Water Management

(Agro. 201 Lecture Notes)

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Preface

This book is intended as a professional basic textbook for undergraduate level students of irrigation water management in agriculture and horticulture faculty. At the postgraduate level also it will be very useful for students of agronomy, soil science and horticulture. In addition the text book will be a valuable reference on irrigation aspects for the candidates appearing in competitive examinations including agricultural research services. Professional training institutes like KVKs, polytechnics, rural institutes etc dealing in on-farm water management would find this text book of immense value.

The text book covers all the areas of irrigation related to agriculture. The book is written in a very simple form with up to date data and statistics. It is a comprehensive basic text book on water resources, soil water plant relations, soil moisture measurement, crop water requirements & irrigation scheduling, methods of irrigation, irrigation water quality and water management practices for important field and horticultural crops in Andhra Pradesh. Descriptions of necessary equipment, class room problems and examples have been included to facilitate the understanding of the subject matter. Tables, figures, formulae and images are also given for better illustration. A list of important references is given at the end of the manual.

The authors would welcome suggestions from the readers to improve the text book.

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Lecture No. 1
Irrigation – Introduction, Importance, Definition & Objectives

1.1 Introduction

Sustainable development and efficient management of water is an increasingly complex challenge in India. Increasing population, growing urbanization, and rapid industrialization combined with the need for raising agricultural production generates competing claims for water. There is a growing perception of a sense of an impending water crisis in the country. Some manifestations of this crisis are:

a) There is hardly any city which receives a 24-hour supply of drinking water. Besides in many rural habitations there are pockets where arsenic, nitrate, and fluoride concentration in drinking water are posing a serious health hazard.

b) Increasing costs of developing new water resource – Many major and medium irrigation projects seem to remain under execution forever as they slip from one plan to the other with escalating cost and time overruns.

c) Siltation of reservoirs and owing to lack of maintenance, the capacity of the older irrigation systems seems to be going down.

d) Declining groundwater table due to over-exploitation imposing an increasing financial burden on farmers who need to deepen their wells and replace their pump sets and on State Governments whose subsidy burden for electricity supplies rises.

e) Water pollution and degradation of water-related ecosystems - Water in most parts of rivers is not fit for bathing, let alone drinking. Untreated or partially treated sewage from towns and cities is being dumped into the rivers. Untreated or inadequately treated industrial effluents pollute water bodies and also contaminate groundwater,

f) Wasteful use of already developed water supplies, often encouraged by the subsidies and distorted incentives that influence water use,

g) Rise in water-logging and salinity resulting in degradation of soils in irrigated areas,

h) Increasing water conflicts about water rights between upper and lower riparian states in a river, conflicts about quality of water, people's right for rainwater harvesting in a watershed against downstream users, industrial use of groundwater and its impact on water tables and conflicts between urban and rural users etc

i) The gross irrigated area does not seem to be rising in a manner that it should be, given the investment in irrigation. The difference between potential created and area actually irrigated remains large. Unless we bridge the gap, significant increase in agricultural production will be difficult to realize.

a) Floods are a recurring problem in many parts of the country. Degradation of catchment areas and loss of flood plains to urban development and agriculture have accentuated the intensity of floods.

India with 2.4% of the world's total area has 16% of the world's population; but has only 4% of the total available fresh water. This clearly indicates the need for water resource development, conservation, and optimum use.

1.2 Importance of irrigation water management

The importance of irrigation in the world is well stated by N.D. Gulhati of India: "Irrigation in many countries including India is an age-old art – as old as civilization – but for the whole world it is a modern science – science of survival".

The pressure of survival and the need for additional food supplies are necessitating a rapid expansion of irrigation throughout the world including India. Production and productivity of agricultural lands is primarily dependent upon the availability of irrigation water to crops. Expansion of irrigation has paid rich dividends in India. After independence, production registered nearly 4.52 times increase from around 50.8 million tons in 1950-51 to about 230 million tons in 2007-08. This has been mainly attributed to three factors viz., high yielding cereals, expansion of area under irrigation and fertilizer use. Irrigation may be considered as the major factor of modern intensive agriculture as it aids in efficient use of costly fertilizers and other inputs besides meeting crop water needs.

On the other hand, improper irrigation causes wastage of large amounts of water, leach mineral nutrients from the root zone into the deeper layers contaminating groundwater, and impairs the productivity of soil, or yield losses may occur if insufficient water applied. Excessive application of water causes waterlogging and increase high water tables or seepage spots to develop which may be corrected only by the construction of expensive drainage systems. In addition, salts accumulate and an alkali soil may develop. Water for irrigation and other uses is becoming more and more valuable due to increasing cost of irrigation projects and a limited supply of good quality water. Therefore, we must learn how to make optimal use of water to prevent an excessive wastage to preclude the degradation of the land and bring about its improvement for maximizing water productivity.

1.3 Irrigation – Definition

It is generally defined as "application of water to soil for the purpose of supplying the moisture essential for normal plant growth and development". In other words it is the human manipulation of hydrological cycle to improve crop production and quality and to decrease the economic effects of drought. However, a broader and more meaningful definition is that irrigation is the application of water to the soil for the following purposes:

- To add water to the soil for supplying moisture essential for normal plant growth and development
- To provide crop insurance against short duration droughts
- To leach or dilute excessive salts in the crop root zone, thereby providing a favourable environment in the soil profile for absorption of water and nutrients

- ♦ To soften tillage pans
- ♦ To cool the soil and atmosphere, thereby making more favourable microenvironment for plant growth

1.4 Objectives of irrigation

The broad objectives of irrigation are as follows:

a) To increase crop production on sustainable basis where water is a limitation
   - To increase national income/national cash-flow
   - To increase labour employment
   - To increase standard of living

b) Modification of soil & climatic environment
   - For leaching of salts
   - For reclamation of sodic soils
   - For frost protection

c) To mitigate i.e., lessen the risk of catastrophes caused by drought
   - To overcome food shortages
   - To protect high value crops/trees

d) To increase population of arid and sparsely populated areas
   - For national defense
   - For population re-distribution

e) National security i.e., self sufficiency in food grain production

Lecture No. 2

Water Resources and Irrigation Development in India

2.1 Surface Water Resources

India is blessed with an average annual rainfall of about 1194-mm. However, the bounty is not evenly spread both in time and space with the result flood-drought-flood syndrome still persists. As much as 85-90% of the rainfall is received only in the south-west monsoon season of June to October. It is that during the four rainy months of June to September the Arabian Sea branch of the monsoon carries moisture amounting to about 770 million ha meters and the Bay of Bengal branch about 340 million ha meters of water. Of the monsoon moisture, about 25 – 30% precipitates in the form of rainfall. During the remaining eight months an approximate precipitation of 100 million ha meters including a small portion of snow pour over the country. There are on average 130 rainy days in a year in the country.

The rainfall when considered over the geographical area of 329 million ha amounts to 392.8 million ha meters. This may be rounded off to 400 million ha meters including snowfall whose potential is not yet fully recorded (Fig. 2.1).

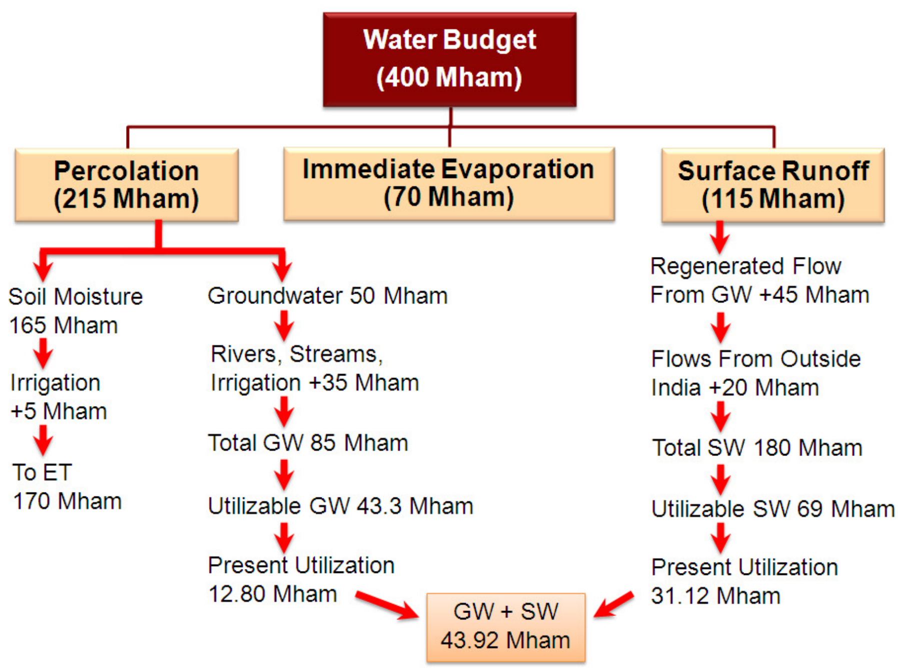


Fig. 2.1. Water resources of India

Out of the estimated 400 million ha meters precipitation, about 70 million ha meters is lost to atmosphere as evaporation, about 115 million ha meters flows as surface run-off and the remaining 215 million ha meters infiltrates into the ground. The total surface water resources of India after considering the above have been assessed at 180 million ha meters, which is of the same magnitude as is available to United States of America annually, though India's geographical area is only about 40% of that of the United States. This 180 million ha meters includes about 20 million ha meters brought in by streams and rivers from catchments lying outside the country and about 45 million ha meters pertains to regenerated flow from groundwater as assessed from river flows during non-rainy months. The remaining 115 million ha meters constitutes direct contribution by precipitation, of which about 10 million ha meters is received as snowfall. Of the 180 million ha meters, due to limitations imposed by topography, climate, soil conditions etc., only about 69 million ha meters are considered utilizable. The present utilization of the surface water is estimated to be about 31.12 million ha meters, of which about 95% is used for irrigation with the remaining being put to other uses. The major surface river basins of India are presented in Fig. 2.2.

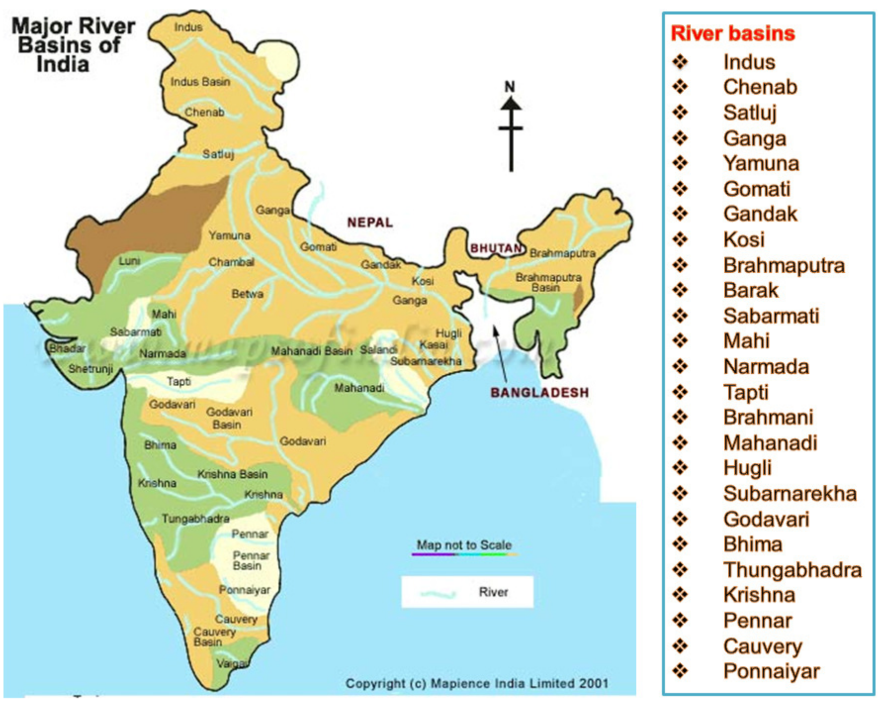


Fig. 2.2. Major river basins of India

2.2 Groundwater Resources

Of the annual precipitation of 400 million ha meters, about 215 million ha meters has been estimated to soak into the ground (Fig. 2.1). As much as 165 million ha meters is retained as soil moisture and is used by vegetation, thus leaving only 50 million ha meters (12.5%) of the total precipitation for the country as a whole to reach the ground water table. This value is likely to increase with the development of water resources i.e., percolation through rivers, streams, and irrigation systems, which add to recharge. The Central Groundwater Board puts the annual exploitable groundwater potential at 43.3 million ha meters. Presently, the groundwater utilization is about 12.8 million ha meters and here again a major portion of 85% is being used for irrigation with the remaining going for other uses.

The total water resource availability in the country though remained constant, the per capita availability of water has been steadily declined from 5300 in 1951 to the present level of 1700 m^3 due to population growth, large scale urbanization & rapid industrialization (Fig. 2.3).

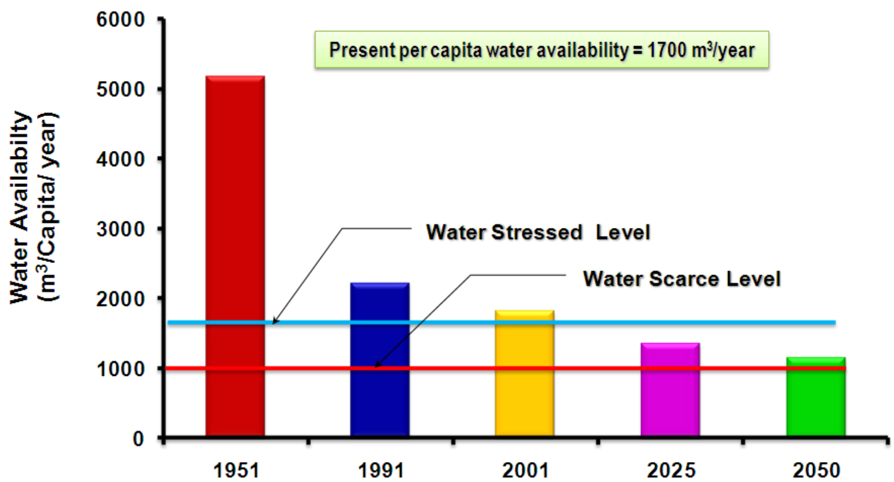


Fig. 2.3. India – Per capita water availability

The National Commission on Integrated Water Resource Development Plan constituted by the Government of India in its report submitted in December, 1999 has estimated the total water resource of the country as 195.3 Mham and the total water requirement of the country as 69.4 to 71.0 Mham by the year 2010, 78.4 to 85.0 Mham by the year 2025 and 97.3 to 118.0 Mham by the year 2050.

2.3 Irrigation development in India

2.3.1 Medieval India

There is evidence that irrigation was practiced in India during Vedic periods. The concepts of storing river flows behind a dam, distribution of stored water through canals so as to ensure equity among farmers and adequate irrigation to the crops were well known and practiced even before 3000 B.C. as is evidenced by the following quotations:

"No grain is ever produced without water, but too much water tends to spoil the grain. An inundation is as injurious to growth as dearth of water".

- **Narada Smriti XI, 19.**

"Rishi Narada enquired from emperor Yudhishtara whether the farmers were sturdy and prosperous and whether dams had water for distribution in different parts of the kingdom"

- **Kaushika Sutra**

Further, the remains of Indus Valley Civilization that flourished up to 1750 B.C also revealed the existence of the farm communities in the Indian sub-continent. The Grand Anicut across the river Cauvery in Tamilnadu was constructed by Chola kings as early as in the 2^{nd} Century A.D., and was providing irrigation to about 0.24 million hectares, when its renovation was taken up by the British. Likewise the Viranarayana and Gangaikonda-Cholapuram tanks in Tamilnadu and Anantarajasagara in Andhra Pradesh were constructed during 10^{th} and 13^{th} Century, respectively. Ghiyasuddin Tughluq (1220 – 1250) is credited to be the first ruler who encouraged digging canals. Subsequently in the 14^{th} Century during the reign of Feroz Shah Tughlaq and Shahjahan the development of canal irrigation was given impetus and the western and Eastern Jamuna Canal in Haryana was laid out. Maste Canal followed these on the river Ravi during the 18^{th} Century. It was also noticed that the Chandel Kings in Bundelkhand region constructed large number of tanks that continued to be used till the 18th Century.

2.3.2 British period

Irrigation development under British rule began with the renovation, improvement and extension of the then existing works. Later the period from 1836 – 1866 marked the investigation, development and completion of four major river-diversion works of considerable size viz., Upper Ganga Canal, Upper Bari Doab Canal, Krishna & Godavari Delta systems. In 1867, the British Government adopted the practice of taking up works, which promised a minimum net return. Thereafter, a number of projects were taken up. These included major canal works like the Sirhind, the Lower Ganga, the Agra and the Mutha Canals, and the Periyar Dam and canals. Some other major canal projects were also completed on the Indus river during this period. These included the Lower Swat, the Lower Sohag and Para, the Lower Chenab and the Sidhnai Canals, all of which went to Pakistan in 1947. However, as a result of the famine during 1876 – 1878, the country received serious setback in agricultural production. Consequently, the First Famine Commission was setup by the Government in 1880, which recommended for irrigation development in drought prone areas. Significant protective works constructed during the period were the Betwa Canal, the Nira Left Bank Canal, the Gokak Canal, the Khaswad Tank and the Rushikulya Canal. The good harvest during the next 15 years led to complacency and no comprehensive plan for irrigation was prepared.

The last two years of the 19^{th} Century (1899 – 1900) again witnessed devastating famines. This led to the appointment of First Irrigation Commission in the year 1901 to ascertain the usefulness of irrigation against famines. Big spurt in irrigation development was thus, observed in the first quarter of 20^{th} Century. The total irrigated area through public works in 1920-21 rose to 19.3 million hectares over a base of 13.3 million ha in 1900. About 8.9 million ha more area was brought under irrigation up till 1946-47. Thus, before partition the total irrigated area was 28.2 million ha inclusive of Princely State's private irrigation (4.7 million ha). At the time of partition in 1947, about 8.8 million ha irrigated area went to Pakistan and 19.4 million ha remained with India. To cope up with the demand of food grains for growing population, a good number of Multipurpose River Valley Projects *viz.,* Bhakra Nangal, Damodar Valley and Hirakud dams were initiated soon after independence. At the beginning of First Five Year Plan in 1950-51 the irrigated area was 22.6 million ha (9.7 million ha under major and medium irrigation projects and 12.9 million ha under minor irrigation schemes from both surface and groundwater sources).

The post independence era through Five-Year Plans witnessed planned efforts in irrigation development in the country. The Rajasthan Canal, Gandhisagar Dam, Gandak, Kosi, Nagarjunasagar, Tungabhadra, Malprabha, Ghataprabha and Farakka irrigation projects were taken up during the first two Five Year Plans (1950-51 to 1960-61). Subsequently projects such as Tawa, Ramganga, SriRamsagar, Ukai, Kadana, Teesta, Tehri, Jayakwadi, Beas, Gandak, Sardar Sarovar, Chambal, Mahi, Mahanadi delta, Idukki, Koyna, Narmada Sagar Valley etc., were initiated (Table 2.1).

Table 2.1. Important major irrigation projects in India

S.No.	Name of the Project	River	Beneficiary States
1	Bhakranagal Project	Satluj	Punjab, HP, Haryana & Rajasthan
2	Damodar Valley Project	Damodar	Bihar & West Bengal
3	Hirakud Dam	Mahanadi	Orissa
4	Thungabhadra Project	Tungabhadra	Andhra Pradesh & Karnataka
5	Nagarjuna Sagar Project	Krishna	Andhra Pradesh
6	Kosi Project	Kosi	Bihar
7	Farakka Project	Ganga Bhagirathi	West Bengal
8	Gandak Project	Gandak	Bihar, Uttar Pradesh, Nepal
9	Beas Project	Beas	Rajasthan & Punjab
10	Rajasthan Canal	Satluz	Rajasthan, Punjab, Haryana
11	Chambal Project	Chambal	Madhya Pradesh & Rajasthan
12	Ukai Project	Tapti	Gujarat
13	Tawa Project	Narmada	Madhya Pradesh
14	Sri Ram Sagar Project	Godavari	Andhra Pradesh
15	Malaprabha Project	Malprabha	Karnataka
16	Mahi Project	Mahi	Gujarat
17	Mahanandi Delta	Mahanadi	Orissa
18	Indukki Project	Periyar	Kerala
19	Koyna Project	Koyna	Maharastra
20	Upper Krishna Project	Krishna	Karnataka
21	Ramganga Project	Cnuisot Stream	Uttar Pradesh
22	Tehri Dam	Bhilanganga & Bhagirath	Uttar Pradesh
23	Narmada Sagar	Narmada	MP, Rajasthan, Gujarat & Maharastra

Tere was therefore a great spurt in irrigated area which increased from 22.6 million ha in Pre-plan period to 87.23 million ha by the end of the 10th Five Year Plan (34.42 million ha under major & medium irrigation projects and 52.81 minor irrigation schemes) (Fig. 2.4). With an average irrigation intensity of 140%, the actual net irrigated area is likely to be around 62.31 million ha, which is only 43% of the net sown area of the country (142 million ha).

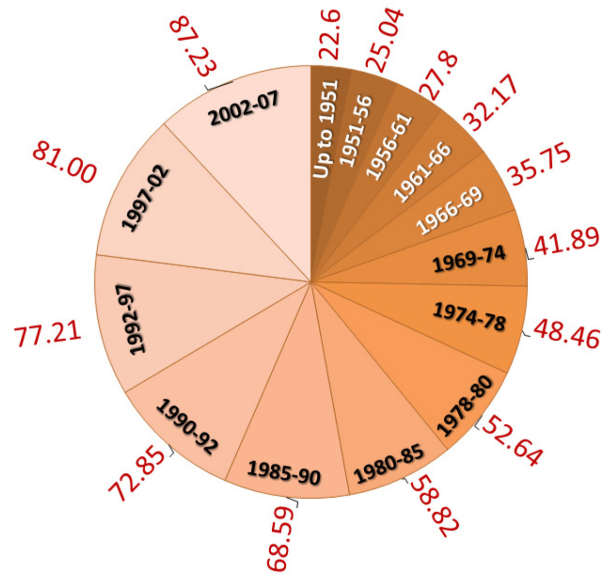


Fig. 2.4. Progressive irrigation development in India

According to latest estimates, it has been assessed that the gross cropped area that can ultimately be irrigated would be 139.89 million ha without inter-basin sharing of water and 175 million ha with inter-basin sharing of water. Even after achieving the ultimate irrigation potential of 139.89 million ha and considering the average irrigation intensity of 140%, the ultimate irrigated area in the country would be only 70% of the net sown area. The source-wise irrigated area in India is presented in Fig. 2.5.

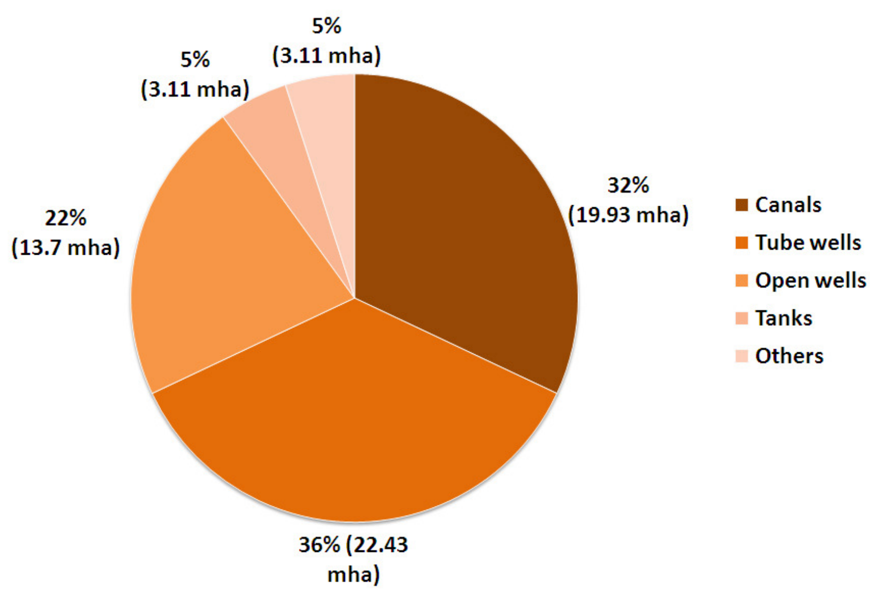


Fig. 2.5. Sourcewise irrigated area in India

According FAO estimates of 2009, out of the total 1628 million ha of cultivated area in the world, only 17.0% (277 million ha) is under irrigation (Fig. 2.6). The largest irrigated area in the world is in India (62.3 million ha) followed by China (56 million ha) and USA (28 million ha) (Fig. 2.6).

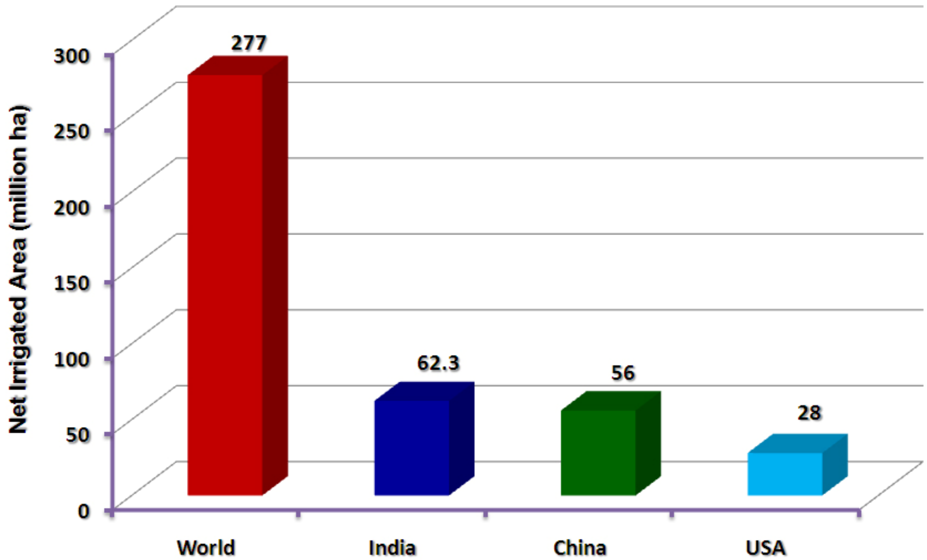


Fig. 2.6. World irrigated area

Lecture No. 3

Water Resources and Irrigation Development in Andhra Pradesh

3.1 Surface water resources

The state is endowed with a variety of natural resources for irrigation and is popularly known as the “River State”. The mean annual rainfall of the state is 940mm. Major portion (66.4%) of the rainfall is contributed by South-west monsoon from June to September followed by North-east monsoon (23.8%) from October to December. The rest 9.8% of the rainfall is received during the winter & summer months of January to May. Further, it has the advantage of having most of the East flowing rivers in the heart of the state bringing copious supplies from the Western and Eastern Ghats and Deccan Plateau up to Bay of Bengal. Of these, the most important major river systems are The Godavari, The Krishna and The Pennar besides 9 inter state rivers and 28 intra state rivers totaling to about 40 river basins (Table 3.1).

Table 3.1. Surface water resources of Andhra Pradesh

River basin	Catchment area (Km^2)	Per cent of CA to the total area	Annual water yield				Riparian state
			M.ha.m	Million m^3	TMC	Per cent	
Godavari	73, 201	26.45	4.2470	42470	1500	55	Maharashtra, Andhra Pradesh, Madhya Pradesh, Orissa & Karnataka
Krishna	74, 382	26.88	2.2660	22660	800	29	Maharashtra, Andhra Pradesh & Karnataka
Pennar	48, 111	17.39	0.2700	2700	97	3.5	Andhra Pradesh & Karnataka
Other 9 inter-state rivers	81, 006	29.28	0.2860	2860	101	3.5	Andhra Pradesh, Karnataka Orissa & Tamilnadu
28 Intra-state rivers			0.6800	6800	240	9.0	Andhra Pradesh
TOTAL	**2, 76, 700**	**100.0**	**7.749**	**77, 490**	**2, 738**	**100**	

The three major river systems *viz.,* The Godavari, The Krishna and The Pennar together drain about 70% of the state’s land area (the Godavari basin accounting for 26%, the Krishna basin for 27% and the Pennar basin for 17%). The Godavari and Krishna river systems have major part of their catchment in other states (Maharashtra, Karnataka, Madhya Pradesh and Orissa), whereas; a small part of the catchment of Pennar river system is in Karnataka State. Since these are inter-state rivers, the availability of water to Andhra Pradesh State is dependent on established riparian rights. It is assessed that two major river systems flowing through the state *viz.,* the Godavari and the Krishna contribute about 84% of the utilizable surface water of the state. Besides these, nine other minor inter-state rivers flowing through the territories of Orissa, Tamilnadu, Karnataka and Andhra Pradesh contribute another 3.5% of the total surface flows. In addition to these 12 inter-state rivers, 28 other smaller river systems, which lie entirely within the state boundary, contribute the balance 9% of the surface flows (Table 3.1).

Thus, the total surface water wealth available from all the river basins of the state is therefore, of the order 77490 million m^3 (equivalent to 2748 TMC or 7.749 million ha meters). All the rivers in the state are highly seasonal, and even in the case of perennial rivers, more than 90% of the total water flows occur during the monsoon period of June to November. In view of this, construction of expensive retention dams and reservoirs has been involved for irrigation development in the state.

3.2 Groundwater Resources

Sizable reserves of groundwater are available in the state. The utilizable ground water reserves for irrigation in the state are assessed to be 2.71 million ha meters. Out of which the present utilization is only 0.73 million ha meters of water for irrigation purposes mostly through dug wells & filter points. This leaves a balance of 1.98 million ha meters for further exploitation, which can bring about additional 1.3 million ha under assured irrigation supplies. The maximum groundwater potential available is in Nellore district and lowest in Rangareddy district. With regard to net draft of water, the Nizamabad district ranks first with 44.4% followed by Karimnagar (42.9%) and Chittoor district (41.7%).

3.3 Irrigation Development in Andhra Pradesh

During successive Five-Year Plans, the state has put in planned efforts in the area of irrigation sector. As a result of this several irrigation schemes were initiated and implemented. The list of major irrigation projects, the districts benefited and the cultural command area are given in Table 3.2. The major irrigation sources in the state are canals, tanks, tube wells, open wells and others (Fig. 3.1).

The total net and gross irrigated area in the state is 4.45 million ha and 6.07 million ha, respectively. However, the major source of irrigation is through canals accounting for about 36.7% of the gross irrigated area in the state. This is followed by tube wells (32.4%); open wells (14.3%), tanks (12.7%) and other sources (3.8%). The percentage of gross area irrigated to the total gross cropped area in the state is about 47.4%. The ultimate irrigation potential in the state is assessed at 9.2 million ha.

Out of the total 6.07 million ha of gross irrigated area in the state during 2006-07 (Table 3.3), rice crop alone accounted for 3.845 million ha of gross irrigated area (63.3%) followed by sugarcane (0.4 million ha), groundnut (0.281 million ha), maize (0.260 million ha), cotton (0.208 million ha) and sunflower (0.141 million ha). All other crops *viz.,* jowar, bajra, chillies, turmeric, sesame etc., account for only 14.3% of the irrigated area in the state.

Table 3.2. Irrigation schemes in Andhra Pradesh

S.No.	Name of the Irrigation Project	District benefited
1.	Neelam Sanjeeva Reddy Sagar (Srisailam) Project	Kurnool & Cuddapah
2.	Priyadarsini Jurala Project	Mahaboobnagar
3.	Nagarjuna Sagar Project	Nalgonda, Khammam, Krishna, Guntur & Prakasham
4.	Prakasham Barriage	West Godavari, Krishna & Guntur
5.	Tungabhadra Project	Kurnool, Anantapur & Cuddapah
6.	Sriram Sagar Project	Adilabad, Nizamabad, Karimnagar & Warangal
7.	Lower Manair Reservoir	Karimnagar & Warangal
8.	Kadam Project	Adilabad
9.	Sir Arther Cotton Barriage	East Godavari & West Godavari
10.	Rajolibanda Diversion Scheme	Mahaboobnagar & Kurnool
11.	Vamsadhara Project	Srikakulam
12.	Somasila Project	Nellore
13.	Yeleru Reservoir	Vishakapatnam & East Godavari
14.	Kurnool – Cuddapah Canal	Mahaboobnagar, Cuddapah & Kurnool
15.	Nizamsagar Project	Nizamabad
16.	Gazuladinne Project	Kurnool
17.	Kandaleru Project	Chittoor & Nellore
18.	Pulivendala Canal Scheme	Cuddapah
19.	Madduvalasa Reservoir Scheme	Srikakulam
20.	Thandava Reservoir Scheme	Vishakapatnam & East Godavari
21.	Janjhavati Project	Srikakulam
22.	Yerrakalava Reservoir	West Godavari
23.	Thotapalli Regulator	Vizianagaram
24.	Narayanapuram Anicut	Srikakulam
25	Indira Sagar (Polavaram) Project	East Godavari, West Godavari, Krishna & Vishakapatnam
26	AMPRP & Udaya Samudram Balancing Reservoir	Nalagonda
27	Telugu Ganga Project	Kurnool, Kadapa, Nellore, Chittooe
28	K.L.Rao Sagar – Pulichintala Project	Krishna, East Godavari, West Godavari, Guntur, Prakasham
29	Koyal Sagar Lift irrigation scheme	Mahaboobnagar
30	Sripada Sagar Ellampalli Lift Irrigation Scheme	Karimnagar, Medak

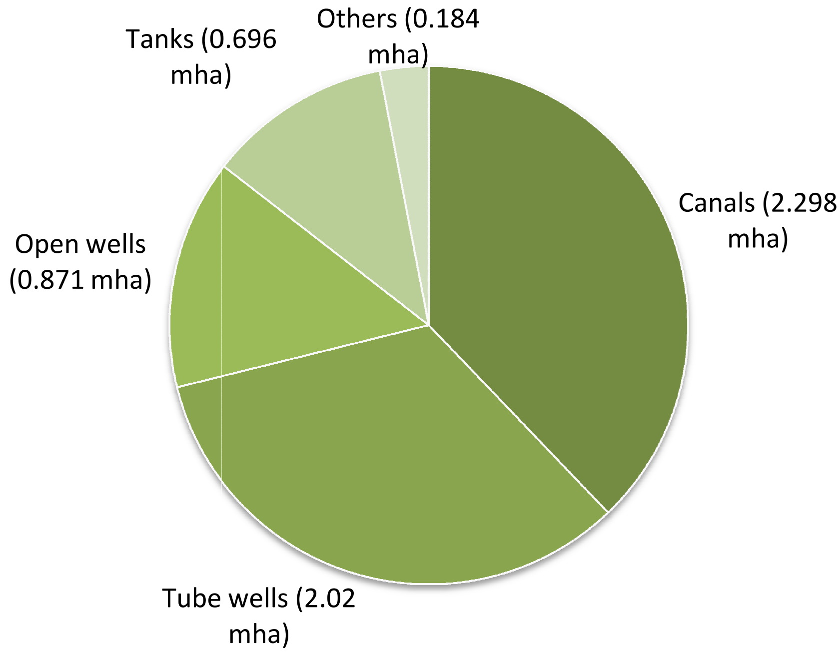


Fig. 3.1. Sourcewise irrigated area in Andhra Pradesh

Table 3.3. Irrigated area source-wise under different crops in Andhra Pradesh during 2006 – 07

Crop	Area under different sources (000' ha)					Total irrigated area (000' ha)	% of irrigated area under crop to the total irrigated area
	Canals	Tanks	Tube wells	Open wells	Others		
Rice	2000	714	719	297	189	3845	63.3
Sugarcane	69	28	258	37	8	400	6.7
Groundnut	22	6	166	81	6	281	4.7
Maize	36	10	119	93	2	260	4.3
Cotton	23	3	59	120	3	208	3.5
Sunflower	16	3	103	18	1	141	2.4
Chillies	20	Neg.	51	46	10	127	2.1
Turmeric	4	1	35	27	1	68	1.1
Other crops							8.7
Total	2231	772	1969	867	231	6070	100.0

Lecture No. 4

Command Area Development and Water Management

4.1 Introduction

During the post independence period high priority was accorded to increase agricultural production and productivity for providing food security to the people and as such a number of irrigation projects were initiated and constructed. The irrigation potential, which stood at 22.6 million ha till 1950-51 had increased to 33.57 million ha by the end of Third Five Year Plan. In the later years, during successive Five Year Plans Government of India realized that in spite of the large investments made in the irrigation sector and the phenomenal growth in the irrigation potential, there existed a gap between irrigation potential created (Fig. 4.1) besides the return from the investment both in terms of agricultural productivity as well as finance were very disappointing. The increasing gap between irrigation potential created and irrigation potential utilized prompted the Irrigation Commission in 1972 to make specific recommendations for systematic and integrated development of commands of irrigation projects. Following this, a Committee of Ministers in 1973 suggested creation of a broad-based Area Development Authority for every major irrigation project to undertake the work of comprehensive area development and management.

