalance within the plants. The adverse effects of high- Na on physical and chemical properties of soils can be mitigated by the use of amendments which contain calcium e.g. gypsum. Acids or the acid forming substances such as sulphuric acid or pyrites which on reaction with soil $CaCO_3$ release Ca^{2+} in solution can also be used. The quantity of gypsum for neutralization of each me/L of RSC is 86 kg/ha per 1000 m^3 (or depth of irrigation = 10cm) of water. The agricultural grade gypsum is usually 70-80% pure. The need of gypsum application for ameliorating the sodic irrigation effects is of recurring nature. Application of gypsum has earlier been recommended when RSC of irrigation water exceeds 2.5 me/L. However later researches have shown that factors such as the level of the existing deterioration of the soil, cropping intensity and the water requirements of the crops to be raised will ultimately decide the amount of gypsum required. Field trials have shown that gypsum helps in maintaining yields of the crops irrigated with sodic waters (RSC > 5 me/L) especially when paddy is grown in rotation and rainfall of the area being is < 50 cm. In wheat-fallow rotation, no response to gypsum has been reported on well drained light textured (sandy loam) soils when irrigated with waters having RSC upto 10 me/L..

Once the role of amendments is established for raising crops with alkali waters, questions regarding its mode, amount and time of application have to be answered. Gypsum applied at each irrigation is more effective for increasing crop yields in rice/millet-wheat sequence irrigated with higher RSC (> 10 me/L) waters causing appreciable increase in soil sodicity during the season itself as compared to its single dose applied annually where as response to gypsum, either applied annually as one dose or at each irrigation is similar at lower RSC. While comparing the time of application of gypsum, its application before the onset of monsoons is better than its application before presowing irrigation of the rabi crops.

Conclusion: Gypsum additions to ameliorate effects of high RSC (> 5 me/L) irrigation water is recommended especially when rice-wheat system is practised in areas with annual rainfall < 50 cm

Gypsum Beds

Results of the several studies indicate that gypsum application at each irrigation proves better or at least equal in alleviating the deleterious effects of RSC waters in rice-wheat system. Translation of these results in practical terms require some mechanism for dissolution of gypsum in the irrigation water itself. Such a practice will also eliminate the costs involved in powdering, bagging and proper storage before its actual use. In view of the costs involved, dissolution of gypsum directly in water through the use of gypsum beds or its application to the irrigation channels appears to be an economical preposition. Dissolution of gypsum is affected by factors such as size distribution of gypsum fragments, flow velocity, salt content and chemical composition of water. For flowing water to pick up Ca through dissolution of gypsum, special gypsum bed has been designed (Fig. 3) but it may be mentioned here that gypsum bed water quality improvement technique may not dissolve > 8 me/l of Ca^{2+}.

Conclusion: Passing of high RSC waters through specially designed beds eliminates the costs involved in powdering, bagging and proper storage of gypsum before its actual use.

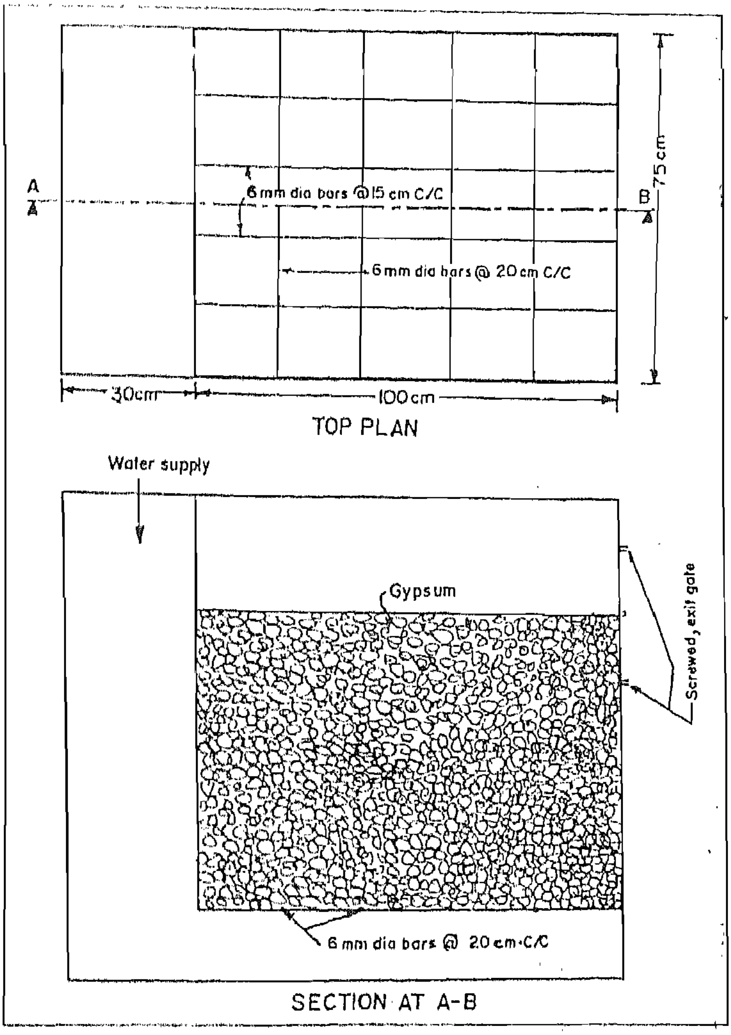


Fig. 3. Design of the tank for gypsum tank

Whether or not to use amendments for saline-sodic conditions should be judged from their effectiveness in improving soil properties and crop growth in relation to the cost involved. It is usually opined that Ca contents in highly saline soils will always be more that the critical (> 2 mmol/L) contents required for plants and desodication occur simultaneous to desalinisation when such soils are leached. But there are instances where leaching of saline-sodic soils lead to rise in their pH, dispersion and disaggregation. Moreover, high SAR-saline soils are prone to infiltration and water stagnation problems mainly during monsoon rains and the changes are irreversible when long term consequences of using high-SAR saline waters are considered. This is contrary to the general faith that saline waters with electrolytic concentrations more than flocculation values help regaining infiltration capacity. With the movement of clay during cycles of irrigations with saline waters and rain water infiltrations during monsoons, the steady infiltration rates are controlled by layers below plough layer where re-mixing of soil separates is not expected to occur. Such soils require small additions of amendments like gypsum to maintain electrolyte concentrations for the stability of aggregates during rain infiltration and hence help in avoiding or alleviating problems of such reduced infiltrability. Since reduced infiltration and crusting problems may also result for the use of saline waters with Mg:Ca > 3 and rich in silica, use of gypsum may prove beneficial.

Conclusion: Use of 1-2 t/ha of gypsum before monsoon rains is recommended when SARw >20, Mg/Ca >3 and saline water is rich in silica to alleviate surface sealing and thus permeability problems.

4.5 Cultural Practices

4.5.1 Planting procedures

Failure to achieve satisfactory germination and thus the required plant population is the major factor limiting crop production with saline waters. Crops like wheat, barley and safflower, though can tolerate fairly high levels of salinity, these are very sensitive at germination and early seedling stages. Thus, planting practices should ensure suitable environment in the seeding zone. Conventional seeding of most crops is done when optimum moisture conditions for tillage and seedbed preparation are attained following a presowing irrigation. After the application of presowing irrigation, the movement of salts towards the surface via. evaporative drying both upto seeding and during the periods of germination and emergence exposes the seeds to soil water of higher salinity especially when saline irrigation is practiced (ECsw > ECiw). This makes the seed germination and emergence even more critical for summer crops seeded under high evaporative conditions. Therefore, the objectives of presowing irrigation should include leaching out the salts of seeding zone through a heavy application of non-saline water wherever possible. The other technique which seems safe to establish crops is to go in for a post-sowing irrigation to push the salts deeper and maintain better moisture conditions. But the timing of this irrigation should be such as to avoid the subsequent crusting problem.

Conclusion: Dry seeding and keeping the surface soil moist through sprinkler/ post-sowing saline irrigation can help in better establishment of crops.

Modifications in the shape of the seed beds can also reduce the salt accumulation near the seed (Fig. 4). The alternative in this direction is sowing near the bottom of the furrows on both sides of the ridges and to apply irrigation in alternate row and seed on the north-east side of the ridges, because the salts move along with water to the drying surfaces and accumulate at the top. For the larger seeded crops, the seeds can be planted in the furrows. The advantage of such a practice can be that the seed will be placed in a wet and a less saline zone as more saline surface soil goes to the ridges during their preparation and a postsowing irrigation will leach the salts of furrow soil more efficiently than those of the ridge soil. In addition to creation of favourable water regimes in the rooting zone during irrigations to furrow (2.5 m apart) planted tree saplings, this method shows the advantage of pushing the salts towards inter-row areas with monsoon rains. Thus, the concept of furrow planting has also been utilised for creating favourable "niches" for the establishment of trees plantations through saline irrigation.

Conclusion: Seed bed modications to create better salt and water regimes can help in better crop establishment with saline irrigation

4.5.2 Row spacing/plant density

As stunted growth and poor tillering of crops are the major cause of yield reductions in saline water irrigated crops, the crop yield, which is the product of stand density (number of plants or tillers per unit area) and yield per plant or tiller, should increase if densities of stunted plants are increased. This can be achieved by narrowing the inter-row and/or intra-row spacings of row crops. Therefore, seeding at 25% extra seed rate is recommended under saline and sodic irrigation conditions.

Conclusion: Reduce inter/intrarow spaces and use 20-30% extra seed to ensure better plant density under saline irrigation.

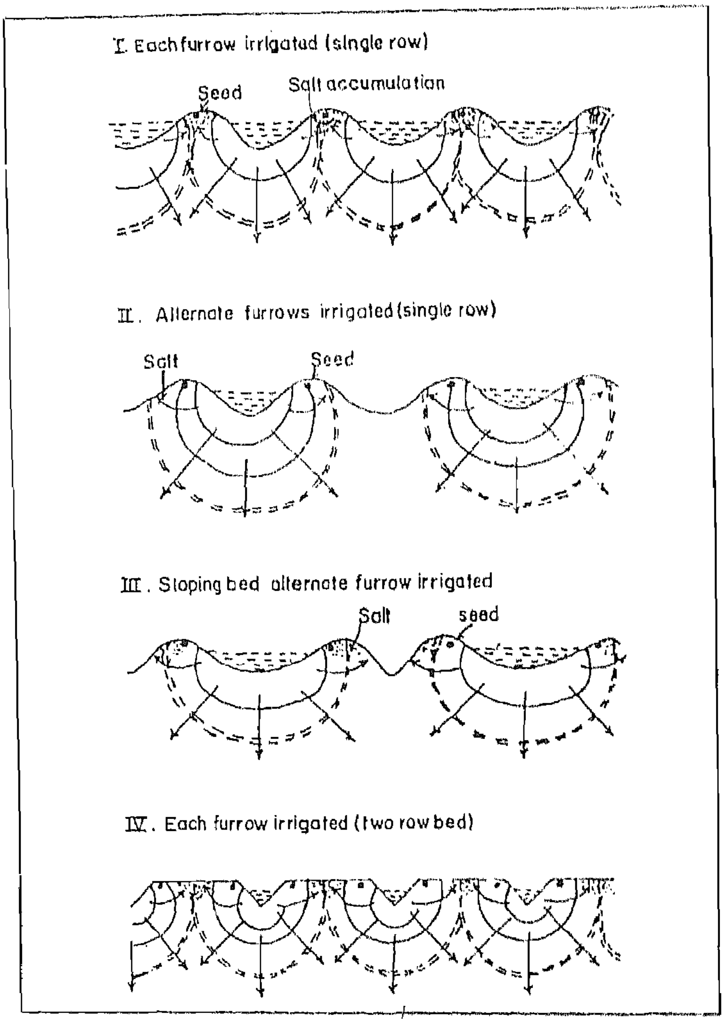


Fig. 4.Schematic diagram showing salt and water movement for various furrow modifications

4.5.3 Tillage/mulching

Tillage and other moisture conservation practices play a crucial role in salt leaching during monsoons when most saline water irrigated soils remain fallow. The emphasis during monsoons should be to maximise the infiltration of rain water into soil and minimise its losses due to run off and evaporation during the periods in between. To achieve this the fields should be properly leveled and bunded, surface soil should be kept open and protected against the beating action of rain drops. This can be achieved through ploughing in between the rains and by adopting other water conservation practices. Besides increasing the intake of rain water, ploughing also helps in controlling the unproductive losses of water through weeds and evaporation. This practice will also reduce the upward movement of salts between rainfall events and increase salt removal by rains. Use of straw mulches can also enhance leaching of salts by rainfall but shortages of straw in saline areas is a serious impediment in adopting this practice.

