1.0 INTRODUCTION

1.1 General

Water and air, which compete for the same positions in soil in the root zone,are both needed for plant growth. The soil moisture deficiency is abated through irrigation and the oxygen deficiency is done away with by providing drainage facilities in the agricultural field. It is convenient to divide overall drainage into two types: Land drainage and Field drainage.

Land drainage is large scale drainage where the object is to drain surplus water from a large area by such means as improving the flow of the streams and rivers, excavating large open drains,erecting dykes and leeves and pumping. Schemes of this nature are associated with large areas of low lying land, frequently in coastal areas and involve major civil engineering work. Field drainage is removal of surplus water, that otherwise restricts crop growth from agricultural land.The surplus water may accumulate because of rain or surface flow and cannot naturally be drained away fast enough.The function of field drainage is directed towards accelerating or increasing the natural outflow,by improving the hydraulics of flow starting from the outflow either over the ground or by a system of closed under drains as feasible. If the primary object is to avoid surface water logging then surface drainage is provided, but if a permanent lowering of water table is desired besides removing the water from the root zone, then a system of sub surface drain is often used.

1.2 Soil Salinisation and Drainage

Efficient use of land and water resources is to a greater extent dependent upon the control of salinisation problem. The long history of irrigation has recorded severe deterioration of land resources due to salinisation and waterlogging. It is a well known phenomenon that, when an area is irrigated excessively over an extended period of time, the groundwater level rises. When the water table reaches a height, which is within the capillary lift of the soil, the soil moisture is brought to the surface where it evaporates. Salts, which were originally present in the irrigation water or which were dissolved in the rising groundwater, get concentrated on the land surface by the so called 'tea kettle effect'. This causes soil salinity and some times alkalinity which are harmful to plant growth. When a saline water table rises and remains in the root zone longer than about 48 hours, resulting in an abnormally high saline moisture condition, agricultural production is usually seriously affected. Vast areas, which once upon a time were productive under irrigation, have become sterile and saline waste land in Mesopotamia, North Africa and in the Far East. In modern times, the rate of salinisation and land destruction has been greatly accelerated, especially in areas irrigated with plentiful, low cost water, which contains dissolved salts. Areas affected by waterlogging, soil salinity and alkalinity in different states are shown in Table 1.1. Table 1.2 indicates the extent of waterlogging and soil salinity in selected irrigation projects in the country.

Table 1.1 : Extent of Waterlogged Area as estimated by various agencies (lakh ha.)

State	As per National Commission for Irrigation (1972)	As per National Commission on Agriculture (1976)	As estimated by Min. of Agriculture (1990)
1	2	3	4
Andhra Pradesh	N.R.	3.39	3.39
Assam	N.R	N.R	4.50
Bihar	N.R	1.17	7.07
Gujarat	N.R	4.84	4.84
Haryana	6.5	6.20	6.20
Jammu & Kashmir	N.R	0.10	0.10
Karnataka	.07	0.10	0.10
Kerala	N.R	0.61	0.61
Madhya Pradesh	0.57	0.57	0.57
Maharashtra	0.28	1.11	1.11
Orissa	N.R	0.60	0.60
Punjab	10.9	10.90	10.90
Rajasthan	3.48	3.48	3.48
Tamil Nadu	N.R	0.18	0.18
Uttar Pradesh	8.10	8.10	19.80
West Bengal	18.5	18.50	21.80
Delhi	N.R	0.01	0.01
TOTAL	48.40	59.86	85.26

N.R: Not Reported

Table 1.2: Extent of Waterlogging and Soil Salinity in Selected Irrigation Projects in India (thousand hectares)

Irrigation Project	*Extent of*	
	Waterlogging	Soil Salinity
Gandak	211.01 (21.11)	400.00(40.03)
Sarda Sahayak	303.00*(28.34)	50.00(4.68)
Ramganga	195.00 (32.99)	352.42(59.62)
Chambal	98.70(20.31)	40.00 (8.23)
Tawa	- -	6.64(3.79)
Rajasthan Canal	43.10(7.98)	29.11(5.39)
Ukai-Kakrapar	16.25(4.32)	8.29(2.20)
Mahi Kadana	82.00*(16.81)	35.76(7.33)
Malaprabha	1.05*(0.99)	- -
Tungabhadra	4.65(1.27)	24.48(6.69)
Sriramsagar	60.00(47.62)	1.00(0.79)

* Figures included waterlogging and soil salinity
Figures in parentheses are the percentages of the irrigation potential created in the respective command area.