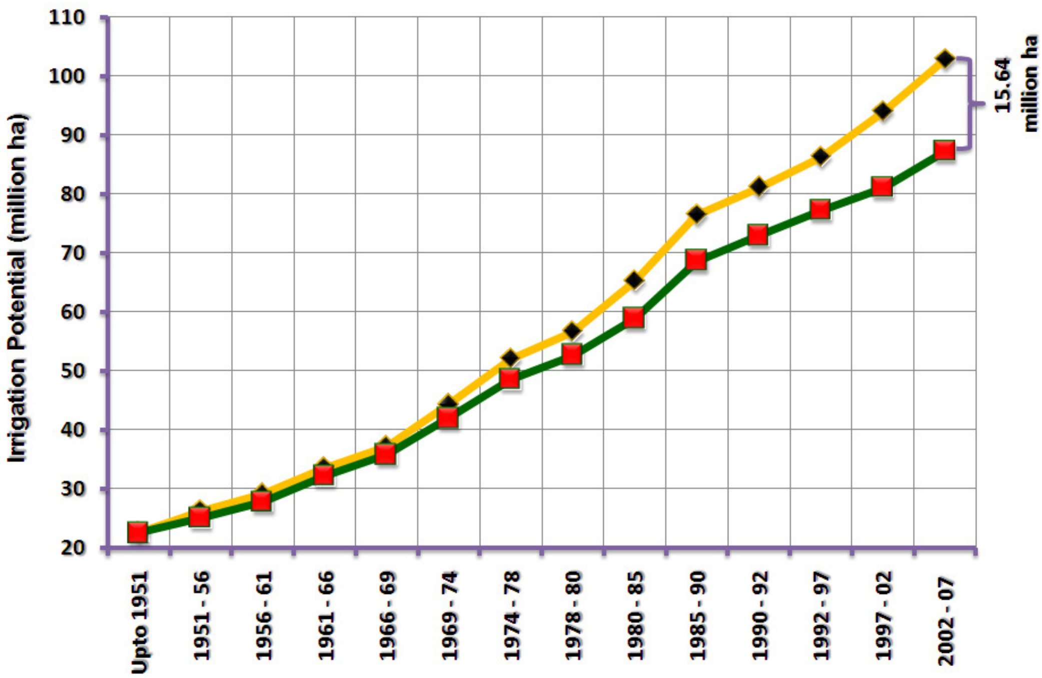


Fig. 4.1. Planwise irrigation potential created and utilized

On the basis of the recommendations of the Committee of Ministers, Government of India launched a Centrally Sponsored Scheme of Command Area Development Programme in 1974-75. The programme envisaged an integrated and coordinated approach to the development and management of command areas by constituting a multi-disciplinary team under the overall control of the Command Area Development Authorities. The programme was restructured and renamed as "Command Area Development and Water Management (CADWM) Programme" from 1st April 2004. The CAD programme was initiated with 60 major and medium irrigation projects. So far 332 irrigation projects with a Culturable Command Area (CCA) of about 29 million ha spread over 23 States and 2 Union Territories have been included under the programme, out of which 138 projects are currently under implementation.

4.1.1 CADWM – Objective

"To bridge the gap between the irrigation potential created and that utilized through increase in irrigated areas and thereon to increase efficient utilization of irrigation water and improve the agricultural productivity in the irrigation commands".

4.2 Reasons for lag in irrigation potential created to that of utilization

a) Deficiencies in design and operational procedures
b) Unlined conveyance systems and uncontrolled and improper water distribution systems
c) Lack of on-farm development works and land consolidation for better water management
d) Irrigation methods followed are biblical in nature i.e., field to field irrigation with uncontrolled wild flooding system
e) Irrigation scheduling in most projects is still based on conventional approaches
f) Complete negligence of drainage component in command areas
g) Inappropriate irrigation water pricing policy i.e., pricing based on irrigated acreage rather than irrigation quantity
h) Changes in cropping pattern assumed at the time of designing the project and that followed by farmers
i) Cultivation of rice in areas localized for ID crops
j) Absence of feed-back from farmers
k) Lack of coordination between different agencies i.e., extension workers, irrigation engineers, research scientists and farmers
l) Inadequate infrastructure of extension services

4.3 Functions of CADWM

1. On-farm development through systematic land leveling and land shaping of areas under the projects
2. Planning & construction of field channels, drains and farm roads
3. Modernisation, maintenance & efficient operation of irrigation systems

4. Development, maintenance & operation of drainage systems
5. Selection, introduction and enforcement of suitable cropping patterns
6. Introduction & enforcement of a proper rotational irrigation practice i.e., warabandhi system and equitable distribution of water to the individual fields
7. Conjunctive use of surface and ground water resources
8. Introduction of suitable cropping patterns
9. Propagation, demonstration and implementation of improved water management techniques, education and training of farmers in irrigated agriculture
10. Localization and relocalisation of lands on sound principles
11. Strengthening of existing agricultural extension activities
12. Planning for timely and adequate supply of various crop production inputs viz., seeds, fertilizers, pesticides, herbicides vis-à-vis credit facilities
13. Creation and development of marketing, processing and warehouse facilities

Lecture No. 5

Soil Physical Properties Influencing Soil Water Relations

5.1 Introduction

Soil water relations deal with those physical properties of soils and water that affect movement, retention and absorption of water by plants and which must be considered in order to plan or improve an irrigation system.

5.2 Soil – A three phase disperse system

The soil is a heterogeneous, polyphasic *viz.,* solid, liquid and gaseous, particulate, disperse and porous system (Fig. 5.1). The solid phase constitutes the soil matrix, the liquid phase consists of soil water, which always contains dissolved substances so that it should properly be called the soil solution and the gaseous phase is the soil atmosphere.

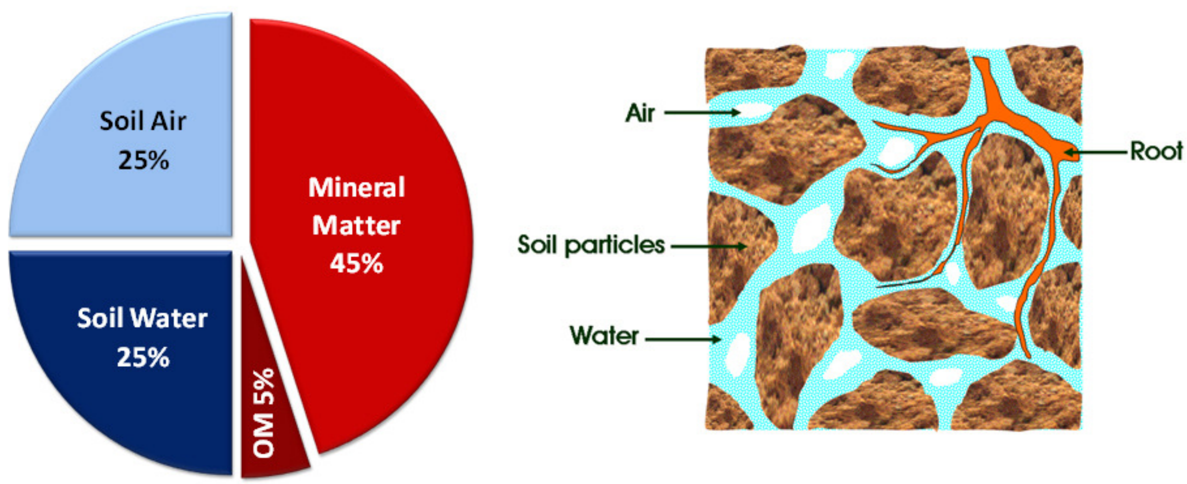


Fig. 5.1. Volume composition & sectional view of soil

The solid matrix of the soil includes particles, which vary in chemical and mineralogical composition as well as in size, shape, and orientation. It also contains amorphous substances, particularly organic matter, which is attached to the mineral particles and often binds them together to form aggregate. The organisation of the solid components of the soil determines the geometric characteristics of the pore spaces in which water and air are transmitted and retained.

The liquid portion of the soil which consists of water, dissolved minerals and soluble organic matter fills part or most of the spaces between the solid particles. This water is absorbed by the plant roots and must be periodically replenished by rain or irrigation for the successful production of crops. Thus, the soil serves as a reservoir for moisture. This moisture reservoir and knowledge of its capacity are principle factors governing the frequency and amount of irrigation water to be applied to the land.

The gaseous or vapour portion of the soil occupies that part of the spaces between the soils particles not filled with water. This is an important phase of the soil system, as most plants require some aeration of the root system, with the exception of aquatic plants such as rice. Irrigation practice is important in maintaining a reasonable balance between the soil moisture and air.

Finally, soil water and air vary in composition, both in time and space.

5.3 Soil properties influencing soil-water relations

5.3.1 Soil depth

Soil depth refers to the thickness of soil cover over hard rock or hard substratum below which roots cannot penetrate. The soil depth is directly related to the development of root system, water storage capacity, nutrient supply and feasibility for land leveling and land shaping. Soil Conservation Division, Ministry of Agriculture, New Delhi, recognizes the following classes for irrigation purposes:

Table 5.1. Soil depth classification

Soil depth (cm)	Class
Less than 7.5cm	Very shallow
7.5 – 22.5	Shallow
22.5 – 45.0	Moderately deep
45.0 – 90.0	Deep
More than 90	Very deep

A shallow soil has limited moisture holding capacity, restricted feed zone and root growth, therefore would need frequent irrigations with less water depth. Shallowness of soil is further unfavourable in areas needing land leveling and shaping because it affects soil-water relations besides nutrient retention & availability. Deep soil on the other hand, has good moisture holding capacity, larger feeding zone and good possibilities for development of root system. Soil depth is also important for interpreting water storage capacity.

5.3.2 Soil texture

Soil texture is the most important and fundamental property of the soil that is most intimately related to soil water relationship. It refers to the relative proportion of mineral particles of various sizes in a given soil i.e., the proportions of coarse, medium and fine particles, which are termed sand, silt and clay, respectively. Various combinations of these fractions are used to classify soil according to its texture. Using the name of the predominant size fraction designates texture. Three broad and fundamental groups of soil textural classes are recognized as sandy, loamy and clayey (Table 5.2).

Table 5.2. Common textural classes encountered in the field

Common name	Texture	Basic soil textural class
Sandy soils	Coarse	Sands & Loamy sand
Loamy soils	Moderately coarse	Sandy loam & Fine sandy loam
	Medium	Very fine sandy loam, Loam, Silt loam & Silt
	Moderately fine	Sandy clay loam, Silty clay loam & Clay loam
Clayey soils	Fine	Sandy clay, Silty clay & Clay

The textural class of a soil can be accurately determined in the laboratory by mechanical analyses. Sand, silt and clay are size groupings of soil particles as shown below in Table 5.3:

Table 5.3. Size groupings of soil particles

Soil texture	Size grouping in diameter
Coarse sand	2.0 – 0.2 mm
Fine sand	0.2 – 0.02 mm
Silt	0.02 – 0.002 mm
Clay	< 0.002 mm

The soil texture is closely related to:

a) Water holding capacity of the soil
b) Quantity of water to be given at each irrigation i.e., irrigation water depth
c) Irrigation interval and number of irrigations
d) Permeability i.e., ability of the soil to transmit water & air
e) Infiltration rate

For example, coarse textured soils (sandy soils) have low water holding capacity and facilitate rapid drainage and air movement. Therefore, crops grown on these soils require frequent irrigations with less irrigation water depth at each irrigation. On the other hand, fine textured soils (clayey) have relatively high water holding capacity, however the permeability for water and air is slow thus resulting in poor drainage and sometimes the soils get waterlogged. Considering its various effects, the soils with loamy texture are the ideal soils for growing most crops under irrigated conditions.

5.3.3 Soil structure

The structure of a soil refers to the arrangement of the soil particles and the adhesion of smaller particles to form large ones or aggregates (Fig. 5.2). On the surface, soil structure is associated with the tilth of the soil.

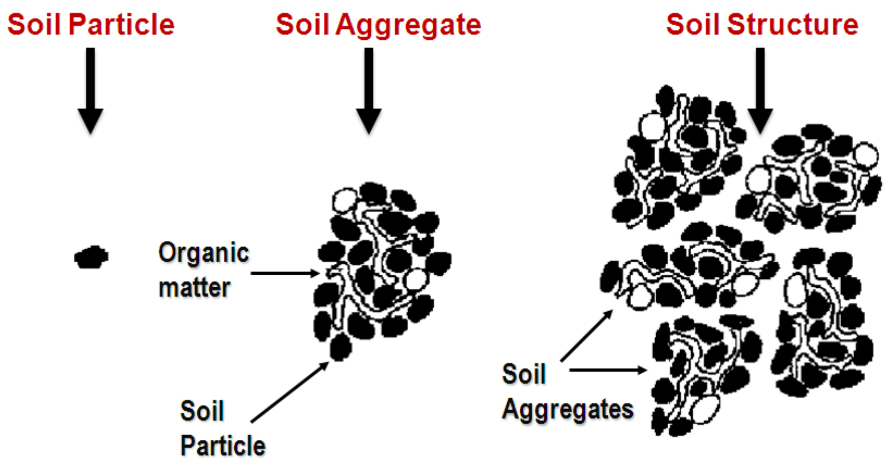


Fig. 5.2. Soil structure

The dominant shape of aggregates in a horizon determines their structural type, such as speroidal (granular or crumbly subtypes), platy; prism like (columnar or prismatic subtypes) and block like (cube and sub-angular subtypes) (Fig. 5.3). On surface the soil structure is associated with tilth of the soil.

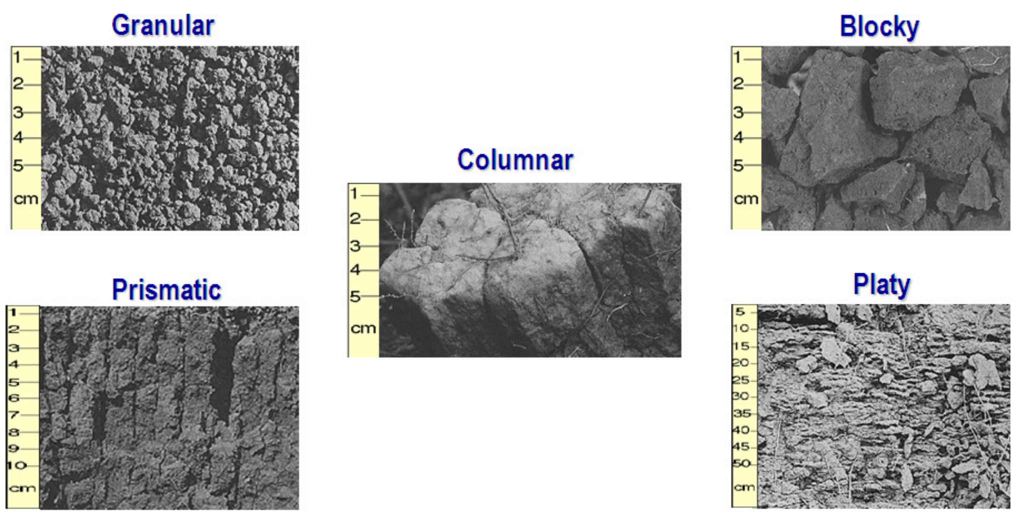


Fig. 5.3. Soil structural types

The soil structure influences primarily:

a) Permeability for air and water
b) Total porosity and in turn water storage capacity in a given volume of soil
c) Root penetration and proliferation

Soils without definite structure may be single grain types, sands or massive types such as heavy clays. For example a structure-less soil allows water to percolate either too rapidly or too slowly. Platy structure restricts the downward movement of water. Crumbly, granular and prismatic structural types are most desirable for efficient irrigation water management and normal crop growth (Fig. 5.4).

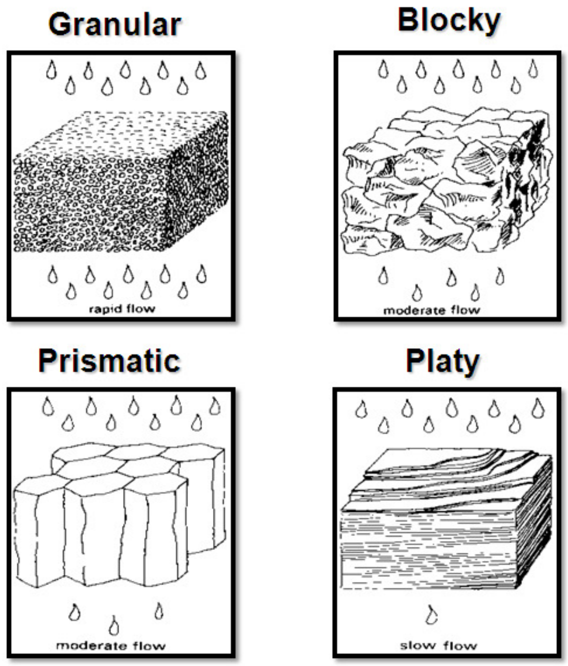


Fig. 5.4. Effect of structural type on permeability for water

5.3.4 Density of soil solids

There are two ways to express the soil weight – particle density and bulk density.

5.3.4.1 Particle density (ρp): It is the ratio of a given mass (or weight) of soil solids to that of its volume. It is usually expressed in terms of g/cm^3. Thus if 1 cm^3 of soil solids weigh 2.6g, the particle density measures 2.6 g/cm^3. Although considerable range may be observed in the density of individual soil minerals, the values for most mineral soils usually vary between the narrow limits of 2.6 to 2.75 g/cm^3. This soil property is independent of size of the soil particles and the arrangement of the soil solids. Knowledge of particle density is necessary for determination of total, capillary and non-capillary porosity.

5.3.4.2 Bulk density (ρb): It refers to the ratio of a given mass of an oven dried soil to that of its field volume (i.e., solids + pore spaces). The bulk density is calculated by the following formula:

$$\textbf{Bulk density}\left(\frac{\textbf{g}}{\textbf{cm}^3}\right)(\rho\textbf{b}) = \frac{\textbf{Wds}}{\textbf{Vt}} = \frac{\textbf{Weight of an oven dried soil (g)}}{\textbf{Total field volume of soil}\ (\textbf{cm}^3)}$$

Knowledge of bulk density is of particular importance in the determination of depth of water for a given depth of soil and total, capillary and non-capillary porosity. The permeability of soil for water, air and penetration of plant roots is also influenced by bulk density. Compression or compaction of soil particles increases bulk density, consequently it lowers the porosity in turn the soil water storage capacity; this directly affects the crop performance particularly where water availability is sub-optimal, which is a characteristic feature of light soils. The bulk density values for various soil textural classes are given in Table 5.4.

Table 5.4. Bulk density values of various soil types (USDA - SCS)

Soil texture	Bulk density (g/cm^3)
1. Sandy	1.60 – 1.70
2. Loamy sand	1.60 – 1.70
3. Sandy loam	1.55 – 1.65
4. Fine sandy loam	1.50 – 1.60
5. Loamy soil	1.45 – 1.55
6. Silty loam	1.40 – 1.50
7. Silty clay loam	1.35 – 1.45
8. Sandy clay loam	1.40 – 1.50
9. Clay loam	1.30 – 1.50
10. Clay soil	1.25 – 1.35

Sample problem: Calculate the bulk density from the following data
Fresh weight of soil = 2501g; Weight of water = 750g; Height of core = 10cm and Diameter of the core = 12cm
Answer:

$$\boldsymbol{Bulk\ density\ (g/cm^3)(\rho b) = \frac{Wds}{Vt} = \frac{2501 - 750}{1130.4} = \frac{1751}{1130.4} = 1.549\ g/cm^3}$$

$$\boldsymbol{Vt = \pi r^2 h = 3.14 \text{ x } 6^2 \text{x } 10 = 1130.4}$$

5.3.5 Pore space

Soil total porosity (f) is an index of pore volume in the soil. It is the space in a given volume of soil that is occupied by air and water or not occupied by the soil solids. The total porosity is calculated as follows:

$$\boldsymbol{Total\ porosity\ (f)(\%) = \left(1 - \frac{\rho b}{\rho p}\right) 100 = \left(1 - \frac{bulk\ density}{particle\ density}\right) 100}$$

Total porosity value generally lies in the range of 30 to 60% for arable soils. Coarse textured soils tend to be less porous (35 – 50%) than the fine textured soils (40 – 60%), though the mean size of individual pores is greater (>0.06mm in diameter) in the former than in the latter. Total porosity is inclusive of both, capillary (micro pores) and non-capillary porosity (i.e., macro pores). In a sandy soil, in spite of the relatively low total porosity, the movement of air and water is surprisingly rapid because of the dominance of the macro pores. Therefore the size of the individual pore spaces rather than their combined volume is an important consideration for optimum soil-water relations. For ideal conditions of aeration, permeability, drainage and water distribution, a soil should have about equal amount of macro and micro pore spaces.

Knowledge of porosity in a given volume of soil is very important with respect to irrigation water management, because it is an index of moisture storage capacity and aeration conditions, the two most important factors that influence the plant growth and development.

Sample problem:

Given – Bulk density = 1.32 g cm^{-2} and particle density = 2.65 g cm^{-2}. Calculate what part of the soil is pore space (%).

Answer:

$$\boldsymbol{Total\ porosity}\ (\boldsymbol{f})(\%) = \left(\mathbf{1} - \frac{\mathbf{1.32}}{\mathbf{2.65}}\right)\mathbf{100} = \mathbf{50.18}\%$$

Lecture No. 6
Water Retention in Soil

6.1 Adhesion & Cohesion

Hydrogen bonding accounts for two basic forces responsible for water retention and movement in soils:

Adhesion: Attraction between water molecules and solid surfaces

Cohesion: Attraction of water molecules for each other.

By adhesion some water molecules are held rigidly at the surfaces of soil solids. In turn these tightly bound water molecules hold by cohesion other water molecules farther away from the solid surfaces (Fig. 6.1).

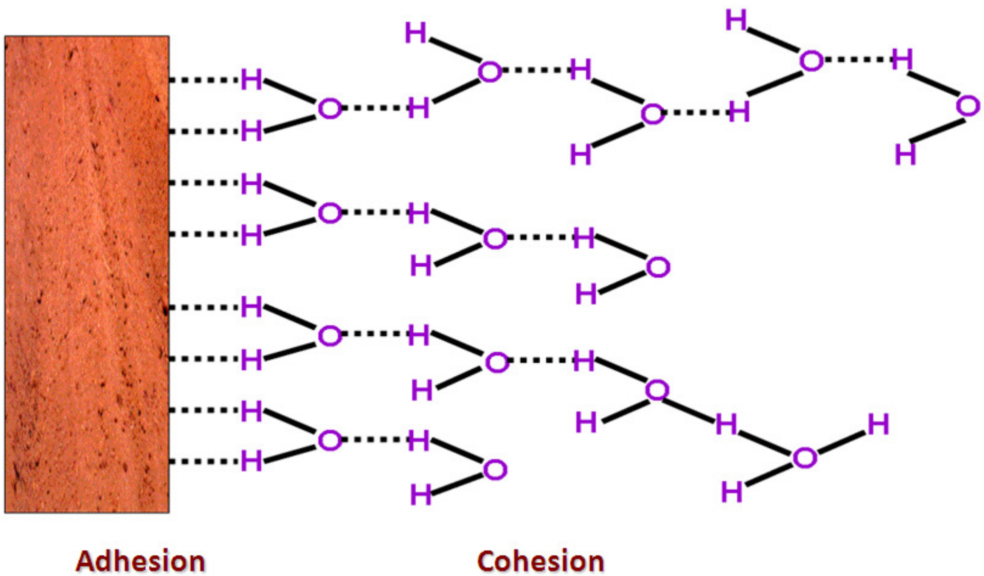


Fig. 6.1. The forces of adhesion and cohesion in a soil-water system

The adhesive force diminishes rapidly with distance from the solid surface. The cohesion of one water molecule to another results in water molecules forming temporary clusters that are constantly changing in size and shape as individual water molecules break free to join up with others. The cohesion between water molecules also allows the solid to indirectly restrict the freedom of water for some distance beyond the solid-liquid interface. Thus together, the forces of adhesion and cohesion make it possible for the soil solids to retain water and control its movement and use.

6.2 Soil moisture tension

The moisture held in the soil against gravity may be described in terms of moisture tension. Thus, soil moisture tension is a measure of the tenacity with which water is retained in the soil and reflects the force per unit area that must be exerted by plants to remove water from the soil. Several units have been used to express the force (energy) with which water is held in the soil. A common means of expressing tension is in terms of a bar, which equals the pressure exerted by a vertical water column. For instance, a pressure of one bar is approximately equal to the hydrostatic pressure exerted by a vertical column of water having a height of 1023 cm or a hydraulic head of 1023 cm. Similarly 1.0 bar is equivalent to 0.9869 atmospheres. This value approximates the standard atmosphere, which is the average air pressure at sea level i.e., equal to 14.7 lbs/in^2 or a mercury head of 76 cm or 760mm. The suction of water having a height of 10cm is equal to 0.01 bars or 10 millibars, that of a column of 100 cm high about 0.1 bar or 100millibars. Similarly 1.0 bar is equal to 100 centibars. Thus the higher the height of water column or bars or atmospheres the greater the tension or suction measured.

6.3 pF

In attempting to express the matric potential (or soil moisture tnsion) of soil water in terms of an equivalent hydraulic head (or energy per unit weight), it is understood that this head may be of the order of –100 cm or even –100000 cm of water. To avoid the use of such cumbersomely large numbers, Schofield (1935) suggested the use of pF (by anology with the pH acidity scale), which is defined as the logarithm of the negative pressure (soil water tension or suction) head in cm of water. A tension of 10 cm of water is, thus, equal to a pF of 1. Likewise, a tension head of 1000 cm is equal to a pF of 3, and so forth. Approximate equivalents among expressions of soil water tension are given below in Table 6.1.

Table 6.1. Approximate equivalents among expressions of soil water tension

Soil moisture tension (bars)	Soil water potential (kPa)	Hydraulic head (cm)	pF value
–0.01	1	10.2	1.0
–0.1	10	102	2.0
–0.33	33	337	2.52
–1.0	102	1023	3.0
–15.0	1534	15345	4.2
–31.0	3171	31713	4.5

6.4 Soil moisture characteristic curves

The graphical representation of the relationship between soil moisture suction or tension and soil water content is known as soil moisture characteristic curve or water retention curve. The soil moisture characteristic curves are determined in the laboratory using pressure plate and pressure membrane apparatus. The relationship between soil water tension and moisture content for various soil types varying in texture is shown through Fig. 6.2.

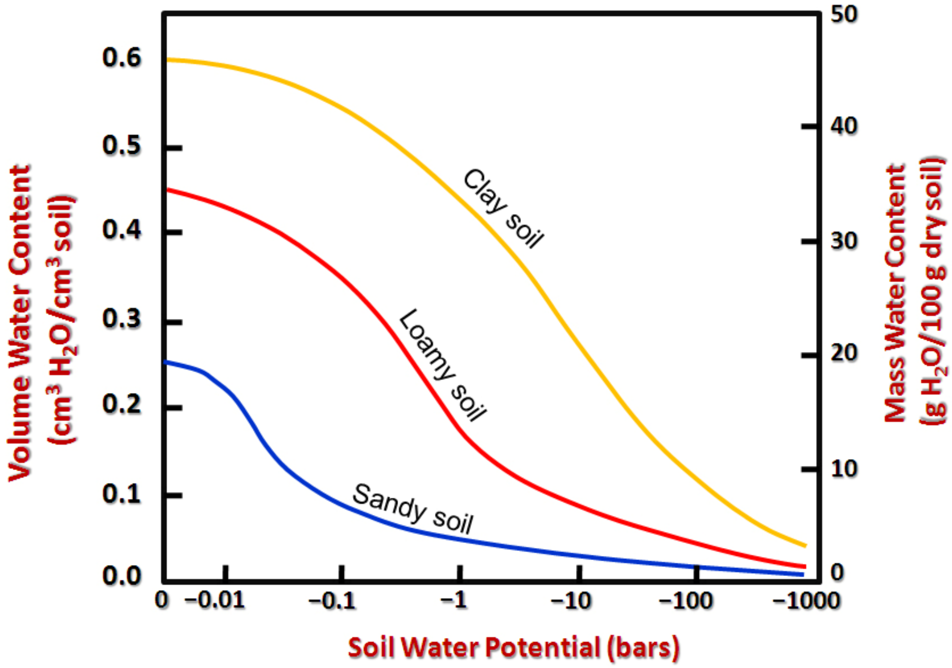


Fig. 6.2. Soil moisture characteristic curves for soils varying in texture

The soil moisture characteristic curve is strongly affected by soil texture. The greater the clay content, in general, the greater the water retention at any particular suction, and the more gradual the slope of the curve (Fig. 6.2). In a sandy soil, most of the pores are relatively large, and once these large pores are emptied at a given suction, only a small amount of water remains. In a clay soil, the pore size distribution is more uniform, and more of the water is adsorbed, so that increasing the suction causes a more gradual decrease in water content.

The soil moisture characteristic curves have marked practical significance. They illustrate retention-energy (suction) relationships, which influence various field processes, the two most important of which are the movement of water in soils and the uptake and utilization of water by plants. Thus help in scientific scheduling of irrigation's to field crops at optimum time and in proper quantity.

Lecture No. 7

Water Movements in Soil

7.1 Infiltration

Infiltration is the entry of fluid from one medium to another. In irrigation practice it is the term applied to the process of water entry into the soil, generally by downward flow through all or part of the soil surface is termed as infiltration.

Infiltration rate or infiltrability is defined as the volume of water flowing into the profile per unit of soil surface area per unit time. It is mathematically expressed as:

$$\boldsymbol{i} = \frac{\boldsymbol{Q}}{\boldsymbol{A} \times \boldsymbol{T}}$$

Where,

$\boldsymbol{i}$ = Infiltration rate (mm or cm/min or h)

$\boldsymbol{Q}$ = Volume quantity of water (m^3) infiltrating,

$\boldsymbol{A}$ = Area of the soil surface (m^2) exposed to infiltration, and

$\boldsymbol{T}$ = Time (min or h).

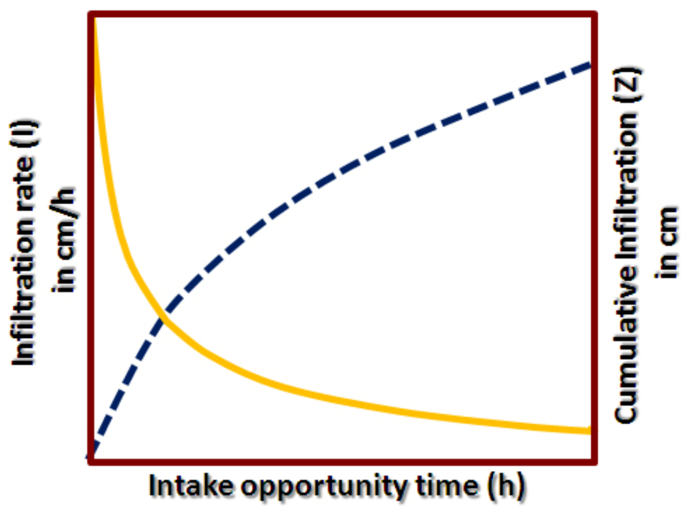


Fig. 7.1. Infiltration rate and cumulative infiltration

The infiltration rate is not constant over time. Generally, infiltration rate is high in the initial stages of infiltration process, particularly where the soil is quite dry, but tends to decrease monotonically and eventually to approach asymptotically a constant rate, which is often termed as basic intake rate or steady state infiltration rate (Fig. 7.1). Whereas, the cumulative infiltration, being the time integral of the infiltration rate, has curvilinear time dependence, with a gradually decreasing slope as shown in Fig. 7.1. The infiltration rate of a soil may be easily measured using a simple device known as a double ring infiltrometer insitu. The variation of infiltration rate in different soil textures is shown in Fig. 7.2. The steady state infiltration rate for various soil types is given in Table 7.1. The factors influencing infiltration rate are time from the onset of rain or irrigation, initial water content, hydraulic conductivity, presence of impeding layers in the profile and vegetative cover.

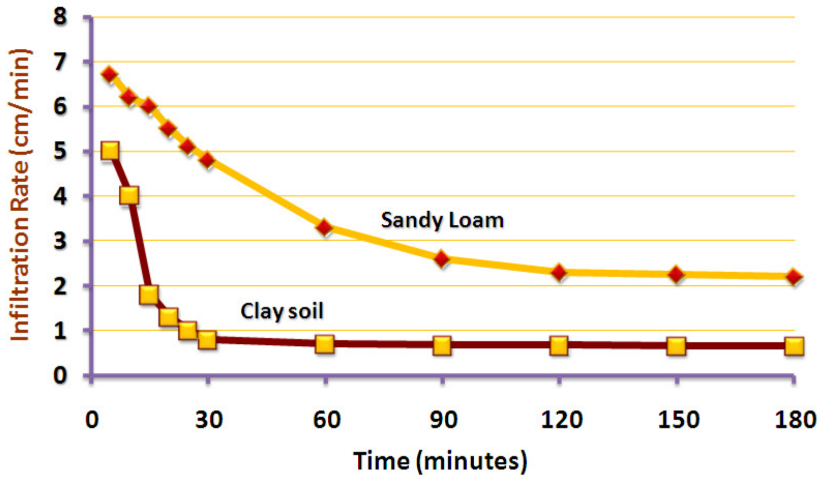


Fig. 7.2. Infiltration rate in different soil types

Table 7.1. Steady state infiltration rates of various soil types

Soil type	Steady state infiltration rate (mm/hour)
Sandy	**30**
Loamy sand	**20 – 30**
Sandy loam	**12 – 20**
Silt loam	**7 – 12**
Clay loam	**3 – 7**
Clayey	**< 3**

7.2 Seepage

The lateral movement of water through soil pores or small cracks in the soil profile under unsaturated condition is known as seepage.

7.3 Permeability

It indicates the relative ease with which air and water penetrate or pass through the soil pores. Permeability of soils is generally classified as rapid, moderate and slow. Thus the permeability is rapid in coarse textured soils and slow in fine textured soils.

7.4 Deep percolation

Infiltration is a transitional phenomenon that takes place at the soil surface. Once the water has infiltrated the soil, the water moves downward into the profile. This post-infiltration water movement downward with in the soil profile under the influence of both gravity and hydrostatic pressure is termed as deep percolation. Sandy soils facilitate greater percolation when compared to clayey soils due to dominance of macro pores. Likewise the loss of water by percolation in cropped fields is generally less than that in bare soils.

7.5 Hydraulic conductivity

The hydraulic conductivity of a soil is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient. Hydraulic conductivity is defined by Darcy's law, which, for one-dimensional vertical flow, can be written as follows:

$$V = K\frac{h1 - h2}{L}$$

Where, V is Darcy's velocity (or the average velocity of the soil fluid through a geometric cross-sectional area within the soil), h1 and h2 are hydraulic heads, and L is the vertical distance in the soil through which flow takes place. The coefficient of proportionality, *K,* in the equation is called the hydraulic conductivity.

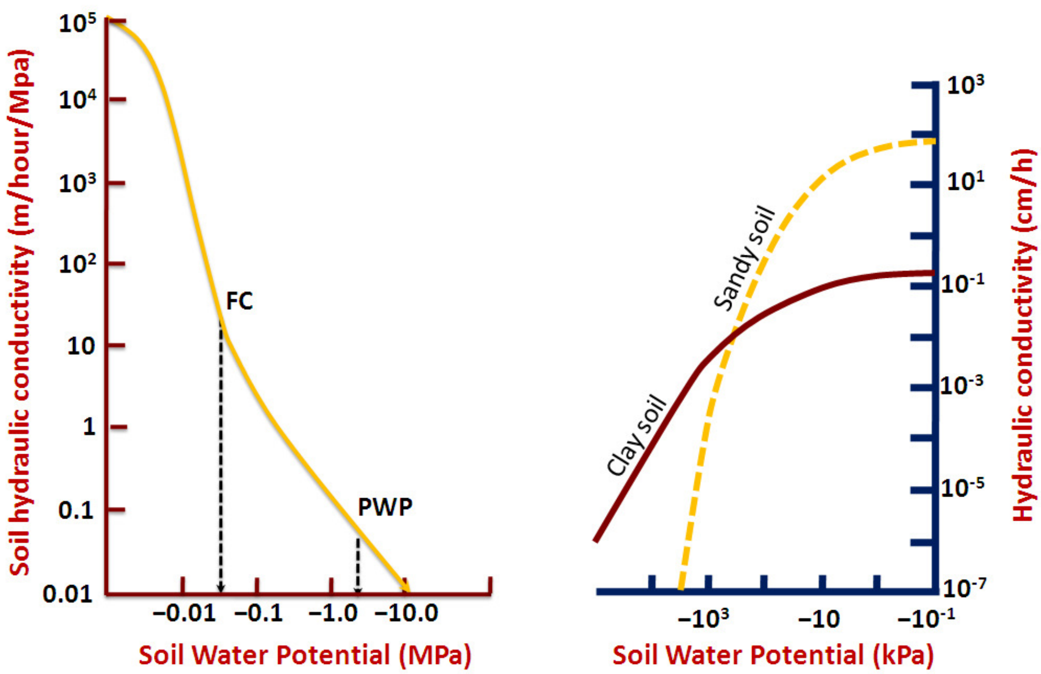


Fig. 7.3. Soil hydraulic conductivity versus

Thus, the hydraulic conductivity is defined as the ratio of Darcy's flow velocity at unit hydraulic gradient. The dimension of *K* is the same as that for velocity, that is, length per unit of time (L/T). In a soil having a stable structure the hydraulic conductivity is more or less constant, but as the soil structure, density and porosity change, there is a change in the hydraulic conductivity. With variation in soil texture the hydraulic conductivity values are different. For example a clay soil with a large proportion of fine pores shows poor hydraulic conductivity as compared to a sandy soil with higher proportion of larger pores (Fig. 7.3). Higher bulk density and massive structure reduce the hydraulic conductivity of the soil. Saturated hydraulic conductivity for a particular soil is always constant, whereas unsaturated hydraulic conductivity is a function of soil water content (Fig. 7.3).

7.6 Types of water movement

Movement of water in the soil is complex because of various states and directions in which water moves and because of the forces that cause it to move. As water is dynamic soil component, generally three types of water movement within the soil are recognized – saturated flow, unsaturated flow and water vapour flow. The former two flows involve liquid water in contrast to water vapour flow. In all cases water flows in response to energy gradients, with water moving from a zone of higher to one of lower water potential.

7.6.1 Saturated water movement

The condition of the soil when all the macro and micro pores are filled with water the soil is said to be at saturation, and any water flow under this soil condition is referred to as saturated flow. The flow of water under saturated conditions is determined by two factors viz., the hydraulic force driving the water through the soil (hydraulic gradient) and the ease with which the soil pores permit water movement (hydraulic conductivity). The quantity of water per unit of time $\boldsymbol{Q/t}$ that flows through a column of saturated sol can be expressed by Darcy's law, as follows:

$$\frac{Q}{t} = AK_{sat}\frac{\Delta\Psi}{L}$$

Where, A is the cross-sectional area of the column through which the water flows, K_{sat} is the saturated hydraulic conductivity, $\Delta\Psi$ is the change in water potential between the ends of the column (for example, $\Psi_1 - \Psi_2$, and L is the length of column) (Fig. 7.4).