Conclusion: Adaptation of measures for better intake of rainwater and its conservation in soil via checking unproductive evaporation losses is recommended during monsoon season.

5.0 Water quality Guidelines for Irrigation

As is evident from above discussion that apart from its composition, determination of suitability of a specific water require specifications of conditions of its use (soil, climate, crops etc), irrigation and other management practices followed. Because of inherent problems in integrating the effects of above factors, rigid water quality standards are difficult to develop for universal use. Therefore, broad guidelines for assessing suitability of irrigation waters have been suggested from time to time for average use conditions. A committee of consultants recommended the guidelines for utilising poor quality waters in 1990 for their wider applicability in different agro-ecological zones of India (Table 6). For meeting site specific water quality objectives, factors like water quality parameters, soil texture, crop tolerances and rainfall have been given due considerations. Some of the addendums added to these guidelines for saline waters include use gypsum for saline water having SAR > 20 and/or Mg:Ca > 3 and rich in silica, fallowing during rainy season is helpful when SAR > 20 and higher salinity waters are used in low rainfall areas, additional phosphorous application is beneficial, especially when $Cl:SO_4$ ratio is > 2.0, canal water preferably be used at early growth stages including presowing irrigation for conjunctive use with saline waters, putting 20% extra seed rate and a quick post-sowing irrigation (with in 2-3 days) will help better germination, when ECw < ECe (0-45cm soil at harvest of rabi crops), saline water irrigation just before the onset of monsoons will lower soil salinity and will raise the antecedent soil moisture for greater salt removal by rains, use of organic materials in saline environment improve crop yields, for soils having (i) shallow water table (within 1.5m in kharif) and (ii) hard subsoil layers, the next lower ECiw/alternate modes of irrigation (canal/saline) is applicable.

Table 6. Guidelines for using saline irrigation waters in India

a. **Saline water (RSC < 2.5 me/L)**

Soil texture (% clay)	Crop Tolerance	ECw (dS/m) limit for rainfall region < 350	350-550	> 550 mm
Fine	Sensitive	1.0	1.0	1.5
(>30)	Semi-tolerant	1.5	2.0	3.0
	Tolerant	2.0	3.0	4.5
Moderately	Sensitive	1.5	2.0	2.5
fine	Semi-tolerant	2.0	3.0	4.5
(20-30)	Tolerant	4.0	6.0	8.0
Moderately	Sensitive	2.0	2.5	3.0
coarse	Semi-tolerant	4.0	6.0	8.0
(10-20)	Tolerant	6.0	8.0	10.0
Coarse	Sensitive	--	3.0	3.0
(<10)	Semi-tolerant	6.0	7.5	9.0
	Tolerant	8.0	10.0	12.5

b. **Sodic waters (RSC > 2.5 me/L, EC_{iw} < 4.0 dS/m)**

Soil texture (% clay)	SAR $(mmole/l)^{½}$	Upper limit of RSC (me/L)	Remarks
Fine (> 30)	10	2.5-3.5	Limits pertain to *kharif* fallow/*Rabi* crop rotation when annual rainfall is 350-550 mm. When the waters have Na < 75% (Ca+Mg > 25%) or rainfall is > 550 mm, the upper limit of the RSC range becomes safe. For double cropping neutralization of RSC with gypsum is essential based on quantity of water used during the rabi season. Grow low water requiring crops during *kharif.* Avoid rice.
Moderately fine (20-30)	10	3.5-5.0	
Moderately coarse (10-20)	15	5.0-7.5	
Corase (> 10)	20	7.5-10.0	

EPILOGUE

Long term sustainability of irrigation with saline and alkali waters is possible if favourable salt balance is maintained in the soil and also it does not suffer from physical and chemical degradation. A wealth of data developed by the researchers advocates to follow specified soil-water-crop management practices for safe utilisation of poor quality waters. Substantial evidences generated proved that existing water quality standards were too conservative for the monsoonal climate. Thus to meet site specific water quality objectives, new guidelines were put forward to use saline and sodic waters for irrigation. In addition to water quality parameters, factors like soil texture, solution concentration, crop tolerance and rainfall of the area were given due considerations. For enhancing the ground water development in areas underlain with saline aquifers, the technical knowledge, that gathered over the years, should be transferred through demonstrations. This will test the salient options and guidelines for controlling the build up of salinity/sodicity and sustaining crop yields on farmers fields irrigated with poor quality waters. In addition, feed backs will also come in terms of constraints in their adoption and get possible ideas and needs of farmers those should be incorporated in research.

Associated with saline waters are the problems of toxic elements like B, NO_3 etc. in some pockets and those with sodic waters are the problems of F, Se etc toxicity which may further limit the use of such waters. Water quality guidelines were recently prepared for extensive usage but no recommendation on the use of waters containing such toxic ions could emerge due to lack of data related to their use for irrigation purpose. Therefore, there seems an urgent need to develop strategies for the safer utilisation of such waters. Moreover, with enhanced use of waters in other sectors of economy, greater volumes of industrial effluent, toxic wastes, sewage waters etc. will have to be disposed. Since most of the effluents are land disposed, these are bound to effect ground water quality unless suitable alternate uses are evolved.

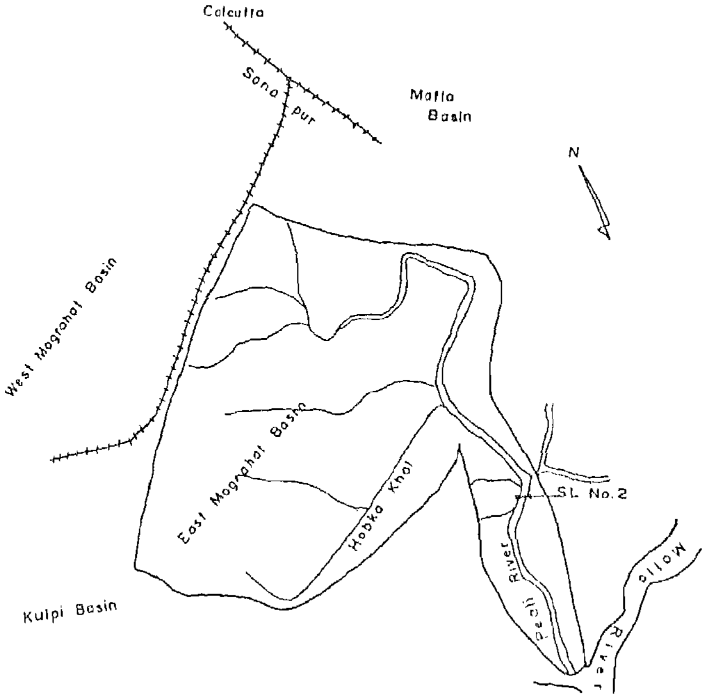


Figure 4.4: Location of East Mograhat Basin drainage project

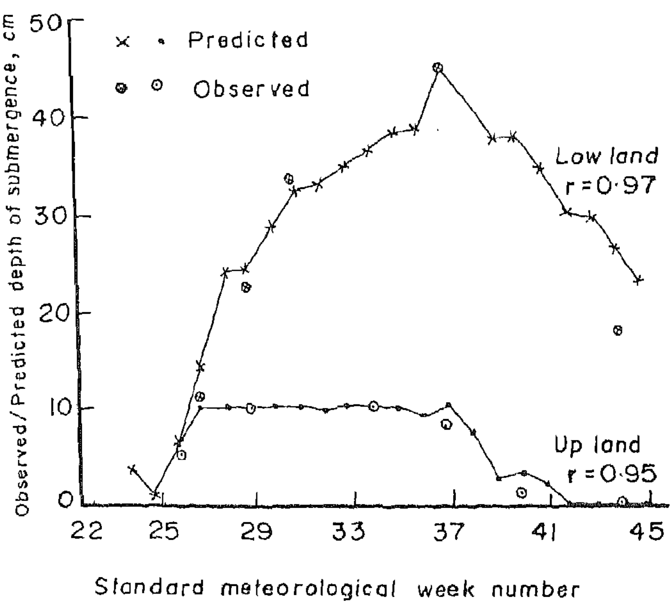


Figure 4.5: Comparison of observed and simulated depth of water submergence

4.4 DESIGN OF ON-FARM RESERVOIR (OFR)

The low cost of construction has made OFR increasingly popular in the Sundarbans region. The design parameters are shape, size, depth, side slope, capacity and location. The dugout type of OFR is most common in flat topography. The prevailing trapezoidal OFR with bund and without bund were considered to determine optimal size of OFR. The length-width ratio of OFR was taken 1:1 as it is having minimum parameter and therefore, attains maximum storage. As groundwater is at shallow depth and saline in nature, the depths of OFR were taken as 2 m and 3 m. The side slope for silty clay loam soil was kept as 1:1.

Probable weekly rainfall values at 2-year return period were used for design of OFR. The initial size of OFR was kept at 40 percent of the farm area. The location of OFR was varied to allow runoff from 10 to 100 percent of farm area. If OFR was found empty a negative increment to size of OFR was provided for further computation. When OFR got filled, the size was considered as optimal and the process was terminated. Computations were made at percolation losses of 3, 4 and 5 mm/day.

A nomograph has been developed to determine the hydrologic and hydraulic features of OFR in unit farm area for various combinations (Figure 4.6). It represents three type of curves i.e. the design dimension curve, OFR capacity curves and rainwater availability curves. Since OFR was considered square in shape the design dimension curve represents the equal length and width of the selected size of OFR. The OFR capacity curves give the information on total volume that can be stored in the OFR of different size.

The capacity curves were plotted for OFR with bund and without bund with 2 and 3 m depths. The rainwater availability curves for different size of OFR i.e. 10, 20, 30 and 40 percent of farm area were generated for construction of OFR at different locations i.e. 10, 50 and 100 percent below farm area which contribute runoff from 10, 50 and 100 percent farm area, respectively. Further, rainwater availability for different percolation losses, as mentioned earlier, were generated.