1.3 Waterlogging and Salinization

Plants require oxygen as well as water for their growth. They obtain their oxygen requirement from two sources: from the soil air and from the open atmosphere. Oxygen supply through the leaves and from the open atmosphere. Oxygen supply through the leaves and from there through the plant to the terminal oxidases in the roots is sufficient to maintain growth in plants adapted in aquatic condition (i.e. rice), and to support at least the upper 2 cm of roots in many cereal seedlings (Jen sen et al, 1964, Greenwood and Good man 1971; vide Briggs and Courtney, 1985). Nevertheless it is rarely adequate to satisfy requirements in more active and mature arable crops. Consequently, conditions affecting the supply of oxygen from the soil air are critical.

Movement of oxygen through the pore system of the size of the plant roots is only indirectly a function of the size of the pores. In air-filled pores, oxygen diffusion is rapid and oxygen deficiencies are rare. In saturated pores the effective coefficient of oxygen diffusion is much lower, possibly only 1/1000th or less of the rate in free air (Briggs and Courtney, 1985). During waterlogged condition oxygen diffusion is unable to sustain root or microbial requirements for any length of time. In the absence of sufficient oxygen, substance such as alcohol and cyanide may be formed in the plant tissues and plant growth may be severely curtailed (Rose 1968, Smith and Russel 1969). It is ,however, not only the direct consequence of a reduced supply of oxygen which inhibits plant growth in waterlogged soils. Under certain circumstances, toxic compounds may build up as a result of oxygen deficiencies. The various effects of waterlogging combine to influence crop yield to a marked extent. The effect of seven days waterlogging on crop yields in Hungary is given in Table 1.3(a). Based on field survey, the following information regarding effect of shallow water table position at different depths below ground surface on crop yield has been reported (Table 1.3(b)). The information does not reflect the water quality aspect and duration of the occurrence of water table position.

The allowable groundwater table is closely related to the root system of the crop concerned. The allowable groundwater table for a number of crops are given in Table 1.4.

From studies conducted on newly reclaimed sea bottom soil (IIRI, 16(III), 1973) the critical water depth during off season period is found to be 30 cm. During growing season the root zone is developed to a much greater depth. Water logging reduces crop yield severely if it occurs in the middle of the growing season, than if it happens during the off season. IIRI (1973) has suggested the following desirable water (Table 1.5) levels for dutch conditions for grassland and field crops during the growing season.

Although the depth of the ground-water table has no direct influence on crop growth, it indirectly determines the prevailing moisture conditions, and therefore has an infleunce on water supply, aeration condition and heat properties in soil. Visser (1985) has described an intensive survey of the prevailing ground-water table depths in the Netherlands. During a 3-year period, observations of water-table depths were collected for about 2.2 million ha of agricultural land with an intensity of one observation/100 ha. To describe the effect of water-table depth on crop yields, the soils were divided into seven classes and for each class the relation between relative yield of arable crops and water table has been obtained as given in fig 1.1. All the curves show an increasing yield as depth increases at shallow depths, a certain optimum range, and a yield decline at greater ground-water depths. A possibly explanation for this form of the curves is that at shallow depths the crops will suffer from a lack of aeration while at greater depths water deficiency is the cause of yield depressions. The optimum depth of water table position for arable crops in different types of soils can be visualised from the graphs given by Visser. However to specify a desired water table depth it is at least necessary to know the requirements of the crop species, soil characteristics, watering procedure and climatological conditions.