For a given column, the rate of flow is determined by the ease with which the soil transmits water (K_{sat}) and the amount of force driving the water, namely the **water potential gradient** $\Delta\Psi/L$. For saturated flow this force may also be called the **hydraulic gradient.** By analogy, think of pumping water through a garden hose, with K_{sat} representing the size of the hose (water flows more readily through a larger hose) and $\Delta\Psi/L$ representing the size of the pump that drives the water through the hose. The units in which K_{sat} is measured are length/time, typically cm/s or cm/h.

7.6.2 Unsaturated water movement

The soil is said to be under unsaturated condition when the soil macro pores are mostly filled with air and the micro pores (capillary pores) with water and some air, and any water movement or flow taking place under this soil condition is referred to as unsaturated flow. Under field conditions most of the soil water movements occurs only when the soil pores are not completely saturated with water. However, water movement under these conditions is very sluggish compared to that when the soil is at saturation. This is because at or near zero tension, the tension at which saturated flow occurs the hydraulic conductivity is orders of magnitude greater than at tensions of 0.1 bars and above, which characterize unsaturated flow.

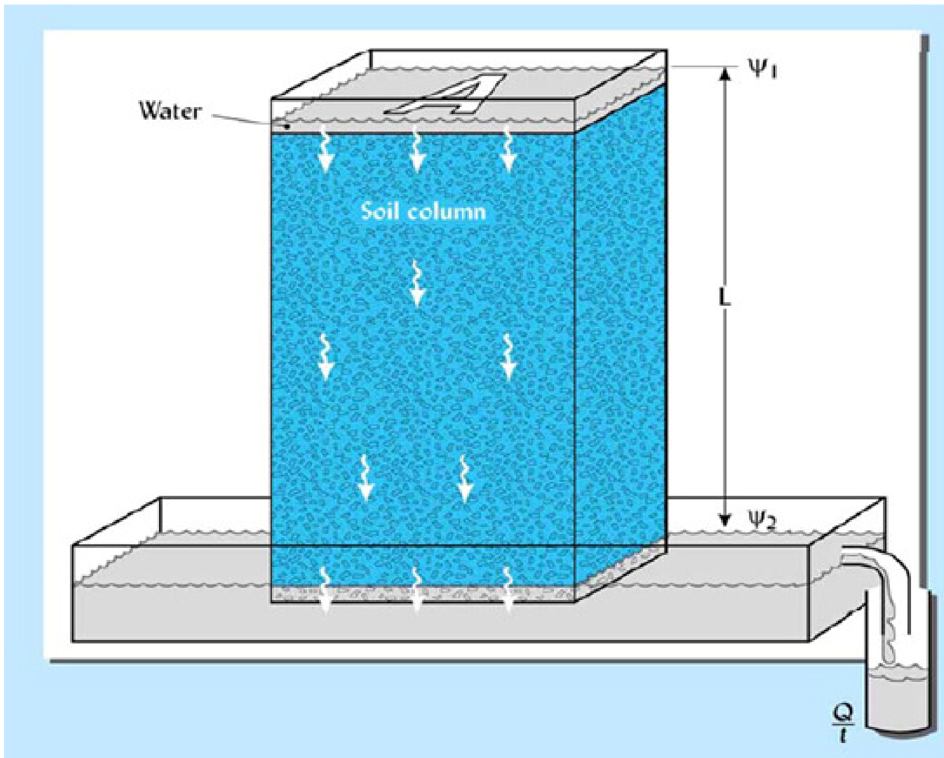


Fig. 7.4. Saturated flow in a column of soil

Further under unsaturated soil conditions at low tensions, the hydraulic conductivity is higher in sandy soils compared to clayey soils. The opposite is true at higher tension values.

Unsaturated flow is governed by the same general principles affecting saturated flow i.e., its direction and rate are related to the hydraulic conductivity and to a driving force, which in this case is moisture tension gradient or moisture suction gradient. This gradient is the difference in tension between two adjoining soil zones. Thus, the water movement will always be from a zone of low tension (high matric potential) to one of high tension (low matric potential) or from a zone of thick moisture films to where the films are thin. The force responsible for this tension is the attraction of soil solids for water (i.e. adhesion). The higher the water contents in the moist zone, the greater is the tension gradient and more rapid is the flow.

Lecture No. 8

Physical Classification of Water

8.1 Introduction

The water held within the soil pores is referred to as soil moisture. The manner in which it is held in the soil and to what extent it is translocated into plant system forms a basis of observation of drying of wet soils and of plants growing on these soils, water may be divided into three categories *viz.,* gravitational water, capillary water and hygroscopic water (Fig. 8.1).

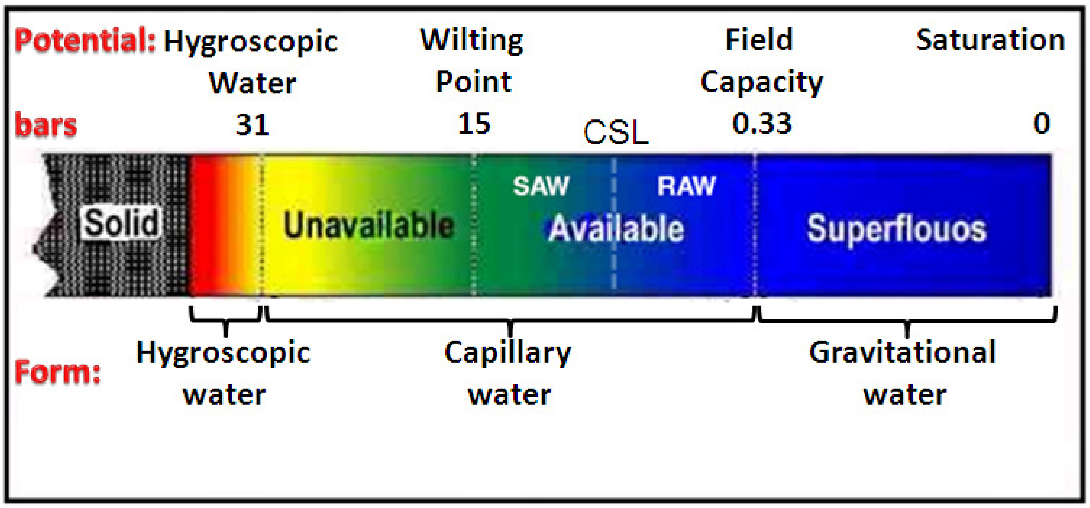


Fig.8.1. Physical classification of soil water

8.2 Gravitational water

Water held between 0.0 to 0.33 bars (0 to –33 kPa) soil moisture tension, free and in excess of field capacity, which moves rapidly down towards the water table under the influence of gravity is termed as gravitational water (Fig. 8.1). Even though the gravitational water is retained with low energy, it is of little use to plants, because it is present in the soil for only a short period of time and while in the soil, it occupies the larger pores i.e., macro pores, thereby reducing soil aeration. Therefore, its removal from the soil profile through natural drainage is generally regarded as a pre-requisite for optimum plant growth and development.

8.3 Capillary water

As the name suggests capillary water is held in the pores of capillary size i.e., micro pores around the soil particles by adhesion (attraction of water molecules for soil particles), cohesion (attraction between water molecules) and surface tension phenomena. It includes available form of liquid water extracted by growing plants and is held between field capacity (0.33 bars or –33 kPa) and hygroscopic coefficient (31 bars or –3100 kPa) (Fig. 8.1). However, the water within the capillary range is not equally available i.e., it is readily available starting from 0.33 bars up to a certain point often referred to as critical soil moisture level (for most crops it varies between 20 to 50% depletion of available soil moisture) and thereafter up to 15 bars (–1500 kPa) it is slowly available. Further below, when the soil exerts tensions between 15 bars and 31 bars, the water is held very tightly in thin films and is practically not available for plant use. The capillary water moves in any direction but always in the direction of increasing tension and decreasing potential.

8.4 Hygroscopic water

The water held tightly in thin films of 4 – 5 milli microns thickness on the surface of soil colloidal particles at 31 bars tension (–3100 kPa) and above is termed as hygroscopic water (Fig. 8.1). It is essentially non-liquid and moves primarily in vapour form. Plants cannot absorb such water because, it is held very tenaciously by the soil particles (i.e., > 31 bars). However, some microorganisms may utilize it. Unlike capillary water which evaporates easily at atmospheric temperatures (i.e., it requires very little energy for its removal), hygroscopic water cannot be separated from the soil unless it is heated at 100°C and above for 24 hours.

Lecture No. 9

Soil Moisture Constants

9.1 Introduction

The water contents expressed under certain standard conditions are commonly referred to as soil moisture constants. They are used as reference points for practical irrigation water management. The usage of these constants together with the energy status of soil water gives useful knowledge. These constants are briefly explained below:

9.2 Saturation capacity

Saturation capacity refers to the condition of soil at which all the macro and micro pores are filled with water and the soil is at maximum water retention capacity" (Fig. 9.1). The matric suction at this condition is essentially zero as the water is in equilibrium with free water. Excess water above saturation capacity of soil is lost from root zone as gravitational water (Fig. 9.1).

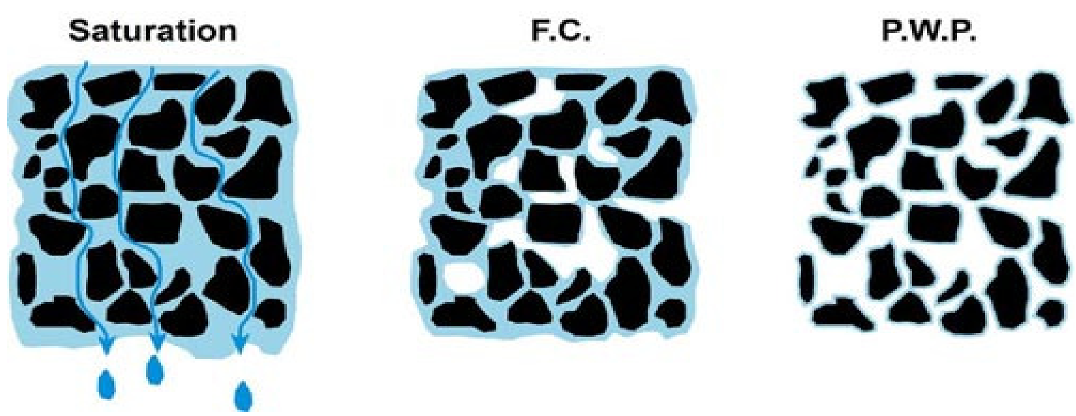


Fig. 9.1. Soil condition at Saturation, Field Capacity and Permanent Wilting Point

9.3 Field capacity

According to Veihmeyer and Hendrickson (1950) the field capacity is "the amount of water held in soil after excess water has been drained away and the rate of downward movement has materially decreased, which usually takes place within 1 – 3 days after a rain or irrigation in pervious soils having uniform texture and structure (Fig. 9.1). At field capacity, the soil moisture tension depending on the soil texture ranges from 0.10 to 0.33 bars (or –10 to –33 kPa). Field capacity is considered as the upper limit of available soil moisture. The field capacity is greatly influenced by the size of the soil particles (soil texture), finer the soil particles higher the water retention due to very large surface area and vice versa. Thus, at field capacity, a m^3 of a typical sandy soil will hold about 135 liters of water, a loamy soil about 270 liters and a clay soil about 400 liters.

9.4 Permanent wilting point

It is the condition of the soil wherein water is held so tightly by the soil particles that the plant roots can no longer obtain enough water at a sufficiently rapid rate to satisfy the transpiration needs to prevent the leaves from wilting. When this condition is reached the soil is said to be in a state of permanent wilting point, at which nearly all the plants growing on such soil show wilting symptoms and do not revive in a dark humid chamber unless water is supplied from an external source (Fig. 9.1). The soil moisture tension at permanent wilting point is about 15 bars (or –1500 kPa) equal to a suction or negative pressure of a water column 1.584×10^4 cm (pF = 4.2). Permanent wilting point is considered as lower limit of available soil moisture. Under field conditions PWP is determined by growing indicator plants such as sunflower in small containers. In the laboratory pressure membrane apparatus can be used to determine the moisture content at 15 bars.

9.5 Available soil moisture

It has been a convention and even now it is a customary to consider "the amount of soil moisture held between the two cardinal points *viz.,* field capacity (0.33 bars) and permanent wilting point (15 bars) as available soil moisture" (Fig. 9.2).

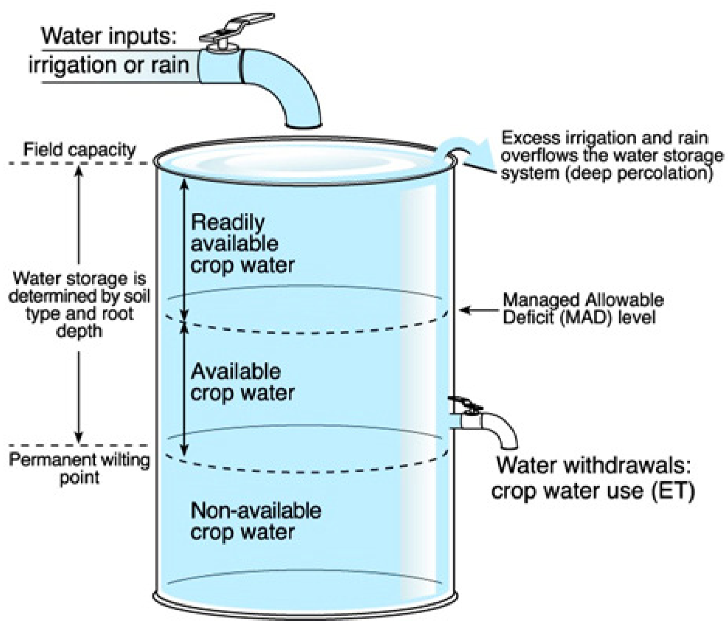


Fig. 9.2. Soil water availability

Though considerable soil moisture is present below the permanent wilting point, it is held so tightly by the soil particles that the plant roots are unable to extract it rapidly enough to prevent wilting. Thus, practically it is not useful for the plants and forms the lower limit of available soil moisture. Similarly, the water above the field capacity is not available to the plants owing to quick drainage. The available soil moisture is expressed as depth of water per unit of soil and is calculated according the following formula:

$$\boldsymbol{Available\ Soil\ Moisture\ (mm/depth\ of\ soil) = \frac{(FC - PWP)\ x\ \rho b\ x\ ds}{10}}$$

Where,

$FC \quad = Field\ capacity\ moisture\ (\%) on\ oven\ dry\ weight\ basis$

$PWP = Permanent\ wilting\ point\ moisture\ (\%) on\ oven\ dry\ weight\ basis$

$\rho b \quad = soil\ bulk\ density\ (g/cm^3)$

$ds \quad = Depth\ of\ soil\ (cm)$

$ASM \ = Available\ soil\ moisture\ (mm/m\ depth\ of\ soil)$

Sample problem

A soil has an average soil moisture content of 36.5% at field capacity and 13.5 % at permanent wilting point on dry weight basis. The bulk density of the soil is 1.6g cm^{-3}. Find out the available soil per meter depth of soil profile.

Answer:

$$ASM = \frac{(FC - PWP)\ x\ \rho b\ x\ ds}{10} = \frac{(36.5 - 13.5) x\ 1.6\ x\ 100}{10} = 288\ mm/m\ depth\ of\ soil$$

The field capacity moisture content, permanent wilting point, available soil moisture and infiltration rates in different soil types is given in Table 9.1.

Table 9.1. Moisture holding properties of in different soils varying in texture

Soil texture	Saturation capacity (%)	FC (%)	PWP (%)	ASM		Infiltration rate (mm/hr)
				%	mm/m	
Clayey	60	40	20	20	200	3
Clay loam	50	30	15	15	150	3 – 7
Silt loam	45	22	12	10	100	7 – 12
Sandy loam	42	14	6	8	80	12 – 20
Loamy sand	40	10	4	6	60	20 – 30
Sandy	38	6	2	4	40	30

9.6 Hygroscopic coefficient

It is defined as the amount of water that the soil contains when it is in equilibrium with air at standard atmosphere i.e., 98% relative humidity and at room temperature. In other words it is the amount of moisture absorbed by a dry soil when placed in contact with an atmosphere saturated with water vapour (100% relative humidity) at any given temperature, expressed in terms of percentage on an oven dry basis. The matric suction of soil water at this moisture content is nearly about 31 bars.

9.7 Theories of soil water availability

Optimum plant growth and development normally take place at field capacity moisture content. It is not known whether the water is equally available for plant growth over the entire available soil moisture range. There are three theories of soil water availability to plants, as follows (Fig. 9.3):

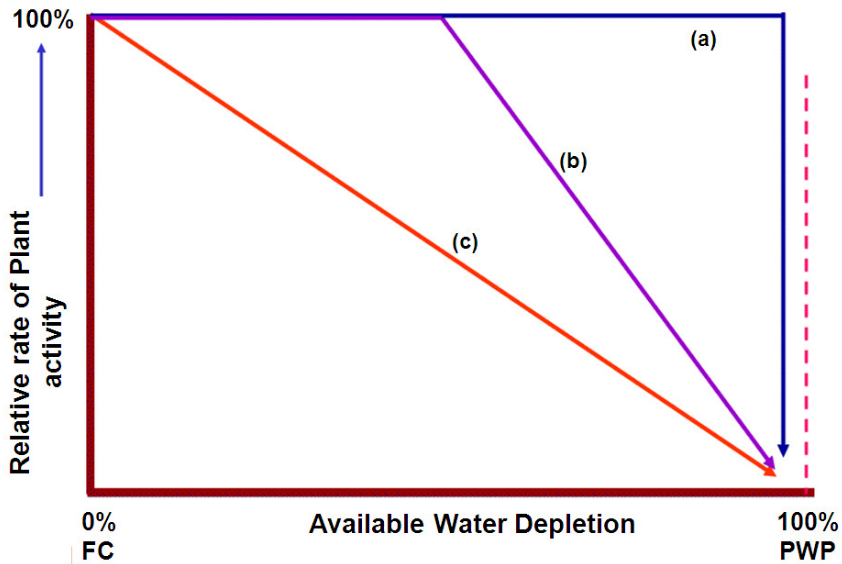


Fig. 9.3. Classical hypotheses of soil water availability

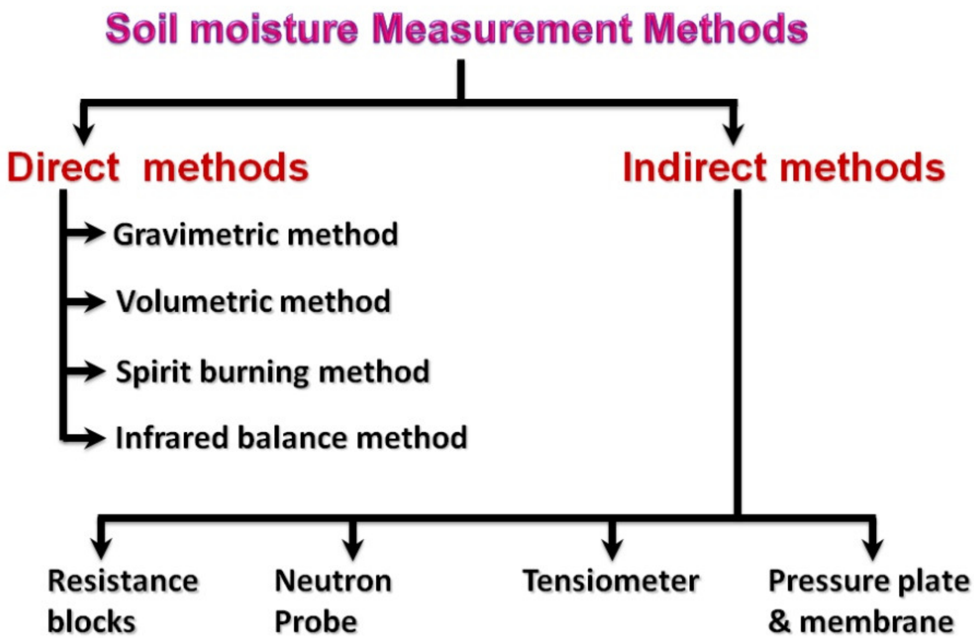
- **Veihmeyer and Hendrickson (1950)** proposed that soil water is equally available to plants equally throughout a definable range of soil wetness, from an upper limit FC to a lower limit PWP, both of which are characteristic and constant for a given soil (Curve 'a' in Fig. 9.3). According to this theory, plant functions remain unaffected by any decrease in soil wetness until PWP is reached, at which plant activity is curtailed, often abruptly.
- Other investigators notably **Richards and Wadleigh (1952)** indicated that soil water availability to plants actually decreases with decreasing soil wetness and that a plant may suffer water stress before wilting is reached (Curve 'c' in Fig. 9.3).
- **Still others** attempted to divide available range of soil wetness into readily available and decreasingly available zones and searched for a critical level somewhere between FC and PWP as an additional criterion of soil water availability (Curve 'b' in Fig. 9.3).

Lecture No. 10

Measurement of Soil Moisture

10.1 Introduction

The measurement of soil moisture is needed to determine when to irrigate and the amount of water needed when irrigating, to evaluate evapotranspiration, and to monitor soil matric potential. The soil moisture is measured in two ways – direct and indirect methods as follows:



10.2 Direct methods

10.2.1 Gravimetric method

The gravimetric method is a direct measurement of soil water content and is therefore the standard method by which all indirect methods are calibrated. The gravimetric water content, also called mass water content, is the ratio of the weight loss in drying to the dry weight of the soil sample. The mass water content can be expressed as mass water percentage by multiplying it with 100 (θm). This method involves collecting soil sample from the field using soil probe or auger from representative depths in the root zone and then determining its moist and dry weights. The moist weight is determined by weighing the soil sample as it is at the time of sampling, and the dry weight is obtained after drying the soil sample in an oven at 105°C for 24 hours or more to get a constant dry weight. The weight loss represents the soil water.

$$\boldsymbol{\theta m = \frac{(Wms - Wds)}{Wds}\, x\, 100 = \frac{Weight\ of\ moist\ soil - Weight\ of\ oven\ dry\ soil}{Weight\ of\ oven\ dry\ soil}\, x\, 100}$$

10.2.2 Volumetric method

The volumetric water content (θv) is defined as the volume of water present in a given volume (usually 1 m^3) of dry soil. When (θv) multiplied by 100 it gives volume water percentage. This method involves collecting soil sample from the field using core sampler of known volume from representative depths in the root zone and then determining its moist and dry weights and calculating the volume wetness by the following relationship:

$$\boldsymbol{\theta v = \frac{(Wms - Wds)}{Vt\ x\ \rho w}\ x\ 100}$$

$$\boldsymbol{\theta v = \frac{Weight\ of\ moist\ soil\ (Wms) - Weight\ of\ oven\ dry\ soil\ (Wds)}{Volume\ of\ core\ (Vt) x\ Density\ of\ water (\rho w)}\ x\ 100}$$

To calculate the volume water content from gravimetric water content, we need to know the bulk density (ρb) of dried soil and is calculated as follows:

$$\boldsymbol{\theta v = \theta m\ x\ \rho b = Gravimetric\ water\ content\ \text{x}\ bulk\ density}$$

Because in the field we think of plant root systems as exploring a certain depth of soil, and because we express precipitation and irrigation components, as depth of water (for example mm of rain or irrigation), it is often convenient to express the volumetric water content as a depth ratio (depth of water per unit depth of soil). Conveniently, the numerical values for these two expressions are the same. For example, for a soil containing 0.1 m^3 of water per m^3 of soil (10% by volume) the depth ratio of water is 0.1 m of water per metre depth of soil.

$$\boldsymbol{Depth\ of\ water\ (mm) per\ unit\ soil\ depth\ (ds) = \theta m\ x\ \rho b\ x\ ds = \ \theta v\ x\ ds}$$

Merits

- Ease of handling
- Low cost
- Minimum technical skill required
- Standard method of soil moisture determination with which other methods are compared

Demerits

- Time consuming
- Accuracy is subject to weighing and sampling errors
- Destructive soil sampling method
- Laborious

10.2.3 Spirit burning method

Soil moisture from the sample is evaporated by adding alcohol and iginiting. Provided the sample is not too large, the result can be obtained in less than 10 minutes. About 1.0 ml of spirit or alcohol per g of soil sample at field capacity and 0.5 ml at permanent wilting point is adequate for evaporating the soil moisture. This method is not recommended for soils with high organic matter content.

10.2.4 Infrared moisture balance

It consists of a 250 watt infrared lamp, sensitive torsion balance and autotransformer (Fig. 10.1). All housed in an aluminium cabinet. The radiation emitted by infrared lamp quickly vaporizes the soil moisture. The instrument is directly calibrated in per cent moisture. It gives fairly reliable moisture estimates in about 5 minutes.

Fig.10.1. Infrared moisture balance

10.3 Indirect methods

10.3.1. Electrical resistance blocks

Gypsum blocks or electrical resistance blocks, with two electrodes, is placed at a desired soil depth and allowed to equilibrate (Fig. 10.2). Electrical resistance of the block is measured by a meter based on the principal of Whetstone Bridge. Electrical resistance of the soil decreases with increase in water content. Soil water content is obtained with calibration curve, for the same block, of electrical resistance against known soil water content. Resistance blocks read low resistance (400 – 600 ohms) at field capacity and high resistance (50,000 to 75,000 ohms) at wilting point.

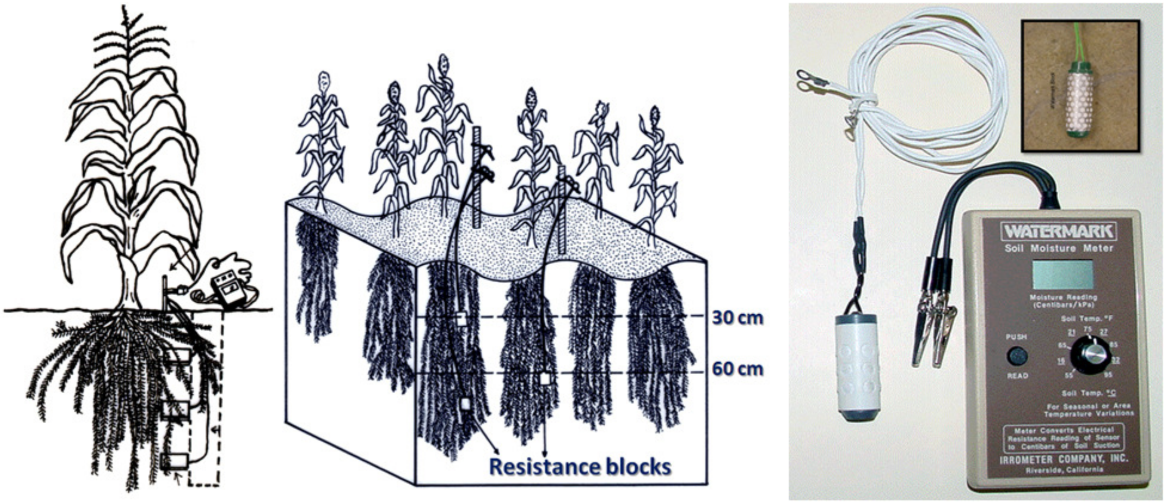


Fig.10.2. Measurement of soil moisture by Resistance blocks

Merits

- Relatively inexpensive
- Easy to install
- Gives quick readings
- Suitable for irrigation scheduling to crops raised in fine textured soils

Demerits

- Not useful in coarse textured soils
- Resistance blocks readings are sensitive to soil salinity, which may affect readings
- Blocks may get damaged over time (2 – 3 years) and require replacement

10.3.2 Neutron scattering technique

First developed in the 1950s, the neutron scattering method has gained widespread acceptance as an efficient and reliable technique for monitoring soil moisture in the field. The neutron moisture meter consists of two main components (Fig. 10.3) viz., a probe containing a source of fast neutrons (americium and beryllium) and boron trifluoride (BF_3) gas as a detector of slow neutrons, which is lowered into a hollow access tube pre-inserted into the soil; and a scaler or rate meter usually battery powered and portable to monitor the flux of the slow neutrons that are scattered and attenuated in the soil. The fast neutrons (having an energy range of 2 – 4 MeV and an average speed of about 1600 km/sec) are emitted radially into the soil, where they encounter and collide elastically with hydrogen nuclei (namely protons). Through repeated collusions, the neutrons are deflected and "scattered", and they gradually loose some of their kinetic energy. As the speed of the initially fast neutrons diminishes, it approaches a speed of 2.7 km/sec, equivalent to a energy of about 0.03 eV. Neutrons slowed down to such a speed are said to be thermalized and are called slow neutrons. The slow neutrons thus produced scatter randomly in the soil, quickly forming a cloud of constant density around the probe. The density of sow neutrons formed around the probe is nearly proportional to the concentration of hydrogen in the medium surrounding the probe, and therefore approximately proportional to the volume fraction of water present in the soil. The slowed or thermalized neutrons are detected by slow neutron detector containing BF_3 gas, which is then transmitted through electric pulses to the scaler and is displayed as moisture content.

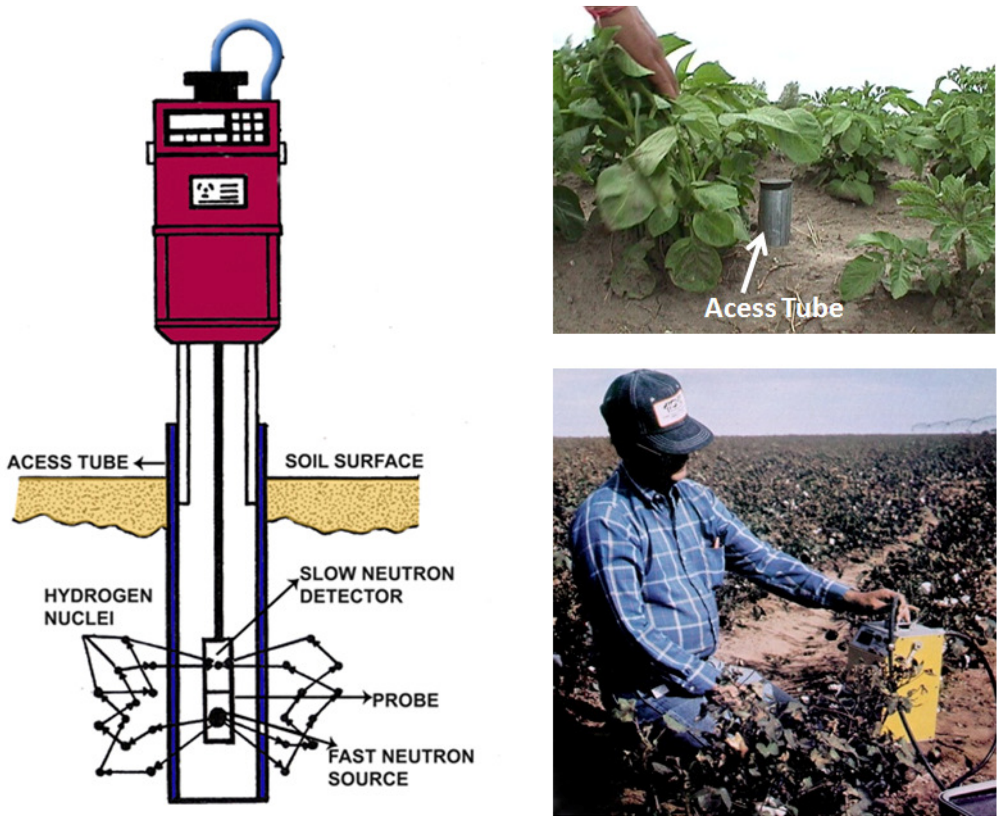


Fig. 10.3. Measurement of soil moisture by neutron probe

Merits

- Less laborious
- Rapid results
- Non-destructive method after initial installation
- Repeated measurements can be made at the same location and depth
- Independent of temperature and pressure

Demerits

- High initial cost of the equipment
- Probe must be calibrated for each soil & access tube
- Difficult to measure the soil moisture in the top 15 cm soil depth due to escape of neutrons into atmosphere
- Health hazards due to exposure to neutron & gamma radiation

10.3.3 Tensiometer

The tensiometer is an instrument designed to provide a continuous indication of the soil's matric suction (also called soil-moisture tension) in situ (Fig. 10.4). The essential parts of Tensiometer are shown in Fig. 10.4. The tensiometer consists of a porous ceramic cup, connected through a tube to a vacuum gauge (or manometer), all parts filled with water. When the cup is placed in the soil where the suction measurement is to be made, the water inside the cup comes into hydraulic contact and tends to equilibrate with soil water through the pores in the ceramic walls. When initially placed in the soil, the water contained in the tensiometer is generally at atmospheric pressure (essentially, 0 bars tension). Soil water, being generally at substmospheric pressure (or higher tension), exercises a suction, which draws out a certain amount of water from the rigid and air tight tensiometer. Consequently, the pressure inside the tensiometer falls below atmospheric pressure. The subpressure is indicated by a vacuum gauge or manometer. A Tensiometer left in the soil for a period of time tends to track the changes in the soil's matric suction. As soil moisture is depleted by drainage or plant uptake, or as it is replenished by rainfall or irrigation, corresponding readings on the Tensiometer gauge occur.

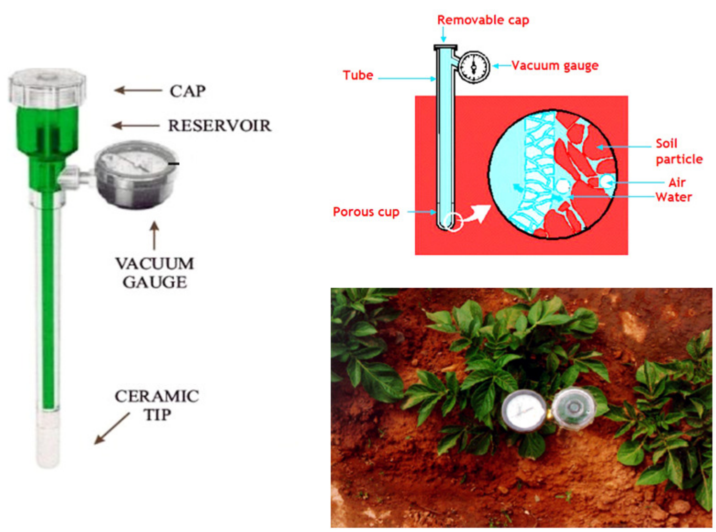


Fig. 10.4. Measurement of soil moisture tension by Tensiometer

Suction measurements by tensiometry are generally limited to matric suction values below 1 bar or 100 kPa. However in practice, under field conditions the sensitivity of most tensiometers is a maximal tension of about 0.85 bars or 85 kPa.

Merits

- Repeated measurements at the same location
- Nondestructive method

- Suitable for scheduling irrigations to crops raised in coarse textured soils where majority of ASM is between 0 – 0.8 bars or 0 to 80 kPa or centibars and requiring frequent irrigations

Demerits

- Measurements limited to 0.8 bars suction only
- Maximum depth of insertion is about 5 m only
- Water in the tensiometer must be maintained always at a constant height
- Requires few hours for equilibration after initial installation

10.3.4 Pressure plate & Pressure membrane apparatus

Laboratory measurements of soil water potential are usually made with pressure membrane and pressure plate apparatus. It consists of ceramic pressure plates or membranes of high air entry values contained in airtight metallic chambers strong enough to withstand high pressure of 15 bars or more (Fig. 10.5). The apparatus enables development of soil moisture characteristic curves over a wide range of matric potential.

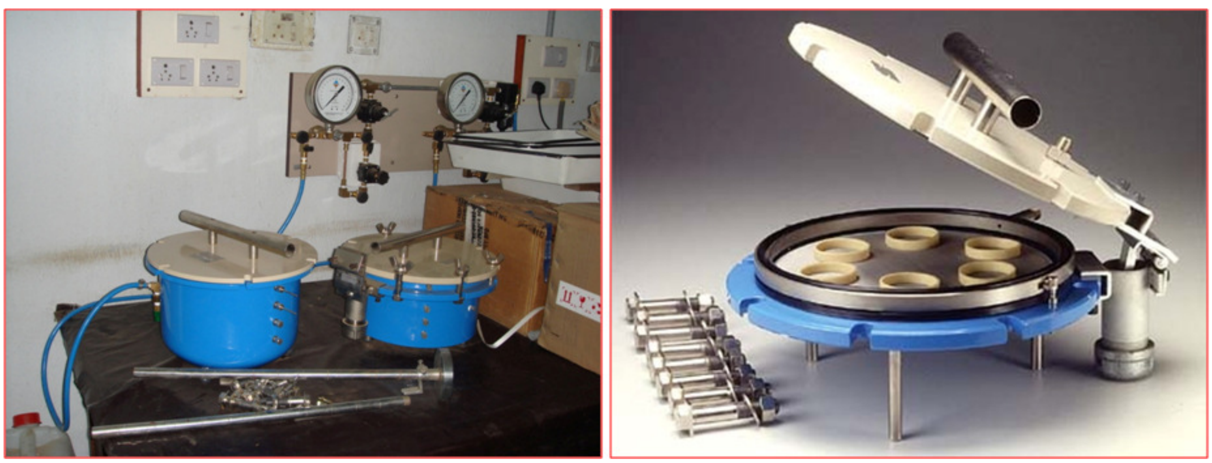


Fig. 10.5. Pressure plate and membrane apparatus

The porous plates are first saturated and then soil samples are placed on these plates. Soil samples are saturated with water and transferred to the metallic chambers. The chamber is closed with special wrenches to tighten the nuts and bolts with required torque for sealing it. Pressure is applied from a compressor and maintained at a desired level. It should be ensured that there is no leakage from the chamber. Water starts to flow out from saturated soil samples through outlet and continues to trickle till equilibrium against the applied pressure is achieved. Soil samples are taken out and oven dried to constant weight for determining moisture content on weight basis. Moisture content is determined against pressure values varying from –0.1 to –15 bars. The values of moisture content so obtained at a given applied pressure are used to construct soil moisture characteristic curves.

