Manual on

Enhancing Water Use Efficiency in Canal Commands

Coordinating Unit

AICRP on Water Management

Directorate of Water Management

(Indian Council of Agricultural Research)

Bhubaneswar-751 023

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FOREWORD

Water, as an input to agriculture, is critical for sustaining the food security. India faces the daunting task of increasing its food grain production to a level of 300-325 million tons by 2025. Amidst competition from non-agricultural uses in households, industry and environment, supply of irrigation will have to keep pace with the targeted annual agricultural growth rate of over four percent, therefore, demand-supply management in water sector and efficiency in its every use is critical for providing sustainable water-food security to the country.

More than 60% of country's food grain production is now contributed from irrigated agriculture. The irrigation potential of the country has increased from 22.6 M ha by 1950-51 to more than 100 M ha through construction of 382 major projects, 1147 medium projects and millions of minor irrigation schemes. Most of the irrigation systems are reported to have serious problems relating to the distribution of water and its use efficiency. The overall irrigation efficiency of irrigation projects is estimated around 35 percent. Excessive loses in conveyance systems, over irrigation and wastage of water in field are the biggest bane of irrigation practices in our country and have resulted in low yields and cropping intensity. Over irrigation in the canal commands have also resulted in water logging and salinity. The performance of the irrigation sector thus needs an improvement through improved water delivery and application systems. It is estimated that by reducing conveyance losses and increasing water application efficiency by 10-15 percent, it is possible to significantly add to the irrigated area. Achieving water savings in existing uses through increased water used efficiency in agriculture has been suggested as the most readily available path to meet the current and future demands. Thus, irrigated agriculture is increasingly feeling the pressure to improve its performance. Depending on the local conditions in the irrigation system, series of agronomic, technical, managerial, and institutional improvements can have large positive impacts on water use efficiencies.

All India Coordinated Project on Water Management (AICRPWM) has made spectacular progress in developing a variety of strategies and technologies for improving sustainable use, planning and management of available water resources which can improve water use efficiency to a great extent. I am happy to know that Coordinating Unit has compiled publication entitled **"Manual on Enhancing Water Use Efficiency in Canal Commands"**. I congratulate the authors, contributors and scientists of AICRPWM who have put in lot of efforts in compilation of this important publication. I hope this compilation *Manual on Enhancing Water Use Efficiency in Canal Commands* will serve as a useful guide for the planner, irrigation experts, extension personnel and field officials for guiding the end users.

A.K. Singh
Deputy Director General (NRM)
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PREFACE

Efficient use of available limited water resources holds the key for enhancing and sustaining agricultural production. Introduction of irrigation coupled with other management practices during the last five decades has helped in boosting agricultural production. Even the present share of water for irrigation is expected to decrease in future to meet the growing demand of other users. Irrigation facilities created by the government at huge cost, but the optimum benefits from irrigation water were not obtained and there is considerable wastage of water in the major and medium canal commands. The project irrigation efficiency of major projects is less than 35 percent. Inadequate natural drainage, rising water table in brackish ground water and canal irrigated areas, decreasing water table due to over exploitation of underground water, poor irrigation efficiency, high seepage losses from conveyance system, poor land development and mismanagement of the irrigation water resources are major problems for poor performance of the canal system. Realizing that the development of water resources is very costly, therefore, the urgent need is to adopt location specific efficient water management technologies. Agriculture being major consumer of water, even a marginal improvement in the efficiency of water use in irrigation sector will result in saving of substantial quantity of water which can be utilized either for extending irrigated area or diverting saving to other sectors of water use.

Keeping the above in view, the publication entitled **"Manual on Enhancing Water Use Efficiency in Canal Commands"** attempts to familiarise the extension workers, field functionaries, planners, research worker and farmers about the efficient water management technologies generated by the scientists over four decades of research. The dissemination and adoption of the technologies by the farmers would certainly help in the enhancing water productivity and maintaining soil quality. The authors express sincere gratitude to Dr. A. K. Singh, Deputy Director General (NRM) and Dr. P. S. Minhas, ADG (Soil and Water Management) for their guidance, cooperation and keen interest in conducting network research. We also express our sincere thanks to the contributors who have taken keen interest in writing relevant chapters in the field of their specialization. We fervently hope that this compilation will prove worthy to agricultural planners, policy makers, irrigation engineers, extension personnel and field workers who are directly or indirectly related to agricultural water management.