Table 1.3 (*a*) :

The effect of seven days Waterlogging on crop yields

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept.	Oct.	Nov.	Dec.
	Month of waterlogging											
	(% of reduction in yield)											
Grass	-	-	10	15	20	20	20	10	-	-	-	-
Sugar beet	-	-	50	50	50	40	40	40	40	10	-	-
Potatoes	-	-	80	80	90	100	100	100	40	-	-	-
Winter wheat	5	5	15	25	40	50	-	-	-	-	-	-

Table 1.3 (b);

Percentage of direct yield reduction resulting from watertable at various depths (Barber, 1985).

Depth to Watertable m	Mango	Cotton	Oilseed	Sugarcane	Wheat	Rabi Fodder	Kharif Fodder
		% reduction in yield					
< 0.30	100	94	85	85	77	74	71
0.30-0.45	100	71	66	66	49	45	27
0.45-0.60	100	55	54	54	35	30	0
0.60-0.75	100	46	42	42	24	19	0
0.75-0.90	91	37	32	32	15	11	0
0.90-1.00	76	29	22	28	9	5	0
1.00-1.20	61	22	13	13	4	2	0
1.20-1.50	38	15	5	5	1	0	0
1.50-1.80	7	6	1	1	0	0	0
1.80-2.10	0	3	0	0	0	0	0
> 2.10	0	0	0	0	0	0	0

Table 1.4 Allowable depth to ground water table from ground surface

Allowable Depth	Cropy Type
0 cm	Wet land rice
30-50 cm	Grassers, vegetables such as Kale, lettuce, potatoes and plants grown for their vegetative parts
40-55 cm	leguminous crops, clovers, pulse crop, alfalfa, bulb crops *(onion)*
90-100 cm	a group of plants with a root system at an intermediate depth e.g. cotton, cereal, sugar beet and sugarcane
>100 cm	Fruit trees

Table 1.5 Recommended depth of groundwater table

Soil texture	Water table depth which should not be exceeded for more than brief periods	
	Grass land	Field Crops
Coarse	0.4 - 0.6 m	0.6 - 0.9 m
Medium	0.6 - 0.9 m	0.9 - 1.2 m
Fine	0.9 - 1.2 m	1.2 - 1.5 m

A water table at a depth more than 1m below soil surface during irrigation season should be sufficient to permit adequate aeration in most soils and normal root development of most annual crop plants. For perennial crops a somewhat deeper water table position about 1.5 to 1.8m below ground surface may be required (Framji, 1976). For a short period immediately after irrigation, a rise in the water table to 0.3 m below soil surface should not be detrimental. An area can be considered to be waterlogged if the water table which is not saline lies within

1.5m below soil surface during the crop growth.

The most widespread and direct factor in the formation of contemporary saline soils in different parts of the world is groundwater evaporation and transpiration where run-off is either reduced or non-existent. Both the intensity of groundwater evaporation and the salt accumulation processes attain their maximum in arid climate conditions when the groundwater levels reaches a depth of 2-3m or less. A saline soil is one which contains sufficient soluble salts to injure or reduce the growth of many plants. Saline soils have electrical conductivities of saturation extracts higher than 4mmhos/cm. A determination is made by saturating a sample with water, extracting the water by vacuum, and measuring the conductivity. Saline soils have less than 15% of their cation-exchange capacity occupied by exchangeable Na+. Sodic soils have more than 15% of their cation-exchange capacity occupied by exchangeable N+. They are low in total salt content and electrical conductivity. Saline sodic soils have electrical conductivities higher than 4 mmhos / cm and have more than 15% exchangeable Na+. The only important difference between saline-sodic and saline soils is that leaching changes saline-sodic soils into sodic soils. The three main kinds of salinity are shown in Fig.1.2 (Hudson, 1983). Both saline and saline sodic salts form a white deposit on dry soil. The soluble salts make it more difficult to plant roots to absorb water. Plants are more sensitive to salinity during the germination and seedling stages than they are during the rapid growth period. In table 1.6, the tolerance of crops during their rapid growth period in terms of electrical conductivity of saturated soil extracts is given. Very few soils are as unproductive and as difficult to reclaim as sodic soils. The high Na+ percentage causes the soil colloids to disperse and the PH to rise above 8.5 when the Na+ is not marked by a high salt concentration. The dispersed colloids reduce the permeability of very sandy soils to 1 or 2mm/hour and make silty or clayey soils essentially impermeable. A smooth, crusted, barren surface is formed which is so slippery when wet that sodic soils are commonly called slick spots. The organic matter content of sodic soils is usually less than 1%, and what organic matter there is, becomes soluble in alkaline conditions and moves with the soil water. Some moves to the soil surface where it forms a thin black covering and is known as black alkali (Torech et al, 1980). Alkalinization is more serious than salinization because its harder to remedy. Salinization can be remedied by applying water. Sodium, unlike other soluble salts, does not leach away because it is absorbed on the surface of clay and organic matter (Mohonk Trust, 1979).