Lecture No. 11

Soil – Plant and Plant – Water Relations

11.1 Introduction

To design a successful irrigation system, it is essential to know the plant rooting characteristics, effective root zone depth, moisture extraction pattern and moisture sensitive periods of crops.

11.2 Rooting characteristic of plants

The purpose of irrigation is to provide adequate soil moisture in the immediate vicinity of the plant roots. All plants do not have the similar rooting pattern i.e., root penetration and proliferation. Some plants have relatively shallow root system (for example annual crops), while others develop several meters under favourable conditions (for example tree crops). It is obvious, therefore, that if one is to plan an efficient irrigation schedule for providing adequate soil moisture to plant roots, it is necessary to understand rooting habits of plants.

11.2.1 Soil properties influencing root development

a) **Hard pan:** Root penetration is seriously affected by presence of a hard pan or compacted layer in the soil profile. Thus roots cannot penetrate a hard layer except through cracks, if any (Fig. 11.1). Thus, in shallow soils, crop roots may be confined to a thin layer of soil irrespective of their normal genetic rooting pattern in a soil having uniform structure and texture.

b) **Soil moisture:** Since roots cannot grow in soil that is depleted in moisture down to and below the permanent wilting point, a layer of dry soil below the surface in the profile can restrict root penetration (Fig. 11.1).

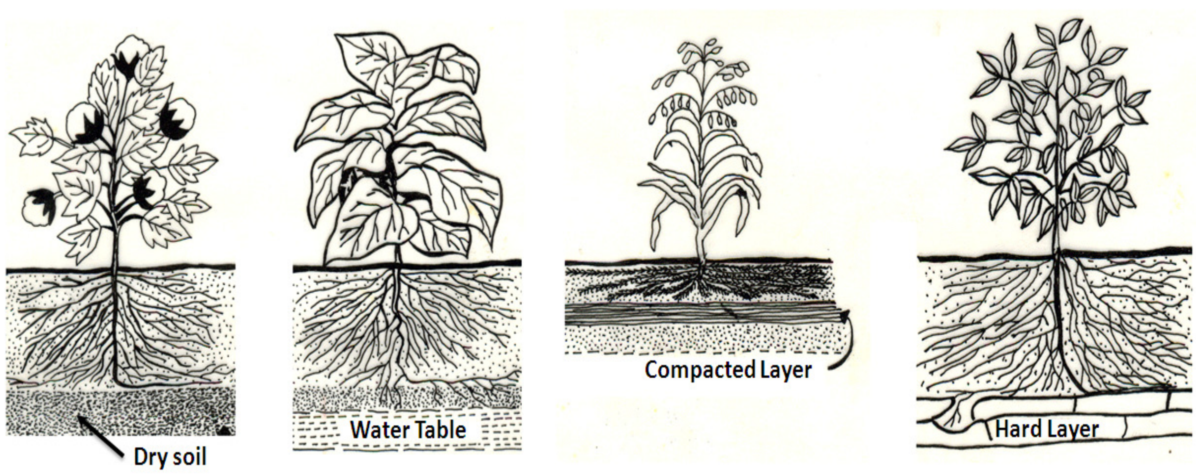


Fig. 11.1. Soil properties influencing root development

c) **Water table:** A high water table limits root growth, and a rising water table may kill roots that have previously grown below the new water level (Fig. 11.1).

d) **Toxic substances:** Presence of toxic substances in the sub-soil also limits root growth and development. Saline layers or patches in the soil profile therefore inhibit or prevent root penetration and proliferation.

11.3 Effective root zone depth

The soil depth from which the crop extracts most (nearly 90%) of the water needed to meet its evapotranspiration requirements is known as effective crop root zone depth. It is also referred to as design moisture extraction depth, the soil depth used taken into account to determine the irrigation water requirements for scheduling irrigation's to crops. For best results, it is the depth in which optimum available soil moisture must be maintained for higher productivity of crops. It is not necessarily the maximum rooting depth for any given crop, especially for plants that have a long tap root system.

Since root development for any one crop varies in different agro-climatic zones because of soil and climatic differences, the design depth should be based on local moisture-extraction data for locally adapted crops. If two or more plant species with different rooting characteristics are to be grown together, the design depth should be that of the plant having the shallower root system. In the absence of any local moisture extraction pattern data for design, the information given below in Table 11.1 may be used as a guide.

Table 11.1. Design moisture extraction depths for crops grown on very deep, well drained soils

Rooting depth	Crop (s)
Shallow rooted crops (60cm)	Cauliflower, Cabbage, Onion, Potato, Lettuce, Rice
Moderately deep rooted (90cm)	Carrots, French bean, Garden pea, Chilli, Muskmelon, Tobacco, Wheat, Castor, banana, and Groundnut
Deep rooted (120cm)	Cotton, Tomato, Watermelon, Maize, Sorghum, Sugarbeet, Soybeans, Pearl millet
Very deep rooted (180cm)	Lucerne, Citrus, Apple, Guava, Grapevine, Coffee, Tea, Sugarcane, Safflower, Mango, Pomegranate

11.4 Moisture extraction pattern

The moisture extraction pattern refers to the amount of soil moisture expressed as percentage extracted from different layers in the soil profile. In most plants, the concentration of absorbing roots is greatest in the upper part of the root zone (usually in the top 45cm) and near the base of the plant. Hence extraction of water from the topsoil layers is usually more as compared to lower layers. Since water also evaporates from upper few inches of soil, it is lost rapidly from the upper layers. As the amount of moisture in the upper part of root zone in the vicinity of roots is diminished, soil moisture tension increases and a moisture suction gradient is created between the upper layers and the far away lower layer from where moisture has not been extracted previously. This causes water to move towards the upper layers to attain equilibrium between two zones, thus, the plants get moisture from lower parts of the root zone.

In uniform soils that are fully supplied with available soil moisture, plants use water rapidly from the upper part of the root zone and slowly from the extreme lower part. The basic moisture extraction curve indicates that for all crop plants growing in a uniform soil with adequate available water supply exhibits similar moisture-extraction pattern. The usual extraction pattern (Fig. 11.2) shows that about 40% of the soil moisture extracted is contributed from upper quarter of the root zone, 30% from the second quarter, 20% from the third quarter, and 10% from the bottom quarter. Values for individual crops may vary within the range of 10%.

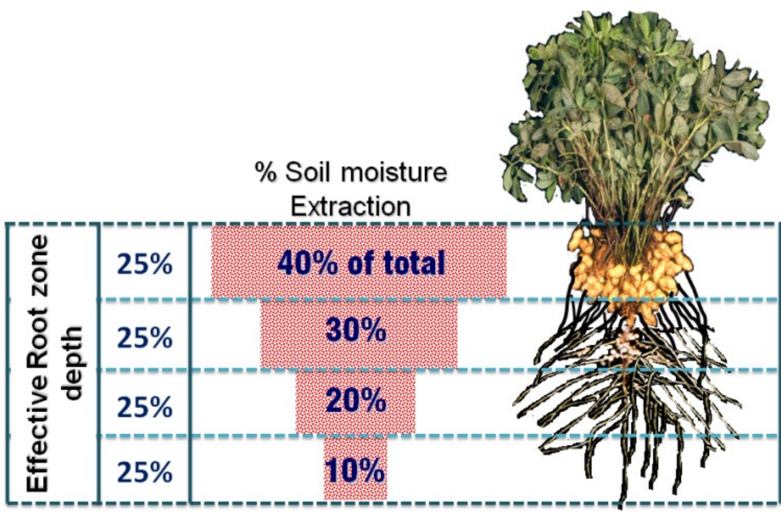


Fig.11.2. Basic soil moisture extraction curve

Any barrier in the soil that restricts root development changes the basic moisture extraction pattern for a given crop. Similarly, if the moisture level in the upper layers of the soil drops much below field capacity, a plant's extraction pattern differs greatly from its usual pattern.

11.5 Moisture sensitive periods

The optimal moisture for plant growth varies with the stage of crop growth i.e., it is low in the initial stages (establishment & early development), increases with advancement of crop life and attains peak value during reproductive stage, thereafter it decreases towards ripening and maturity phases. Thus, not all the crop growth phases are equally sensitive, certain stages are more sensitive to soil moisture/stress when compared to other stages. These are known as moisture sensitive periods or critical growth stages for moisture.

"Critical growth period is the stage or stages of growth of the crop at which moisture stress has the greatest effect on quality & quantity of yield. Therefore, any stress during these stages will irrevocably reduce the yield and provision of adequate water and other management practices at other growth stages will not compensate the yield lost".

In general moisture stress during germination and early seedling stage may have deleterious effect on field crop emergence and plant establishment because of soil crusting and small root system resulting in low plant population per unit area. Stress during vegetative stage has little effect on subsequent production unless it is so severe as to drastically reduce leaf area index and leaf area duration. Moisture stress during flowering causes flowers drop & pollen desiccation and affects fertilization; while that during grain development leads to production of shriveled grains and low mean test weight. Critical stages for various fields, vegetable and fruit crops are presented in Table 11.2, which serve as a guideline for management of limited water supplies.

Table 11.2. Critical growth periods of crops for water supply

Crop	Critical growth period for water supply
Rice	Primordial development, Heading & Flowering
Sorghum	Booting, Blooming, Milky & Dough stages
Ragi	Primordial initiation & Flowering
Maize	Tasseling, Silking & Pollination
Bajra	Heading & Flowering
Wheat	Crown root initiation, Shooting & Earing
Groundnut	Flowering, Peg penetration & Pod development
Sesame	Flowering to Maturity
Sunflower	Star formation, Flowering & Seed development
Safflower	Rosette, flowering and Seed development
Soybean	Flowering & Seed formation
Cotton	Flowering & Boll development
Sugarcane	Formative & Stem elongation
Tobacco	Rapid growth & Topping stage
Chillies	Flowering & Fruit development
Potato	Tuber initiation to Tuber maturity
Onion	Bulb enlargement to Ripening
Tomato	Flowering & Fruiting
Citrus	Flowering, Fruit set & Fruit enlargement
Banana	Adequate soil moisture throughout growth period & fruit development
Mango	Flowering & fruit development

Lecture No. 12
Evapotranspiration

12.1 Evapotranspiration (ET = Evaporation + Transpiration)

Evaporation is a diffusive process by which water from natural surfaces, such as free water surface, bare soil, from live or dead vegetation foliage (intercepted water, dewfall, guttation etc) is lost in the form of vapour to the atmosphere. It is one of the basic components of hydrologic cycle.

Likewise transpiration is a process by which water is lost in the form of vapour through plant surfaces, particularly leaves. In this process water is essentially absorbed by the plant roots due to water potential gradients and it moves upward through the stem and is ultimately lost into the atmosphere through numerous minute stomata in the plant leaves (Fig. 12.1). It is basically an evaporation process. However, unlike evaporation from a water or soil surface, plant structure and stomatal behaviour operating in conjunction with the physical principles governing evaporation modify transpiration.

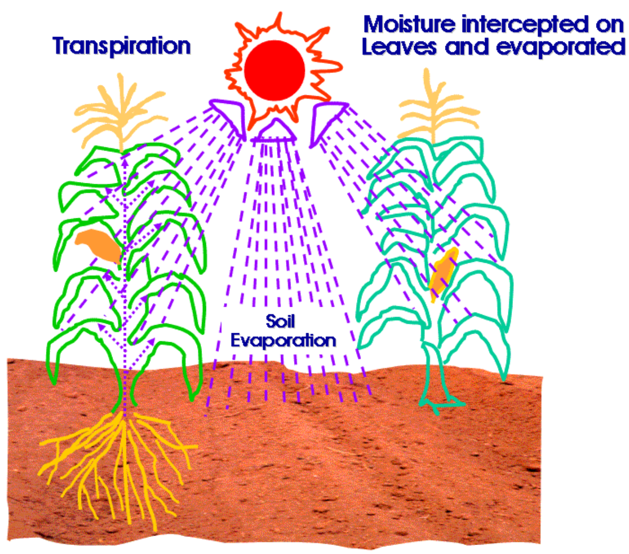


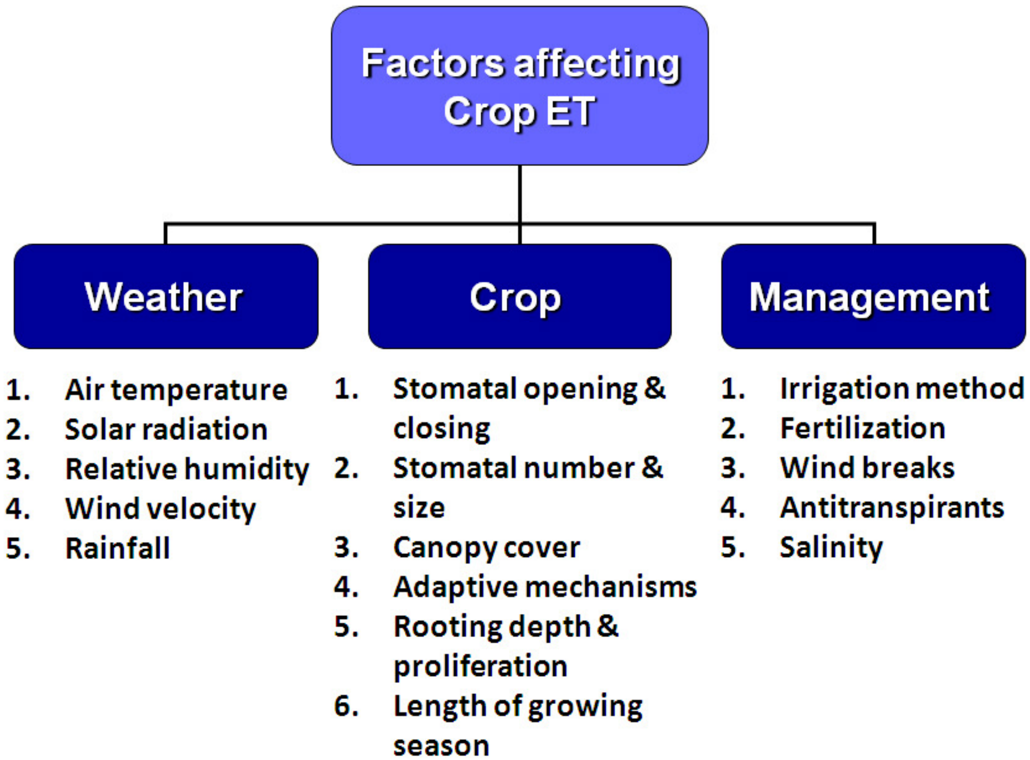
Fig.12.1. Evapotranspiration process

Thus, evapotranspiration is a combined loss of water from the soil (evaporation) and plant (transpiration) surfaces to the atmosphere through vaporization of liquid water, and is expressed in depth per unit time (for example mm/day). Quantification of evapotranspiration is required in the context of many issues:

1. Management of water resources in agriculture
2. Designing of irrigation projects on sound economic basis
3. Fixing cropping patterns and working out the irrigation requirements of crops
4. Scheduling of irritations
5. Classifying regions climatologically for agriculture

12.2 Factors influencing evapotranspiration

Water losses to the atmosphere are primarily determined by both environmental and plant factors, besides to a certain extent by management factors. The environmental effect on ET is called atmospheric demand or evaporative demand of the atmosphere. The following factors influence the atmospheric demand and in turn the ET of a crop.



12.2.1 Climatic or environmental factors

The meteorological factors, which have a significant bearing on the ET, are as follows (Fig. 12.2):

a) **Solar radiation:** Solar or thermal energy is necessary to evaporate the water from both soil and plant surfaces. Thus, of the total solar radiation intercepted by the leaf, only 1 to 5% is used for photosynthesis and 75 to 85% is used for radiating the canopy surface i.e., leaves and for transpiration. Hence, increased solar radiation increases atmospheric demand and in turn evapotranspiration.

b) **Ambient temperature:** increasing the temperature increases the capacity of air to hold water i.e., vapour pressure deficit is high, which means a greater atmospheric demand i.e., greater ET.

c) **Relative humidity:** The greater the water content of air, the higher the air water potential which means that atmospheric demand decreases resulting in low ET with increasing relative humidity.

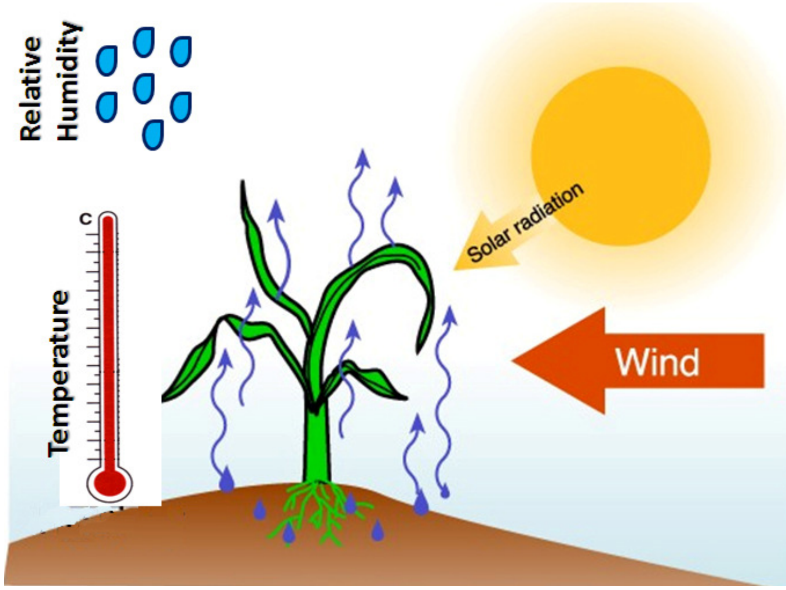


Fig. 12.2. Climatic factors influencing crop evapotranspiration

d) **Wind:** Transpiration occurs when water diffuses through the stomata. A diffusion gradient barrier builds up around stomata (i.e., leaf) when the air is still. This means that water diffusing from the wet leaf interiors is almost matched by water buildup outside the leaf, which reduces the diffusion gradient and thus reduces transpiration. When wind turbulence removes the water vapour next to the leaf, the difference in water potential inside and immediately outside the stomatal opening is increased and net water diffusion from the leaf is increased.

e) **Soil moisture:** Generally speaking the ET from a cropped field will increase with increase in soil water content due to enhanced soil evaporation. However, the effect of soil water content on evapotranspiration varies with crop and is conditioned primarily by type of soil and its water holding properties, crop rooting characteristics and the meteorological conditions determining the level of evapotranspiration.

12.2.2 Plant factors

Plant factors, as well as atmospheric demand; modify the ET rate by affecting the resistance to water movement from soil to air.

a) **Stomatal closure and opening:** Most transpiration occurs through stomata because of the relative impermeability of the cuticle, and little transpiration occurs when stomata are closed. As stomata open wider, more water is lost but the loss increase is less for each unit increase in stomatal width. Many factors influence stomatal opening and closing, the major ones under field conditions being light and moisture level. In most crop plants light causes stomata to open. A low moisture level in the leaf (low leaf water potential) causes guard cells to loose turgor, resulting in stomatal closure.

b) **Stomatal number and size:** Most leaves of productive crops have many stomata on both sides of their leaves. Stomatal number and size, which are affected by both genotype and environment, have much less effect on stomatal transpiration than stomatal opening and closing.

c) **Leaf area or canopy cover:** The higher the leaf surface area, the greater the transpiration owing to more transpiring surface. However, the increase in water loss for each unit increase in the leaf area index is less. It has been shown that ET crop will not increase with increase in the leaf area index over that required intercepting 85% of solar radiation.

d) **Adaptive mechanisms:** Many plants have mechanisms in leaves that favour reduced transpiration when water becomes limiting. For example some grass species, like maize & sorghum reduce their exposed leaf area by leaf rolling. While crops with broad leaves have other mechanisms to reduce water loss; for example, soybean has a tendency to roll the leaves upside down so the silvery pubescence (hair) on the exposed lower surface can reflect more light i.e., albedo and reduce energy load.

e) **Rooting depth and proliferation:** The availability and extraction of soil moisture by the crop is highly dependent on rooting depth and proliferation. Deeper rooting increases water availability and root proliferation (roots per unit soil volume) increases water extraction from a unit volume of soil before permanent wilting occurs. Therefore higher rooting depth & proliferation ensures higher water extraction hence promotes transpiration.

f) **Length of growing season:** As the crop duration increases the amount of water needed for completion of its life cycle increases, hence, the ET crop increases.

12.2.3 Management factors

The following management factors influence the ET crop.

a) **Method of irrigation:** Different methods imply different rates of water application due to large variations in the water balance components. The advantages of one method over another are therefore determined by differences in total irrigation water applied and the effectiveness with which crop requirements can be met. Irrigation water requirements are generally higher with surface irrigation methods viz., furrow, border strip, check basin etc in comparison to over head sprinkler, microsprinkler and drip methods of irrigation.

b) **Fertilizers:** The use of fertilizers has only a little effect on ET crop, unless crop growth was previously adversely affected by low soil nutrition delaying full crop canopy cover. Irrigation imposes a greater demand on fertilizer nutrients. Adequately fertilized soils produce much higher yields per unit of irrigation water than do poor soils, provided the fertilizer is at the level in the soil profile where soil water is extracted by the plant. The movement of soluble nutrients and their availability to the crop is highly dependent on method and frequency of irrigation.

c) **Wind breaks:** Artificial and vegetative wind breaks Reduce wind velocities downward from it. This may reduce ET crop by about 5% to 30% under windy, warm, dry conditions depending on the horizontal downward distance from the wind break. However, in most cases shrubs and trees are used and, due to transpiration of the vegetative barrier, overall ET crop may be more.

d) **Anti-transpirants:** The use of anti-transpirants, natural or artificially induced variations in plant foliage properties and soil conditioners to reduce ET crop are found to be effective, but cheap and practically suitable materials for field application are yet be identified.

e) **Salinity:** The ET crop can be affected by soil salinity since the soil water uptake by the plant can be drastically reduced due to higher osmotic potential of saline water. Reduced water uptake under saline conditions is shown by symptoms similar to those caused by drought, such as early wilting, leaf burning, a bluish-green colour in some plants, reduced growth and small leaves. The same level of soil salinity can cause more damage under high than under low evaporative conditions. The negative effect of soil salinity can be partly offset by maintaining a higher soil water regime in the root zone to maintain the optimal ET crop values.

12.3 Consumptive use

The term consumptive use (Cu) is used to designate the sum of losses due to evaporation + transpiration from the cropped field as well as that water utilized by the plants in its metabolic activities for building up of the plant tissues. Since the water used in the actual metabolic processes is insignificant (about 1% of evapotranspiration losses) the term consumptive use is generally taken equivalent to evapotranspiration. It is expressed similar to ET as depth of water per unit time i.e., mm/day or cm/day.

a) **Daily consumptive use:** It is the total amount of the water used in ET plus water used in metabolic activities by a crop during a single day or 24-hours period and is expressed in mm/day or cm/day.

b) **Seasonal consumptive use:** The total amount of water used by the crop in ET and metabolic activities for building up of plant tissues during its total growing season. It is expressed as depth of water in mm or cm per season. Seasonal consumptive use values are needed to evaluate and determine seasonal irrigation water supplies and irrigated crop acreages.

c) **Peak period consumptive use:** The average daily water use rates in terms of ET plus that consumed in metabolic process during the highest consumptive use period (6 – 10 days) of the season is called peak period consumptive use rate. This is the design rate to be used in planning an irrigation system. The peak-use consumptive period generally occurs when the crop is starting to buildup its harvestable produce, wherein the canopy area is maximum and capable of intercepting maximum photosynthetically active radiation and atmospheric demand is high.

Lecture No. 13

Reference Crop Evapotranspiration

13.1 Introduction

Owing to the difficulty of obtaining accurate field measurements, ET is commonly computed from weather data. A large number of empirical or semi-empirical equations have been developed for assessing crop or reference crop evapotranspiration from meteorological data. Numerous researchers have analysed the performance of the various calculation methods for different locations. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the reference evapotranspiration, ET_o. Some of the methods which are only valid under specific climatic and agronomic conditions and cannot be applied under conditions different from those under which they were originally developed were also discussed below.

13.2 What is Reference crop evapotranspiration?

The evapotranspiration from an extensive surface of green grass of uniform height (0.12m), actively growing, completely shading the ground with an albedo of 0.23 and not short of water is called reference crop evapotranspiration and is denoted by ET_o (Fig. 13.1).

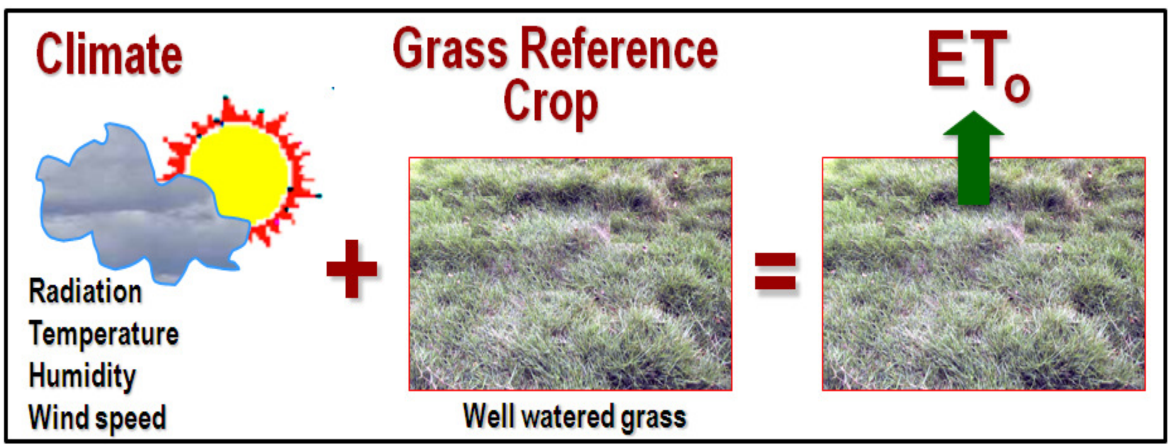


Fig. 13.1. Estimation of reference crop evapotranspiration

The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. It obviates the need to define a separate ET level for each crop and stage of growth. ET_o values measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface. The only factors affecting ET_o are climatic parameters. Consequently, ET_o is a climatic parameter and can be computed from weather data.

ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. Typical ranges for ET_o values for different agroclimatic regions are given in Table 13.1.

Table 13.1 . Average ET_o for different agroclimatic regions in mm/day

Regions	Mean daily temperature (°C)		
	Cool (~10°C)	Moderate (20°C)	Warm (> 30°C)
Tropics and subtropics			
Humid and Sub-humid	2 - 3	3 - 5	5 – 7
Arid and Semi-arid	2 - 4	4 - 6	6 – 8
Temperate region			
Humid and Sub-humid	1 - 2	2 - 4	4 – 7
Arid and Semi-arid	1 - 3	4 - 7	6 – 9

13.3 Measurement of ET_o by different methods

13.3.1 Blaney Criddle Method

The relationship is expressed as follows:

$$\boldsymbol{ET_o\ (mm/day) = c[p(0.46T + 8)]}$$

Where:

ET_o = Reference crop evapotranspiration in mm/day for the month considered

T = Mean daily temperature on °C over the month considered

P = Mean daily percentage of total annual daytime hours obtained for a given month & latitude

c = Adjustment factor which depend on minimum relative humidity, sunshine hours and day time wind estimates

Application & Limitations

a) This method is suggested for areas where available climatic data cover air temperature data only.
b) Not recommended for equatorial regions, small islands and coastal areas at high altitudes and in climates with a wide variability

13.3.2 Thornthwaite method

The relationship is expressed as:

$$\boldsymbol{E = 1.6\ (10T/I)^a}$$

Where:

E = Monthly potential evapotranspiration (cm) or reference crop ET (i.e., ET_o)
T = Mean monthly temperature (°C)
I = A heat index for a given area which is the sum of 12 monthly index values ***i***.

$\boldsymbol{i}$ is derived from mean monthly temperatures using the following formula:

$$\boldsymbol{i} = (\boldsymbol{T}/\mathbf{5})^{\mathbf{1.514}}$$

$\boldsymbol{a}$ = an empirically derived exponent which is a function of $\boldsymbol{I}$,

$$\boldsymbol{a} = \mathbf{6.75} \times \mathbf{10^{-7}} \boldsymbol{I}^{\mathbf{3}} - \mathbf{7.71} \times \mathbf{10^{-5}} \boldsymbol{I}^{\mathbf{2}} + \mathbf{1.79} \times \mathbf{10^{-2}} \boldsymbol{I} + \mathbf{0.49}$$

Application & Limitations

a) This method is suggested for areas where available climatic data cover air temperature data only.
b) Not recommended for equatorial regions, small islands and coastal areas at high altitudes and in climates with a wide variability

13.3.3 Radiation method

The relationship is expressed as:

$$\boldsymbol{ET_0}\ (\boldsymbol{mm/day}) = \boldsymbol{c}\ (\boldsymbol{W.Rs})$$

Where:

ET_o = Reference crop evapotranspiration in mm/day for the period considered
Rs = Solar radiation in equivalent evaporation in mm/day
W = Weighting factor which depends on temperature and altitude
c = Adjustment factor which depends on mean relative humidity and day time wind conditions

Application & Limitations

a) Recommended for areas where measured climatic data include air temperature and sunshine, cloudiness or radiation, but not measured wind and humidity
b) Knowledge of general levels of humidity and wind is required
c) It is reliable than Blaney - Criddle method for equatorial regions, on small islands and at high altitudes

13.3.4 Modified Penman method

The relationship is expressed as:

$$\boldsymbol{ET_0}\ (\boldsymbol{mm/day}) = \boldsymbol{c}[\underbrace{\boldsymbol{W.Rn}}_{\boldsymbol{Radiation}} + \underbrace{(\mathbf{1}-\boldsymbol{W}).\boldsymbol{f}(\boldsymbol{u}).(\boldsymbol{ea}-\boldsymbol{ed})}_{\boldsymbol{Aerodynamic}}]$$

Where:

ET_o = Reference crop evapotranspiration in mm/day
W = Temperature related weighing factor
Rn = Net radiation in equivalent evaporation in mm/day
f(u) = Wind related function
(ea – ed) = Difference between the saturation vapour pressure at Tmean and the mean actual vapour pressure of the air both in mbar

c = Adjustment factor to compensate for the effect of day and night weather conditions

Application & Limitations

a) Suitable only where measured data is available on all weather parameters
b) Wide applicability i.e., in arid, semi-arid, humid, sub-humid conditions
c) Gives a very satisfactory estimate of ET_o since it accounts for all the weather factors affecting the crop evapotranspiration

13.3.5 Penman – Monteith method

Allen et.al. (1998) proposed the Penman – Monteith equation. The mathematical relationship is as follows:

$$ET_O = \frac{0.408\Delta\,(R_n - G) + \gamma\,\frac{900}{T+273}U_2\,(e_s - e_a)}{\Delta + \gamma\,(1 - 0.34U_2)}$$

Where:

ET_o = Reference crop evapotranspiration (mm/day)
R_n = Net radiation at the crop surface (MJ/m²/day)
G = Soil heat flux density (MJ/m²/day)
T = Air temperature at 2 m height (°C)
U_2 = Wind speed at 2 m height (m/s)
e_s = Saturation vapour pressure (kPa)
e_a = Actual vapour pressure (kPa)
$(e_s - e_a)$ = Saturation vapour pressure deficit (kPa)
Δ = Slope vapour pressure curve (kPa/°C)
γ = Psychrometric constant (kPa/°C)

Application & Limitations

a) Suitable only where measured data is available on all weather parameters
b) Wide applicability i.e., in arid, semi-arid, humid, sub-humid conditions
c) Gives a very satisfactory estimate of ET_o since it accounts for all the weather factors affecting the crop evapotranspiration

13.3.6 Pan evaporation method

The relationship is expressed by:

$$ET_o\,(mm/day) = K_{pan}.E_{pan}$$

Where:

ET_o = Reference crop evapotranspiration in mm/day for the period considered
K_{pan} = Pan evaporation in mm/day and represents the mean daily value of the period considered
E_{pan} = Pan coefficient

Application & Limitations

a) The method requires measured data only pan evaporation
b) Wide applicability i.e., in arid, semi-arid, humid, sub-humid conditions
c) Gives a very satisfactory estimate of ET_o since it integrates the effect of all weather factors affecting the crop evapotranspiration in to a single entity

Lecture No. 14
Crop Coefficients

14.1 Crop coefficient

Crop coefficient refers to the ratio between crop evapotranspiration and reference crop evapotranspiration. It is calculated as follows:

$$\boldsymbol{Crop\ coefficient\ (Kc) = \frac{Crop\ Evapotranspiration}{Reference\ Crop\ Evapotranspiration} = \frac{ET_c}{ET_O}}$$

Crop coefficient curve is constructed by dividing crop growing period into four growth periods and placing straight line segments through each of these periods with the lines through the initial and mid-season periods being horizontal. The four growth stages of crop growing period are as follows:

a) Initial period – planting to 10% ground cover
b) Crop development – 10% ground cover to effective cover i.e., flowering
c) Mid-season – Effective cover to start of maturity i.e., senescence of leaves
d) Late season – Start of maturity to harvest.

Crop coefficient values vary with the development stage of the crop. In the case of annual crops, Kc is typically low at seedling, emergence and establishment stage, increases with increase in ground cover and attains maximum value at mid-season stage and thereafter decreases towards ripening and maturity stage (Fig. 14.1).

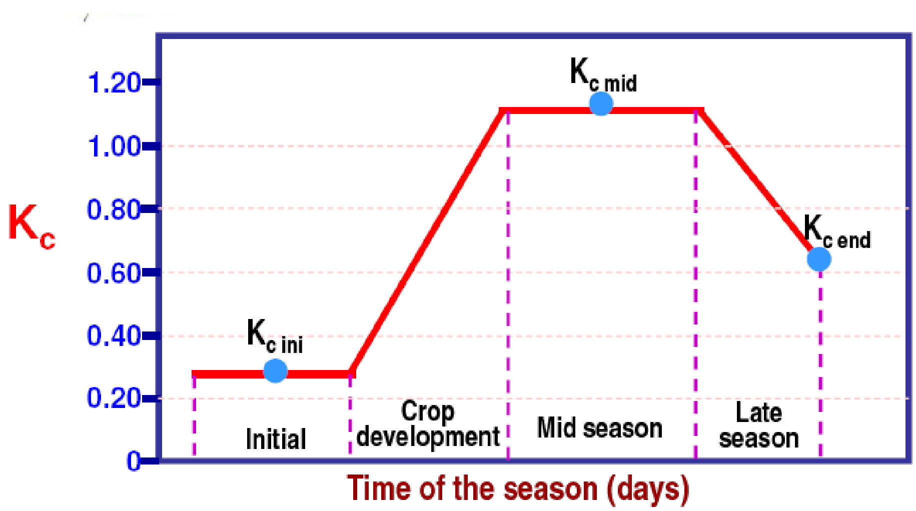


Fig. 14.1. Crop coefficient curve

For most crops the value for total growing period is between 0.85 to 0.90 with the exception of a higher value for rice and banana. In general Kc is higher in hot, windy and dry climates than in cool, calm and humid climates. The Kc values vary among crops due to differences in reflectivity, crop height and roughness, degree of ground cover and canopy resistance to transpiration. Crop coefficient values for various crops are presented in Table 14.1.

Table 14.1. FAO Crop Coefficients (Kc) for major crops (Allen et.al., 1998)

Crop	Crop development stage					
	Initial	Development	Mid season	Late season	Harvest	Total period
Wheat	0.30 – 0.40	0.70 – 0.80	1.05 – 1.20	0.65 – 0.75	0.20 – 0.25	0.80 – 0.90
Rice	1.10 – 1.15	1.10 – 1.50	1.10 – 1.30	0.95 – 1.05	0.95 – 1.05	1.05 – 1.20
Maize	0.30 – 0.50	0.70 – 0.85	1.05 – 1.20	0.80 – 0.95	0.55 – 0.60	0.75 – 0.90
Sorghum	0.30 – 0.40	0.70 – 0.75	1.00 – 1.15	0.75 – 0.80	0.50 – 0.55	0.75 – 0.85
Groundnut	0.40 – 0.50	0.70 – 0.80	0.95 – 1.10	0.70 – 0.80	0.55 – 0.60	0.75 – 0.80
Sunflower	0.30 – 0.40	0.70 – 0.80	1.05 – 1.20	0.70 – 0.80	0.35 – 0.45	0.75 – 0.85
Soybean	0.30 – 0.40	0.70 – 0.80	1.00 – 1.15	0.70 – 0.80	0.40 – 0.50	0.75 – 0.90
Sugarcane	0.40 – 0.50	0.70 – 1.00	1.00 – 1.30	0.75 – 0.80	0.50 – 0.60	0.85 – 1.05
Cotton	0.40 – 0.50	0.70 – 0.80	1.05 – 1.25	0.80 – 0.90	0.65 – 0.70	0.80 – 0.90
Tobacco	0.30 – 0.40	0.70 – 0.80	1.00 – 1.20	0.90 – 1.00	0.75 – 0.85	0.85 – 0.95
Cabbage	0.40 – 0.50	0.70 – 0.80	0.95 – 1.10	0.90 – 1.00	0.80 – 0.95	0.70 – 0.80
Onion	0.40 – 0.60	0.60 – 0.75	0.95 – 1.05	0.95 – 1.05	0.95 – 1.05	0.65 – 0.80
Tomato	0.30 – 0.40	0.70 – 0.80	105 – 1.25	0.80 – 0.95	0.60 – 0.65	0.75 – 0.95
Potato	0.40 – 0.50	0.70 – 0.80	1.05 – 1.20	0.85 – 0.95	0.70 – 0.75	0.75 – 0.90
Banana	0.40 – 0.50	0.70 – 0.85	1.00 – 1.10	0.90 – 1.00	0.75 – 0.85	0.70 – 0.80
First value: Under high humidity (RHmin > 70%) and low wind velocity (U < 5/m/sec) **Second value: Under low humidity (RHmin < 20%) and strong wind velocity (U > 5/m/sec)**						

14.2 Prediction of ETc

Experimentally determined ratios of ET_c/ET_o, called crop coefficients (Kc), are used to relate crop evapotranspiration (ET_c) to reference crop evapotranspiration (ET_o) as follows:

$$ETc = Kc \ x \ ET_o$$

Example: Crop – Maize Crop Period – January to April

Crop growth sub-periods	Germination & Establishment	Vegetative period	Tasseling, Silking & Pollination period	Kernel development & maturity period
Period (days)	20	30	40	30
Kc	0.40	0.80	1.10	0.80
ETo (mm/day)	3.60	4.50	5.10	5.40
ETc (mm/day)	1.44	3.60	5.61	4.32
ETc (mm/period)	28.8	108.0	224.4	129.6
Seasonal crop ET	**490.8 mm**			

Lecture No. 15

Water Requirements

15.1 Water requirement

It is defined as the quantity of water regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth & development under field conditions at a given place. In other words it is the total quantity of water required to mature an adequately irrigated crop. It is expressed in depth per unit time.