2nd May, 2011
Bhubaneswar

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1.0 SURFACE WATER RESOURCE AND CANAL IRRIGATION MANAGEMENT

ASHWANI KUMAR

*W*ater is one of the most essential natural resources for sustaining life, food production and economic development. Efficient use of water resource is the basic to survival of the ever-increasing population of a country. India receives average annual rainfall of 1194 mm with a variation of 100 mm / year in western regions to 11,690 mm / year in Mousinram, Cherapunji of eastern region. With 4000 billion cubic meter (BCM) of annual rainfall, average runoff generated is only 1869 BCM. Due to various constraints about 1,122 BCM of water can be put to beneficial use of which 690 BCM is through surface water and 432 BCM by groundwater (Table 1.1). Out of 690 BCM of surface water, so far about 213 BCM of storage are built through major and medium irrigation projects. Another 184 BCM of storage are under construction / consideration. Similarly, out of 432 BCM of groundwater resource, about 360 BCM of groundwater is expected to be available for irrigation, out of which present usage is about 135 BCM.

Table 1.1 : Water resources of India

Water resource	Volume in Billion Cubic Meter (BCM)
Annual precipitation	4000
Available water resources	1869
Utilizable water resources	1122
Surface water (storage and diversion)	690
Groundwater (replenishable)	432

In spite of massive infrastructure built, the storage capacity of India as compared to many other countries remains low at just 200 m^3 per capita, while USA and Australia are at about 5000 m^3 per capita, China 2500 m^3 per capita, and even Morocco and South Africa remains at 500 m^3 per capita. The per capita water availability in the year 2005 was 1703 cubic meter which is projected to further reduce to 1401 and 1191 cubic meter by the years 2025 and 2050 respectively (Table 1.2). Therefore, there is a need for proper planning, development and management of this precious natural resource.

Table 1.2 : Per capita water availability of India

Year	Per capita water availability (M^3)
1950	5300
1990	2200
2005	1703
2025	1465
2050	1235

1.1 Irrigation sector : an evaluation

In India, irrigation development has been received high priority in the successive five year plans since independence to enhance the agricultural production. A record food grain production of 233.88 M tones was achieved in 2008-09 from 50.8 M tones in 1950. About 60% of country's food grain production is now contributed from irrigated agriculture. The ultimate irrigation potential of the country through major, medium and minor irrigation projects has been assessed as 139.9 M ha by conventional storage and diversion works. The cultivable area of the country is estimated to be about 186 M ha out of which about 142 M ha is under cultivation. With rise in population and industrialisation putting pressure on land, it is expected that net cultivated area will stabilise at 140-145 M ha.

The irrigation potential of the country has increased from 22.6 M ha by 1950-51 to about 100 M ha through construction of 382 major projects, 1147 medium projects, 146 Extension, Renovation and Modernisation (ERM) schemes and millions of minor schemes. The decadal growth in cropped and irrigated area of the country since 1951 is given in Table 1.3. Total water use in agriculture at current level of development is of the order of about 525 BCM which is about 83 percent of total present water use in the country. This may get progressively reduced to about 75 percent in future, due to increased demand of other sectors. Being, major consumer of water, even a marginal improvement in the efficiency of water use in irrigation sector will result in saving of substantial quantity of water which can be utilized either for extending irrigated area or diverting saving to other sectors of water use.

Table 1.3 : India's cropped and irrigated area from 1951 to 2005

Year	Area in M ha				Irrigation intensity
	Net sown area	Gross sown area	Net irrigated area	Gross irrigated area	
1950-51	118.75	131.89	20.85	22.56	17.1
1960-61	133.20	152.77	20.66	27.98	18.3
1970-71	140.27	165.79	31.10	38.19	23.0
1980-81	140.00	172.63	38.72	49.78	28.8
1990-91	143.00	185.74	47.78	62.47	33.6
2000-01	141.16	185.71	54.83	75.87	40.9
2005-06	141.89	192.80	60.20	82.63	42.9

In irrigation sector of the country, the overall irrigation efficiency of the major and medium irrigation projects is estimated around 35 %.The uneven distribution of water over the length of the canal system has resulted in low yields and cropping intensity. Over irrigation in some of the canal command areas has also resulted in waterlogging and salinity. The performance of the irrigation sector thus needs an improvement through improved water delivery and application systems.

Irrigation projects, in general, are under performing due to inadequate system maintenance mainly on account of financial constraints. This could be attributed to low water rates and revenue recovery from farmers. Even though it is well recognized and recommended that water charges may have to be so fixed so as to meet at least annual costs of operation and maintenance in order to make the system self - sustainable though this has not been implemented in many states. This affects the planned efficiency of projects and their performance. It is imperative to devise a mechanism for proper water rates and recovery of water charges.