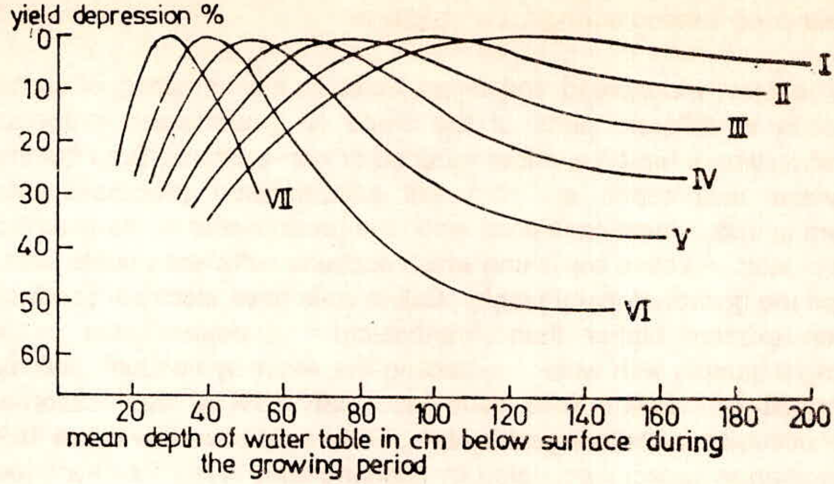

Fig.1.1 Yield depressions as a function of the mean depth of the water table during the growing season for various soil types

I - heavy river and sea clay
II - loamy humus-rich sand
III - light river and sea clay
IV - old sandy cut-over peat soils
V - coarse sandy reclaimed heath soils
VI - clay overlying peat
VII - peat soils

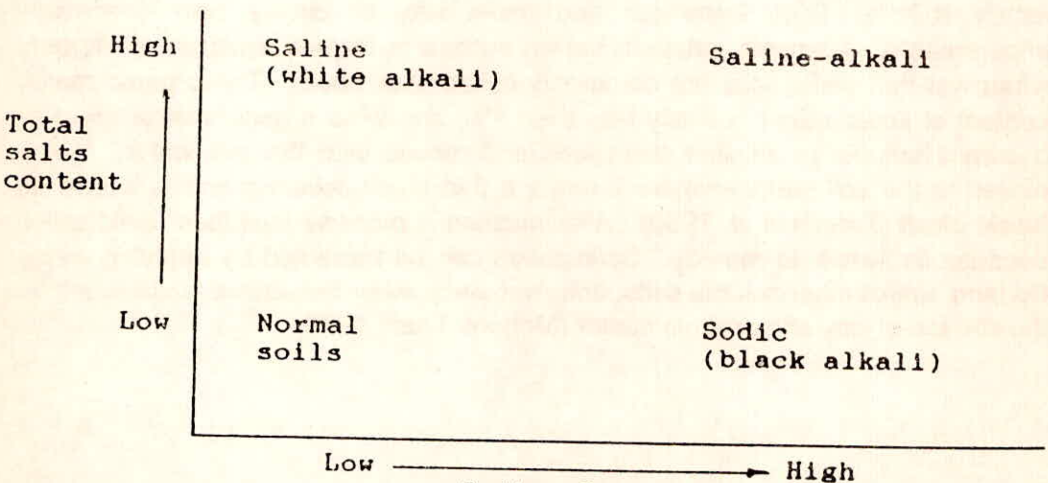

Fig. 1.2 Soils with salt problems

Table 1.6 Salt tolerance of crops during their rapid growth period in terms of electrical conductivities of saturated soil extracts