Water requirement, if considered as a demand, it includes the quantity of water needed to meet the losses due to evapotranspiration (ET), plus the losses during the application of irrigation water (unavoidable losses) and the additional quantity of water required for special operations such as land preparation, transplanting, leaching of salts below the crop root zone, frost control etc.

$$WR = ET \ or \ Cu + Application \ Losses + Special \ needs$$

It can also be expressed in supply terms as $WR = IRR + ER + \Delta S + Gwc$

Where:

IRR = Total depth of irrigation water during crop life

ER = Effective rainfall received during crop life

ΔS = Profile water use i.e., difference in soil moisture in the crop root zone at the beginning and end of the crop

Gwc = Groundwater contribution, if any.

Water requirements of important field, vegetable and fruit crops are given in Table 15.1.

Table 15.1. Water requirement of various crops

Crop	Water requirement (mm)	Crop	Water requirement (mm)
Rice	1200	**Tomato**	600 – 800
Wheat	450 – 650	**Potato**	500 – 700
Sorghum	450 – 650	**Pea**	350 – 500
Maize	500 – 800	**Onion**	350 – 550
Sugarcane	1500 – 2500	**Chillies**	400 – 600
Sugarbeet	550 – 750	**Cabbage**	380 – 500
Groundnut	500 – 700	**Banana**	1200 – 2200
Cotton	700 – 1300	**Citrus**	900 – 1200
Soybean	450 – 700	**Grapes**	700 – 1200
Tobacco	400 – 600	**Mango**	1000 – 1200
Beans	300 – 500	**Turmeric**	1200 – 1400

Accurate crop water requirement data is essential in irrigated agriculture for:

- Economic appraisal of irrigation projects
- Design and operation of irrigation schemes
- Fixing cropping patterns and irrigated areas
- Irrigation scheduling to crops
- Efficient use of limited water

15.2 Irrigation requirement

It is the total amount of water applied to a cropped field for supplementing effective rainfall, soil profile and groundwater contribution to meet the crop water requirements for optimum growth. In other words irrigation requirement is exclusive of $\boldsymbol{ER + \Delta S + Gwc}$.

$$\boldsymbol{IRR = WR - (ER + \Delta S + Gwc}$$

15.3 Net irrigation requirement

It is the amount of irrigation water just required to bring the soil moisture content in the effective crop root zone depth to field capacity. Thus, the net irrigation requirement is the difference in depth or percentage of soil moisture between field capacity and the soil moisture content in the root zone just before application of the irrigation water. in terms of depth, it can be expressed as:

$$\boldsymbol{NIR = \sum_{i=1}^{n} \frac{M_{fc} - M_{bi}}{10} \; x \; \rho b_i \; x \; ds_i}$$

Where,

$\boldsymbol{NIR}$ = Net irrigation requirement to be applied at each irrigation (mm)

$\boldsymbol{n}$ = Number of soil layers considered in root zone depth ds

$\boldsymbol{M_{fc}}$ = Gravimetric moisture percentage at field capacity in i^{th} layer

$\boldsymbol{M_{bi}}$ = Gravimetric moisture percentage just before irrigation in i^{th} layer

$\boldsymbol{\rho b_i}$ = Soil bulk density in i^{th} soil layer (g/cm^3)

$\boldsymbol{ds_i}$ = Depth of i^{th} soil layer (cm)

Problem

From the data given below calculate the net irrigation requirement.

Soil depth (cm)	Field capacity (%)	Moisture content before irrigation (%)	Bulk density (g/cm^3)
0 – 25	21.4	14.5	1.45
25 – 50	20.5	13.4	1.47
50 – 75	18.6	15.2	1.51
75 – 100	18.5	15.5	1.54

Answer:

$$NIR = \frac{21.4 - 14.5}{10} \text{ x } 1.45 \text{ x } 25 = 25.01\ mm$$

$$NIR = \frac{20.5 - 13.4}{10} \text{ x } 1.47 \text{ x } 25 = 26.09\ mm$$

$$NIR = \frac{18.6 - 15.2}{10} \text{ x } 1.51 \text{ x } 25 = 12.83\ mm$$

$$NIR = \frac{18.5 - 15.5}{10} \text{ x } 1.54 \text{ x } 25 = 11.55\ mm$$

NIR in soil profile (0 – 100 cm) = 25.01 + 26.09 + 12.83 + 11.55 **= 75.48 mm**

15.4 Gross irrigation requirement

Though there are several irrigation systems and methods of water application to field crops, none of these methods are cent per cent efficient and it has been found that considerable water is lost during conveyance, distribution and application. Hence, excess water is needed than the actual crop water needs to offset these losses if any. Thus gross irrigation requirement is the total amount of water required to bring the crop root zone to field capacity (NIR) inclusive of the water required offsetting the application losses. Which in other words, NIR + Application & other losses. It can be calculated as follows:

$$GIR = \frac{NIR}{E_a} \text{ x } 100 = \frac{Net\ irrigation\ requirement}{Irrigation\ Application\ Efficiency} \text{ x } 100$$

Problem:

Given – a) Net irrigation requirement = 84.5 mm
b) Irrigation application efficiency = 65%
c) Calculate GIR

Answer:

$$GIR = \frac{84.5}{65} \text{ x } 100 = 130\ mm$$

15.5 Irrigation interval

It is the number of days between two successive irrigations during the period without precipitation for a given crop and field. It depends on the crop ET rate and on the available water holding capacity of the soil in the crop root zone depth. Sandy soils require in general more frequent irrigations as compared to fine textured soils.

15.6 Irrigation period

It refers to the number of days that can be allowed for applying one irrigation to that of the next in a given design area during the period of highest consumptive use of the season. It is mathematically expressed as follows:

$$\boldsymbol{Irrigation\ period\ (days) = \frac{NIR}{Peak\ period\ consumptive\ use}}$$

It is taken as the basis for designing irrigation system capacity. Irrigation systems are to be designed in such a way that the irrigation period is not greater than irrigation interval.

Problem:

Given – a) Net irrigation requirement = 65.5 mm
b) Peak period Cu = 7.2 mm
c) Calculate irrigation period

Answer:

$$\boldsymbol{Irrigation\ period = \frac{65.5}{7.2} = 9.1 \sim 9\ days}$$

Lecture No. 16

Duty of Water And Conjunctive Use of Water

16.1 Duty of water

It is the relationship between the irrigation water and the area of the crop that matures fully with the given amount of water. Duty is expressed as follows:

1. Area per unit rate of flow (ha/cumec)
2. Depth of water or Delta (ha/depth of water)
3. In terms of stored water (ha/million m^3 of stored water)

16.1.1 Base period

The time between first irrigation to a crop at sowing or planting and last irrigation before harvest on a given field.

16.1.2 Relationship between duty, delta and base period

- Let there be a crop of base period 'B' period
- Let 1 cumec of water be applied to this crop on the field for 'B' days.
- The total quantity of water applied in 'B' days = 1 x B x 24 x 60 x 60 m^3.
- Let this be equal to **V** = 1 x B x 24 x 60 x 60 m^3
- Let **V** m^3 of water bring to maturity 'D' ha of land A = D x 10000 m^2

$$\boldsymbol{Delta\ (\Delta) = \frac{V}{A} = \frac{B \text{ x } 24 \text{ x } 60 \text{ x } 60}{D \text{ x } 10000} = 8.64\frac{B}{D}\ m = 864\ \frac{B}{D}\ cm}$$

Problem

A tank has a water spread area of 40 ha with an average depth of 3m of water. Calculate the area of rice (120 days base period) that can be irrigated if the duty is expressed as:

a) 960 ha m^3/sec; b) 110 ha cm; and c) 90 ha/million m^3 of water.

Answer:

$$\boldsymbol{Total\ available\ water = 40 \text{ x } 3 \text{ x } 100\ ha.cm}$$

$$\boldsymbol{Delta = \frac{B}{D}cm = 864\frac{120}{960} = 108\ cm}$$

$$\boldsymbol{Area = \frac{40 \text{ x } 3 \text{ x } 100}{108} = 111\ ha}$$

$$Area = \frac{40 \text{ x } 3 \text{ x } 100}{110} = 109\ ha$$

$$Area = \frac{40 \text{ x } 1000\ m^2 \text{ x } 3}{10,00,000} = 1.2\ million\ m^3 x\ 90\ ha = 108\ ha$$

16.2 Conjunctive Use of water

It is estimated that in India about 11 million ha m of water diverted from reservoirs is lost through seepage and percolation from canal systems and return flows from irrigation contribute to ground water recharge. This water can be extracted and conjunctively used for irrigation in part of command areas to tide over the peak demands and water shortages.

Conjunctive use refers to "management of multiple water resources in a coordinated operation such that the water yield of the system over a period of time exceeds the sum of yields of the individual components of the system, resulting from in coordinated operation".

16.2.1 Systems of conjunctive use

1. Canal water and Groundwater system
2. Rainfall and Irrigation water system
3. Saline water and Fresh water system

16.2.2 Conjunctive use – Advantages

a) Use of ground water helps to reduce peak demands of irrigation, size of canals and hence construction costs
b) Supplemental supplies from groundwater ensures proper irrigation scheduling raising multiple crops and early sowing even if rainfall is delayed
c) Increased water resources ensure supply to tail end areas and areas of higher elevation
d) Groundwater exploitation lowers the water table and reduces danger of water logging and consequent wastage of water for leaching salts
e) Surface and subsurface out flows are minimized causing reduction in peak run off and flood discharge
f) Conjunctive use when integrated with an artificial recharge project, need for lining canals is reduced as seepage from canal recharges ground water
g) During periods of peak water demand, irrigation requirement can be met by surface water sources, so power saved can be diverted to other sources

Lecture No. 17
Effective Rainfall

17.1 Introduction

The primary source of water for agricultural crop production in most parts of the world is rainfall. All the rainwater, however, cannot be useful for crop production. The extent of the rainfall received and its utility in crop production in a given location determines its effectiveness. In simplest terms, effective rainfall means useful or utilizable rainfall. From the point of view of the crop water requirement Dastane (1974) has defined effective rainfall as **"that portion of the total annual or seasonal rainfall which is useful directly and/or indirectly for meeting the crop water needs in crop production at the site where it falls but without pumping".** It therefore includes water intercepted by living or dry vegetation, that lost by evaporation from puddles on soil surface, lost by evapotranspiration during crop growth, that fraction which contributes to leaching & percolation or facilitates other cultural operations either before or after sowing without any harmful effect on yield and quality of the field crops. Consequently ineffective rainfall is that portion, which is lost by surface runoff, unnecessary deep percolation losses, the moisture remaining in the soil after the harvest of the crop and which is not useful for the succeeding crop. This concept of effective rainfall is suggested for use in planning and operation of irrigation projects.

17.2 Factors influencing Effective Rainfall

Several factors influence the proportion of effective rainfall in the total rainfall received and these may act singly or collectively and interact with each other. Any factor, which affects infiltration, run-off or evapotranspiration, affects the value of effective rainfall. The following factors have been shown to influence the effective rainfall significantly:

a) **Rainfall characteristics:** Amount, intensity and distribution of rainfall influence surface runoff and hence its effectiveness. Greater amount of rainfall at high intensities reduce the effective fraction of the rainfall. Similarly, uneven distribution decreases the extent of effective rainfall. In India during *kharif* season from July to September the rainfall intensity, frequency and amount is high, hence the effectiveness of rainfall is very low. On the other hand, during winter season from November to April, most of the rainfall is effective due to its low intensity, frequency and amount. Other meteorological parameters which increase the ET increase the effectiveness of the rainfall. Higher evaporative demand of the atmosphere encourages greater depletion of moisture in the soil and therefore the proportion of effective rainfall in the total increases.
b) **Land characteristics:** The time interval between receipt of rain water and its recession by soaking into soil is known as opportunity time. Water stays longer on flat and

leveled land and this has longer opportunity time than on slopping land, leading to higher fraction of effective rain than on undulating lands.

c) **Soil characteristics:** Higher infiltration and permeability rates increase effectiveness of rainfall. Fraction of the effective rainfall increases with increasing water holding capacity of the soil. The proportion of effective rainfall is lower in irrigated than the unirrigated areas where there is often greater deficiency of soil moisture.

d) **Ground water characteristics:** The amount of effective rainfall is greater when the water table is deep than when it is shallow. Upward capillary movement of water decreases the deficit of moisture and hence the amount of effective rainfall.

e) **Management practices:** Any management practice influencing runoff, infiltration, permeability or evapotranspiration also influences the degree of effective rainfall. Bunding, terracing, ploughing, ridging and mulching reduce runoff and increase effective rainfall.

f) **Crop characteristics:** Higher crop ET rates create greater depletion of soil moisture. Hence, effective rainfall is directly proportional to the rate of water uptake by the crop. Degree of ground cover, root zone depth and growth stage influences the rate of water uptake. Rainfall which reduces the yield (such as downpours which often cause lodging in cereals when the latter are at the grain formation stage) must be regarded as ineffective

17.3 Drum culture technique

This method was devised by Dastane et.al., (1966) for assessing crop evapotranspiration, percolation, effective and ineffective rainfall of a rice crop simultaneously under the field conditions (Fig. 17.1).

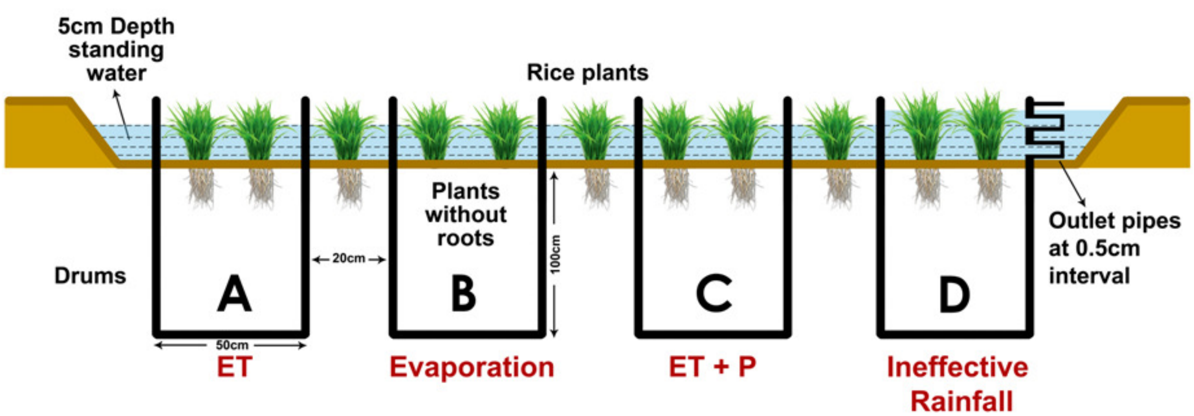


Fig. 17.1. Drum culture technique for assessing water balance components in rice

Four containers (metallic drums) A, B, C and D of about 40 gallons (182 liters) capacity (50cm in diameter and having 125cm height) are embedded in a rice field, leaving about 31 to 32 cm of their height above ground level. The bottoms of drums C and D are removed, thus allowing percolation below the root zone. Further for drum D outlet pipes are fitted at 0.5cm intervals to the above 31 – 32 cm for precise water control. These outlet pipes can be connected to a water receiver. The drums are filled with the representative soil compacted to field density and rice seedlings are transplanted in drum A, C and D, along with the adjoining field crop. Whereas in drum B rice plants are transplanted every week selected from the bulk crop surrounding the drums. However before transplanting remove the roots of rice plants. These rootless plants in drum B shade the soil as plants in other drums and affect the evaporation. Water levels in the drums are maintained at the same level as outside.

The drum D is intended to measure the ineffective rainfall. The height of the rice crop and height of the field bunds govern the maximum depth of submergence, whichever is less. Any rainfall which submerges the crop beyond a predetermined level or which exceeds the height of the bunds is ineffective. As the height of the crop increases, the outlets are plugged till the bund height becomes the limiting factor. The water level is set at a selected height in drum D. This height can be adjusted with increase in growth of plants. Evapotranspiration and percolation continue and create a deficit every day. When rain falls, it first makes up this deficit and the surplus flows out through the outlet pipes, this is termed as ineffective rainfall. If there are no rains, the water level in drum D will gradually reach the soil surface and the crop will be irrigated according to normal practice. Water level in the drums is measured every day and losses due to ET and percolation are replaced.

a) Difference in water level in drum A = Daily Evapotranspiration
b) Difference in water level in drum B = Daily Evaporation
c) Difference in water level in drum C = Total daily water needs
d) Difference in water level between drum A and B = Daily Transpiration
e) Difference in water level between drum A and C = Daily Percolation losses
f) Ineffective rainfall = Water collected in receiver tank from outlet pipes of drum D
g) Effective Rainfall = Total rainfall received – Ineffective rainfall

Lecture No. 18

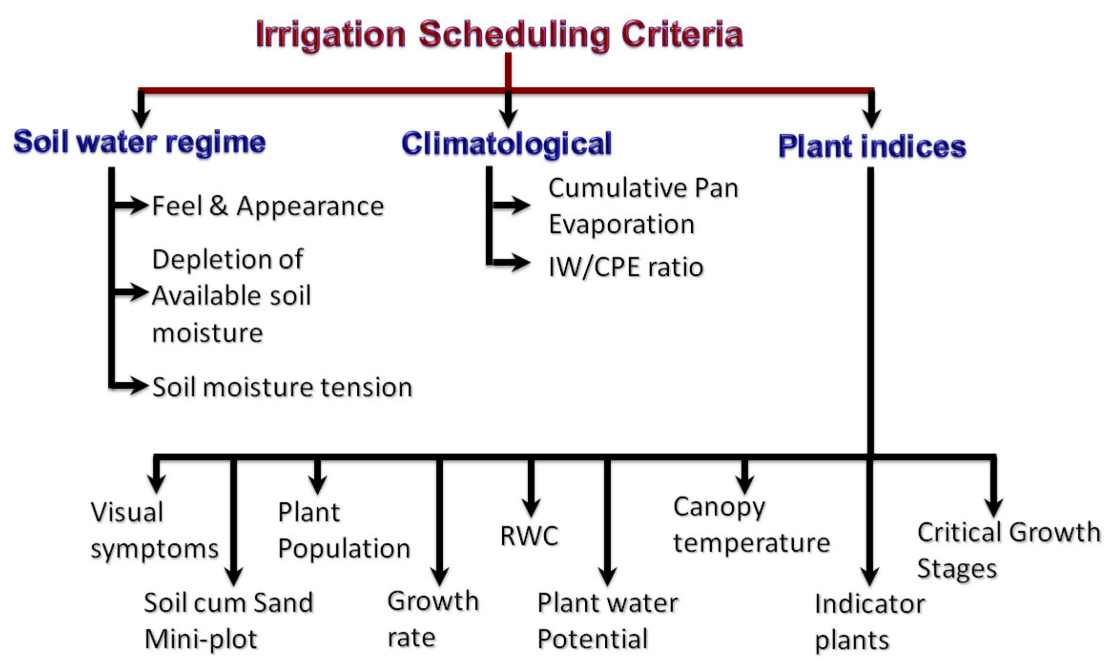
Scheduling of Irrigation to Crops – Soil Water Regime Approach

18.1 Introduction

Scientific irrigation scheduling is a technique providing knowledge on correct time and optimum quantity of water application at each irrigation to optimize crop yields with maximum water use efficiency and at the same time ensuring minimum damage to the soil properties.

18.2 Criteria for scheduling irrigation

With the advancement of knowledge in the field of soil-plant-atmospheric system several criteria for scheduling irrigations are now available and are being used by investigators and farmers. All the available criteria can be broadly classified into the following three categories:



However, criteria most suitable for scheduling irrigation's would vary with soils, plants, climatic and management factors.

18.2.1 Advantages of Irrigation Scheduling

Irrigation scheduling offers several advantages:

a) It enables the farmer to schedule water rotation among the various fields to minimize crop water stress and maximize yields.

b) It reduces the farmer's cost of water and labor through fewer irrigations, thereby making maximum use of soil moisture storage.

c) It lowers fertilizer costs by holding surface runoff and deep percolation (leaching) to a minimum.
d) It increases net returns by increasing crop yields and crop quality.
e) It minimizes water-logging problems by reducing the drainage requirements.
f) It assists in controlling root zone salinity problems through controlled leaching.
g) It results in additional returns by using the "saved" water to irrigate non-cash crops that otherwise would not be irrigated during water-short periods.

18.2.2 Soil water regime approach

In this approach the available soil water held between field capacity and permanent wilting point in the effective crop root zone depth described in several ways is taken as an index or guide for determining practical irrigation schedules. Alternatively soil moisture tension, the force with which the water is held around the soil particles is also sometimes used as a guide for timing irrigations. Different methods of scheduling irrigation following soil moisture regime approach are as follows:

18.2.2.1 Feel and appearance of soil

This is one of the oldest and simple methods of determining the soil moisture content. It is done by visual observation and feel of the soil by hand (Fig. 18.1). The accuracy of judgement improves with experience.

Fig. 18.1. Feel and appearance of soil

Based on several years of experience guidelines have been developed (Table 18.1) which help the farmers to judge the soil moisture present in the soil samples drawn from the crop root zone depth and based on depletion of available soil moisture (DASM) irrigations are scheduled. Though it is a crude method it can be used satisfactorily for some purpose if experience is backed by other local information. Further this method is subjective. Thus, different people who examine the same soil condition may obtain different answers.

Table 18.1. Guidelines for judging soil moisture by feel & appearance of soil

Available soil moisture range	Coarse texture (loamy sand)	Moderately coarse (sandy loamy)	Medium texture (loamy and silt loamy)	Fine texture (clay loamy and silty clay loamy)
Above field capacity	Free water appears when soil is bounded in hand	Free water is released with kneading	Free water can be squeezed out	Puddles; free water forms on surface.
At Field capacity (100%)	On squeezing no free water appears on soil, but wet outline of ball is left on hand	Same as for coarse textured soils at field capacity	Same as for coarse textured soils at field capacity	Same as for coarse textured soils at field capacity
75% to 100%	Tends to stick together slightly, may form a very weak ball under pressure	Forms weak ball that breaks easily, does not slick	Forms a ball, very pliable, sticks readily if relatively high in clay	Easily ribbons out between fingers; has a slick feeling
50% to 75%	Appears to be dry, does not form a ball under pressure	Forms a ball under pressure but seldom holds together	Forms a ball under pressure; somewhat plastic, slicks slightly under pressure	Forms a ball; ribbons out between thumb and forefinger
25% to 50%	As above, but ball is formed by squeezing very firmly	Appears to be dry, do not form a ball unless squeezed very firmly	Somewhat crumbly but holds together with pressure	Somewhat pliable, forms a ball under pressure
0 to 25%	Dry, loose & single grained, flows through fingers.	Dry and loose, flows though fingers	Powdery dry, sometimes slightly crusted, but breaks down easily into powder.	Hard, baked and cracked, has loose crumbs on surface in some places

18.2.2.2 Depletion of the available soil moisture (DASM)

In this method the permissible depletion level of available soil moisture in the effective crop root zone depth is commonly taken as an index or guide for scheduling irrigations to field crops. In general, for many crops scheduling irrigation's at 20 – 25% DASM in the soil profile was found to be optimum at moisture sensitive stages. While at other stages irrigations scheduled at 50% DASM were found optimum. Some of the examples are given in Table 18.2.

Table 18.2. Optimum DASM levels for various crops

Crop	Optimum soil moisture depletion level
Maize	25 – 50% DASM in Hyderabad, Andhra Pradesh
Sugarcane	25 – 65% DASM in Lucknow, Uttar Pradesh
Groundnut	25 – 40% DASM in Tirupathi, Andhra Pradesh
Cotton	65% DASM in Coimbatore, Tamilnadu
Sesame	50% DASM in Parbhani, Maharashtra
Leafy vegetables	20% DASM in Delhi
Tobacco	35% DASM in Rajahmundry, Andhra Pradesh
Wheat	50% DASM in Delhi & Jobner, Rajasthan

18.2.2.3 Soil moisture tension

Soil moisture tension a physical property of film water in soil, as monitored by tensiometers (Fig. 18.2) at a specified depth in the crop root zone could also be used as an index for scheduling irrigations to field crops.

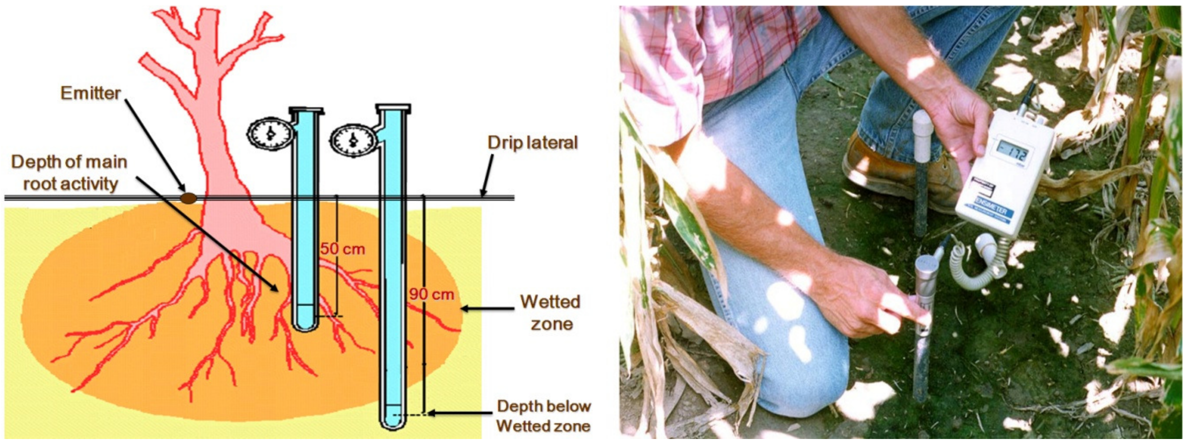


Fig. 18.2. Tensiometers for irrigation scheduling

Pertinent water storage properties of soil and water use rated as affected by climatic conditions and plant vigour are intrinsically accounted for in such an irrigation schedule programme without measuring them. Tensiometers are installed in pairs, one in the maximum rooting depth and the other below this zone. Whenever critical soil moisture tension is reached say for example 0.4 or 0.6 or 0.75 bars etc in the upper tensiometer the irrigation is commenced. While the lower one (tensiometer) is used to terminate the irrigations based on the suction readings in the below soil profile zone. It is generally used for irrigating orchards and vegetables in coarse textured soils because most of the available soil moisture is held at lower tensions. Further the determination of critical soil moisture tension at which irrigation should be given has been the subject of much research, as summarized in Table 18.3.

Table 18.3. Threshold soil moisture tension values for scheduling irrigation

S.No.	Crop	Critical soil moisture tension (Centibars)	Depth of maximum rooting density (cm)
1.	**Sugarcane**	30 – 65	30
2	**Maize**	25 – 50	30
3	**Cotton**	40 – 50	30
4	**Sorghum**	50 – 65	60
5	**Tobacco**	30 – 40	30
6	**Soybean**	50 – 60	30
7	**Wheat**	40 – 50	30
8	**Potato**	25 – 50	30

Lecture No. 19

Scheduling of Irrigation to Crops – Climatological Approach

19.1 Introduction

The potential rate of water loss from a crop is primarily a function of evaporative demand of the atmosphere under adequate soil water conditions. Thus in this method the water loss expressed in terms of either potential evapotranspiration (PET) or cumulative pan evaporation (CPE) over short periods of time are taken as an index for scheduling irrigation's. Different climatological approaches are described below:

19.1.1 Potential evapotranspiration (PET)

Penmen (1948) introduced the concept of PET and he defined it as "the amount of water transpired in a unit time by short green crop of uniform height, completely covering the ground and never short of water". He further stated that PET cannot exceed pan evaporation under the same weather conditions and is some fraction of pan evaporation. PET can be estimated by several techniques *viz.,* lysimetric methods, energy balance, aerodynamic approach, combination of energy balance and empirical formulae etc., and irrigation's can be scheduled conveniently based on the knowledge of PET or water use rates of crops over short time intervals of crop growth.

19.1.1.1 Lysimeter

By isolating the crop root zone from its environment and controlling the processes that are difficult to measure, the different terms in the soil water balance equation can be determined with greater accuracy. This is done in lysimeters where the crop grows in isolated tanks filled with either disturbed or undisturbed soil (Fig. 19.1).

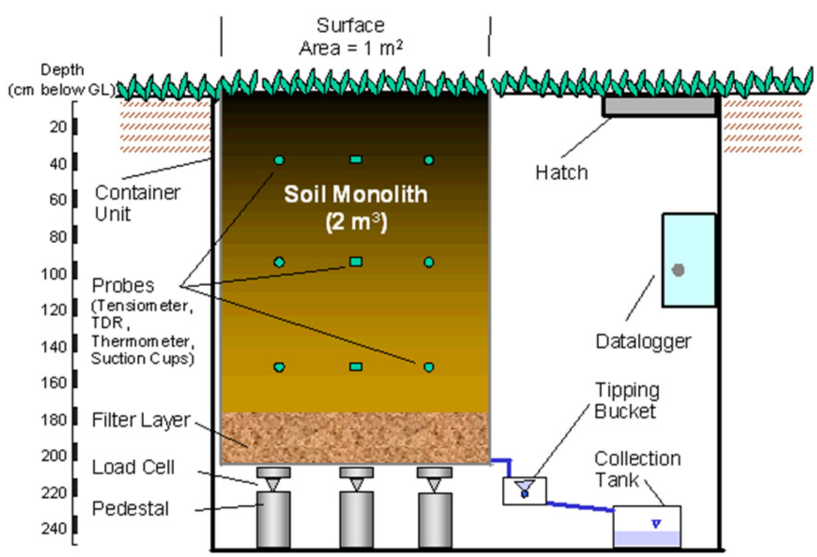


Fig. 19.1. schematic view of Lysimeter

Different types of lysimeters vary widely in the accuracy with which changes in soil water are detected. In precision weighing lysimeters, where the water loss is directly measured by the change of mass, evapotranspiration can be obtained with an accuracy of a few hundredths of a millimetre, and small time periods such as an hour can be considered. In non-weighing lysimeters the evapotranspiration for a given time period is determined by deducting the drainage water, collected at the bottom of the lysimeters, from the total water input.

A requirement of lysimeters is that the vegetation both inside and immediately outside of the lysimeter be perfectly matched (same height and leaf area index). Lysimeters provide the direct estimates of water balance components viz., E, T, ET, drainage, runoff, effective rainfall etc in a cropped field against which other methods can be tested and calibrated. As lysimeters are difficult and expensive to construct and as their operation and maintenance require special care, their use is limited to specific research purposes.

19.1.2 Cumulative pan evaporation

Earlier investigations have shown that transpiration of a crop is closely related to free water evaporation from an open pan evaporimeter (Fig. 19.2). Thus, the open pan evaporimeter being simple and as they incorporate the effects of all climatic parameters into a single entity i.e., pan evaporation could be used as a guide for scheduling irrigation's to crops. For example,

- Wheat required 75 to 100 mm CPE at Ludhiana
- Sugarcane required 75 mm CPE in Maharashtra
- Greengram required 180 mm CPE at Ludhiana
- Sunflower required 60 mm CPE at Bangalore

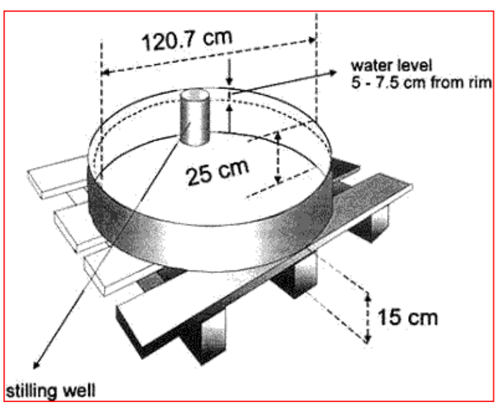


Fig. 19.2. USWB Class A Pan evaporimeter

Based on the same analogy, an alternative, simple can evaporimeter was devised by Jain (1975). The evaporation from it was shown to be closely related to pan evaporation as well as soil moisture depletion, hence it could also be satisfactorily employed in place of evaporimeter for scheduling irrigation to crops.

19.1.3 IW : CPE ratio

Prihar *et al.* (1974) advocated irrigation scheduling on the basis of ratio between the depth of irrigation water (IW) and cumulative evaporation from U.S.W.B. class A pan evaporimeter minus the precipitation since the previous irrigation (CPE). An IW/CPE ratio of 1.0 indicates irrigating the crop with water equal to that lost in evaporation from the evaporimeter. Few examples of optimal IW/CPE ratios for important crops are given in Table 19.1.

Table 19.1. Optimum IW/CPE ratios for scheduling irrigation in important crops

Crop	Optimum IW/CPE ratio
Groundnut	♦ 0.75 to 1.0 IW/CPE ratio depending on crop developmental stages in Andhra Pradesh, Maharashtra & West Bengal
Sunflower	♦ 0.5 to 1.0 IW/CPE ratio depending on crop developmental stages at Hyderabad & Kanpur
Wheat	♦ 1.0 IW/CPE ratio at Ludhiana, Kanpur and Bikramganj
Bengal gram	♦ 0.4 IW/CPE ratio at Ludhiana
Mustard	♦ 0.4 IW/CPE ratio at Hissar
Maize	♦ 0.75 to 1.0 IW/CPE ratio depending on crop developmental stages at Delhi & Hyderabad
Sugarcane	♦ 0.5 to 1.0 IW/CPE ratio depending on crop developmental stages at Lucknow

However, the criterion does not take into consideration the critical growth stages for irrigation. It may also not hold well under the following situations.

1. For crops requiring 1-2 irrigations only
2. Determining timing of first and last irrigation
3. Under low temperature/ frost/ salt stresses

Further, the optimum value of CPE for fixed/ variable depth of irrigation has to be worked out for different crops and locations.

Lecture No. 20

Scheduling of Irrigation to Crops – Plant Indices Approach

20.1 Introduction

The plant in one form or the other expresses water deficits in the soil, since it is the one, which is affected by the water, stress. Any plant character, related directly or indirectly to water deficits and which responds readily to the integrated influences of soil water, plant and environmental parameters may serve as a criterion for timing irrigation to crops. Some of the plant indices commonly used are discussed below:

20.1.1 Visual plant symptoms

In this method the visual signs of plants are used as an index for scheduling irritations. For instance, plant wilting, drooping, curling and rolling of leaves in maize is used as indicators for scheduling irrigation (Fig. 20.1). Change in foliage colour and leaf angle is used to time irrigations in beans. Water stress in some crops leads to appearance of carotenoid (yellow and orange colour) and anthocyanin pigments; shortening of internodes in sugarcane and cotton; retardation of stem elongation in grapes; leaf abscission and lack of new growth and redness in terminal growth points of almond, which can be used as indices for scheduling irrigations to crops.

Fig. 20.1. Rolling of leaves in maize and change of leaf angle in beans

20.1.2 Soil-cum-sand mini-plot technique

This method is also referred to profile modification technique and is commonly used for scheduling irrigations to crops. The principle involved in this technique is to reduce artificially the available water holding capacity of soil profile (i.e., effective root zone depth) in the mini-plot by mixing sand with it. When this is done plants growing on the sand mixed plot show wilting symptoms earlier than in the rest of the field. An area of 1.0 x 1.0m is selected in the field and a pit of 1.0m depth is excavated. About 5% of sand by volume is added to the dug up soil and mixed well. The pit is then filled back with the mixture and while filling up every 15 cm layer is well compacted, so that the soil in the pit retains the original bulk density as that of surrounding soil. Crop is sown normally and is allowed to grow as usual with the rest of the field. As and when the plants in the mini-plot show wilting symptoms it is taken as a warning of impending water need and cropped field is irrigated.

20.1.3 Plant population

Increase in plant population by 1.5 to 2.0 times that of optimum in some representative spots of (1 m x 1m area) in the cropped field alternative to mini-plot technique also serves as a reliable index for scheduling irrigation's to crops. This happens because when more plants are there per unit area, the available water within that zone is depleted rapidly as compared to other area wherein optimum number of plants is maintained per unit area. This result in drooping or wilting of plants earlier, which can be taken as an indication of water deficits and accordingly irrigations are scheduled to crops.

20.1.4 Rate of growth

Growth of a plant is dependent on turgor, which in turn is dependent on a favourable soil water balance. So fluctuations in the water balance are reflected by parallel fluctuations in the growth rate of expanding organs. Stem elongation is markedly reduced when the available soil moisture level approaches the critical level, but accelerates again after irrigation.

In cotton elongation of internodal length by 0.5 to 1.0-cm day^{-1} indicated the approach of critical available soil moisture level. Likewise in oranges, when the growth rate of fruit circumference falls below 0.2 to 0.3-mm d^{-1}, irrigations have to be scheduled.