How to use nomograph

The basic steps for using the nomograph are:

i) note the volume of a particular size of OFR by projecting vertical line to OFR capacity curves and extending it towards volume

ii) note the location of OFR to meet the rainwater availability curve for that

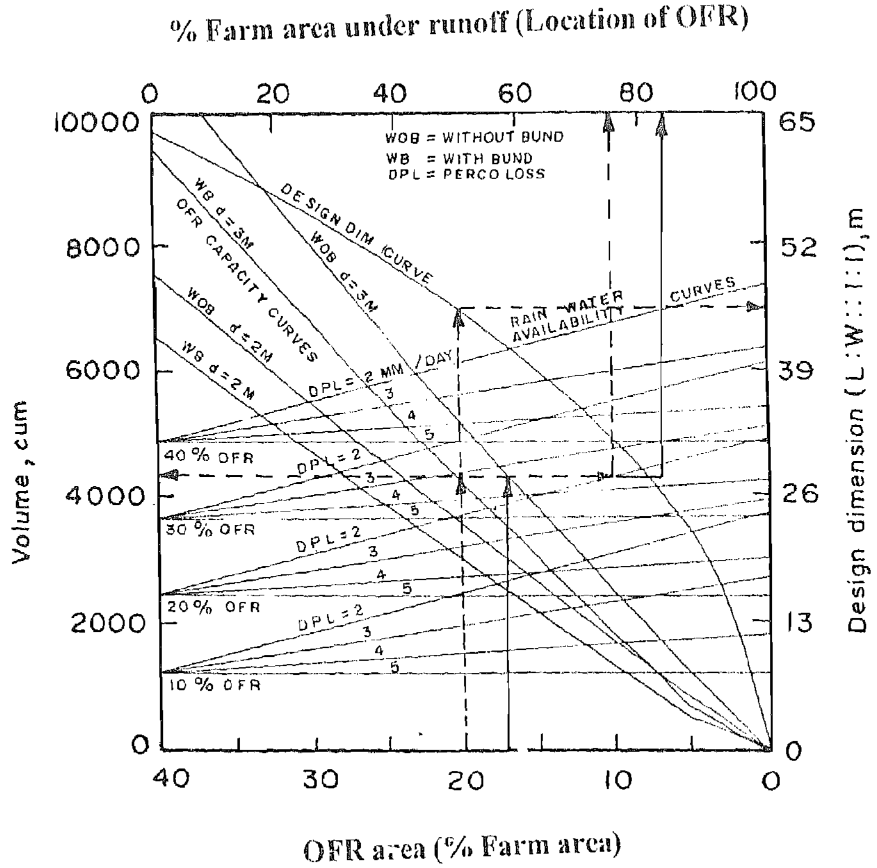


Figure 4.6. A nomograph for optimising hydraulic and hydrologic features of OFR for 1 ha farm area

particular size of OFR and for known deep percolation rate and

iii) note the dimension of OFR by projecting vertical line to design dimension curve.

For example, the solid line in Figure 4.6 represents an optimal 3 m deep OFR without bund in 17 percent farm area in soils with percolation loss rate 2 mm day^{-1} to be placed such that it receives runoff from 83 percent of the farm area to fill rainwater to its designed capacity of 4268 m^3. Similarly the dotted line represents an optimal size of 3 m deep OFR with bund in 20 percent farm area for such soils and placed such that it receives runoff from 75 percent of the farm area. The length and width of OFR in 20 percent area of a hectare should be (44.7 m * 44.7 m). Therefore, it was suggested to convert 17 percent and 20 percent of the farm area into OFR in case of OFR without bund and with bund respectively. However, for making recommendation to farmer's, it was suggested to bring 20 percent of the farm area under OFR in Sundarbans region. The design features of OFR for a unit farm area are shown in Figure 4.7.

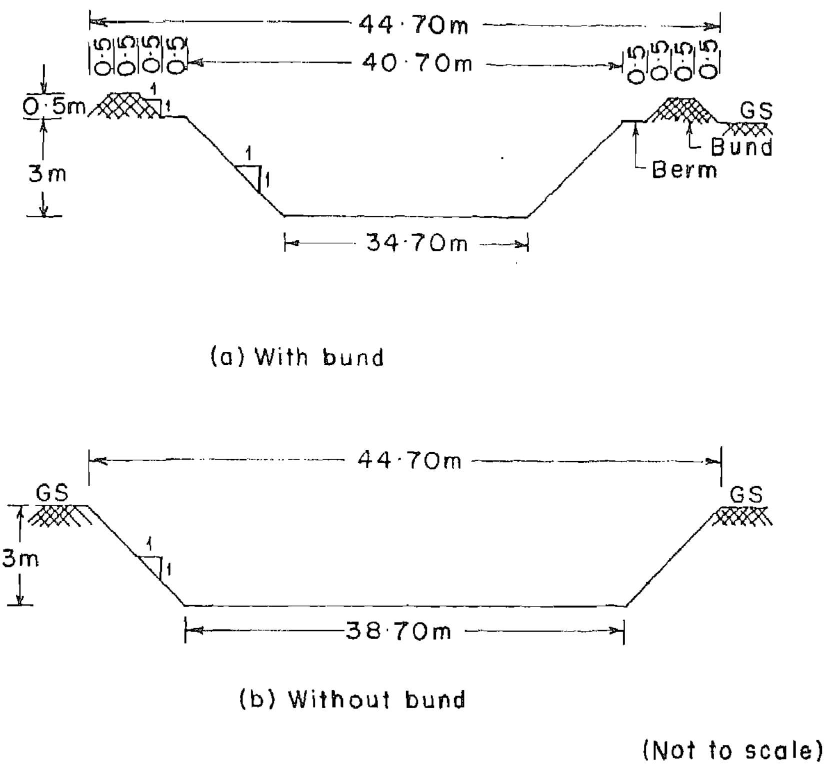
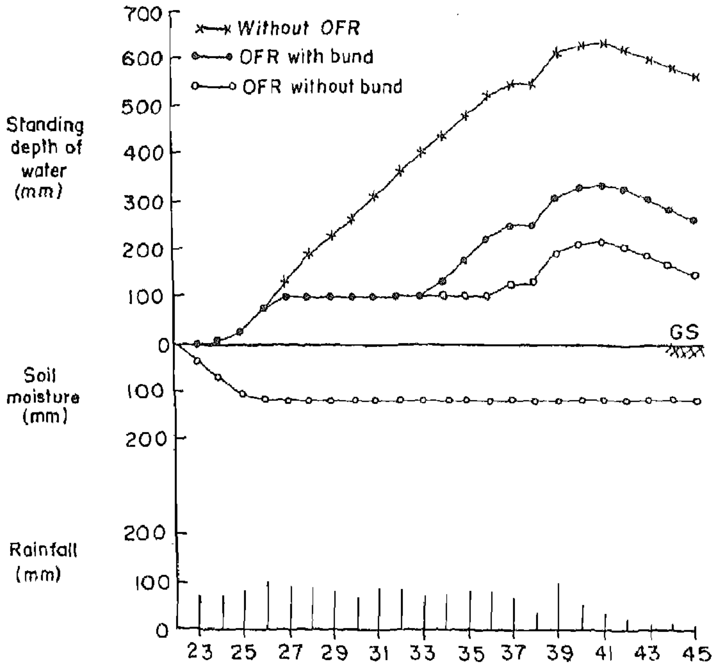


Figure 4.7: Cross section of excavated OFR (20 %) for 1 ha farm area

4.5 SURFACE DRAINAGE IMPROVEMENT DUE TO OFR

In low lying areas of the region, the scope for cultivation of high yielding dwarf rice varieties is almost negligible due to surface waterlogging during critical growth stages. The simulation study was made to assess the improvement in weekly surface waterlogging in lowland areas by diverting excess rainwater into the OFR (with bund and without bund) in 20 percent area over existing low lying area without OFR (Figure 4.8).



Standard meteorological week number

Figure 4.8: Drainage improvement through OFR in lowland rice lands

The water depth hydrographs were generated with probable weekly rainfall at 5 years return period. It was estimated that in a lowland catchment with no drainage, the water submergence may reach as high as 63 cm (Figure 4.8) and therefore the cultivation of HYV rice crop is not possible under existing condition. The water depth hydrograph with OFR (with bund) occupying 20 percent of the area indicated about 45 percent reduction in depth of standing water. It was also estimated that up to 33rd week OFR got filled and thereafter, the water level might reach 35 cm at panicle initiation and flowering stages which are critical to excess water with adverse effect on crop production. In case of OFR without bund in 20 percent farm area, the maximum standing depth of water was estimated 18 cm at the beginning of grain formation stage, which requires optimum submergence. Though, some reduction in crop yield may occur due to excess water at this stage but that would not be significant. In this case the reduction in standing depth of water is to the extent of 75 percent. Therefore, construction of OFR not only provides water for irrigation but also improves surface drainage and thus, makes it possible to grow HYV of rice in lowlands of Sundarbans delta.

4.6 SUPPLEMENTAL IRRIGATION DEMAND

In order to assess the requirement of supplemental irrigation (SI) during *kharif* rice and formulate different water availability constraint for optimal land allocation in *rabi* season, simulation study was made. The pre-conditions for supplemental irrigation (50 mm) were defined as 1) storage in the OFR should be more than one SI for cultivated land; 2) soil moisture in sub-surface should reach below field capacity. On the basis of weekly values at 80 percent annual rainfall (no rainfall after 37^{th} week), it was estimated that at least one supplemental irrigation is needed at the time of grain formation stage in two out of ten years (Figure 4.9). This will stabilize the crop production against the weather uncertainty.

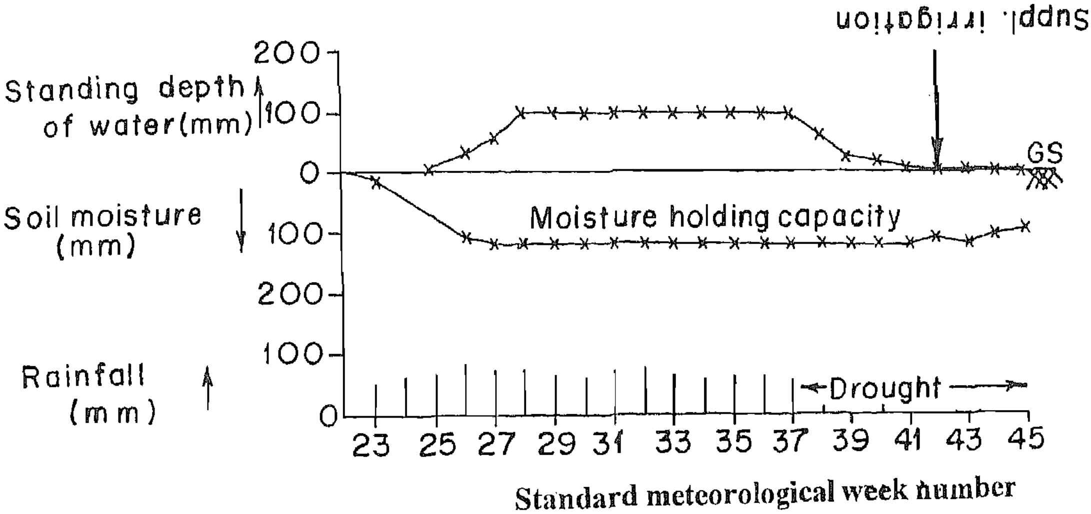


Figure 4.9: Supplemental irrigation demand for *kharif* rice

4.7 CONCLUSIONS

In rainfed humid regions, optimal design of OFR for storage of excess rainwater is not only important for supplemental irrigation and life saving irrigation for crop cultivation but it also improves the surface drainage. A soil water balance model for rainfed rice cultivated in humid, deltaic rice land was developed to estimate the excess rainwater availability. It was recommended to convert 20 percent of the farm area into OFR to harvest excess rainwater. The proposed OFR design nomograph is of great use for developmental agency as ready reckoner. The procedure suggested may be used for optimal design of on-farm reservoir in different agro-ecological conditions. Improvement in surface drainage through rainwater storage in OFR provides scope for introduction of high yielding rice varieties in rainfed rice lowlands.