	Conductivity in m mhos/cm at 25°C causing yield reduction		
	10%	25%	50%
Forage crops;			
Bermudagrass	13	16	18
Tall wheatgrass	11	15	18
Crested wheatgrass	6	11	18
Tall fescue	7	10	15
Perennial ryegrass	8	10	13
Bird's-foot trefoil	6	8	10
Beardless wildrye	4	7	11
Alfalfa	3	5	8
Orchardgrass	2	4	8
Alsike clover, red clover	2	3	4
Field crops;			
Barley	12	16	18
Sugar beets, cotton	10	12	16
Wheat, safflower	7	10	14
Sorghum	6	9	12
Soybeans	6	7	9
Corn, Paddy rice	5	6	7
Flax	3	4	6
Field beans			
Vegetable crops;			
Beets	8	10	12
Spinach	6	7	8
Tomatoes, broccoli	4	6	8
Cabbage	2	4	7
Potatoes, corn, sweet	2	4	6
Potatoes	2	3	5
Lettuce, bell pepper	2	3	5
Onions	2	3	4
Carrots	1	3	4
Beans	1	2	3

The main source of salts in irrigated soil, if mineralized waters are not used for irrigation, is groundwater lying close to the soil surface and salts of the underlying soil. Soil forming rocks and sub-humic horizons of the soils in arid and sub-arid regions practically always contain soluble salts (Chlorides, sulphates, carbonates) which can travel comparatively easily to the top horizon in the form of capillary water solution after the beginning of irrigation. As reported by Kovda (1977), experience in the arid regions of Asia, and in many other arid regions of the world shows that, when the groundwater rises above a depth 1.5 to 2.5m below soil surface the soils are usually strongly salinized. Only those groundwaters that contain less than 5-3 g/l of soluble sulphates, chloride do not cause natural and secondary salinization. These groundwaters favour the formation of highly fertile soils. Therefore a 3-5 g/l mineralization of the groundwaters should be viewed as a ceiling-critical for the majority of irrigated regions of chloride sulphate salinization.

Large concentration of salts in groundwaters (10-150 g/l) play a determining part in the soil salinization of arid regions. With very intensive evaporation and transpiration, capillary solutions of salty groundwater continuously replace evaporating soil moisture, thereby introducing more and more toxic salts into the root zone and leading to plant death. The following formula has been advocated by USSR scientist to estimate the probable critical depth in salty groundwater occurrence:

$$L = 170 + 8t + 15 \qquad (1.1)$$

in which L is the critical depth in cm, t is the average annual temperature in degree Celsius. From 4-5 m depth, the groundwaters cannot provoke soil salinization. Horizontal drainage does not allow to lower the groundwaters to such a depth, but this can be managed with the help of pumping through vertical drainage wells.

1.4 Irrigation with Brackish Water and Drainage

Agriculture with brackish water irrigation is not the same as normal agriculture. Failure to recognize that has resulted in many a disaster. There are some constraints and restriction that must be recognised and kept in mind while applying brackish water for irrigation.

The elements of brackish water agriculture are as follows:

1) Selection of appropriate crops, cropping systems, and crop tolerance to salinity must be thoroughly known on a quantitative basis for all specific ecological conditions of concern. Crops having different salt tolerance limits are shown in table 1-(USDA Agricultural Handbook).

2) Prevention of salt accumulation in the soil, the dynamics of salts in the soil must be quantitatively known for all specific soils, climatic and hydrological concern. Furthermore, the interrelationship of leaching to crop response must also be understood.

3) Use of advanced irrigation and drainage technology Irrigation methods must be adjusted to the use of brackish water and must be very efficient, technically as well as economically.

A drainage system must be provided when necessary. In this respect the pollution aspect of irrigation return flow should not be over looked.

It may be said that the key to successful brackish water agriculture is leaching (Framji, 1976). It controls all aspects of salt accumulation in the soil (concentration, movement, precipitation, exchange and dissolution), and interacts intimately with crop response, cultural practice and pollution of groundwater and river.