20.1.5 Relative water content

This concept was proposed by Weatherly (1950). It is the actual water content of the leaf or plant when sampled relative to water at saturation or turgid. It is expressed as relative water content (RWC) and is calculated as follows:

$$\boldsymbol{RWC = \frac{(Fresh\,Weight - Dry\,Weight)}{(Turgid\,Weight - Dry\,Weight)}}$$

It depends on the lag between evaporative demand of the atmosphere and the rate of water absorption by the roots and has been found to be one of the reliable indices of plant water stress for scheduling irrigation. For instance the critical RWC level (below which reduction in growth occurs) for cotton and sesame was 72% and 75% respectively. Whenever the plant exhibits these values, irrigations can be scheduled. However, the main drawback is it is tedious and time consuming.

20.1.6 Plant water potential

This method measures the energy status of plant water analogous to the tension of film water in the soil, and serves as a better index of physiological and bio-chemical phenomena occurring in the plant. Plant or leaf water potential can be precisely measured either by a pressure bomb or pressure chamber apparatus (Fig. 20.2) in situ or by the dye method in the laboratory.

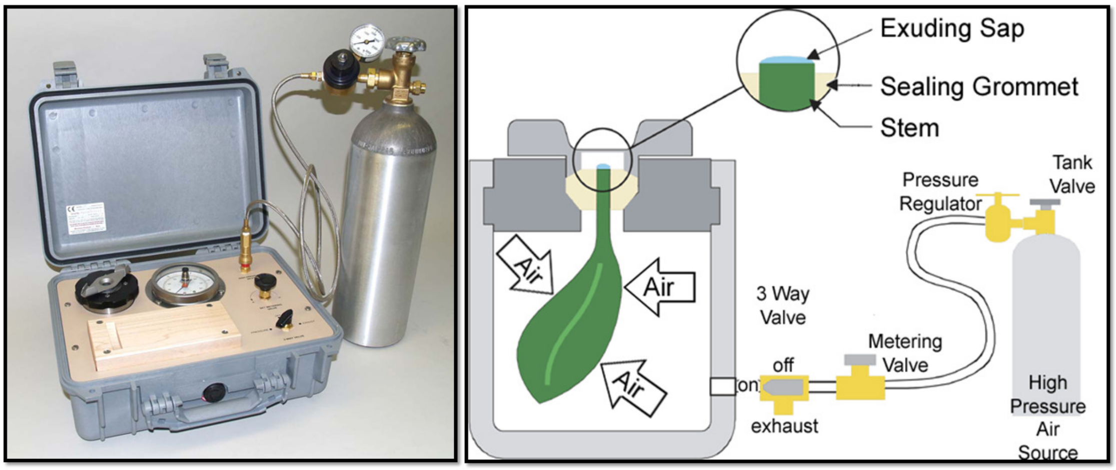


Fig. 20.2. Pressure chamber apparatus

The critical plant water potential values for cotton below which yield reductions are expected were 1.2 to 1.25 MPa throughout the crop life. While for sunflower they were 1.0, 1.2 and 1.4 MPa at vegetative, pollination and seed formation, respectively.

20.1.7 Canopy temperature

Several studies have shown that plant temperature or canopy temperature adequately reflects the internal water balance of the plant, and can be used as a potential indicator for scheduling irrigation to crops. It can be measured by several instruments, which are commercially available *viz.,* porometer, infrared thermometer (Fig. 20.3) etc.

Fig. 20.3. Infrared thermometer for scheduling irrigations to crops

For maize it is shown that if the canopy temperature rises to more than 0.7^0C over ambient temperature during 1330 to 1400 hour's irrigations need to be scheduled. However, tomato showed no sensitivity to water stress with respect to temperature variations.

20.1.8 Indicator plants

Some workers have suggested the use of indicator plants as a guide for scheduling irrigations. In wheat, scheduling irrigations on the basis of wilting symptoms in maize and sunflower gave the highest grain yields.

20.1.9 Critical growth stages

The crop plants in their life cycle pass through various phases of growth, some of which are critical for water supply. The most critical stage of crop growth is the one at which a high degree of water stress would cause maximum loss in yield. Further, studies on irrigation at growth stages may give an indication as to whether scarce water can be used more efficiently by scheduling irrigation's at critical stages.

Scheduling of irrigations on the basis of critical growth stages is simple and easy for the farmers. However, it does not take into account the available soil water in the crop root zone depth. Excessive irrigations without significant soil/ plant water deficit could be harmful to crop plants and might reduce their yield under certain situations. The criterion may not hold well in long duration crops like sugarcane, cotton; crops requiring frequent irrigation's *viz.,* potato or standing/nearly standing water (rice) and where there is interference by rainfall of different amounts. The critical growth stages of various crops for moisture supply are presented in Table 11.2.

Lecture No. 21

Surface Methods of Irrigation

21.1 Introduction

Surface irrigation method refers to the manner or plan of water application by gravity flow to the cultivated land wetting either the entire field (uncontrolled flooding) or part of the field (furrows, basins, border strips). Most irrigated areas have characteristic land features and differ from those in other areas. Hence, for efficient application of water it is important to select such method of irrigation, which fits one's own land. In doing so it may be necessary, or desirable, to use more than one method of irrigation in an area or a given farm (Fig. 21.1).

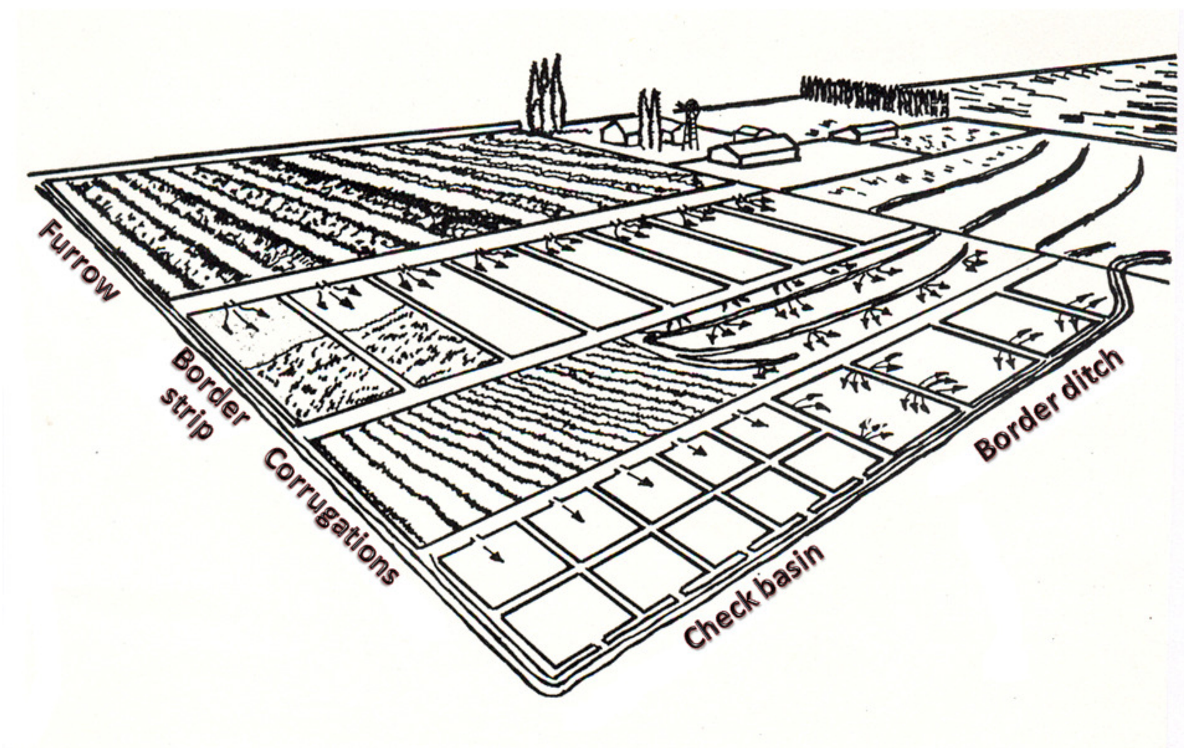
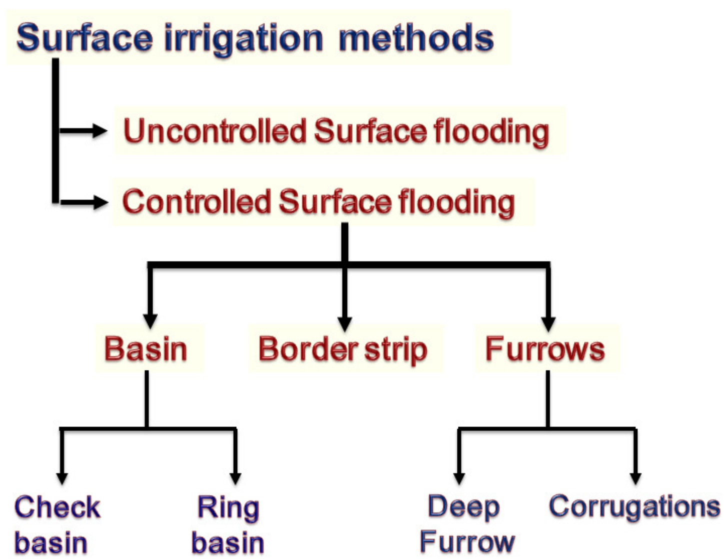


Fig. 21.1. Different methods of irrigation on a farm

The adoption of a certain method need not be necessarily based on convention or that followed in the adjoining farm. The factors, which determine the suitable method of irrigation are local conditions (soil type - its permeability & water storage capacity; land topography, climate, water availability & water quality), crop type, type of technology, previous experience with irrigation, required labour inputs etc. Good yield of crops can be obtained from irrigated land only if the water is applied judiciously to meet the needs of the plant, but not to cause waste and damage. Irrigation water is applied to cultivated land by the following surface methods of irrigation:



21.2 Wild flooding

It consists of applying water to the field without any bunds to guide the flow of water wetting the soil surface completely. Generally it is practiced only when irrigation water is abundant and where land levelling is not followed. Sometimes it is also adopted in the initial stages of land development. This method is most commonly used for irrigation of crops sown by broadcasting method *viz.,* rice, low value pastures, lawns and millets etc.

Advantages

1. No land levelling & land shaping
2. Low labour and land preparation costs
3. Less skill required by irrigator

Disadvantages

1. Applied water is lost by deep percolation & surface runoff
2. Low irrigation application efficiency

21.3 Controlled flooding

21.3.1 Check basin method

In this method the field is divided into square or rectangular plots of 4 to 4000 m^2 guided by bunds on all the sides (Fig. 21.2). This method is usually practiced in nearly levelled lands, thus no run-off of soil or water takes place and wetting depth is more uniform. However, it is particularly useful on fine textured soils with low permeability rate where it is necessary to hold the water on the surface to secure adequate penetration. The field channels supply water to each basin, during which the basins are filled to desired depth and water is retained until it infiltrates into the soil. This method is most commonly used for irrigating crops like groundnut, finger millet, sorghum, vegetable crops etc. Check basins are also used for leaching salts below the crop root zone depth by percolating water in the reclamation of saline soils.

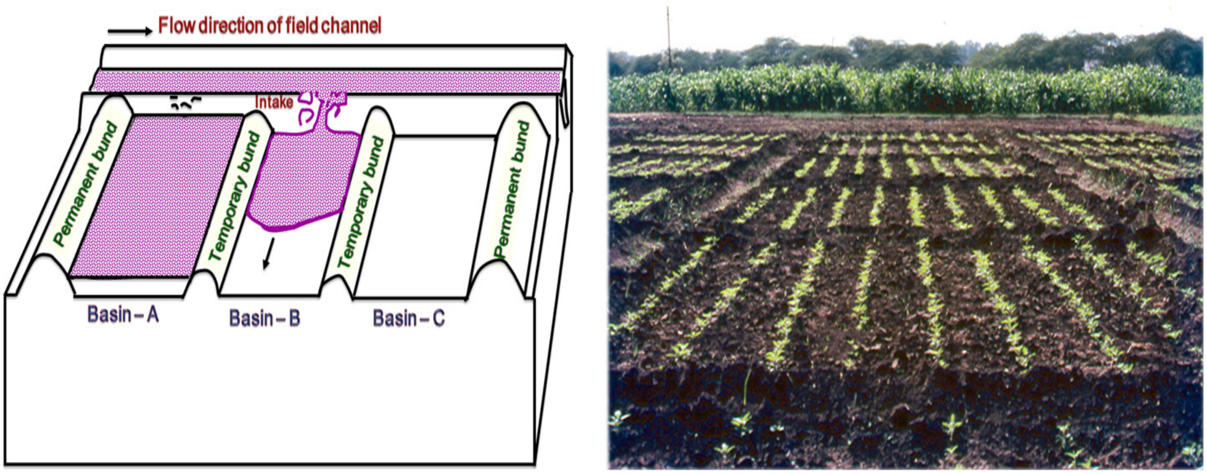


Fig. 21.2. Check basin method of irrigation

Advantages

1. Water can be applied uniformly.
2. Even small streams can be used for irrigation of crops efficiently.
3. Simple and cheap when equipment is used for constructing bunds

Disadvantages

1. Unless the land is levelled, distribution of water in plot is uneven.
2. Considerable area is lost under field channels and bunds i.e. nearly 30% of area.
3. Bunds interfere in working of inter-cultivation equipment
4. More labour is required for field layout and irrigation

21.3.2 Ring basin method

This method is a modification of check basin method and is suitable for sparsely grown orchard crops and cucurbits (Fig. 21.3).

Fig. 21.3. Ring basin method of irrigation

In this method a circular bund is constructed around each tree/plant or group of plants/trees to create a basin for irrigation. These basins are suitably connected to irrigation conveyance channels is such a way that either each basin is irrigated separately or group of basins by flowing water from one basin to another through inter- connections.

Advantages

1. High irrigation application efficiency can be achieved with properly designed system
2. Unskilled labour can be used, as there is no danger of erosion

Disadvantages

1. High labour requirement
2. Bunds restrict use of modern machinery in the field
3. Limited to relatively uniform lands

21.3.3 Border strip method

The cultivated field to be irrigated is divided into a number of long parallel strips, generally 5 to 15 m in width and 75 to 300 m in length separated by small border ridges or low dykes of about 15 cm high, laid out in the direction of the slope (Fig. 21.4).

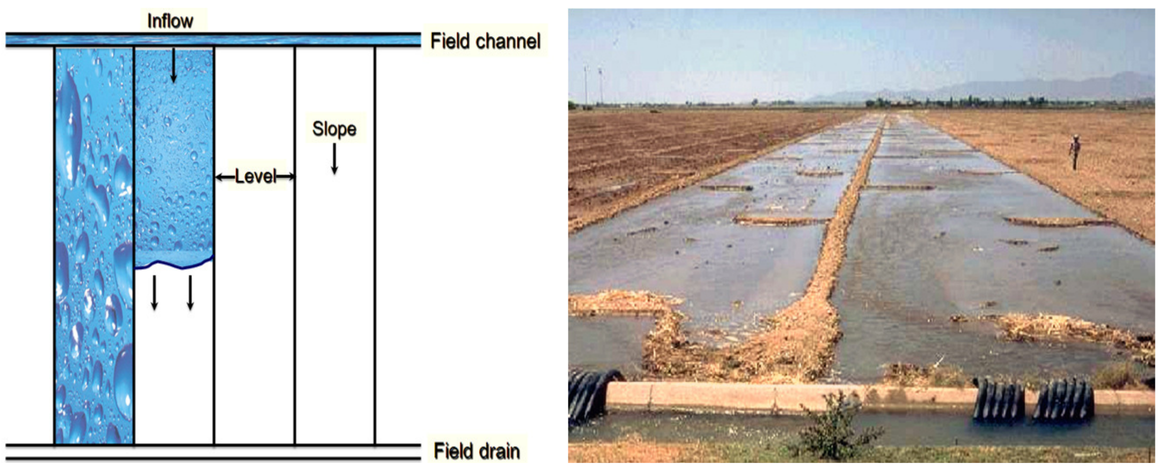


Fig. 21.4. Border strip method of irrigation

The objective is to advance a sheet of water down the narrow strip of land, allowing it to enter the soil as the sheet advances. Irrigation water is released into each strip connected directly to irrigation channel situated at the upstream end of the border strip. After sufficient water has been applied to one strip, the irrigation stream is turned into another strip. A specific requirement in border irrigation is that the longitudinal slope must be uniform, and the transverse slope must be zero or negligible (< 0.03%). This method is suitable for irrigating a wide variety of close growing crops such as wheat, barley, groundnut, bajra and berseem.

Advantages

1. Large water streams can be used safely
2. Provides uniform wetting of soil profile

3. Low labour requirement

Disadvantages

1. Requires relatively large water streams for quick advance of water to minimize deep percolation losses at the upper end of the border strip.
2. Wastage of water by deep percolation in coarse textured soils.

21.3.4 Deep furrow method

In furrow method of irrigation, the flat bed surface is converted into a series of ridges and furrows running down the slope (Fig. 21.5). The spacing of the furrow is ordinarily determined by the spacing of row crop. The length of the furrow and slope depends on several factors *viz.,* texture, intake rate etc.

Fig. 21.5. Furrow method of irrigation

Depending on the soil, crop spacing, farm equipment used etc spacing between furrows varies from 60 to 120 cm. Depending on the soil texture furrow length ranges from 20 to 300 m or even more. To avoid overtopping and scouring problems furrow inflow rates are normally limited to 2 to 15 m^3/hr/furrow. This method can be used either with small or large streams of irrigation water because it can be diverted into any number of furrows. Slope along the furrows may range from 0.2 to 2%. Where the land is too slopy (>5%), the furrows must be constructed on contours. Among the various surface irrigation methods, there is a relative saving of water in furrow method; hence efficient use of water is possible. In case of limited water, alternate furrows may be irrigated without much adverse effect on the crop yield. This method is commonly used for irrigating crops like potato, sugarcane, maize, cotton, melons, sugarbeets and vegetables like lettuce.

When furrow irrigation is practiced under saline and alkaline conditions, the lateral movement of soil moisture coupled with evaporation causes salt to accumulate in the ridges between furrows. If the salt accumulation reaches harmful levels, planting is advocated on the relatively salt free bottom of the furrows following pre-plant irrigation.

Advantages

1. Fairly high irrigation application efficiency among surface irrigation methods
2. Furrows serve as field drains in areas of heavy rainfall
3. Low evaporation losses

Disadvantages

1. Not suitable in coarse textured soils with high infiltration rates
2. Possibility of intra-furrow soil erosion
3. Labour intensive

21.3.5 Corrugations

This is a special method of furrow irrigation. Corrugations or rills are shallow furrows running down the slope from head ditches or laterals, which are sometimes very close to each other (Fig. 21.6).

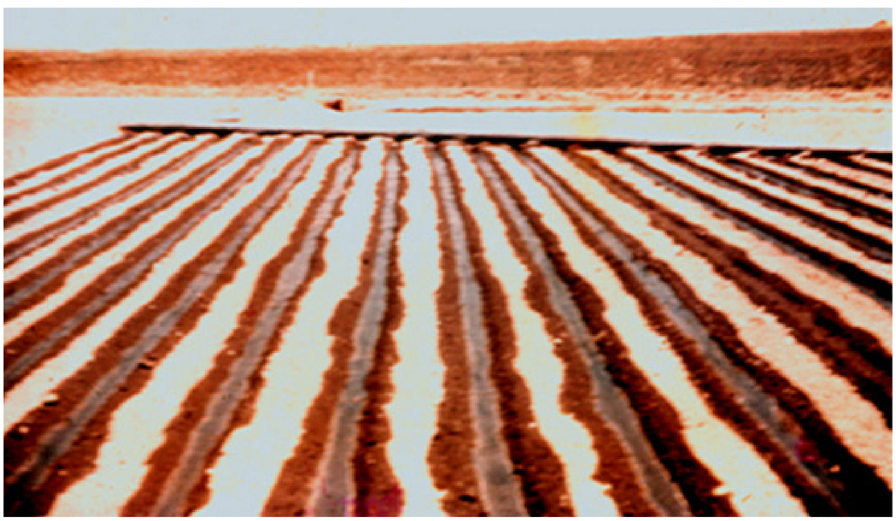


Fig. 21.6. Corrugations method of irrigation

Water moves down through several corrugations simultaneously and soaks laterally through the soil, wetting the area between the corrugations. This method is used for irrigating close growing crops, which do not require inter-culture operations and may also be used in conjunction with border irrigation. Corrugations are often used in fine textured soils that take water slowly and in soils, which tend to seal over and crust when flooded. The spacing and size of the corrugations vary with soil type, but in general, the more porous the soil, the more closely spaced the corrugations to permit rapid wetting between them without excessive deep percolation losses. The length of the corrugations should be such that upper end of the field has not been over irrigated by the time the lower end has received sufficient water.

21.4 Sub-irrigation

Sub-irrigation is the method of applying water beneath the soil surface; close to the plant roots so that either water seeps from the sides of the channels towards the plant roots or through capillary movement upward. It is usually done by creating an artificial water surface at some pre-determined depth, about 30 – 75 cm below the ground, depending upon the texture and rooting characteristics of the crop. Application efficiencies vary from 30-80% depending upon conditions. Water having high salt content cannot be used. This method is expensive, difficult to maintain and operate, and suitable only for few crops. Because of high investment required, it has not been widely adopted in India.

Lecture No. 22
Sprinkler Method of Irrigation

22.1 Introduction

Sprinkler irrigation is a method of applying irrigation water which is similar to natural rainfall (Fig. 22.1). Water is conveyed under desired pressure (2 to 5 kg/cm^2) developed by a pump through a network of pipes, called mainlines and submains to one or more laterals and is sprayed in to the air through sprinkler nozzles or perforations so that it breaks up in to small water drops (0.5 to 4mm in size) which fall over the land or crop surface in an uniform pattern at a rate (0.06-5000 LPH) less than the infiltrability of soil. The pump supply system, sprinklers and operating conditions must be designed to enable a uniform application of water.

Fig. 22.1 Sprinkler irrigation system

Sprinkler irrigation systems may be classified as portable, semiportable, semi-permanent or permanent. They are also classified as set-move (hand-move, tow-move, side-roll and gun-type systems), solid-set or continuous move sprinkler (center-pivot, traveler and linear-move) systems (Fig. 22.2).

Fig. 22.2. Centre pivot, Linear move and traveler sprinkler irrigation systems

22.2 Advantages

a) Elimination of field channels and their maintenance, which increase the production area
b) Harmful ditch weeds, which have allelopethic effects, do not appear with sprinkler irrigation.
c) No water losses in conveyance, which amounts to 35% in surface irrigation methods
d) Close control over water application i.e., no runoff losses because water is applied below or equal to infiltration rate.
e) Convenient for giving light and frequent irrigations.
f) Higher application efficiency over surface methods of irrigation.
g) Sprinklers give a gentle rain that does not clog or compact the soil ensuring better and quicker germination of seeds resulting in more plants per unit area
h) Suitable in undulated lands, soils with shallow depth and areas located at higher elevation than the water source.
i) Feasibility of frequent, short water applications for germination, cooling & frost protection to plants, etc.
j) Higher yield and water saving over surface irrigation methods

22.3 Limitations

a) Uneven distribution of water due to high wind velocities particularly during summer season.
b) Higher evaporation losses when operating under high temperatures.
c) Mechanical difficulties such as sprinklers fail to rotate, nozzles may clog, couplers may leak or engine may require repair.
d) Initial investment and recurrent operating costs are much higher than in surface irrigation methods.
e) Moving the portable lines, when the soil is wet results in the destruction of soil structure
f) Use of saline water for irrigation is not possible since it will be harmful to crops
g) Higher water pressure required hence extra energy cost

22.4 Sprinkler System Components & Layout

A typical sprinkler irrigation system consists of a pumping unit, pump connector, non-return valve, water meter, pressure gauge, pressure regulators, mainline & sub-mainlines, laterals, control valves, hydrants, sprinkler base, sprinkler heads, bends, tees, reducers, end plug, nipples, flanges etc (Fig. 22.3).

The most common type of sprinkler system layout is shown below in Fig. 22.4. The pump unit is usually a centrifugal pump which takes water from the source and provides adequate pressure for delivery into the pipe system.

Fig. 22.3. Sprinkler system components

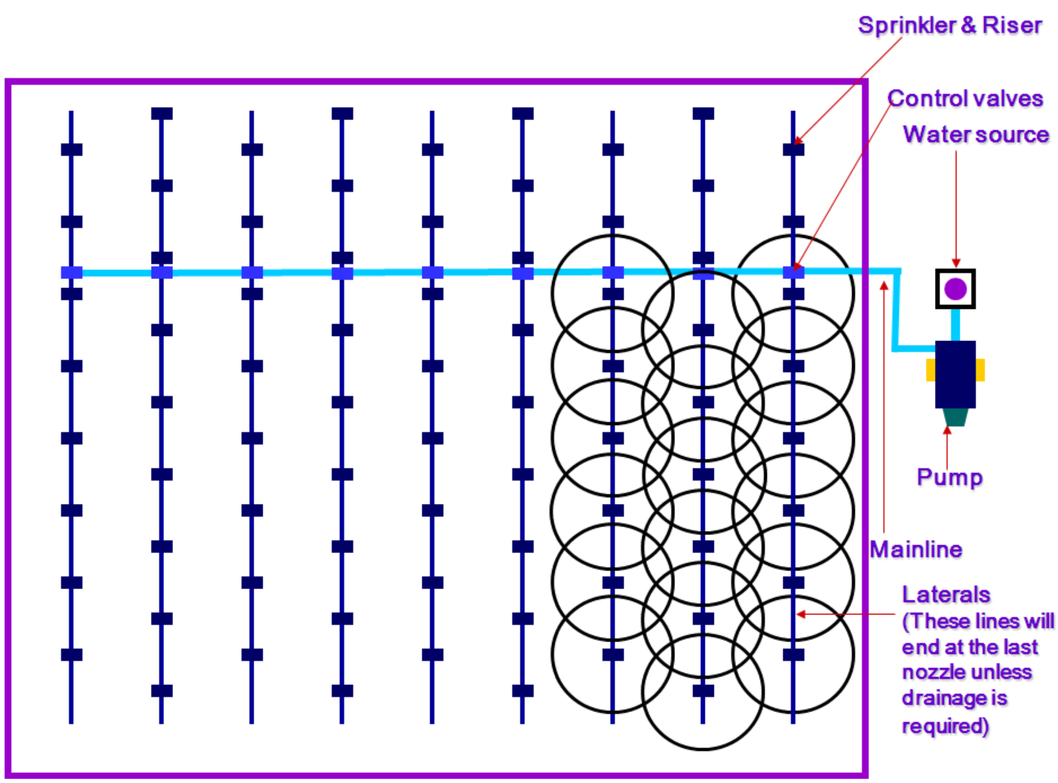


Fig. 22.4. Sprinkler system layout

22.5 Suitable crops

Sprinkler irrigation is suited for most field crops viz., wheat, lucerne, groundnut, bengal gram, green gram, black gram, potato, leafy vegetables, sunflower, barley, bajra, maize, wheat etc wherein water can be sprayed over the crop canopy (Fig. 22.5). However, large sprinklers are not recommended for irrigation of delicate crops such as lettuce because the large water drops produced by the sprinklers may damage the crop. Water containing specific ions such as sodium and chlorides in concentration of more than 3 meq/litre are not suitable for irrigation by overhead sprinklers.

Fig. 22.5. Sprinkler irrigation in maize and lettuce

Lecture No. 23

Drip Method of Irrigation

23.1 Introduction

Irrigation advancements within the last 2 decades have been astounding. Drip or trickle irrigation is one of the latest innovations for applying water, and represents a definite advancement in irrigation technology.

Drip irrigation is defined as the precise, slow and frequent application of small quantities of water to the soil in the form of discrete drops, continuous drops, and tiny streams through emitters located at selected points along a water delivery lateral line. It differs from sprinkler irrigation by the fact that only part of the soil surface is wetted.

Current drip irrigation technology dates back to the work of Symcha Blass (1964). Based on the observation that a large tree near a leaking faucet exhibited a more vigorous growth than other trees in the area, he developed the first patented drip irrigation system. From Israel, the concept spread to Australia, North America and South Africa by the late 1960s, and eventually throughout the world. The availability of low cost plastic pipe for water delivery lateral lines helped to speed up the field use of drip irrigation system. At present the largest area is in the USA and Spain (1.5 million ha each) followed by India (1.43 million ha). Total coverage in the world has increased from 4000 ha in 1972 to over 8 million ha in 2008.

23.1.1 Surface drip irrigation: The application of water to the soil surface as drops or tiny streams through emitters with discharges rate for point-source emitters less than 8 L/h for single outlet emitter and for line-source emitters less than 4 L/h (Fig. 23.1). Often the terms drip and trickle irrigation are considered synonymous.

Fig. 23.1. Surface drip irrigation in bhendi and mango crop

23.1.2 Subsurface drip irrigation: The application of water below the soil surface through emitters, with discharge rate generally in the range of 0.6 to 3 L/h. This method of water application is different from and not to be confused with the method where the root zone is irrigated by water table control, herein referred to as subirrigation (Fig. 23.2).

Fig. 23.2. Subsurface drip irrigation in potato

23.2 Advantages

Many reports have listed and summarized potential advantages of drip irrigation as compared to other irrigation methods.

a) Enhanced plant growth, crop yield and premium quality produce
b) Water Saving due to increased beneficial use of available water and higher water application efficiency
c) Precise and uniform delivery of water to crops due to controlled water application
d) Maintenance of higher soil water potential in the root zone
e) Compact and efficient root system
f) Combined water and fertilizer (fertigation) application minimizes nutrient losses and improves fertilizer use efficiency and contributes to fertilizer saving in some crops
g) Reduced salinity hazards to crop plants when low quality saline water is used for irrigation
h) Suitable for irrigating high-value crops raised in greenhouses, plastic tunnels, potted plants and under plastic mulches
i) Lower operating pressures means reduced pumping energy costs
j) Limited weed growth because only a fraction of the soil surface is irrigated
k) Reduced operational and labour costs due to improved weed control and simultaneous application of water, fertilizers, herbicide, insecticide, fungicide and other additives through the drip irrigation system

l) Feasible to irrigate crops raised in small & irregularly shaped narrow lawns, and on undulated land terrains
m) Maintenance of dry foliage means improved disease and pest management
n) Suitable to highly permeable & low water holding sandy and desert soils, saline and slowly permeable alkaline soils, wastelands, slopy lands and rocky hills, road embankments, abandoned mine areas etc
o) Improved and continuous cultural operations such as spraying, weeding, thinning and harvesting of tree and row crops is possible without interrupting the drip irrigation cycle for any prolonged period of time.
p) Environmental protection and ecological security

23.3 Limitations

Despite observed successes, some important possible limitations of drip irrigation as compared to other irrigation methods have been encountered for some soils, water quality and environmental conditions, which include:

a) Sensitivity to emitter clogging
b) Salt accumulation in soil
c) Mechanical damage to system components
d) Lack of microclimate control such as frost protection and evaporative cooling.
e) Operational constraints such as high technical skills, stringent filtration and operating pressures etc

23.4 Drip Irrigation System Layout and Components

The drip irrigation system consists of three subsystems viz., control head unit, water carrier system and water distribution system besides water source & pumping station (Fig. 23.3).

a) Head control unit – Non return valve, Air release valve, Vacuum breaker, Filtration unit, Fertigation unit, Throttle valve, Pressure gauge, Water meter, Pressure regulator and Pressure relief valve.
b) Water carrier system – PVC main pipeline, PVC submain pipeline, Control valve, Flush valve and other fittings
c) Water distribution system – Drip lateral, Emitters, Grommet, Start connecter, Nipple, End cap.

23.5 Suitable crops

Drip irrigation, like other irrigation methods, will not fit every agricultural crop, specific site or objective. Presently drip irrigation has the greatest potential in the following crops:

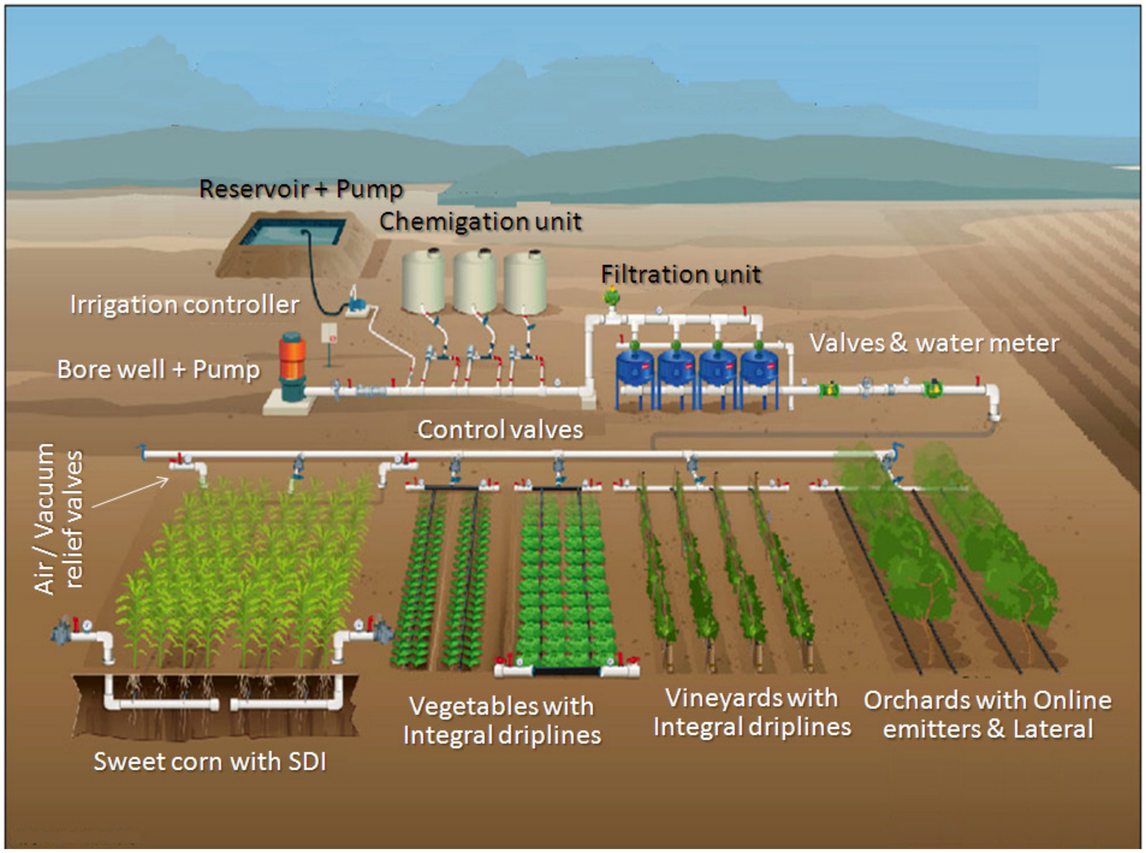


Fig.23.3. Drip head control unit and system components

a) Fruit crops – Mango, citrus, grapes, guava, pomegranate, banana, papaya, watermelon, Litchi, Fig, Ber, Amla, Sapota etc
b) Vegetable crops – Tomato, Brinjal, Bhendi, Cabbage, Cauliflower, Capsicum, Chillies gourds etc
c) Plantation crops – Oil palm, Coconut, Arecanut, Cashewnut, Coffee, Tea etc
d) Field crops – Cotton, Sugarcane, Tobacco, Sugarbeet, Castor etc
e) Tuber & Bulb crops – Potato, Cassava, Onion, Sweet potato, Radish, Colocasia etc
f) Spices – Turmeric, Ginger, Cardamom etc
g) Flowers – Roses, Rose, Gerbera, Orchids, Anthurium, Gladiolus, Carnations, Jasmine, Chrysanthemum, Marigold etc.

Further this method of irrigation continuous to be important in greenhouse production of vegetables & flowers. Drip irrigation is also used for landscaping of parks, highways, commercial developments and residences. As labour, water and land preparation costs increase, more drip irrigation systems will be substituted for conventional irrigation methods.

Lecture No. 24

Water Use Efficiency of Crops

24.1 Introduction

Irrigation plays a vital role in Indian agriculture. The impact of irrigated agriculture on water resources is significant since it uses 85% of the total water resources in the country. The limits to the availability of water and land for irrigated agriculture necessitate the careful use of water resources for achieving higher water use efficiency.

The term "water use efficiency" originates in the economic concept of productivity. Productivity measures the amount of any given resource that must be expended to produce one unit of any good or service. In a similar manner, water use efficiency measures the quantity of water taken up by the crop during its crop life to produce a unit quantity of the output i.e., crop yield. In general, the lower the water resource input requirement per unit of crop yield produced, the higher the efficiency.

Further water use efficiency is closely related to water conservation. The growing water scarcity and the misuse of available water resources are nowadays major threats to sustainable agricultural development. Therefore, water use efficiency has a clear role to play in sustainable development, in other words, the use of the earth's water resources by today's inhabitants while assuring that future generations have sufficient capacity to meet their own needs.