CHAPTER V

CROP PLANNING

Crop planning involves selection of crops, varieties and planting schedules to suit the land topo-sequences, soil type, availability of water and other inputs. Since more than 80 percent cultivated area in the region is medium to low lying, scope of *kharif* crops other than rice hardly exists. Therefore, planning efforts are limited to selection of rice varieties (duration as criteria) and their planting schedule under different topo-sequences with water availability constraints during *kharif* and optimal sowing period for *rabi* crops to safeguard damage due to heavy rainfall at the time of harvest.

5.1 METHODOLOGY

The following steps are involved in development of improved crop plan for Sundarbans region:

1. Water balance analysis to prioritise the problem of different topo-sequences

2. Assessment of onset of monsoon for *kharif* planning.

3. Development of *kharif* planting strategies for various farming situations prevailing in Sundarbans delta.

4. Assessment of probability of pre-monsoon showers at the time of crop harvest for *rabi* planting.

5.2 PROBLEM PRIORITIZATION

The model described in the previous chapter (4.1) is used to assess the extent and magnitude of surface waterlogging/moisture stress for the different topographic conditions i.e. low, medium and up lands which exists in Sundarbans delta. The heights of field dike (H_{FD}) for low, medium and up lands are taken as 700 mm, 350 mm and 150 mm respectively. The excess water more than the H_{FD} is considered as excess water spilled to the drainage system. The probable rainfall at 5 and 2 year return periods are used to assess the extent of surface waterlogging and drought respectively (Figures 5.1-5.4).

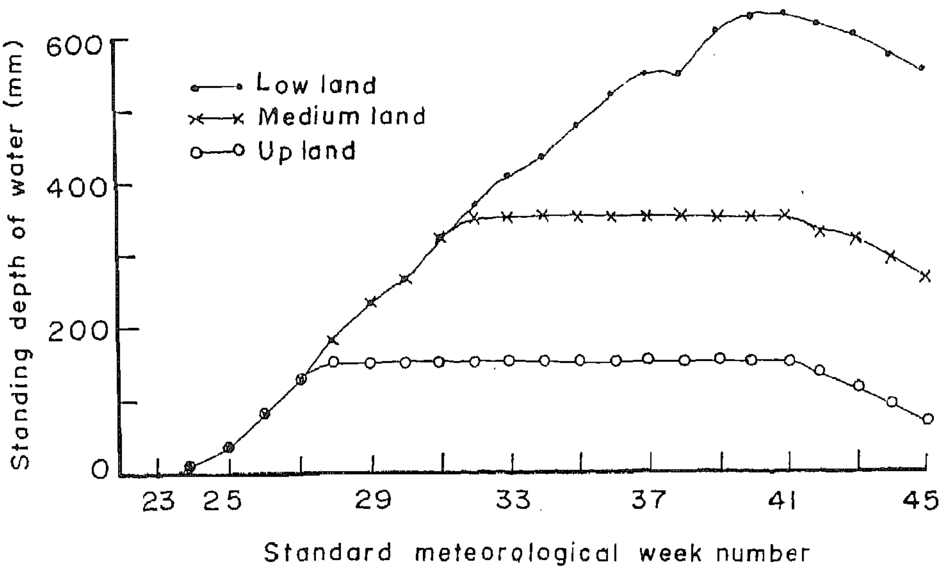


Figure 5.1: Surface waterlogging in different topographic conditions (at 5 years return period rainfall)

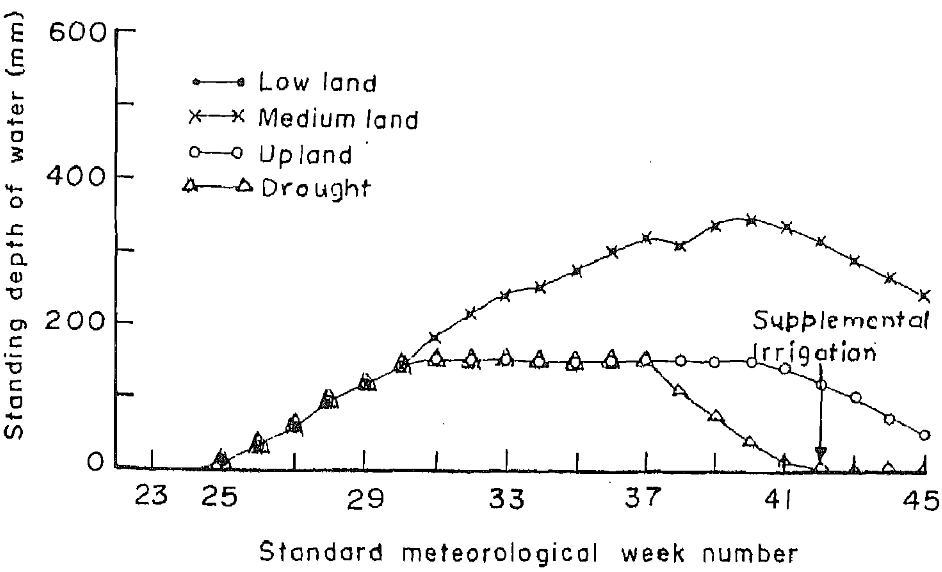


Figure 5.2: Surface waterlogging in different topographic conditions (at 2 years return period rainfall)

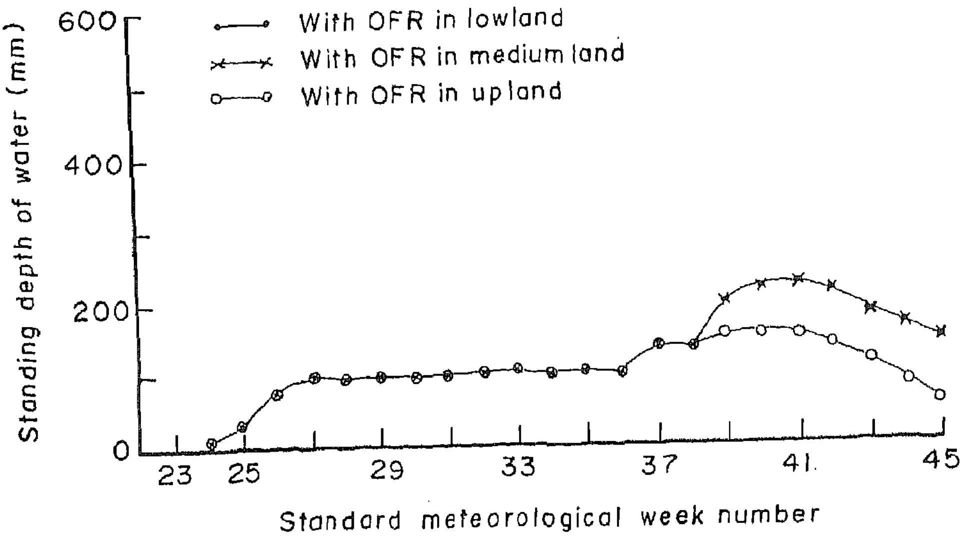


Figure 5.3: Reduction in surface waterlogging due to storage in OFR (at 5 year return period)

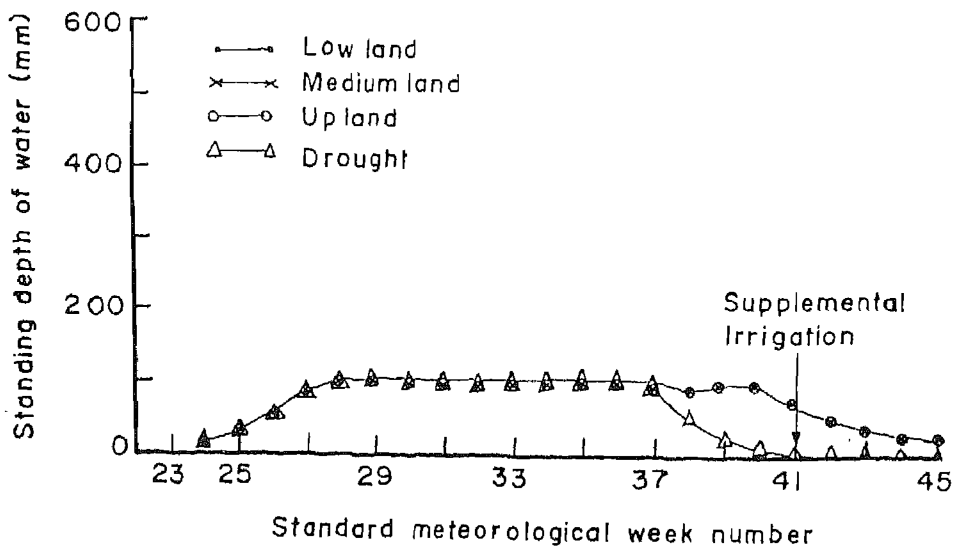


Figure 5.4: Reduction in surface waterlogging due to storage in OFR (at 2 year return period)

It is observed that once in five year, the standing depth of water (SDW) in low-lying area would reach to as high as 63 cm (Figure 5.1). In medium and up lands, SDW is observed to reach the respective height of their field dikes and remains almost for entire crop growth period. When simulated with rainfall at 2 year return period, the SDW in low and medium land reached to only 34 cm but, for a major period SDW is observed quite high (Figure 5.2). The cultivation of high yielding dwarf rice variety is seen possible only in case of upland areas where SDW remains at the height of field dike. However, in case of prolonged drought (no rain after 37[th] week) as observed in the study area, a supplemental irrigation is required at later stage of crop growth.

The low cost of construction has made OFR increasingly popular in Sundarbans region. Therefore, the water balance simulation is also made to study the reduction in surface waterlogging when OFR in 20 percent farm area provided in all the three topographic conditions. It is observed that even at 5 year return period rainfall, the optimum SDW can be maintained for a considerable period (Figure 5.3). The crop production will be affected only at later stage of crop growth. It is also observed that every alternate year (at 2 year return period rainfall) the potential crop production can be taken if OFR is provided in the farm (Figure 5.4). In case of prolonged drought the supplemental irrigation can be met through OFR. The water balance components at 5 year return period for different topographic conditions are given in Table 5.1.

Table 5.1
Water balance parameters for different topographic conditions
(at 5 years return period rainfall, mm)

	Lowland	Lowland +OFR	Medium land	Medium land+OFR	Upland	Upland +OFR
Rainfall	1707	1707	1707	1707	1707	1707
Evaporation	189	189	189	189	189	189
Evapotranspiration	551	550	550	550	550	550
Percolation loss	280	280	280	280	280	280
Final MC at the end	120	120	120	120	120	120
Excess rainwater to OFR	-	409	-	409	-	409
Excess rainwater drained	-	-	280	-	495	20
Final SDW at the end	567	158	287	158	72	38

5.3 ONSET OF MONSOON

To determine the time of pre-sowing and sowing operations in case of *kharif* rice, probability of monsoon onset was assessed (Figure 5.5). The chances of receiving at least 100 mm rainfall during pre-monsoon showers (19th-23rd week) was 60 percent. Therefore, it is suggested to initiate off-season tillage practices from 19th week. Since the area is mostly saline in nature, sowing is not recommended during 19th to 23rd week. It is suggested to allow storage of rainwater in the field to flush/leach down the salts accumulated in the soil surface/profile during the dry season. The rainfall at all probability levels increases after 23rd week. The minimal assured weekly rainfall exceeds 20 mm in every eight out of ten years from 24th week onwards. It may therefore be desirable to sow rice nursery from 24th week onward.