1.5 Leaching and Drainage Need

Suitable irrigation water, appropriate means of application and good drainage are required for reclaiming saline soils. Large quantities are needed with low enough salt content to leach salts from the soil and leave it sufficiently low in salinity for the desired purpose. A depth of water equal to half the depth of the soil will remove about 50% of the salts from the soil profile. A water depth equal to the soil depth will remove about 80% of the salts; 1.5 times the soil depth removes about 90% of the salts. Flood irrigation is usually preferred because the entire soil surface needs to be covered, often for two or three days or longer. Methods such as furrow and trickle irrigation would reclaim part of the soil at the expense of the rest by causing much of the salt to accumulate in the drier parts of the soil.

A good drainage system is required to remove the leaching water fast enough while a saline soils is being reclaimed. Without adequate natural drainage or a properly constructed artificial drainage system, leaching will inevitably result in an increase in water table height with its consequent resalinization of the soil and poor aeration. Sometimes the leaching is done intermittently both to save water and to give more time for drainage. Intermittent leaching requires only 70% as much leaching water as continuous leaching if the time intervals are long enough to dissolve more salts but short enough to avoid large evaporation losses (a day or two usually appropriate) (Troeh et al, 1980).

Table 1.7 Crops having different salt tolerance limits

Low salt-tolerance	*Medium salt-tolerance*	*High salt-tolerance*
Field crops		
beans	rye, wheat, oats, sorghum, maize, rice sunflower castor beans	barley sugar beet cotton rape
Forage crops		
most kinds of clover	sweet clover, Hubam clover	alkali sacaton
	most grasses *most grass crops when* taken for hay	salt grass *Cynoden spp.* Chloris spp. Agropyron spp. Barley (for hay)
Vegetables		
radish	tomato lettuce cabbage	asparagus
celery	cauliflower potatoes	spinach
green beans	carrots onions peas	kale
Fruits		
all citrus fruit	fig olive	date palm
deciduous fruits for example, apple, pear, plum	grape pomegranate	
berries, for example, strawberries		

The traditional leaching requirement has been used on salt concentration *in irrigation water and drainage water*:

$$\text{Leaching water} = \frac{\text{salt conc. in irri. water}}{\text{salt conc. in drainage water}} \times \text{amount of irr. water}$$

The salt concentration in drainage water is often taken as the concentration that would cause 50% decrease in yield in uniformly saline soil. (Troech et al, 1980).

1.6 Benefits from Drainage

Benefits from drainage are very extensive (Costle et al, 1984). Crops and live stock are immensely benefited and machinery performance is improved due to properly drainage. In the crop calender generally envisaged, one needs to ensure 110-120 days of availability of land free of drainage congestion at least in Rabi season for at least one good crop. Thus designing an irrigated area to be free of congestion by Oct.-Nov. is a requirement in many areas/commands. Soundly conceived reclamation-drainage can save land resources and bring back them for farming. If the existing drainage is poor for which yields are low, and cultivation and harvesting are difficult, significant benefits may be expected after drainage. Through implementation of proper drainage system it may be possible to change from one farming system to more profitable one i.e. low out put grass land can be changed for cereal production.

When water is removed from the top soil by drainage, further rainfall is able to infiltrate the soil surface rather than accumulating and forming surface run-off. Reduction in surface run-off leads to reduction in soil erosion.

The seed requires a balance of temperature and moisture during germination and establishment. In temperate climate, wet conditions in the seed bed are associated with low temperature and there is evidence that drainage can influence the soil temperautre, whilst the temperature in the soil surface layers will also be influenced by the air temperature, humidity, wind run and sun shine hours. The effect of drainage on soil temperature is greatest in the top 80mm of the soil. This is the first zone to dry out as the water table is lowered or as moisture is lost to evaporation. It is also the maximum depth at which most crops are grown. Feddes (1972) has shown that a 1 C increase in soil temperature by drainage may take up 10 days difference in the emergence of spring barley. The effect of drainage, therefore, will be greatest when soil moistures are close to the minimum temperature for germination for both autumn and spring sown crops. An increase in soil temperature has also been found to increase bacteriological activity breaking down organic matter in the soil, releasing nitrogen availability to crop. All temperate crops require air in the root zone so that roots can take up water and nutrients. As roots are unable to grow in soils which suffer prolonged water logging, a high water table will limit the root zone causing loss of yield. Crops with a shallow-root system will also suffer drought condition when the water table drops during the growing season, causing further yield loss. A well drained soil allows crops to establish a good root system and to fully utiise the soil nutrients and fertilisers applied to the crops. (Fig. 1.3) (Costle et al, 1984)