24.2 Crop water use efficiency

Crop water use efficiency is a ratio between marketable crop yield and water used by the crop in evapotranspiration.

$$\boldsymbol{WUE\ (Kg/ha.mm) = \frac{Y}{ETc}}$$

Where,

WUE = Water use efficiency in kg/ha-mm

Y = Marketable crop yield in kg/ha

ETc = Crop evapotranspiration in mm

24.3 Field water use efficiency

Field water use efficiency is a ratio between marketable crop yield and field water supply which includes water used by the plant in metabolic activities, ET and deep percolation losses.

$$\boldsymbol{FWUE\ (Kg/ha.mm) = \frac{Y}{WR}}$$

Where,

FWUE = Field water use efficiency in kg/ha-mm

Y = Crop yield in kg/ha

WR = Water used in metabolic activities, ET and deep percolation losses in mm

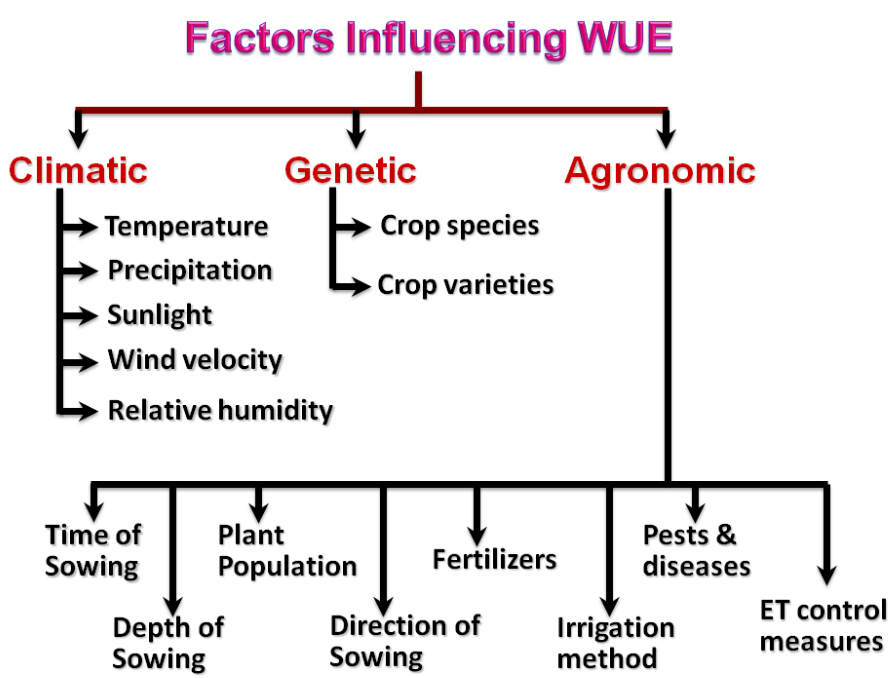
Water use efficiency of various crops is presented below in Table 24.1.

Table 24.1. Water Use Efficiency of Crops

CROP	Water requirement (mm)	Grain yield (kg/ha)	WUE (kg/ha-mm)
Rice	1200	4500	3.7
Sorghum	500	4500	9.0
Pearl millet	500	4000	8.0
Maize	625	5000	8.0
Groundnut	506	4616	9.2
Wheat	280	3534	12.6
Finger millet	310	4137	13.7

24.4 Factors affecting water use efficiency

The factors influencing water use efficiency can be calssified as follows:



24.4.1 Genetic factors

Crop growth and yield is a result of interaction between their genetic constitution and environmental conditions in which they grow. Plant species therefore differ widely in their productivity i.e., crop yield and water use i.e., ET. Water use efficiency of C_4 plant species such as maize, sorghum, sugarcane, pearl millet, finger miller etc is higher (3.14 to 3.44 mg dry weight/g of water) when compared to C_3 species (1.49 to 1.59 mg dry weight/g of water) such as pulses, oilseed crops, wheat, barley, oats etc.

Crop varieties also differ in WUE. High yielding varieties, hybrids, GM crops etc due to their dwarf plant type, responsive to water & fertilizer, pest & disease resistance and high harvest index exhibit higher WUE as compared to traditional varieties characterized by rank vegetative growth, low harvest index, susceptible to lodging, pests & diseases.

24.4.2 Climatic factors

Weather affects both crop yield and crop evapotranspiration. The amount of solar radiation determines the rate of photosynthesis and hence the potential yield. Other components of climate viz., temperature, day length, rainfall etc influence vital physiological processes and thereby determine the actual harvested yield. The lower the relative humidity is, the greater will be the ETc. Therefore, low relative humidity in the atmosphere increases transpiration without any corresponding increase in dry matter production and will reduce WUE. Light and temperature that normally affect both transpiration and dry matter production will either increase or decrease WUE according to which of the two predominates. High wind velocity increase ETc without any concurrent increase in dry matter production hence decrease WUE.

24.4.3 Crop management factors

a) **Time of sowing:** Timely sowing ensures optimal temperatures, soil moisture availability and other soil physical conditions favouring optimal crop growth and development with greater ability to compete with prevalent weed flora, hence increases WUE.
b) **Depth of sowing:** Optimal depth of sowing affects seedling emergence, vigour and finally crop yield, hence improves WUE.
c) **Direction of sowing:** North south row orientation of crop rows influences the interception and utilization of incident solar radiation which in turn influences crop yield and improves WUE as compared to east west direction of row pattern.
d) **Plant population:** Optimal plant population promotes uniform & rapid development of crop canopy without any competition for growth resources viz., light, nutrients, water, CO_2 etc hence improves WUE.
e) **Fertilization:** Fertilization of crops suffering from low nutrition under adequate soil water availability increases crop yield considerably, with a relatively small increase in crop evapotranspiration, therefore, markedly improves WUE.
f) **Insect pests & diseases:** Insect pests and diseases reduce crop yield as well as WUE to varying degrees depending upon the intensity of infestation, because ETc or water

requirement of crop will not change to a significant level except in cases where premature death of plants occurs.

g) **Irrigation method:** Field water use efficiency in general is higher with over head sprinkler, microsprinkler and drip methods of irrigation as compared to surface irrigation methods viz., furrow, border strip, check basin etc owing to higher crop yield and lower seasonal water application.

h) **ET control measures:** Use of mulches, anti-transpirants, shelterbelts and elimination of weeds etc reduce water losses from cropped field in terms of soil evaporation and transpiration without any reduction in crop yield, hence markedly improve WUE.

Lecture No. 25

Irrigation Efficiencies

25.1 Introduction

Irrigation efficiencies are the indices which indicate how best the water applied to the farm is being utilized. These parameters are needed to know the performance of the irrigation activity on the farm. A low value of the irrigation efficiencies in general implies that land, water and the crops are not being managed properly. The net effects of poor irrigation efficiencies are crop loss, and wastage of water and nutrients. The principal factors affecting irrigation efficiency are irrigation system design, quality of land preparation, selection of irrigation methods, stream size, soil texture, soil depth, land topography and skill & care of irrigator. A basin-wise study conducted by Madras Institute of Development Studies (MIDS) using potential evapotranspiration data and gross water withdrawals revealed that the overall irrigation efficiency in the country is 38%. The study further indicated that the Krishna, Godavari, Cauvery, and Mahanadi systems have a very low efficiency of around 27%, while the Indus and Ganga systems are doing better with efficiencies in the range of 43% – 47%. Therefore, identifying the various components for low efficiency and knowing what improvements can be made is essential for making the most effective use of this vital but scarce resource in agricultural areas. There are four common irrigation efficiencies viz., water conveyance efficiency (Ec), water application efficiency (Ea), water storage efficiency (Es) and water distribution efficiency (Ed).

25.2 Water Conveyance Efficiency

It is the ratio between water delivered to the irrigated plot and total quantity delivered from source. It is mathematically expressed as:

$$\boldsymbol{Ec = \frac{W_f}{W_d} \text{ x } 100}$$

Where:

$\boldsymbol{Ec}$ = Water conveyance efficiency (%)

$\boldsymbol{W_f}$ = Water delivered to the plot (L/sec)

$\boldsymbol{W_d}$ = Water delivered from the source (L/sec)

In irrigation distribution network i.e., distributories, water courses, etc., the water conveyance efficiency is used to find out what percentage of the released water at the head gate actually reaches the farm and is an indicator of the seepage losses in the conveyance losses. Thus a low Ec implies that much of the water released from the source is lost due to seepage in transit from source to the field.

25.3 Water Application Efficiency

It is the ratio between quantity of water stored in the root zone and water delivered to the plot. It is mathematically expressed as:

$$\boldsymbol{Ea = \frac{W_s}{W_f}\ \text{x}\ 100}$$

Where:

$\boldsymbol{Ea}$ = Water application efficiency (%)

$\boldsymbol{W_s}$ = Water stored in the root zone (cm)

$\boldsymbol{W_f}$ = Water delivered to the plot (cm)

The concept of water application efficiency can be applied to a project, a farm or a field to evaluate the irrigation practices. All the factors, which influence the design of the surface irrigation system therefore directly, affect the application efficiency. Thus a low Ea implies that much of the applied water has been lost due to deep percolation or runoff.

25.4 Water Storage Efficiency

It is the ratio between water stored in the root zone and water needed in the root zone prior to irrigation. It is mathematically expressed as:

$$\boldsymbol{Es = \frac{W_s}{W_n}\ \text{x}\ 100}$$

Where:

$\boldsymbol{Es}$ = Water storage efficiency (%)

$\boldsymbol{W_s}$ = Water stored in the root zone (cm)

$\boldsymbol{W_n}$ = Water needed in the root zone (cm)

The concept of water storage efficiency is useful in evaluating the irrigation methods especially under limited water supply conditions. It is also important when soils with low infiltration rates are to be irrigated. In such cases adequate time is to be allowed for the required amount of water to penetrate into the soil. This concept is also useful when salt balance of the root zone has to be taken into consideration and leaching requirement needs to be calculated. In such cases higher water storage efficiencies must be desirable to leach out the salts from the root zone. A low storage efficiency implies that water application is much less than actually needed. In a stretch of land one may get poor application efficiency for the upstream part and poor storage efficiency for the downstream section.

25.5 Water Distribution Efficiency

It is the ratio between the average numerical deviations in depth of water stored from average depth stored during irrigation (Y) and the average depth stored during irrigation (d). It is mathematically expressed as:

$$Ed = \left(1 - \frac{Y}{d}\right) x\ 100$$

Where:

Y = Average numerical deviation in depth of water stored from average depth stored during irrigation

d = Average depth of water stored during irrigation

It is a measure of water distribution within the field. A low distribution efficiency means non-uniformity in the irrigation water penetration in the soil due to uneven land levelling. The irrigation water cannot flow over the soil smoothly. There are low patches where water will penetrate more and there are high patches where water cannot reach. This leaves some spots unirrigated unless excess irrigation water is applied. Excess water application lowers irrigation efficiency.

25.6 Project Efficiency

It is the ratio between the average depth of water stored in the root zone during irrigation and water diverted from the reservoir. It is mathematically expressed as:

$$Ep = \frac{W_s}{W_r}\ x\ 100$$

Where:

Ep = Project efficiency (%)

W_s = Water stored in the root zone (cm)

W_r = Water diverted from the reservoir (cm)

The overall irrigation efficiency of a farm is a product of:

$$Ef = Ea\ x\ Es\ x\ Ed$$

The overall irrigation efficiency for a project (i.e., considering irrigation channels) is the product of:

$$Ep = Ea\ x\ Es\ x\ Ed\ x\ Ec$$

Problem:

Canal stream size : 120 LPS

Water delivered to the field : 100 LPS

Area irrigated : 1.5 ha in 8 hours

Effective root zone depth : 1.75 m

Runoff losses : 415 m^3

Available water holding capacity : 200 mm/m depth of soil

Schedule irrigations at : 50% DASM

Depth of application varied linearly : 1.65 m at head end to 1.3 m at tail end

Calculate water conveyance efficiency, water application efficiency, water storage efficiency and water distribution efficiency.

Solution:

$\boldsymbol{Water\ conveyance\ efficiency}$

$$\boldsymbol{Ec = \frac{100}{120} \times 100 = 83.33\%}$$

$\boldsymbol{Water\ application\ efficiency}$

$$Water\ delivered\ to\ the\ field = \frac{100 \times 60 \times 60 \times 8}{1000} = 2880 m^3$$

$$Water\ stored\ in\ the\ root\ zone = 2880 - 415 = 2465 m^3$$

$$\boldsymbol{Ea = \frac{2465}{2880} \times 100 = 85.59\%}$$

$\boldsymbol{Water\ storage\ efficiency}$

$$Water\ holding\ capacity\ in\ the\ rootzone = 200 \times 1.75 = 350\ mm$$

$$Moisture\ in\ the\ root\ zone\ before\ irrigation = \frac{50}{100} \times 350 = 175\ mm$$

$$Additional\ water\ required\ in\ 1.5\ m = \frac{175}{1000} \times 1.5 \times 10000 = 2625 m^3$$

$$\boldsymbol{Es = \frac{2465}{2625} \times 100 = 93.90\%}$$

$\boldsymbol{Water\ distribution\ efficiency}$

$$Mean\ depth\ of\ water\ stored\ in\ the\ root\ zone\ = \frac{1.65 + 1.35}{2} = 1.5\ m$$

$$Numerical\ deviation\ from\ the\ depth\ of\ penetration$$

$$Upper\ end = 1.65 - 1.50 = 0.15\ m$$

$$Lower\ end = 1.50 - 1.35 = 0.15\ m$$

$$Average\ numerical\ deviation = \frac{0.15 + 0.15}{2} = 0.175\ m$$

$$\boldsymbol{Ed = \left(1 - \frac{0.175}{1.5}\right) \times 100 = 90.0\%}$$

Lecture No. 26

Quality of Irrigation Water

26.1 Introduction

All irrigation waters are not pure and may contain some soluble salts. In arid and semi-arid regions successful crop production without supplemental irrigation is not possible. Irrigation water is usually drawn from surface or ground water sources, which typically contain salts in the range of 200 to 2000 ppm (= 200 to 2000 g/m^3). Irrigation water contains 10 – 100 times more salt than rain water. Thus, each irrigation event adds salts to the soil. Crop removes water from the soil to meet its water needs (ETc) leaving behind most of the salts to concentrate in the shrinking volume of soil water (Fig. 26.1). This is a continuous process. Application of saline water may hinder the crop growth directly and may also cause soil degradation. Beyond its effect on crop and soil, irrigation water of low quality can also affect environment by introducing potentially harmful substances in to surface and ground water sources. Therefore, a salt balance in the soil has to be maintained through proper water management practices for continuous and successful cultivation of crops.

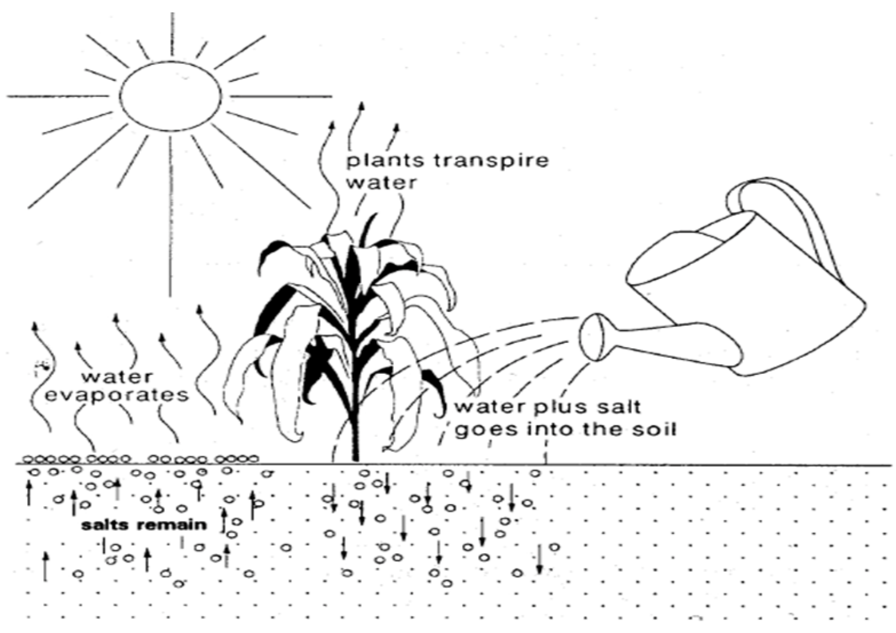


Fig. 26.1. Salinity buildup process in irrigated soils

26.2 Criteria to determine the quality of irrigation water

The criteria for judging the quality of irrigation water are: Total salt concentration as measured by electrical conductivity, relative proportion of sodium to other cations as expressed by sodium adsorption ratio, bicarbonate content, boron concentration and soluble sodium percentage.

26.2.1 Total soluble salts

Salinity of water refers to concentration of total soluble salts in it. It is the most important single criterion of irrigation water quality. The harmful effects increase with increase in total salt concentration. The concentration of soluble salts in water is indirectly measured by its electrical conductivity (ECw). The quality of saline waters has been divided into five classes as per USDA classification given in Table 26.1.

Table 26.1. Salinity classes of irrigation water

Salinity class	Electrical conductivity	
	Micro mhos/cm	Milli mhos/cm
C_1 – Low	< 250	< 0.25
C_2 – Medium	25 – 750	0.25 – 0.75
C_3 – Medium to high	750 – 2250	0.75 – 2.25
C_4 – High	2250 – 5000	2.25 – 5.00
C_5 – Very high	> 5000	> 5.00

Adverse effects of saline water include salt accumulation, increase in osmotic potential, decreased water availability to plants, poor germination, patchy crop stand, stunted growth with smaller, thicker and dark green leaves, leaf necrosis & leaf drop, root death, wilting of plants, nutrient deficiency symptoms and poor crop yields.

26.2.2 Sodium Adsorption Ratio (SAR)

SAR of water indicates the relative proportion of sodium to other cations. It indicates sodium or alkali hazard.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

The ion concentration is expressed as meq per litre. Increase in SAR of water increases the exchangeable sodium percentage (ESP) of soil. There is a linear relationship between SAR and ESP of the soil:

$$ESP = \frac{100\ (0.23 + 0.0042SAR)}{1 + (0.23 + 0.0042SAR)}$$

As per USSSL, the sodicity classes of water are shown in Table 26.2.

Table 26.2. Sodicity classes of water

Sodium class	SAR value
S_1 – Low	< 10
S_2 – Moderate	10 – 18
S_3 – High	18 – 26
S_4 – Very high	> 26

Harmful effects of sodic water include destruction of soil structure, crust formation, poor seedling emergence, reduction in availability of N, Zn and Fe due to increased soil pH, Na toxicity and toxicity of B & Mo due to their excessive solubility.

26.2.3 Residual sodium carbonate

Bicarbonate is important primarily in its relation to Ca and Mg. There is a tendency for Ca to react with bicarbonates and precipitate as calcium carbonate. As Ca and Mg are lost from water, the proportion of sodium is increased leading to sodium hazard. This hazard is evaluated in terms of Residual Sodium Carbonate (RSC) as given below:

$$\boldsymbol{RSC\ (meq/litre) = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})}$$

RSC is expressed in meq per litre. Water with RSC more than 2.5 meq/L is not suitable for irrigation. Water with 1.25 to 2.5 meq/L is marginally suitable and water with less than 1.25 meq/L is safe for use.

26.2.4 Boron content

Though boron is an essential micronutrient for plant growth, its presence in excess in irrigation water affects metabolic activities of the plant. For normal crop growth the safe limits of boron content are given in Table 26.3.

Table 26.3. Permissible limts of boron content in irrigation for crops

Boron (ppm)	Quality rating
< 3	Normal
3 – 4	Low
4 – 5	Medium
5 – 10	High
More than 10	Very high

26.3 Leaching requirement

Leaching requirement (LR) is that fraction of total crop water requirement which must be leached down below the crop root zone depth to control salts within the tolerance level (ECe) of the crop.

$$\boldsymbol{Leaching\ Requirement\ (LR) = \frac{ECw}{5\ (ECe) - ECw}}$$

Where:

ECw = Salinity of applied water in dS/m

ECe = Threshold level soil salinity of the crop in dS/m

26.4 Management practices for using poor quality water

Whenever, it is inevitable to use water of poor quality water for crop production appropriate management practices helps to obtain reasonable yield of crops. Some of the important management practices are as follows:

a) **Application of gypsum:** Chemical amendments such as gypsum, when added to water will increase the calcium concentration in the water, thus reducing the sodium to calcium ratio and the SAR, thus improving the infiltration rate. Gypsum requirement is calculated based on relative concentration of Na, Mg & Ca ions in irrigation water and the solubility of gypsum. To add 1 meq/L of calcium, 860 kg of gypsum of 100% purity per ha m of water is necessary.

b) **Alternate irrigation strategy:** Some crops are susceptible to salinity at germination & establishment stage, but tolerant at later stage. If susceptible stages are ensured with good quality water, subsequent tolerant stages can be irrigated with poor quality saline water.

c) **Fertilizer application:** Fertilizers, manures, and soil amendments include many soluble salts in high concentrations. If placed too close to the germinating seedling or to the growing plant, the fertilizer may cause or aggravate a salinity or toxicity problem. Care, therefore, should be taken in placement as well as timing of fertilization. Application of fertilizers in small doses and frequently improve uptake and reduce damage to the crop plants. In addition, the lower the salt index of fertilizer, the less danger there is of salt burn and damage to seedlings or young plants.

d) **Methods of irrigation:** The method of irrigation directly affects both the efficiency of water use and the way salts accumulate. Poor quality irrigation water is not suitable for use in sprinkler method of irrigation. Crops sprinkled with waters having excess quantities of specific ions such as Na and Cl cause leaf burn. High frequency irrigation in small amounts as in drip irrigation improves water availability and uptake due to microleaching effect in the wetted zone.

e) **Crop tolerance:** The crops differ in their tolerance to poor quality waters. Growing tolerant crops when poor quality water is used for irrigation helps to obtain reasonable crops yields. Relative salt tolerance of crops is given in Table 26.4.

f) **Method of sowing:** Salinity reduces or slows germination and it is often difficult to obtain a satisfactory stand. Suitable planting practices, bed shapes, and irrigation management can greatly enhance salt control during the critical germination period. Seeds have to be placed in the area where salt concentration is less. Salt accumulation is less on the slope of the ridge and bottom of the ridge. Therefore, placing the seed on the slope of the ridge, several cm below the crown, is recommended for successful crop establishment (Fig. 26.2).

Table 26.4. Relative salt tolerance of crops

Tolerant	**Field crops:** Cotton, Safflower, Sugarbeet & Barley **Fruit crops:** Date palm & Guava **Vegetables:** Turnip & Spinach **Forage crops:** Berseem & Rhodes grass
Semi tolerant	**Field crops:** Sorghum, Maize, Sunflower, Bajra, Mustard, Rice & Wheat **Fruit crops:** Fig, Grape & Mango **Vegetables:** Tomato, Cabbage, Cauliflower, Cucumber, Carrot & Potato **Forage crops:** Senji & Oats
Sensitive	**Field crops:** Chick pea, Linseed, Beans, Greengram & Blackgram **Fruit crops:** Apple, Orange, Almond, Peach, Strawberry, Lemon & Plum **Vegetables:** Radish, Peas & Lady's finger

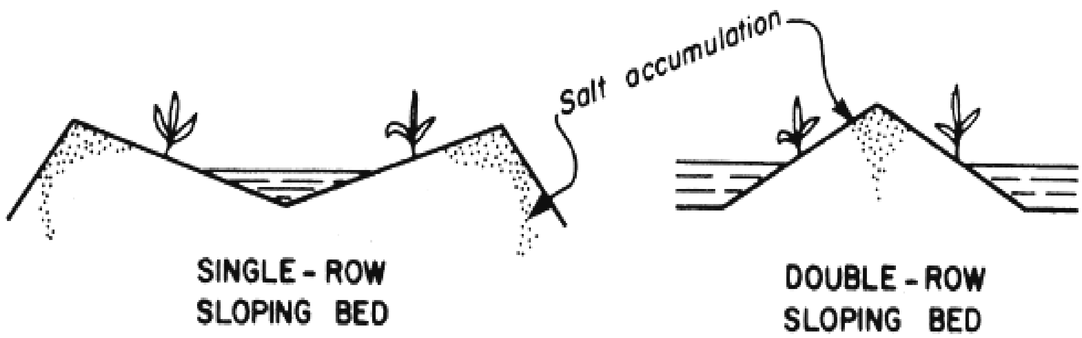


Fig. 26.2. Salinity control with sloping beds

g) Drainage: Provide adequate internal drainage. Meet the necessary leaching requirement depending on crop and EC of water. This is necessary to avoid build of salt in the soil solution to levels that will limit crop yields. Leaching requirement can be calculated from water test results and tolerance levels of specific crops.

h) Other management practices

- **Over aged seedlings in rice:** Transplanting of rice with over aged seedlings at a closer spacing results in better establishment in salt effected soils than normal aged seedlings. In case of other crops like finger millet, pearl millet etc., transplanting is better method than direct sowing of these crops for proper establishment.
- **Mulching:** Mulching with locally available plant material help in reducing salt problems by reducing evaporation and by increasing infiltration.
- **Soil management:** All soil management practices that improve infiltration rate and maintain favourable soil structure reduces salinity hazard.
- **Crop rotation:** Inclusion of crops such as rice in the rotation reduces salinity.

Lecture No. 27
Water Management Practices in Rice

27.1 Introduction

Rice culture at present dominates irrigated agriculture (Fig. 27.1). About 64% of the irrigation water resources in Andhra Pradesh are used for cultivation of rice. An adequate water supply is one of the most important factors in rice production. In many parts of India including Andhra Pradesh rice plants suffer from either too much or too little water because of irregular rainfall and land topography.

Fig. 27.1. Irrigated rice crop

27.1.1 Percolation losses in rice fields

Percolation losses are a function of the local soil and topographic conditions. Therefore, at any time the amount of rainfall or irrigation water entering the soil becomes greater than its water holding capacity, losses by downward movement of free water (vertical percolation) will occur. Percolation is often defined as the movement of water through saturated soils due to gravity, hydrostatic pressure or both.

Thus where the soil is heavy and the water table is close to the soil surface, percolation losses are low, about 1 – 2 mm/day. On the other hand, where the soil is light and the water table is deep, percolation losses may be high, about 8 – 15 mm/day, or more. About 50 to 60% of applied water to rice is lost by deep percolation. The percolation losses can be reduced by adopting following agronomic practices:

1. Growing rice on clayey soils
2. Scrupulous land levelling
3. Thorough puddling

4. Shallow depth of submergence
5. Sub-soil compaction
6. Application of clay, silt, bentonite etc

Research has shown that a percolation rate of 5mm/day was favourable for supply of dissolved oxygen, the removal of harmful substances and the maintenance of root activity.

27.1.2 Submergence versus saturation

In most areas rice fields are submerged continuously throughout the crop-growing period, though not always essential. Studies have indicated that soil saturation is sufficient for *kharif* rice, while submergence not exceeding 5 cm seems to be essential and adequate for *rabi* rice (Fig. 27.2).

Fig. 27.2. Submerged rice field

27.1.2.1 Advantages of continuous submergence

- Less weed problem
- Fixation of nitrogen by Blue green algae
- Increased availability of nutrients such as P, Fe, Mn, Zn and silicon
- Regulation of soil temperature
- Reduction in labour cost

27.1.2.2 Disadvantages of continuous submergence

- Deep percolation losses of irrigation water
- Surface runoff losses of irrigation water
- Leaching of nutrients particularly nitrogen

- Sulphide injury
- Iron toxicity

27.1.3 Optimum depth of submergence

Optimum depth of land submergence at different growth stages of rice crop for saving irrigation water without reduction in crop yield is given below in Fig. 27.3 and Table 27.1:

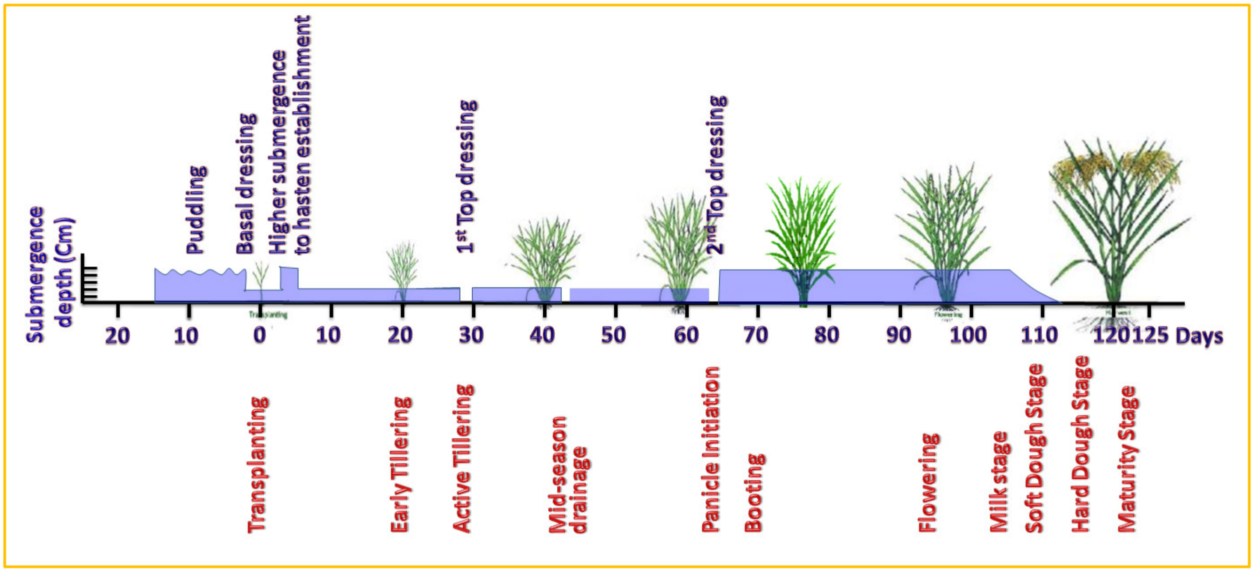


Fig. 27.3. Optimum depth of submergence in rice field

27.1. Optimum depth of submergence in rice field

Crop growth stage	Depth of submergence
At transplanting	2 cm
After transplanting for 3 days	5 cm
3 days after transplanting to maximum tillering	2cm
At maximum tillering (midseason drainage)	Drain water for 3 days
Maximum tillering to panicle initiation	2 cm
Panicle initiation to 21 days after flowering	5 cm
After 21 days after flowering	Drain out water gradually

a) Shallow depth (2 cm) of submergence at transplanting seedling facilitates planting at correct depth, since more depth of water will lead to deep transplanting resulting in reduction of tillering
b) After transplanting for 3 days adequate water is necessary to facilitate development of new roots and to hasten establishment of seedlings
c) After 3 days of transplanting to maximum tillering again shallow depth is favoured by the rice crop because more water depth reduces tillering

d) At maximum tillering in fertile soils i.e., 40 days after transplanting drain the field for three days till the soil shows fine cracks. This is known as mid-season drainage. This is essential because the respiratory function of the roots is highest during this stage and introduction of air into the soil by draining the field leads to vigorous growth of roots and checks the development of non-effective tillers thereby reducing the sterility percentage. It also helps in regulation of nitrogen supply thus controls the production of ineffective tillers.
e) Reproductive growth starts when maximum tiller production is completed and includes the panicle primordia development, booting, heading and flowering stages. A large amount of water is consumed in the major part of the reproductive growth period. Drought at this stage causes severe damage leading to increased panicle sterility, caused by impeded panicle formation, heading, flowering or fertilization. Excessive water at booting stage causes decrease in culm strength and increases lodging.

27.1.4 Average water requirements

Total water requirement includes water needed to raise seedlings, preparation of land and to grow rice crop from transplanting to harvest, the amount is determined by many factors including soil type, topography, proximity to drains, depth of water table, area of contiguous rice fields, maintenance of bunds, fertility of both top and sub soil, field duration of the crop, land preparation method, and most of all the evaporative demand of the atmosphere during growing season. The daily evapotranspiration of rice varies from 4 – 5 mm /day during wet season and 7 – 8 mm/day during the dry season. The total water requirement was estimated to be 1240 mm under Andhra Pradesh agro-climatic conditions (Table 27.2).

Table 27.2. Water requirements of rice under Andhra Pradesh conditions

Crop growth stage	Water Requirement (mm)	Per cent of water requirement
Nursery	40	3.22
Main field preparation	200	16.12
Transplanting to panicle initiation	460	37.00
Panicle initiation to flowering	417	33.66
Flowering to maturity	123	10.00
Total	1240	100.00

Lecture No. 28
Water Management Practices in Wheat and Maize

28.1 Wheat

The dwarf wheat varieties were first introduced into India during 1963. In the very first year of their cultivation, it was realized that the irrigation practices developed for the tall wheat varieties did not suit the dwarf wheat varieties. Consequently studies to determine the optimum irrigation & water requirements of dwarf wheat were taken up at the Indian Agricultural Research Institute and other centers and the following recommendations were given by the ICAR for efficient use of irrigation water in cultivation of dwarf wheat.

28.1.1 Optimum time of first irrigation

The crown root initiation (CRI) stage is the optimum time for first irrigation in dwarf wheat – about 3 weeks after sowing. A delay of 2 – 3 weeks in this irrigation reduces the yield by 500 – 1000kg/ha. Crown roots of wheat generally develop within 2cm below the soil surface. If there is sufficient moisture at this depth, crown roots will develop normally and irrigation would not be necessary at this stage. But generally the top 5 – 6 cm of soil layer gets completely dry by the time the crown roots start developing. The water and nutrient supplies have then to be met only by the seminal roots, which are less vigorous and less efficient. Consequently, the growth of the plant, especially tillering, is much restricted, reducing the grain yield.

Table 28.1 Irrigation scheduling under limited water supply situations

Water available for	Irrigation to be given at
I. Adequate water supply	
Four irrigations	Crown root initiation, Late tillering (tiller completion), Flowering and Milk stages
Five irrigations	Crown root initiation, Late tillering (tiller completion), Late jointing, Flowering and Milk stages
Six irrigations	Crown root initiation, Late tillering (tiller completion), Flowering, Milk and Dough stages
II. Restricted water supply	
One irrigation	Crown root initiation
Two irrigations	Crown root initiation and Boot (Late jointing)
Three irrigations	Crown root initiation, Boot and Milk

28.1.2 Optimum number of irrigations under adequate water supply

If the underground water table is well below the root zone and there is no rainfall during the growing season, 4 – 6 irrigations depending on the climatic conditions, soil type and the variety may be needed for getting the highest yield from the dwarf wheat's. Irrigation at a soil moisture tension of 0.5 bars at a depth of 22.5 cm amounted to the same number of irrigations and resulted in similar grain yields. The schedule for adequate and restricted water supply is given in Table 28.1.

Based on soil water regime approach under south Indian condition irrigations at 25% DASM and 40 – 50% DASM under north Indian conditions were found to be optimum. Likewise irrigations at 0.75 to 1.0 IW/CPE ratio based on climatological approach were found to be optimum for many locations. An IW/CPE ratio of 1.0 was optimum at CRI stage. The critical growth stages for irrigation are crown root initiation, tillering, heading & grain formation. The seasonal crop water requirement varies between 350 to 500mm depending upon the agro-climatic zone. The recommended method of irrigation is check basin and border strip method of irrigation (Fig. 28.1).

Fig. 28.1. Surface basin irrigated wheat crop

28.2 Maize

The maize is one of nature's most amazing energy-storing plants. From a seed, which weighs little more than one-hundredth of an ounce, a plant of 7 – 10 feet tall develops in about nine weeks. Thus corn has a high water requirement but is one of the most efficient field crops in producing higher dry matter per unit amount of water used (Fig. 28.2).

The effective root zone depth of the maize crop varies from 0.9 to 1.5 m. For maximum production a medium duration grain crop of maize requires between 400 to 600 mm of water depending upon the soil-plant and climatic factors. The furrow method of irrigation is commonly practiced in India. For estimating crop evapotranspiration begin with 0.3 Kc of daily ETo in the initial period, raise it to 0.8 to 0.9 at vegetative stage, 1.2 at tasseling, silking & pollination stages, and decrease it to 0.5 at maturity of corn.

Frequency and depth of irrigation has a pronounced effect on grain yield. Maize appears relatively tolerant to water deficits during the vegetative and ripening periods. Greatest decrease in grain yield is caused by water deficits during the flowering period including tasseling-silking and pollination, mainly due to a reduction in grain number per cob. Water deficits particularly at the time of silking & pollination may result in little or no grain yield due to silk drying. Water deficits during the ripening period have marginal effect on grain yield.

Fig. 28.2. Irrigated corn field

To obtain good stand and rapid root development, the root zone should be wetted at or soon after sowing. Taking into account the level of evaporative demand to meet full water requirement irrigations have to be scheduled at 40% DASM in the germination and seedling & establishment stages. Whereas during vegetative, tasseling, silking, pollen shed and kernel development stages irrigations have to be scheduled at 55 to 65% DASM and up to 80% DASM during ripening or maturation period. Likewise irrigation at an IW/CPE ratio of 1.0 at critical growth stages and 0.75 – 0.5 at other stages was found to be optimum. The threshold soil moisture tension levels for scheduling irrigations based on tensiometer readings vary between 30 to 60 centibars at different growth stages. Higher grain yields of maize were recorded when irrigations were scheduled between −14 to −20 bars leaf water potential depending on the crop growth stage using pressure bomb or pressure chamber apparatus. Water quality threshold electrical conductivity values 3.2 dS/m in sandy soil, 1.8 dS/m in loamy soil and 1.1 dS/m in clay soil, above which yield decreases.

Under conditions of marginal rainfall and limited irrigation water supply, the number of possible irrigation applications may vary between 2–5. A suggested schedule of these irrigation applications is given in Table 28.2. The recommended method of irrigation is furrow method of irrigation.

Table 28.2. Irrigation scheduling under limited water supply situations

Water available for	Irrigation to be given at
Two irrigations	Establishment and Flowering
Three irrigations	Establishment, Vegetative and Kernel development
Four irrigations	Establishment, Vegetative, Flowering and Kernel development
Five irrigations	Establishment, Vegetative, Flowering, Kernel development & Ripening

Lecture No. 29
Water Management Practices in Sugarcane and Groundnut

29.1 Sugarcane

Sugarcane being a long duration crop producing huge amounts of biomass is classed among those plants having a high water requirement and yet it is drought tolerant. Out of the total cropped area (0.4 million ha) of sugarcane in Andhra Pradesh nearly 97% is irrigated. The crop duration varies from 12 months in seasonal crop, 13 – 14 months in pre-seasonal and 16 – 18 months in adsali crop.