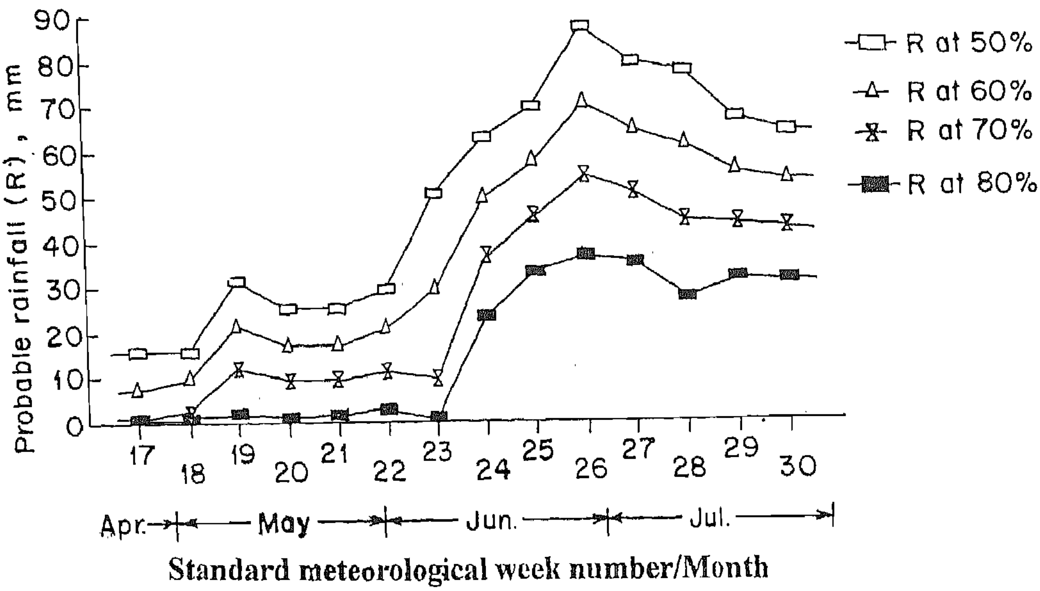


Figure 5.5: Probable onset of monsoon

5.4 OPTIMAL *KHARIF* PLANTING

In order to make best use of the expected weekly rainfall potential and its distribution at critical growth stages, sowing time are adjusted for different crop duration (long - 22 weeks, medium -19 weeks and short - 16 weeks) varieties. The period of nursery is taken for commonly practiced varieties (long & medium - 4 weeks, and short - 3 weeks) in the region (Table 5.2), whereas the critical stages are worked out (Figure 5.6) on the basis of the growth patterns reported by Tanka (1976).

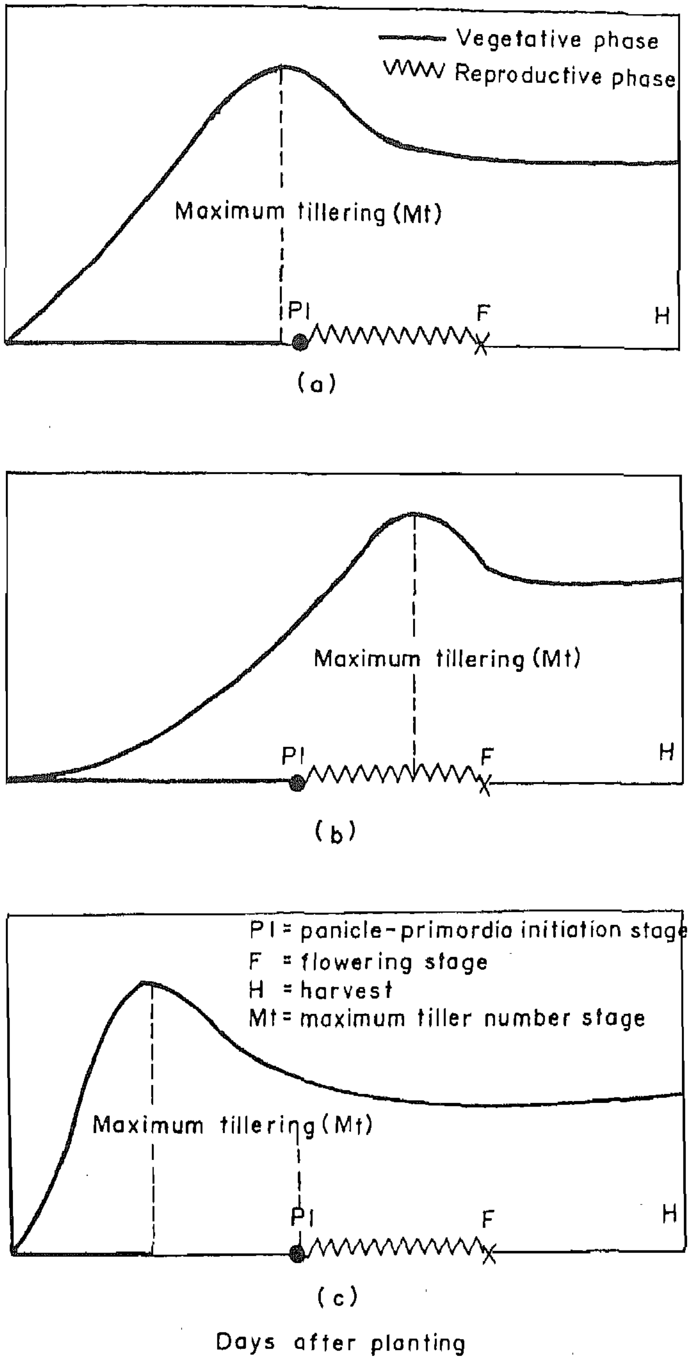


Figure 5.6: Growth pattern of short (a), medium (b) and long (c) durations rice

Table 5.2
Common rice varieties in Sundarbans region

Depth of water (cm)	Variety	Duration (days)	Yield (t/ha)
Up to 15 cm	Ratna, Cauvery, CSR-4	110	1.7-4.0
15 - 25 cm	Jaya, IR8	120-130	1.5-4.0
	Mashuri, Pankaj	>130	1.5-4.0
25 - 50 cm	SR-26B, Kalamota, Nona-Bokra	>130	1.5-2.5

(Source: Sinha, 1981)

Rice being semi-aquatic plant needs continuous submergence for potential crop yield. Biswas *et al.*, (1982) reported that at least 2.5 cm continuous water submergence was essential for obtaining the potential yield of rice crop. However, under excess submergence the normal physiological functions of the plants may be impaired. Pandey (1976) observed reduction in yield in the order of 18-50 percent due to excess submergence (> 25 percent of the plant height) at any of the critical stages, i.e. initial tillering (I_T), panicle initiation (P_I) and flowering. Further, it was indicated that panicle initiation stage was the most susceptible stage to excess submergence. Mishra and Khandelwal (1987) also made the similar observation. In terms of moisture stress, on the other hand, grain formation (G_F) stage is taken as most susceptible.

Keeping above agronomic requirements for potential crop production, evapotranspiration (AET) demand of different duration variety with different sowing period was generated using equations 3.3 & 3.4. The least assured rainfall (R) at different probability levels are super-imposed (Figures 5.7) for crop planning under various situations.

5.41 Lowland Condition

In rice lowlands, the surface waterlogging is considered important from planning purposes. The water balance study in lowlands where OFR are not available indicates that the magnitude of surface waterlogging remains high for almost entire crop growth period. Therefore, short duration dwarf varieties are bound to suffer from surface waterlogging as there are five chances out of ten years of having weekly rains more than 60 mm up to 37th week, which may cause significant reduction in production or even total crop failure. Long duration tall variety is the only alternate in such areas as it has very high tolerance to water submergence (Figure 5.7a). It is suggested to sow long duration varieties from 24th week (AET_{24}) at expected onset of monsoon in order

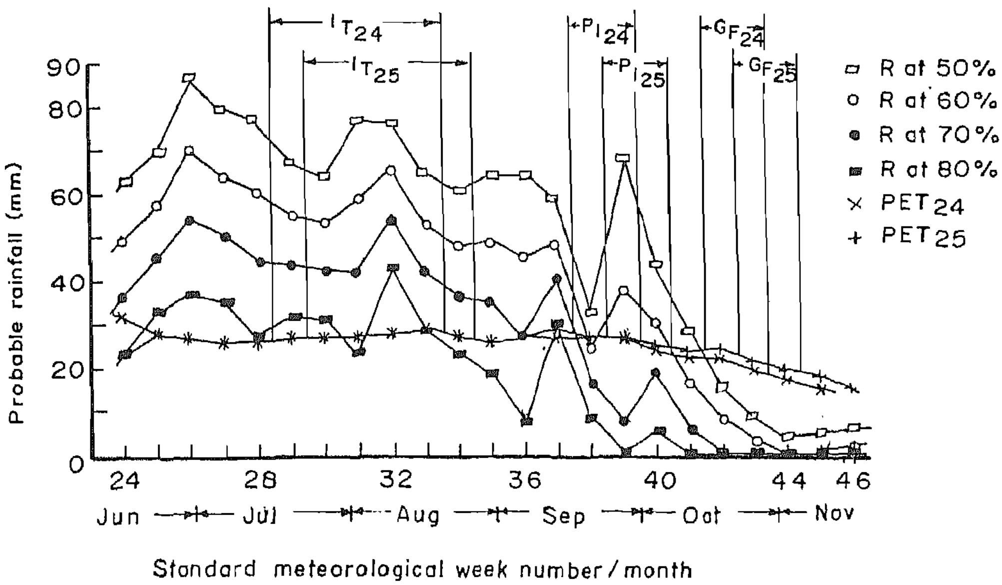


Figure 5.7(a): Probable R-AET relationship for long duration rice during *kharif* season

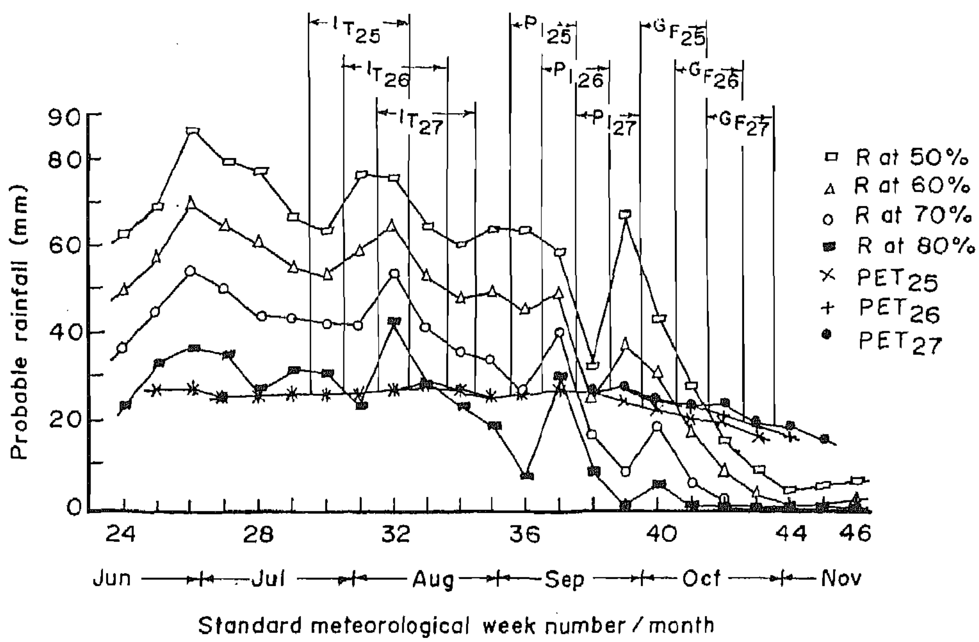


Figure 5.7(b): Probable R-AET relationship for medium duration rice during *kharif* season