Water logged crops tend to be under stress and are therefore more prone to disease. Expensive chemicals are then applied to combat against the diseases whilst still having a crop yielding below its full potential. Crops also suffer from competition of weeds as wet land encourages water loving plants.

1.7 Irrigation Planning and Drainage

Experience has shown, often quite forcefully, that it is better to fully equip a restricted area than to put water on a greater surface without sufficient provision for application efficiency and appropriate drainage. Drainage is required in different methods according to local conditions and according to the quality of groundwater. If the groundwater is not saline and consequently usable by crops, the aim of drainage network is to get rid of excess water in the root zone quickly, keeping the water table at a rather high level in order to benefit from capillary movement. By avoiding over drainage, the water table can be drawn to an optimum level. If the groundwater is brackish, water movement towards the root zone and soil surface must be eliminated. In such cases the drawdown speed is not the first target, and instead of an optimum level, it is a critical level which must be kept in mind. A shallow drainage system would be inappropriate under such situation.

Whenever irrigation is planned it will be dangerous to ignore the peculiarities of the natural soil situation, the mineralization and chemical composition of groundwater, salinity of ground and soil and unsatisfactory natural drainage. In order to project irrigation system construction cheaper, deep drainage system if necessary should not be ignored. Construction of irrigation system without drainage installation in arid countries leads to a gradual decrease of their efficiency and is a waste of labour and investment. Most scientists and irrigation specialists of the world agree that, excessive use of water for irrigation should be curbed and that drainage should be provided. The only point of disagreement is on ways of so doing.

1.8 Indian Experience

The work carried out in surface and sub surface drainage at Rajasthan Agricultural Drainage Research Project (RAJAD) and at Central Soil Salinity Research Institute (CSSRI), Karnal is briefly given in Appendix- 'A' .

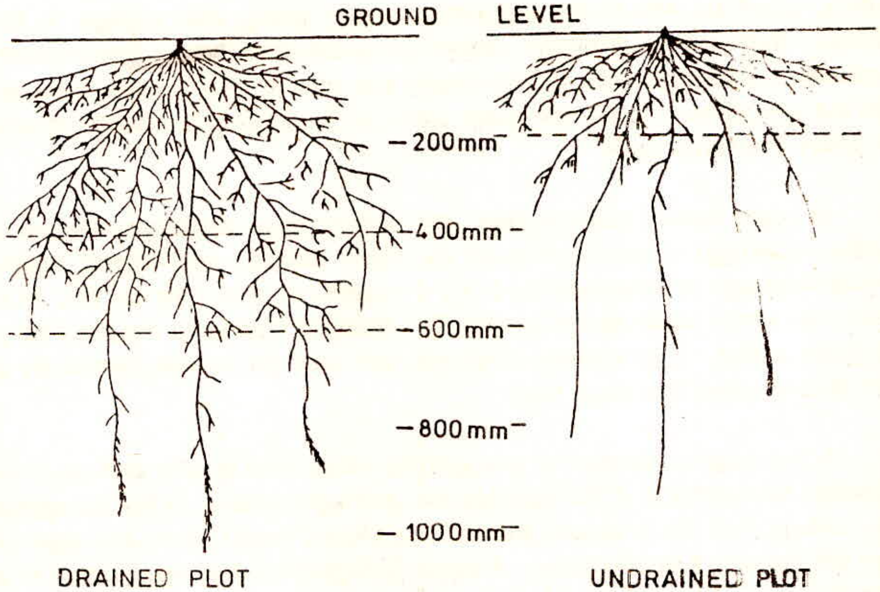

Figure 1.3 Difference in root development between drained and undrained plots