29.1.1 Physiological factors to be considered for efficient water management

- **a)** A liberal water supply reduces the cane yield and/or sugar yield, while mild water stress enhances the yield
- **b)** Excessive watering at tillering should be avoided since it coincides with active root development and hinders nutrient uptake due to poor o_2 diffusion
- **c)** Since there is no secondary thickening of the stem in sugarcane the length of the cane determines the sink available for sugar storage
- **d)** A 'drying off' or 'cut out' period of 4 – 6 weeks prior to harvest ensures an optimum sugar yield
- **e)** Restricted water application during the 'ripeness to flower' stage helps to control tassels or arrows
- **f)** Sugarcane has an intrinsic ability to circumvent water shortages and can more than make up for the potential yield loss.

29.1.2 Water requirements & Irrigation scheduling

During the initial germination, field emergence and establishment of young seedlings the crop requires less water, hence light and frequent irrigation water applications are preferred. Water deficits at this stage desiccate germinating buds leading to a lower and delayed germination. On the other hand over irrigation leads to bud rotting due to lack of aeration, fungal attack and low soil temperature. Thus both under and over irrigation is detrimental for germination, resulting in low stalk population per unit area.

During the early vegetative period (formative) the tillering is in direct proportion to the water application. An early flush of tillers is ideal because this furnishes shoots of approximately same age. Any water shortage during tillering phase would reduce tiller production, increase tiller mortality and ultimately the stalk population-an important yield component. However, excess irrigation during tillering phase is harmful particularly in heavy soils, since it coincides with active root development, which may be hampered by anaerobic condition. Scheduling of irrigations at 25% DASM or 0.75 to 1.0 IW/CPE ratio equivalent to an irrigation interval of 6 days was found to be optimum during formative stage.

The yield formation or grand growth period is the most critical period for moisture supply in sugarcane. This is because the actual cane yield build-up or stalk growth takes place in this period. The production and elongation of inter-nodes, leaf production on the stalk and its expansion, girth improvement, ultimately the stalk weight takes place in this period. It is also the period for production of sugar storage tissues. Therefore, crop reaches its peak water requirement in this stage. With adequate water supply to maintain a sheath moisture content of 84 – 85% in the leaf sheaths of 3,4,5 and 6^{th} leaf from the top during this period of active growth produces longest inter-nodes with more girth (thick cane) and the total cane weight is greater. On the other hand water deficits in grand growth period reduce stalk elongation rate due to shortening of inter-nodes resulting in less cane weight and the effect is well marked on yield at harvest. Severe water deficits during the later part of the grand growth period forces the crop to ripen. However in the absence of sufficient rains during this period, scheduling of irrigations at 50% DASM or 0.75 IW/CPE ratio was found to be optimum.

In ripening period, a restricted water supply or mild water deficit (sheath moisture content of 74 – 76%) is necessary to bring the crop to maturity by reducing the rate of vegetative growth, dehydrating the cane and forcing the conversion of total sugars to recoverable sucrose. This can be achieved by scheduling irrigations at 75% DASM or 0.5 IW/CPE ratio equivalent to 21 days irrigation interval. With the check of vegetative growth, the ratio between dry matter stored as sucrose and that used for new growth increases. On the other hand, plentiful supply of water leads to continued vegetative growth thus affecting sugar accumulation process. An important consideration is that soil should not be allowed to crack, as it would cause root pruning and damage the root system.

Thus the critical stages for irrigation are formative (or tillering) stage and stem elongation (or grand growth period) stage. The effective root zone of the crop varies between 0.9 to 1.2 m. The recommended method of irrigation is either drip or furrow method of irrigation (Fig. 29.1). For predicting crop evapotranspiration begin with 0.4 Kc of daily ETo in the initial period , raise it to 0.7 to 1.05 at tillering & canopy establishment phase, 1.2 at grand growth period and decrease it to 1.15 to 0.95 to 0.7 at ripening & maturity period of sugarcane. Irrigate using tensiometer installed at 20 cm soil depth to maintain 15 – 40 centibars at different crop growth stages to maximize cane yields. Water salinity (ECw) threshold levels are 4.3 dS/m in sandy soil, 2.5 dS/m in loamy soil and 1.4 dS/m in clay soil, above which yield decreases.

Adequate soil moisture throughout the crop growing season is important for obtaining maximum yields because vegetative growth including cane growth is directly proportional to the water transpired. Depending on the agro-ecological conditions, cultivation practices adopted and crop cycle, seasonal water and irrigation requirements of sugarcane in different regions of Andhra Pradesh are given in Table 29.1.

Fig. 29.1. Furrow and surface drip irrigated sugarcane

Table 29.1. Water requirement of sugarcane in different regions of Andhra Pradesh

Crop growth phase	Period	Water requirement (mm)	Irrigation requirement (mm)
I. COASTAL ANDHRA			
Formative phase	February/March to June (120days)	**73.66**	**50.80**
Grand growth period	June/July to end of October / November (150 days)	**69.85**	**6.35**
Maturity phase	November/December to January / February / March (90 days)	**26.67**	**17.78**
Season Total		**170.18**	**74.93**
II. TELANGANA			
Formative phase	January to April (120days)	**91.25**	**87.50**
Grand growth period	May to September (150 days)	**135.00**	**50.00**
Maturity phase	October to December (90 days)	**45.00**	**37.50**
Season Total		**271.25**	**175.00**
III. RAYALASEEMA			
Formative phase	February to June (150days)	**91.44**	**83.82**
Grand growth period	July to end of October (120 days)	**83.82**	**22.86**
Maturity phase	November to January (90 days)	**49.53**	**26.67**
Season Total		**224.79**	**133.35**

29.2 Groundnut

Groundnut is an important oilseed crop of Andhra Pradesh and is cultivated in all the three agricultural seasons *viz., Kharif* (June to September), *rabi* (October to January) and summer (January to May) seasons. Generally the rabi/summer groundnut is raised under irrigated conditions. However supplemental or protective irrigations during rainy season in the event of drought significantly improve the pod yield.

The effective root zone depth of the crops varies between 0.5 to 0.9 m. Depending upon the range of environment, variety and crop duration the seasonal water requirements vary from 400 to 650 mm. The irrigation schedule recommended for efficient use of irrigation water for Spanish bunch variety on a sandy loam soil in Andhra Pradesh is given in Table 29.2. The recommended methods of irrigation are check basin, border strip and sprinkler irrigation (Fig. 29.2).

Table 29.2. Irrigation schedule for rabi & summer groundnut

Crop growth stage	Duration (days)	Irrigation frequency	Crop ET (mm)	ET (mm/day)
RABI SEASON				
Sowing to pegging	**0 – 30**	**2**	**125**	**4.16**
Pegging to pod formation	**30 – 55**	**3**	**150**	**6.00**
Pod formation to maturity	**55 - 90**	**2**	**100**	**2.85**
Total season	**90**	**7**	**375**	**---**
SUMMER SEASON				
Sowing to pegging	**0 – 35**	**3**	**135**	**4.00**
Pegging to pod formation	**35 – 65**	**6**	**270**	**9.00**
Pod formation to maturity	**65 - 100**	**4**	**135**	**4.00**
Total season	**100**	**13**	**540**	**---**


Fig. 29.2. Surface basin and sprinkler irrigated groundnut

For estimating crop evapotranspiration begin with 0.4 Kc of daily ETo in the initial germination & establishment period, raise it to 0.7 to 0.8 at vegetative & flowering stage, 0.95 – 1.1 at pegging, pod initiation & pod addition stages, and decrease it to 0.7 – 0.8 at pod filling & maturity stages of groundnut.

Withholding of first irrigation (after germination) up to 25 – 30 days after sowing induces profuse flowering and fruiting. The critical growth stages for irrigation are Flowering, Peg penetration and early Pod development. In the case of limited water supply, water savings should be made during the periods other than flowering, pegging, pod initiation, pod setting and pod filling periods. Insufficient water in the pod zone can also depress calcium uptake of developing pods and cause more pops, fewer double loculed pods. Excessive soil water in heavy soils at harvest can cause the pods to be torn easily from the pegs with the pods remaining in the soil.

Scheduling of irrigations between 25% to 50% DASM or 0.75 to 1.0 IW/CPE ratio at different growth stages was found to be optimum for producing higher pod yields. Irrigate using tensiometers installed at 30 – 60 cm soil depth to maintain 40 centibars at germination, 60 centibars at early vegetative growth, 40 centibars at pod development and 60 centibars at maturity to maximize pod yields. Threshold water quality (ECw) was found to vary between 1.5 to 4.4 dS/m depending on the soil texture, above which pod yield decreases. Further water containing SAR >5 to 7, boron >0.75 ppm, chloride >400 ppm and sodium >400 ppm is not suitable for irrigating peanuts.

Lecture No. 30

Water Management Practices in Mango, Banana and Tomato

30.1 Mango

Most of the areas cultivated with mango are located in regions of short periods of rain, where water deficit takes place most of the year in the soil water balance. Irrigation scheduling from flowering to fruit ripening stage considering the following factors contributes to higher yield and improved fruit quality.

a) Climatic conditions
b) Crop age – Young and non-bearing orchards differ from the bearing orchards
c) Root penetration and proliferation
d) Fruit-bud differentiation takes place in terminal mature (8 to 10 months) shoots
e) During fruit-bud differentiation and vegetative phase, requirements are antagonistic.
f) Fruit quality depends upon moisture content in soil during fruit development and maturity.

Most of the feeding roots are found at distances from the plant of 0.9 m to 2.6 m and at depths from soil surface to 0.90 m though root penetration was noticed up to 2 m soil depth. The basin and drip method of irrigation are commonly practiced in India (Fig. 30.1). Critical stages for water supply are flowering, pollination and fruit development. Greatest decrease in fruit yield is caused by water deficits during the flowering and fruit development period, due mainly to a reduction in number of flowers, fruit number and fruit size. For estimating crop ET begin with a crop coefficient value of 0.4 during flowering, increase it up to 0.85 in the middle of fruit growth period and decrease it to 0.60 during fruit ripening stage.

Fig. 30.1. Irrigation scheduling in mango using tensiometer readings

Daily water use rates of mango planted at 8 m x 8 m distance were estimated to be 10 – 12 L/tree in the 1st year, 18 – 20 L/tree in the 2nd year, 45 – 50 L/tree in the 3rd year, 60 – 65 L/tree in the 4th year, 75 – 80 L/tree in the 5th year, 90 – 95 L/tree in the 6th year and 100 – 120 L/tree from 7th year on wards. The annual water requirement for a mature orchard of 8 – 10 years old was found to be 1100 – 1300 mm/year.

Taking into account the level of evaporative demand to meet full crop water requirements management allowable depletion level (DASM) during the reproductive phase of mango trees should be 0.35 and in other phases 0.65. Likewise irrigation at an IW/CPE ratio of 0.75 at critical growth stages and 0.5 at other stages was found to be optimum. The threshold soil water potentials for scheduling irrigations based on tensiometer readings for mango should be in the range of -15 centibars to -25 centibars for coarse textured soils and in the range of -30 centibars to –60 centibars for fine textured soils.

30.2 Banana

Banana (*Musa* *spp.*) is one of the most important tropical fruit of India including Andhra Pradesh. Banana is a tropical herbaceous evergreen plant which has no natural dormant phase and hence has a high water demand throughout the year, especially during high temperatures. With respect to water management the important characteristics of the banana plant are:

a) A high transpiration potential due to the large broad leaves and high LAI
b) A shallow root system compared with most tree fruit crops
c) A poor quality to withdraw water from soil beneath field capacity
d) A rapid physiological response to soil water deficit

These factors make banana plants extremely sensitive to even slight variations in soil water content, emphasizing the importance of correct irrigation scheduling. Banana requires an ample and frequent supply of water; water deficits adversely affect crop growth and yields. The establishment period and the early phase of the vegetative period determine the potential for growth and fruiting and adequate water and sufficient nutrient supply is essential during this period. Water deficits in the vegetative period affect the rate of leaf development, which in turn can influence the number of flowers in addition to the number of hands and bunch production. The flowering period starts at flower differentiation, although vegetative development can still continue. Water deficits in this period limit leaf growth and number of fruits. Water deficits in the yield formation period affect both the fruit size and quality (poorly filled fingers). A reduced leaf area will reduce the rate of fruit filling; this leads, at harvest time, to bunch being older than they appear to be and consequently the fruits are liable to premature ripening during storage. Thus the critical growth stages for irrigation in banana are vegetative growth, flowering and fruit development.

The banana plant has a sparse, shallow root system. Most feeding roots are spread laterally near the surface. Rooting depth will generally not exceed 0.9 m. For estimating crop evapotranspiration begin with 0.5 Kc of daily ETo in the initial period , raise it to 0.7 to 0.85 at vegetative development, 1.1 at grand growth period (bunch emergence, flowering & fruit filling period) and decrease it 0.9 to 0.80 at ripening & maturity stages of banana Daily water requirements vary in the range of 3 – 7 mm/day depending on the combination of LAI, temperature, humidity, radiation & wind. The annual water requirements vary between 1200 to 1500 mm depending on climatic conditions and crop duration.

Basin and furrow method of irrigation are commonly used in commercial plantations (Fig. 30.2). However, due to water scarcity conditions and higher yield realization farmers are also using drip irrigation in banana.

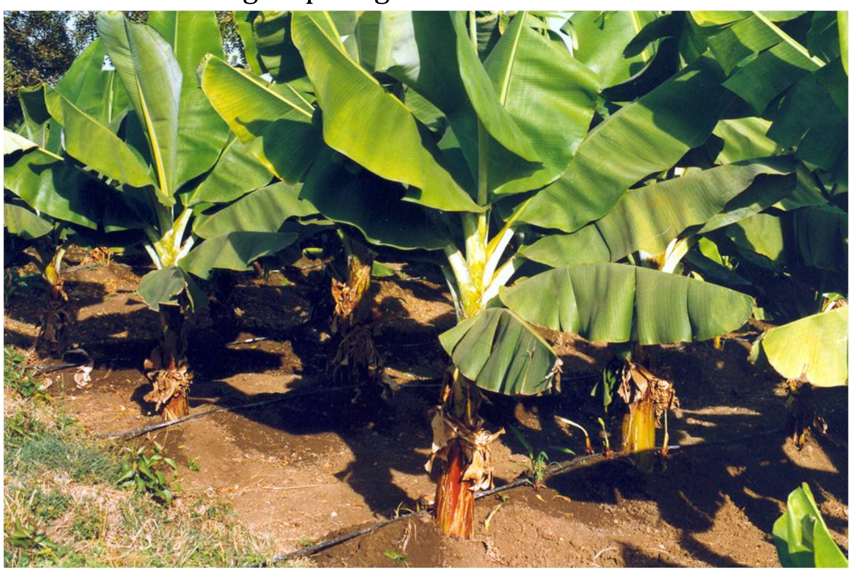


Fig. 30.2. Drip irrigated banana

Irrigation scheduling for bananas involves accurate calculations of the amount of water to be applied at each irrigation, and the interval between irrigations, for each soil-plant-climate combination. Scheduling of irrigations between 25% to 50% DASM or 0.75 to 1.0 IW/CPE ratio at different growth stages was found to be optimum for producing higher fruit yields. Irrigate using tensiometers installed at 30 cm soil depth to maintain 30 – 40 centibars at different growth stages to maximize fruit yields.

30.3 Tomato

Tomato is the second most important vegetable crop next to potato in India. It is rapidly growing crop with a growing period of 120 – 150 days.

The crop has a fairly deep root system and in uniform deep soils roots penetrate up to 1.2m. Over 80% of the total water uptake occurs in the first 50 cm. The crop is most sensitive to water deficit during and immediately after transplanting and during, flowering and fruit development stages. Water deficit during the flowering period causes flower drop. Moderate water deficit during the vegetative period enhances root growth. Excessive watering during the flowering period has been shown to increase flower drop and reduce fruit set. Also this may cause excessive vegetative growth and a delay in ripening. Water supply during and after fruit set must be limited to a rate which will prevent stimulation of new growth at the expense of fruit development. Frequent light irrigations improve size, shape, juiciness and colour of the fruit, but total solids (dry matter content) and acid content will be reduced.

Surface irrigation by furrow is commonly practiced. Under sprinkler irrigation the occurrence of fungal diseases and possibly bacterial canker may become a major problem. Further, under sprinkler, fruit set may be reduced with an increase in fruit rotting. Due to the crops specific demands for a high soil water content achieved without leaf wetting, trickle or drip irrigation has been successfully applied (Fig. 30.3).

Fig. 30.3. A good crop of tomato

Crop coefficients related to reference evapotranspiration (ETo) at different crop development stages are - during the establishment stage 0.4 – 0.5, the vegetative stage 0.7 – 0.8, the flowering & fruit development stage 1.05 – 1.25, the fruit ripening stage 0.6 – 0.65. Seasonal water requirements after transplanting, of a tomato crop grown in an open field for a 150 day crop are 400 – 600mm depending on the climate.

Scheduling of irrigations between 25% to 50% DASM or 0.75 to 1.0 IW/CPE ratio at different growth stages was found to be optimum for producing higher fruit yields. Irrigate using tensiometers' installed at 30cm soil depth to maintain 20 – 30 centibars at establishment phase, 60 centibars at early vegetative growth, 30 – 40 centibars at flowering & fruit development periods to maximize fruit yields.

Lecture No. 31
Agricultural Drainage

31.1 Drainage - Definition

Agricultural drainage is the artificial removal and safe disposal of excess water either from the land surface or soil profile, more specifically, the removal and safe disposal of excess gravitational water from the crop root zone to create favourable conditions for crop growth to enhance agricultural production.

31.2 Benefits of drainage

a) It provides better soil environment for plant growth by creating favourable soil aeration conditions
b) It improves the soil structure and in turn increases the soil infiltration
c) High infiltration capacity reduces soil erosion.
d) It hastens the warming of the soils and maintains desirable soil temperature, which accelerates plant growth and bacterial activity
e) It promotes increased leaching of salts and prevents accumulation of salts in the crop root zone
f) In well drained soils, less time and less labour are required for tillage operations

31.3 Problems or effects of ill-drainage

a) Limitation of aeration.
b) Accumulation of CO_2 and toxic substances like H_2S, ferrous sulfide etc in the crop root zones
c) Reduced water uptake due to reduced activity of roots as a result of oxygen stress
d) Reduced nutrient uptake
e) Development of soil salinity and alkalinity
f) Anaerobic condition and prevalence of plant diseases
g) Stunted plant growth and development which results in reduced yield

31.4 Types of drainage

Broadly drainage systems are of two types- Surface and Sub-surface.

31.4.1 Surface drainage systems

Safe removal and disposal of excess water primarily from land surface or cropped area by a net work of surface drains or constructed channels and through proper land shaping is known as surface drainage. There are four general types of surface drainage systems used in flat areas having a slope of $<2\%$ *viz.,* (a) Random drain system (b) Parallel field drain system (c) Parallel open ditch system and (d) Bedding system

a) Random drain system: This system is usually adopted in areas where the ground surface is characterized by a series and depression (undulating land surface) and where small depressions are to be drained off (Fig. 31.1). Depending upon the possibility the field drains are designed in such a way to connect one depression to another and water is safely conveyed to lateral drains. These lateral drains ultimately guide the water to main outlet drain. The field drains besides occupying the land area are likely to interfere with farm operations.

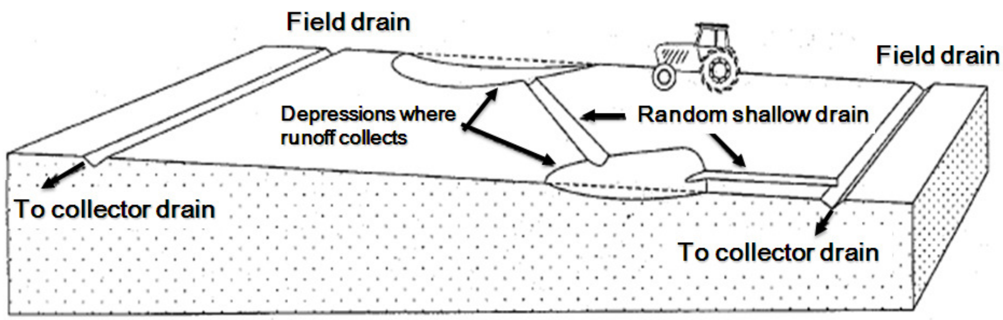


Fig.31.1. Random field drain system

b) **Parallel field drain system:** The parallel field ditch system is used in places where the surface is uniform and has few noticeable ridges or depressions (Fig. 31.2). In this system the surface of individual fields is graded in such a way so that the runoff water drains into field drains, which in turn discharge water into field laterals bordering the field and finally the laterals in turn lead water into the main outlet ditch through protected over falls. Laterals and mains should be deeper than field drains to provide free out-fall. Maximum spacing of parallel field drains is about 200 m for sandy soils and about 100 m for clay soils. It is the most desirable surface drainage method and is well suited both for irrigated and rainfed areas.

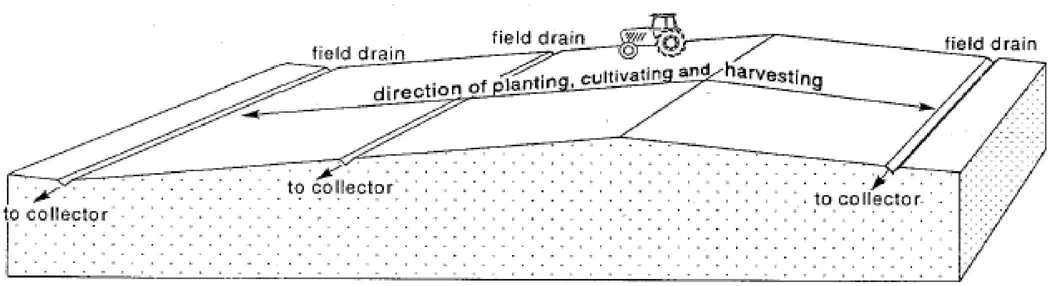


Fig. 31.2. Parallel field drain system

c) **Parallel open ditch system:** The parallel open ditch system is similar to parallel field drain system in all respects except that the drains are replaced by open ditches which are comparatively deeper and have steeper side slopes than the field drains (Fig. 31.3). Maximum length of grade draining to ditch should not be > 180 m. The spacing of the ditches depends upon the soil and water table conditions and may vary from 60 – 200m. This system is applicable in soils, which require both surface and sub-surface drainage.

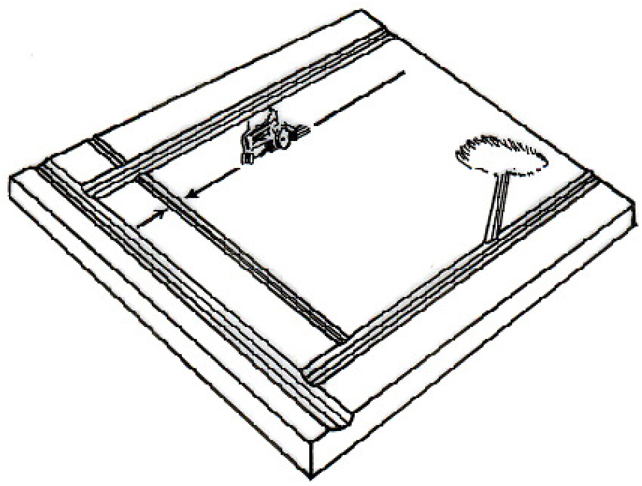


Fig. 31.3. Parallel open ditch system

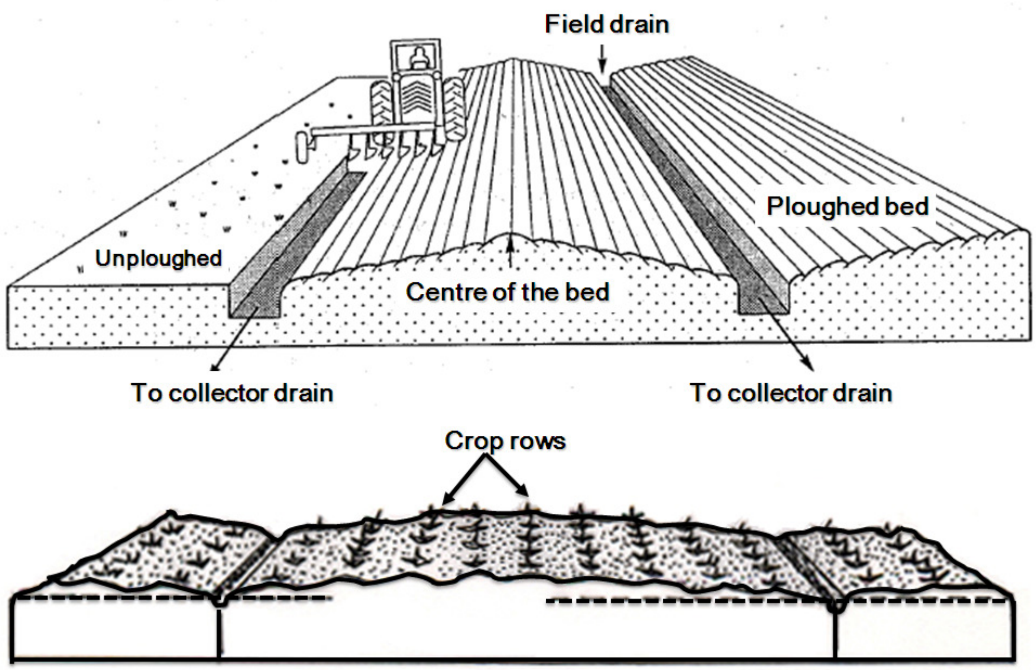


Fig. 31.4. Bedding system

d) **Bedding system:** This system is usually adopted in fields with very little slope, usually 0.5% or less and slowly permeable soils. It is essentially a tillage operation wherein the land is ploughed into a series of parallel beds separated by dead furrows, which run in the direction of greatest slope lateral drains are located perpendicular to slope (Fig. 31.4). The ploughing operations are to be carried out parallel to the furrows. The bed width and length varies between 8 to 30 m and 10 to 300m respectively depending upon field conditions i.e., land use, slope, soil permeability and farming operations. While bed height should not exceed 40 cm.

31.4.2 Sub-surface drainage systems

The removal and safe disposal of excess water that has already entered the soil profile is considered sub-surface drainage. Though several sub-surface systems are available, the most commonly used and effective ones are Tile drainage and Mole drainage systems.

31.4.2.1 Tile drainage systems

Tile drains removes excess water from the soil through a continuous line of tiles (pipes) laid at specified depth and grade. The pipes are made of either concrete or burnt clay. Free water enters through the tile joints and flows out by gravity, so that the water table is lowered below the root zone of the plants. The common tile drainage system layout followed is: Random or natural system, Parallel lines system and Cut off or intercepting system.

a) **Random system:** The random system is used in areas that have scattered wet areas somewhat isolated from each other (Fig. 31.5). Tile lines are laid more or less at random to drain the wet patches.

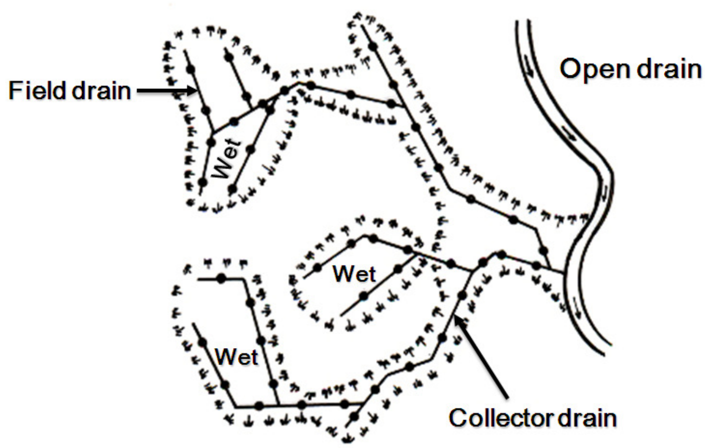


Fig. 31.5. Random tile drain system

b) **Herringbone system:** The system is applicable in places where the main or sub-main is located in a narrow depression i.e., in areas that have a concave surface or a narrow depression with the land sloping to it from both directions (Fig. 31.6). The parallel laterals enter the sub-main from both sides. It is less economical, because considerable double drainage occurs where the laterals and mains join.

c) **Gridiron and parallel systems:** The gridiron and parallel systems are similar to that of herringbone system except that the laterals enter the main or sub-main from only one side (Fig. 31.6). It is the most economical arrangement than herringbone system because one main or sub-main serves as many laterals as possible.

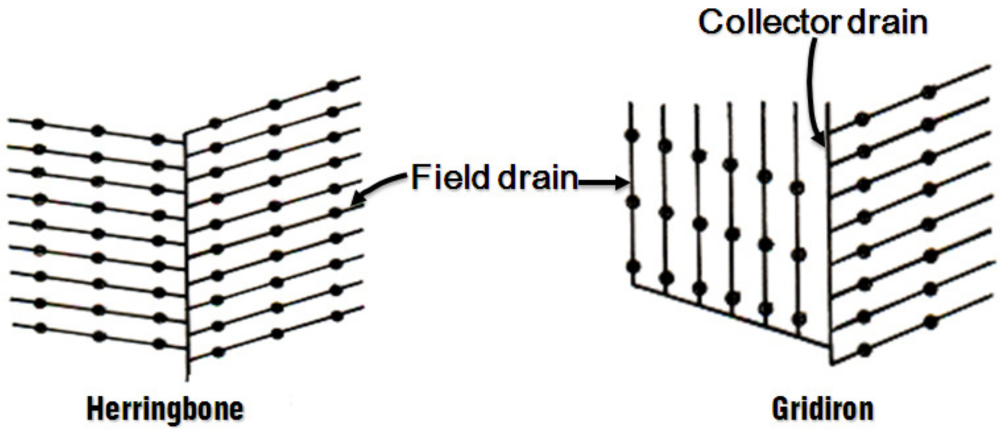


Fig. 31.6. Herringbone and Gridiron tile drain systems

d) **Double main system:** The double main system is a modification of the gridiron system. It may be used where the sub-main is in a broad, flat depression, which frequently is a natural watercourse and sometimes may be wet because of small amounts of seepage water from nearby slopes.

e) **Intercepting system:** This system involves the interception of seepage water that flows over the surface of an impervious sub-soil. The tile line is placed approximately at the impervious layer along which the seepage water travels, so that water will be intercepted and wet condition is relieved. The tile line should be located in such a way that there is at least 60 cm of soil cover over the top of the tile.

31.4.2.2 Mole drainage system

Mole drainage is a semi-permanent method of sub-surface drainage, similar to tile drain in layout and operation (Fig. 31.7). Instead of permanent tiles a continuous circular mole drain (channel) is prepared below the ground surface in the soil profile at desired depth and spacing using a special implement known as mole plough. The depth of the mole drain varies from 4.5 cm to 120 cm depending on the moling equipment and water table. Diameter of the mole varies from 7.5 to 15 cm. The life the mole drain is 10-15 years. It is adapted to a particular type of soil because the soil stability is more important in this type of sub-surface drainage.

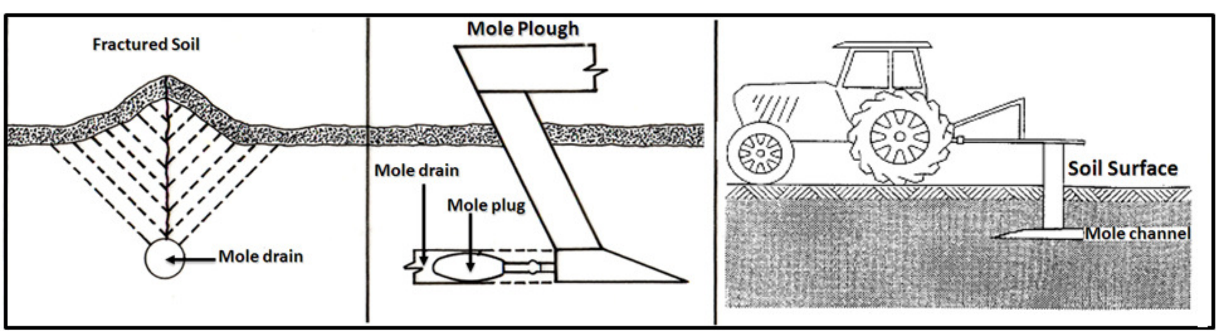


Fig. 31.7. Mole plough

31.5 Drainage coefficient

It is defined as the depth of water (cm) to be removed in 24 hours period from the entire drainage area. It ranges from 0.6 to 2.5 cm/day and in extreme cases 10 cm/day.

Lecture No. 32
Cropping Systems in Irrigated Agriculture

Assured irrigation water facilities provide opportunities for multiple cropping (intercropping, sequential cropping, relay cropping etc). Major sources of irrigation include canal irrigation, tank-fed and well irrigation. Depending on the water availability period, 1, 2 seasons or all the year round the number of crops raised per year on a given piece of land is determined. Thus, the cropping intensity in irrigated agriculture ranges from 200 to 400%. Major crops in different agro-climatic zones vary greatly, depending on their adaptability and irrigation water availability. Crops that follow the main crops in sequence also differ from region to region. Major rice, sugarcane and groundnut based cropping systems in Andhra Pradesh are as follows:

32.1 Rice based cropping systems

The profitable rice based cropping systems followed in different agro-climatic zones of Andhra Pradesh are as follows:

a) **North Coastal zone**

Rice – Greengram/Blackgram in irrigated wet lands
Rice – Maize in irrigated uplands
Rice – Rice
Green manure – Rice
Rice – Rice – Sesame
Rice – Horse gram in upland areas of East Godavari
Rice – Fodder Jowar in upland areas of East Godavari

b) **Krishna Godavari zone**

Rice – Rice
Rice – Maize
Green manure – Rice
Green manure – Rice – Rice
Rice – Castor
Rice – Sunflower
Rice – Groundnut
Rice – Greengram/Blackgram

c) **Southern zone**

Rice – Rice
Rice – Sunflower
Rice – Groundnut
Green manure - Rice
Rice – Vegetables
Rice – Groundnut – Fingermillet

Rice – Finger millet – Groundnut

d) Northern Telangana zone

Rice – Rice
Rice – Groundnut
Rice – Maize
Rice – Sunflower
Rice – Sesame
Rice – Castor
Rice – Jowar
Rice – Chick pea / Pulses
Rice – Mustard
Rice – Vegatables
Rice - Horsegram

e) High Altitude Tribal zone

Rice – Vegetables
Rice – Horsegram

32.2 Sugarcane based cropping systems

The profitable sugarcane based cropping systems followed in different agro-climatic zones of Andhra Pradesh are as follows:

32.2.1 Profitable cropping systems

a) North coastal districts

Sugarcane – Sugarcane – Sesame – Paddy
Sugarcane – Sugarcane – Maize – paddy
Sugarcane – Sugarcane – Sunflower – Paddy

b) Southern zone

Sugarcane – Sugarcane – Groundnut

c) All zones

Sugarcane – Sugarcane – Paddy

d) Godavari zone

Sugarcane – Sugarcane – Greengram/Blackgram

e) Krishna zone

Sugarcane – Sugarcane – Turmeric

f) Nizamabad zone

Sugarcane – Sugarcane – Sunflower
Soyabean – Sugarcane – Sugarcane

32.2.2 Profitable intercropping systems

a) **Western part of Chittoor**

Sugarcane + Rajmash
sugarcane + Tomato
sugarcane + Bhendi

b) **Nellore**
Sugarcane + Watermelon

c) **Medak**
Sugarcane + Potato
Sugarcane + Bengalgram

d) **North-coastal districts**
Sugarcane + Blackgram
Sugarcane + Blackgram

32.2 Groundnut based cropping systems

The profitable groundnut based cropping systems followed in different agro-climatic zones of Andhra Pradesh are as follows:

a) North coastal districts
Groundnut + Redgram
Groundnut – Jowar
Groundnut – Vegatables
Groundnut – Rice
Groundnut – Horsegram

b) Krishna Godavari Zone
Groundnut – Bhendi
Groundnut – Chillies
Groundnut – Redgram
Groundnut – Groundnut
Groundnut – Pulses
Groundnut – Sunflower

c) Southern zone
Sugarcane – Sugarcane – Groundnut
Groundnut – Groundnut
Groundnut – Sunflower / Jowar / Redgram
Groundnut – Castor
Groundnut – Soybean / Sunflower / Vegetables
Groundnut / Horsegram

d) Scarce Rainfall zone
Groundnut – Fodder Jowar
Groundnut – Vegetables / Watermelon

e) North Telangana zone
Rice – Groundnut

Cotton – Groundnut
Groundnut – Horsegram
Groundnut + Redgram
Groundnut + Jowar
Maize – Groundnut
Groundnut – Jowar / Safflower

f) High Altitude Tribal zone

Groundnut – Minor millets
Groundnut – Niger

ABBREVATIONS

ICID	International Commission on Irrigation and Drainage
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
WUA	Water Users Association
WALAMTARI	Water And Land Management Training & Research Institute
CWC	Central Water Commission
CADWM	Command Area Development And Water Management
CCA	Cultural Command Area
WTC	Water Technology Centre
CGWB	Central Ground Water Board
TMC	Thousand Million Cubic Feet
SAR	Sodium Adsorption Ratio
ESP	Exchangeable Sodium Percentage
LR	Leaching Requirement
ρb	Bulk density of soil
ρp	Particle density of soil
Cu	Consumptive Use
ET_c	Crop Evapotranspiration
ET_o	Reference Crop Evapotranspiration
Kc	Crop Coefficient
Epan	Pan Coefficient
ER	Effective Rainfall
Gwc	Ground Water Contribution
IRR	Irrigation Requirement
WR	Water requirement
NIR	Net Irrigation Requirement
GIR	Gross Irrigation Requirement
FC	Field Capacity
PWP	Permanent Wilting Point
ASM	Available Soil Moisture
CPE	Cumulative Pan Evaporation
DASM	Depletion of Available Soil Moisture
E_c	Conveyance Efficiency
E_a	Application Efficiency
E_s	Storage Efficiency
E_d	Distribution Efficiency
E_p	Project Efficiency
RSC	Residual Sodium Carbonate

EC_w	Electrical Conductivity of Water
EC_e	Electrical Conductivity of Soil
WUE	Water Use Efficiency
FWUE	Field Water Use Efficiency
Q_m	Gravimetric Water Content
Q_v	Volumetric Water Content

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