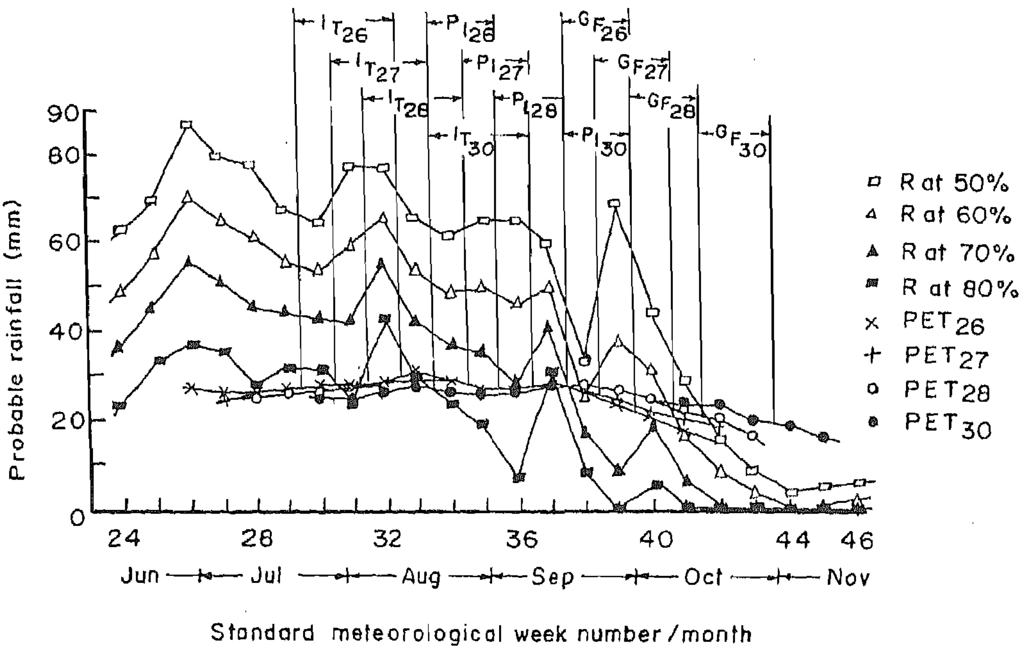


Figure 5.7(c): Probable R-AET relationship for short duration rice during *kharif* season

to minimize the duration of probable drought at later stage of crop growth in the years of deficit rainfall. Transplanting in 28th week will relatively lead to improved environment for initial tillering (I_T) during 28th, 29th and 30th week. There are five out of ten chances to receive rainfall higher than 150 mm during 31st and 32nd weeks at the time of maximum tillering, may not be very harmful as crop attains certain height to tolerate high water level. At 2 year return period, AET requirement is higher than R after 41st week, which indicates moisture stress in every alternate years at the time of grain formation stage, however it will be met by accumulation of rain water in previous weeks. Delay in sowing by a week may even cause reduction in production due to waterlogging in the beginning of panicle initiation (P_{I25}) which is the most sensitive stage, as considerably high amount of rain (at least 200 mm once in five years) is expected in 39th week. On the other hand, duration of probable drought at the time of ripening may also extend.

In low lying areas where OFR is available, it is suggested to sow medium duration varieties in 25th (PET_{25}) week (Figure 5.7b) as once in five year accumulation of rain water at panicle initiation (P_I) and grain formation (G_F) stages may severely affect the short duration high yielding dwarf rice. The excess rainfall more than SDW_{max} may be diverted to OFR and thus it provides appropriate water regime till 36th week and allows proper establishment of seedlings and potential tillering. The required water level in such areas can be maintained even at 2 year return period rainfall. Though, a supplemental irrigation may be required in case of prolonged drought (no rain after 37th week) as observed in the study area, it can be taken care of by providing supplemental irrigation from OFR. Sowing of medium duration crop in lowlands would also provide relatively much longer time for land drying before tilling for second crop cultivation in *rabi*, which is otherwise normally delayed because of excess soil moisture.

5.42 Medium Land Condition

The medium lands (where OFR is not available) are by and large represents the problem of lowland except the low magnitude of waterlogging confined to the height of field dyke (H_{FD}), but the extent of waterlogging remains the same as of lowland. Therefore, sowing of short duration high yielding dwarf rice is not recommended in such areas. Sowing of medium duration varieties is suggested in 25th week as it has fairly high tolerance for submergence (Figure 5.7b). Moreover, the accumulated rainwater in the field can take care of the probable drought in the years of deficit rainfall.

In case of medium land condition where OFR is available and therefore surface waterlogging reduces to a great extent by diverting excess rainwater to OFR, it is suggested to sow short duration dwarf varieties in 30_{th} (PET_{30}) week so as to transplant in 33rd week and thereby avoid the possibility of high waterlogging at the time of panicle initiation (Figure 5.7c). Supplemental irrigation may be provided in case of drought prolongs to grain formation stage. Sowing of short duration dwarf variety before 29th week is not advisable as it has fair chances of yield reduction or crop damage due to high waterlogging at panicle initiation, grain flowering or at the time of ripening.

5.43 Upland Condition

In upland rice, conservation and storage of adequate moisture in soil for sustained growth and development are important aspects of water management. Short duration high yielding dwarf rice with low water demand are only suitable for uplands (with or without OFR) in order to reduce the chances of water stress at critical growth stages. Since optimum water submergence at initial tillering and panicle initiation stage and no submergence at the time of ripening are the prime agronomic requirements for potential yield in case of dwarf varieties, it is observed that sowing of short duration rice in 26th week may ensure essential 2.5 cm of submergence at critical stages as there is continuous wet period upto 37th week (Figure 5.7c). On the other hand, probability of rain is low during ripening. A considerable high amount of rainfall expected at the time of maximum tillering in 31st week, may not be harmful due to runoff of excess water to the drainage system or storage in OFR. However, delay in sowing is not advisable as it increases the chances of damage due to high rainfall at initial tillering which is a crucial stage. Also high rainfall may occur at the time of flowering in 39th week. In uplands, where OFR is not available and moisture stress at later stage of crop growth particularly at flowering is expected, it is suggested to practice *in-situ* moisture conservation techniques (Sen & Bandhyopadhyay, 1989).

Optimal planting time for different topographic conditions with OFR availability constraints are summarized in Table 5.3.

Table 5.3
Recommended duration and planting time for *kharif* rice under different farming situations in Sundarbans

Farming situation	Availability of irrigation (OFR)	Recommended crop duration	Time of Sowing
Upland	Yes	Short duration	26th week (26 Jun - 02 Jul)
	No	Short duration	26th week (26 Jun - 02 Jul)
Medium land	Yes	Short duration	30th week (23 Jul - 29 Jul)
	No	Medium duration	25th week (19 Jun - 25 Jun)
Lowland	Yes	Medium duration	25th week (19 Jun - 25 Jun)
	No	Long duration	24th week (12 Jun - 18 Jun)

5.5 *Rabi* Planting

Though a meager area is under *rabi* crop cultivation in the region, it too gets damaged due to heavy rainfall coupled with cyclone particularly at the time of harvest. Therefore, for *rabi* planting planning is made by assessing the probability of pre-monsoon showers at the time of crop harvest (Figure 5.8). It indicates that there are fair chances of occurrence of rainwater more than 60 mm at 5 years return period after 16th week. The problem area in general is having heavy textured soil and therefore accumulation of water more than 60 mm damages the crop for which reason has to be investigated. It is suggested to start land preparation for *rabi* cultivation from 46th to 48th week, followed by sowing in 49th week and harvest the crop before 16th week. This leaves room for a third short duration summer crop (green manure or fodder) after *rabi* harvest.

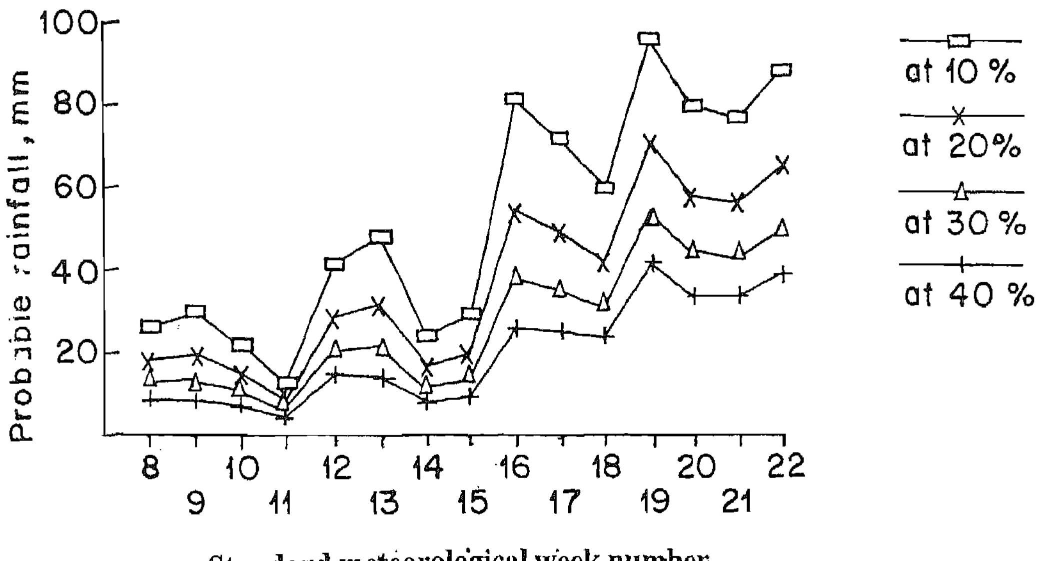


Figure 5.8: Probability of rainfall at *rabi* crop harvest

Based on probable weekly water balance a crop calendar was prepared (Figure 5.9). This takes into consideration the suitability of crops for the region and their agronomic management practices.

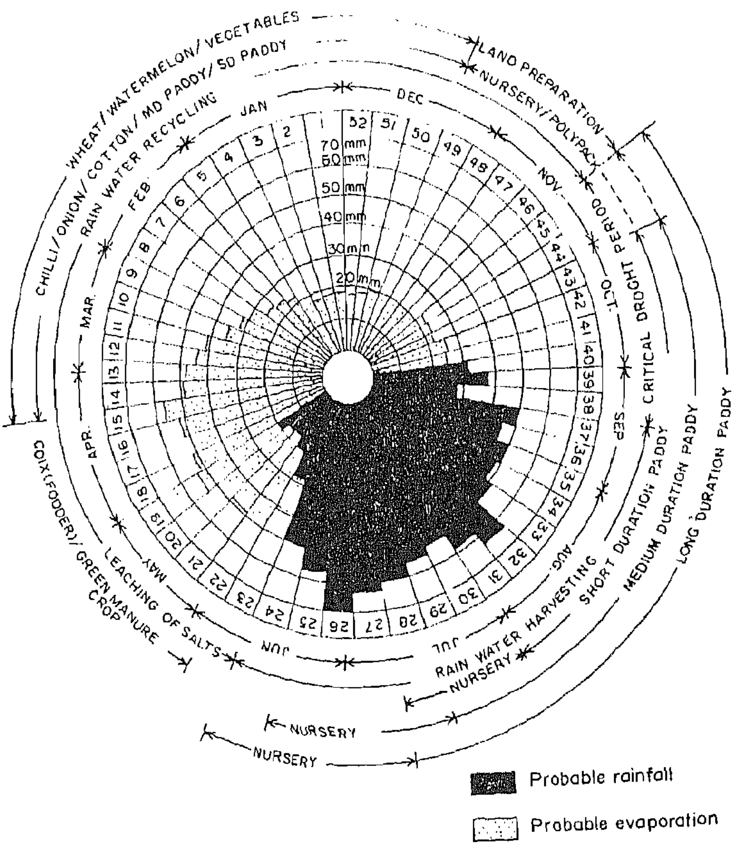


Figure 5.9: Recommended crop calendar for Sundarbans delta

5.6 CONCLUSIONS

In rainfed humid lands, the rainfall amount, pattern, its frequency and intra-seasonal fluctuation influence the cropping schedule as well as selection of crop. The variability in rainfall amount are often correlated with fluctuation in production. In order to stabilize the crop production, weather based crop planning is proposed for various land sequences existing in Sundarbans delta. This includes the planting schedule and the duration of variety with respect to availability of water in on-farm reservoir. A crop calendar is also proposed to schedule the farming operations in Sundarbans delta. The guidelines will help the farmers of the Sundarbans region to schedule farming operations in order to minimize the adverse effect of climate.

CHAPTER VI

RESOURCE PLANNING

Rainwater harvesting through OFR can make available only limited quantity of water. To keep the economics of OFR in favorable range, it is imperative that water is used for crops that are of high value and have higher water productivity. Optimal land and water allocation amongst different crops may help achieving this objective. Linear programming (L.P.) formulations are normally used to arrive at the optimal mix of crop activities (Palanisami, 1992). A simple L.P. model is used in the present case.

6.1 MODEL FORMULATION

The objective herein for application of linear programming algorithm is that the judicious allocation of limited water available in OFR will maximize the net annual profit and therefore, to determine an optimal allocation of land and water that may be adopted for irrigating an area through optimal size of OFR. The objective function therefore, includes returns from the irrigated area under different crops through OFR and cost of water stored in OFR (includes cost of OFR and a penalty cost for making OFR area out of production during *kharif* season). It is assumed that inputs other than land, water and labour are at fixed level.

6.1.1 Objective Function

$$\text{Max } NP = \sum_{i=1}^{n} ((C_i * Y_i) - P_i) * A_i - Cs * S \tag{6.1}$$

Where,

i	= Index for crop
NP	= Net annual profit, Rs/ha
A_i	= Area under crop i, ha
C_i	= Unit sale cost of crop i, Rs/ton
P_i	= Unit cost of production of crop i, Rs/ha
Y_i	= Yield of crops per unit area, ton/ha
Cs	= Unit cost of water in OFR, Rs/m^3
S	= Total stored volume in OFR, m^3

6.1.2 Constraints

Irrigation requirement constraint

Since the limited water is available in OFR, the maximization of net profit depends upon the area allocated and irrigation requirement of the crop. Therefore, the sum of water demand of crops should not exceed available water in OFR (Initial storage - Seepage - Evaporation) during the period of growth.

$$\sum_{i=1}^{n} GIR_i * A_i - (S - WL) < 0 \qquad (6.2)$$

Where,

GIR_i = Gross irrigation requirement for crop i, m^3/ha

WL = Water losses from OFR observed at the rate of 5 mm/day (for 135 days), m^3

Land use constraint

Based on optimal size of OFR (20 percent of the land holding), it is considered that the percentage acreage available for crop cultivation is limited to 80 per cent of total available area. Therefore, the sum of the allocated area under different crops should not exceed to total available area.

$$\sum_{i=1}^{n} A_i - L < 0 \qquad (6.3)$$

Where,

L = Total available land area, ha

However, the acreage under chilli and cotton crops should not exceed a given value due to the risk of crop damage by heavy rainfall at the time of harvest. Rice is the most demanding but safe crop against the weather uncertainty and therefore, the minimum acreage under rice is desirable. The limits on area under different activities are shown as under:

$$A(3) < A_{max}(3) \qquad (6.4)$$

$$A(4) < A_{max}(4) \qquad (6.5)$$

$$A(5) < A_{max}(5) \tag{6.6}$$

$$A(1) > A_{min}(1) \tag{6.7}$$

Where,

A = Area under crop
A_{max} = Maximum area under the crop
A_{min} = Minimum area under the crop

The crop activities and limits placed on the crop area are given in Table 6.1.

Table 6.1
Crop activities and area constraints

Crop	Maximum area (%)	Minimum area (%)
Rice (A1)	-	20
Wheat (A2)	-	-
Cotton (A3)	50	-
Chilli (A4)	50	-
Cucumber (A5)	20	-
Watermelon (A6)	-	-
Pumpkin (A7)	-	-
Ridgeguord (A8)	-	-

Labour constraint

Most of the non-rice crops are labour intensive because irrigation is often applied through pitcher and inter-culture operations also require considerable labour. Since, labour availability is low and net profit significantly depends upon the labour requirement for a specific crop, a constraint is placed on labour requirement.

$$\sum_{i=1}^{n} A_i * Lr_i - La < 0 \tag{6.8}$$

Where,

Lr_i = Labour requirement for unit area for crop i, man-days/ha
La = Total labour availability, man-days.

6.2 MODEL APPLICATION

The model is applied for farmer's field at Nikarighata village in Canning block of Sundarbans delta. In this village, storage of rainwater in OFR (both bunded and unbunded) is quite common for domestic purposes but a few farmers use the stored water in OFR for crop cultivation. However, the size of the pond is not sufficient for irrigating the entire land holding under their possession and thus resulting low net returns (in case of low water demanding crop) or in some year they face the problem of crop failure (in case of high water requirement crop).

A set of bunded and unbunded OFR in this village was selected for model application. The hydraulic and storage features of OFR are given in Table 6.2. The total storage in bunded and unbunded OFR was estimated 1050 m^3 and 5225 m^3 at full level. The water losses from OFR were estimated based on measurements of storage, seepage and evaporation losses. Taking the surface area of OFR and crop duration into account, the water losses as seepage and evaporation were estimated to be 270 m^3 and 1355 m^3 for OFR with bund and without bund, respectively.

Table 6.2
Specifications of OFR with and without bund at Nikarighata in Sundarbans delta

Specifications	With bund (Case I)	Without bund (Case II)
Size of OFR, (m)	30.0 * 19.4	60.0 * 33.5
Area of OFR, (Sq m)	582	2010
Submergence area, (Sq m)	400	2010
Depth of OFR, (m)	3.00	2.75
Estimated OFR volume, (m^3)	1100	5225
Net cultivated area, (Sq m)	2325	7933
Estimated water loss from OFR, (m^3)	270	1355

The water requirements of different crops were estimated using pan evaporation method (Doorenbos and Pruitt, 1977). On the basis of 2 years (93-94 and 94-95) experiment in the farmer's field, the input on labour, cost of cultivation (includes pumping cost) and net profit per unit area for different crops were generated (Ambast and Sen, 1994(b)). The inputs on water use, labour requirement and net profit are given in Table 6.3.

Table 6.3
Input use per hectare in Sundarbans delta

Crop	Water use (ha cm)	Labour (days)	Net agril profit (Rs)
Rice	86	105	7280
Wheat	26	94	2910
Cotton	26	168	3275
Chilli	22	475	6550
Cucumber	30	294	4730
Watermelon	26	135	4000
Pumpkin	26	120	3275
Ridgeguard	26	135	2550

6.3 LAND AND WATER ALLOCATION

In the existing cropping pattern rice crop is cultivated through OFR, which causes shortage of water or crop failure in rainfall deficit years. The optimal area allocation to different crops is shown in Table 6.4. As per the allocation during *rabi* season in the years of normal rainfall, rice should be grown only in 20 percent of area and rest should go to non-rice crops in farms provided with bunded OFR. Under non-rice crops 50 percent area is allocated to chilli crop whereas 15 percent area allocated to each cucumber and watermelon. In case of OFR without bund, 40 percent rice and 60 percent non-rice crops (chilli- 50 percent and cucumber 10 percent) show optimal solution to maximum net profit. The increase in cost of rainwater storage in OFR does not change water allocation and henceforth indicates the stability of the suggested crop allocation.

6.3.1 Effect of deficit rainfall

In rainfall deficit years, it is stipulated that a supplemental irrigation (SI) of 5 cm is to be provided during *kharif* and thus would reduce water availability for *rabi* by similar amount. The optimal allocation indicates that the percentage acreage under rice crop is reduced by 10 percent but irrigation intensity (percent area irrigated) remains the same as 10 percent land now allocated to cucumber in case of OFR without bund. In case of OFR with bund the percentage rice area remains the same as there is a constraint on the minimum area under rice but the irrigation intensity reduced to 20 percent.

Table 6.4
Optimal crop allocation for OFR at Nikarighata village

Crop	Area allocation							
	OFR full		OFR empty to a supplemental irrigation (SI)		80 % labour		OFR empty to a SI + 80 % labour	
	Case I	Case II	Case I	Case II	Case I	Case II	Case I	Case II
Rice	464 (20)	3173 (40)	464 (20)	2380 (30)	464 (20)	3173 (40)	464 (20)	2777 (35)
Wheat	-	-	-	-	-	793 (10)	-	-
Cotton	-	-	-	-	-	-	-	-
Chilli	1160 (50)	3967 (50)	1160 (50)	3967 (50)	814 (35)	3174 (40)	928 (40)	3173 (40)
Cucumber	348 (15)	793 (10)	-	1587 (20)	232 (10)	-	116 (5)	-
Watermelon	348 (15)	-	232 (10)	-	812 (35)	793 (10)	348 (15)	1586 (20)
Pumpkin	-	-	-	-	-	-	-	-
Ridgeguard	-	-	-	-	-	-	-	-
Net agril profit in *rabi* (Rs)	759	2420	548	2217	662	2071	496	1867
Net agril profit in *kharif* (Rs)	667	2912	667	2912	667	2912	667	2912
Total profit from OFR(Rs)	1426	5332	1215	5129	1329	4983	1163	4779

Data in parenthesis represents percentage acreage to total area
Additional Income from horticulture - Case I @ Rs 440 and Case II @ Rs 0
Additional Income from pisciculture - Case I @ Rs 2525 and Case II @ Rs 12000

6.3.2 Effect of labour inadequacy

Labour is the major constraint in the region particularly when non-rice crops are irrigated manually with water applied through pitcher. Therefore the effect of labour availability on crop allocation is studied. Sufficiency of labour is estimated on the basis of average demand for chilli and wheat crop, as these are the most and least labour intensive crops. When labour sufficiency is reduced by 20 percent in case of OFR with bund, a reduction by 15 and 5 percent, respectively in chilli and cucumber crop area is noticed but the area of watermelon increased by 20 percent. Therefore, irrigation intensity remains the same. The rice area also remains the same due to constraint on minimum area under rice. In case of OFR without bund, the optimal allocation shows no change in rice area but there is 10 percent reduction in chilli area. The allocation of 10 percent area is shifted to wheat crop, which is the least labour requiring crop.

6.3.3 Effect of interaction of water and labour inadequacy

In case non-availability of labour by 20 percent and reduction in available water during *rabi* due to its use during *kharif* (as SI), it is noticed that the rice area remains the same due to lower limit but chilli and cucumber reduced equally by 10 percent in OFR with bund. Therefore, irrigation intensity reduced by 20 percent. In case of OFR without bund, the reduction in rice area is 5 percent but chilli and cucumber both reduced equally by 10 percent. Since 20 percent area is allocated to watermelon it caused a reduction of only 5 percent irrigation intensity.

6.4 ECONOMIC EVALUATION

To evaluate the economic feasibility of OFR, technical efficiency in terms of cost of water development and productivity per unit water storage are estimated. The life of OFR is taken as 25 years. The annual cost of water harvesting and supply is estimated to be Rs $582/10^3$ m^3 and Rs $557/10^3$ m^3 for OFR with bund and without bund, respectively whereas total agricultural profit per hectare area are estimated at Rs $1295/10^3$ m^3 and Rs $1020/10^3$ m^3. The benefit cost ratio is thus around 2 in both the cases, which justifies investment in OFR.

6.5 CONCLUSIONS

In rainfed humid region, storage of rainwater in OFR constitutes an important component for increasing the irrigation intensity through second crop cultivation. However, under limited quantity of water availability in OFR, optimal allocation of land and water resources is important to maximize the net profit. The optimal crop allocation changes with further reduction in water availability into OFR due to supplemental irrigation during kharif season and with limited labour availability.

A simple linear programming model has been applied to propose an optimal land and water allocation for *rabi* (winter) crop cultivation for various constraints to arrive at contingency plans for maximization of profit. In normal years of rainfall, it was proposed that rice should be grown in 20 percent area and 80 percent area should be cultivated with non-rice area in case of bunded OFR. Whereas, it was 40 and 60 percent area for rice and non-rice crop, respectively in case of unbunded OFR. The study also indicates the benefit cost ratio around 2 (excluding income from pisciculture and horticulture) for both bunded and unbunded OFR and thus justifies the investment in OFR.

CHAPTER VII

SUMMARY AND CONCLUSIONS

In humid rainfed regions, the diverse nature of problems related with rainwater are often encountered when intensive-cropping system is to be achieved. Sundarbans delta in West Bengal is a region where agriculture is primarily dependent on rainfall, which is stochastic in nature. The rainfall distribution, onset of monsoon and the nature of intra-seasonal surface waterlogging or moisture stress greatly influence the agricultural production system in this region. Rice during *kharif* is the principal crop, faces problems of surface waterlogging in the early period and drought at later stage of crop growth during ripening. It confines the farmers to resort to a more certain and low cost input technologies resulting in very low or fluctuating crop yields. Further, there is no water for second crop cultivation during *rabi* season. The study pertains to the solution of these problems by weather based crop planting and by rainwater management in the region. Following are the salient findings of the study:

1. The analysis shows that the region has an average (1963-92) annual rainfall of 1768 mm ranging from 1030 mm to 2462 mm. It also indicates that the month of July and August is the wettest and there is probability of severe damage to the crop due to waterlogging in these months. The water balance analysis shows considerable scope for conservation of excess rainwater in on-farm reservoirs. It was also estimated that on an average about five weeks droughts may occur during the *kharif* season and about three weeks continuous drought is expected during the ripening stage as compared to none during both vegetative and reproductive stage for rice crop.

2. Estimates of excess rainwater availability are important for designing an on-farm reservoir (OFR) to provide supplemental and life saving irrigation and to improve surface drainage. Soil water balance model for rainfed rice cultivated in humid, deltaic lowland was developed to estimate the excess rainwater availability. It was recommended to convert 20 percent of the watershed area into OFR to harvest excess rainwater. The optimal design of OFR is of great use for developmental agency as ready reckoner. The procedure suggested may be used for optimal design of on-farm reservoir in different agro-ecological conditions.

3. Probability analysis of weather data including rainfall and evaporation, as a measure of crop water demands, has been used to propose an optimal planting schedule during *kharif* for different farming situations in order to minimize the climatic hazards. Based on *kharif* and *rabi* planting schedule and crop suitability in the region, a crop calendar for optimal farming operations was prepared with the objectives of stabilizing

production and minimizing recurrent production losses due to uncertain weather. Similar studies can be made for crop planning in rainfed areas of different agro-ecological conditions to cope up the problems of climatic hazards.

4. In rainfed humid lowlands, improvement in surface drainage is possible through rainwater harvesting in OFR. Improvement in weekly surface waterlogging was simulated by providing the optimum size of an OFR in a unit farm area. It was estimated that rainwater storage in OFR improves surface drainage to the extent of 75 percent and thus, provides the scope for cultivation of high yielding rice varieties in rainfed humid lowlands.

5. A simple linear programming model was used to propose an optimal land allocation for *rabi* (winter) cultivation under various limitations of land and water to arrive at contingency plans for maximization of profit. In normal years of rainfall, it was proposed that rice should be grown in 20 percent area and 80 percent area should be cultivated with non-rice area in case of bunded OFR. Whereas, it was 40 and 60 percent respectively for unbunded OFR. The study also indicates the benefit cost ratio around 2 (excluding income from pisciculture and horticulture) for both bunded and unbunded OFR and thus justifies the investment in OFR.

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Appendix I

Probable annual/monthly/weekly rainfall (mm) at various return periods under Extreme value I distribution.

Annual/ Month/ week	Return period (Years) 2	5	10	20	50	100
Annual	1768.27	2082.41	2246.96	2483.46	2534.93	2638.52
January	9.40	36.79	54.92	72.32	94.83	111.11
February	0.83	40.28	53.16	65.51	81.50	93.48
March	29.50	70.07	96.89	122.61	155.90	180.85
April	53.01	110.11	147.91	184.17	231.10	266.27
May	122.74	207.08	262.92	316.48	385.81	437.76
June	292.32	424.12	511.39	595.39	703.46	784.65
July	335.08	448.19	523.08	595.91	687.90	757.57
August	327.00	440.43	515.53	587.57	680.82	750.70
Sept.	268.59	417.49	516.08	610.64	733.05	824.77
October	119.81	180.43	220.57	259.07	308.90	346.24
November	22.77	66.76	95.88	123.82	159.97	187.07
December	7.04	32.57	49.48	65.69	86.68	102.40
1	2.38	12.82	19.73	26.36	34.94	41.37
2	0.93	21.97	35.89	49.25	66.53	9.48
3	1 02	4.87	7.42	9.86	13.03	15.15
4	1.40	9.55	14.94	20.12	26.82	31.84
5	2.80	11.64	17.49	23.11	30.37	35.82
6	3.73	13.93	20.68	27.15	35.54	41.82
7	3.70	13.01	19.17	25.08	32.73	38.46
8	5.37	17.78	26.00	33.89	44.09	51.74
9	4 12	19.79	30.16	40.10	52.98	62.63
10	4.34	14.89	21.89	28.59	37.23	43.78
11	1.94	8.17	12.30	16.27	21.39	25.24
12	9.33	28.41	41.04	53.15	68.84	80.59
13	7.02	31.71	48.06	63.74	84.03	99.24
14	4.51	16.35	24.19	31.71	41.45	48.74
15	5.34	19.77	29.32	38.48	50.34	59.23
16	14.61	54.66	81.17	106.61	139.53	164.19
17	15.67	49.62	72.10	93.66	121.57	142.48
18	15.86	42.25	59.73	76.49	98.19	114.44
19	31.01	70.36	96.42	121.41	153.76	178.00
20	24.90	58.05	80.00	107.73	128.30	148.72
21	24.80	56.62	77.69	104.31	124.06	143.66
22	29.13	65.17	89.04	119.19	141.56	163.76
23	50.17	135.04	191.23	245.13	314.90	367.18
24	62.33	115.67	150.99	184.86	228.71	361.57
25	69.02	118.09	150.58	181.75	222.09	252.32

26	86.35	153.77	198.77	241.23	296.66	338.19
27	78.79	137.92	177.07	214.63	263.24	299.66
28	76.64	143.47	187.72	230.16	285.09	326.26
29	66.78	114.90	146.76	177.32	216.88	246.52
30	63.59	107.92	137.27	165.42	201.86	229.17
31	76.10	147.57	194.88	240.26	299.01	343.03
32	75.93	121.12	151.04	179.74	216.90	244.74
33	64.67	113.66	146.09	177.20	217.48	247.66
34	60.21	110.59	143.94	175.93	217.35	248.64
35	64.10	125.55	166.24	205.27	255.79	293.64
36	63.88	140.49	191.22	239.87	302.85	350.04
37	58.74	97.40	123.00	147.55	179.34	203.15
38	32.40	65.06	86.68	107.41	134.26	154.37
39	68.08	191.83	273.77	352.37	454.11	530.35
40	43.32	94.17	127.84	160.14	201.94	233.27
41	28.17	73.73	103.90	132.84	170.30	198.37
42	15.43	44.98	64.55	83.32	107.60	125.82
43	8.35	28.01	41.02	53.50	69.66	81.76
44	4.21	17.49	26.28	34.72	45.63	53.81
45	5.02	39.88	62.96	85.10	113.75	135.22
46	5.06	20.96	30.82	40.28	52.52	61.70
47	1.50	10.73	16.84	22.70	30.29	35.97
48	1.62	25.32	41.02	56.08	75.57	90.17
49	0.32	16.04	26.44	36.42	49.34	59.03
50	2.65	17.99	28.14	37.88	50.44	59.99
51	0.11	2.01	3.27	4.48	6.05	7.22
52	0.81	5.83	9.15	12.33	16.45	19.54

APPENDIX II

Probable annual/monthly/weekly evaporation (mm) at various return periods under Pearson type III distribution.

Annual/ Monthly/ Weekly	Return period (years)			
	2	5	10	50
Annual	1582.24	1672.15	1718.81	1799.50
January	82.89	92.84	97.71	105.51
February	106.75	118.32	126.24	144.22
March	172.46	192.36	204.22	227.76
April	212.06	229.97	239.01	254.13
May	216.59	247.17	265.96	304.47
June	153.93	172.23	183.04	204.31
July	128.88	143.89	152.71	169.97
August	125.79	137.86	143.48	152.04
September	111.61	123.07	129.79	142.87
October	104.77	117.69	124.62	136.96
November	87.88	97.69	103.04	112.62
December	77.41	87.79	94.04	106.62
1	17.69	20.19	21.57	24.06
2	17.49	20.26	21.63	23.81
3	17.84	20.45	22.21	26.16
4	19.83	22.49	23.56	24.89
5	22.69	25.64	27.10	29.53
6	23.53	26.97	29.00	32.95
7	24.85	29.38	32.38	39.02
8	30.53	34.68	37.27	42.60
9	31.45	36.22	39.20	45.44
10	33.85	41.16	46.72	61.00
11	39.71	45.73	49.19	55.77
12	42.40	47.88	49.37	54.00
13	45.97	51.52	53.22	54.60
14	47.09	52.36	54.70	58.02
15	50.49	55.12	57.68	62.38
16	50.19	55.77	57.29	58.30
17	49.52	56.01	59.61	66.20
18	49.74	58.98	63.91	72.56
19	51.56	59.64	64.14	72.44
20	48.87	57.79	62.96	72.86
21	46.95	55.38	61.01	73.57
22	46.80	55.70	60.05	66.87
23	38.30	47.09	52.35	62.75
24	37.56	45.09	49.03	55.74

26	31.31	37.03	40.05	45.25
27	28.68	34.66	38.74	47.93
28	29.28	33.64	36.39	42.16
29	28.67	34.24	37.16	42.15
30	28.42	33.59	36.65	42.65
31	28.03	31.97	34.25	38.61
32	28.24	33.45	36.38	41.66
33	29.54	35.06	37.73	41.87
34	27.46	30.64	32.50	36.11
35	24.99	29.24	31.92	37.54
36	26.35	29.46	31.17	34.28
37	26.54	31.39	33.65	36.96
38	25.88	29.87	32.21	36.76
39	26.24	29.03	30.08	31.28
40	24.25	28.12	30.38	34.77
41	23.11	26.67	28.50	31.62
42	24.51	28.19	29.99	32.87
43	22.24	25.03	26.43	28.74
44	22.01	25.11	26.66	29.22
45	21.67	24.09	25.21	26.93
46	19.75	22.58	23.95	26.10
47	19.46	22.09	23.46	25.83
48	20.05	22.58	23.87	27.70
49	18.85	21.90	23.70	27.20
50	17.31	19.64	20.89	23.12
51	16.68	19.20	20.68	23.49
52	15.93	18.50	20.26	24.32