In spite of the achievements made so far, the country cannot afford to brook complacency yet as only 38 percent of the cultivated land is irrigated. Further, despite the fact that productivity in irrigated areas has increased, in general, it is seen that in irrigation system without storage back up like Kosi, Gandak etc., such increases are still way below the world standards and even of developing countries like China and Brazil. This low productivity, manifests itself not only through the irrigated yields being less than what it would be possible to achieve but also is not being able to irrigate properly the whole of the area planned for irrigation and in not being able to supply the water in sufficient quantities and with timeliness, reliability and equity all over the command. The problem of equity, timeliness and reliability and the low efficiency in regard to conveyance, distribution and application of irrigation are considered as a main cause for the low productivity of irrigated agriculture and also of the low satisfaction level among the irrigated farmers. The overall efficiency in most irrigation systems is low and in the range of 35 to 40 percent. The main cause of low efficiencies, is observed to be deficiencies in water delivery system due to poor maintenance, inequitable delivery of water to the fields, lack of on-farm development and inefficient water management. Further, productivity of irrigated land ranges from around 1.5 - 4 tonnes per ha for cereal crops as compared to an achievable target of about 5 to 6 tonnes per ha putting additional pressure on water demand for irrigation. Absence of any meaningful co-ordination of multidisciplinary departments at various levels also results in wasteful and unlawful use of water, resulting in low system efficiencies and productivity levels.

1.1.1 Status of irrigation efficiencies in canal command

Irrigation efficiency mainly depends on loss of water in conveyance system including distribution system and in the field. Loss of water in conveyance system is mainly due to seepage and evaporation. Evaporation loss takes place from the exposed water surface. In hot and dry summer months, these losses are maximum but they may seldom exceed about 10 percent of the total conveyance losses. Conveyance and field losses, contributing to overall irrigation efficiency from source to field application, vary widely with the extent of lining, type of strata through which canal system passes, material used and quality of work in the canal lining, preparation of the field, type of soil, stream size, method of water application i.e irrigation practices in vogue etc. Some studies have been carried out to have a general idea about the project features which influence the irrigation efficiencies. Irrigation efficiencies and seepage losses in some existing projects are briefed in Table 1.4 and 1.5. General conclusions of these studies are described below:

- Area served by one distributary ranged between 400 ha to 3000 ha, conveyance efficiency was higher than in schemes where this area was larger or smaller. In schemes where the tertiary units were larger than 200 ha, the average conveyance efficiency was higher than in schemes with tertiary units between 5 and 100 ha.
- In schemes where the size of flow per farm inlet was more than 50 litre/second, the distribution efficiency was higher than in schemes where the size of flow was 50 litre/second or less.

Table 1.4 : Irrigation efficiencies in some of the existing Indian projects

Sl. No.	Particulars	Observed irrigation efficiencies of projects (%)					
		1	2	3	4	5	Average
1	Conveyance efficiency						
	a) Main canal	92	84	85	94	86	88
	b) Distributary / Minor	79	83	75	75	89	80
	c) Field channel	68	64	72	-	67	68
	Overall conveyance efficiency (EC)	49	44	46	70	51	48
2	Field Application efficiency(Ea)	77	69	83	58	59	68
3	Project Efficiency (Ep)	38	31	38	41	30	36

It is observed that such losses are 40 to 50 percent of the discharge at canal head. This includes 15 percent to 20 percent in main canal and branches, 10 to 20 % in distributaries and 10-20 % in water courses. In general, it can be generalized that a considerable amount of water is lost through evaporation and seepage in the canal system from the head of the canal up to the distributaries outlet. National Commission on Integrated Water Resources Development Plan also tried to compile the data for national level assessment of overall irrigation efficiencies but they could not come to any conclusion. However, the National Commission opined that 35 to 40 % efficiency in surface water and 65-70 % efficiency in ground water will be a fair approximation.

Table 1.5 : Seepage losses in some of the existing Indian projects

Sl. No.	Project	Seepage losses in canal system (Cusec per Million Sq. ft.)
1	Harsi Canal System(M.P)	5 to 24
2	Sarda Canal System (U.P)	6 to 8
3	Kaldiya Irrigation Scheme (Assam)	17 to 27
4	Pazhassi Irrigation Project (Kerala)	11 to 21
5	Kangsabati Irrigation Project (W.B)	9 to 70

1.1.2 : Review of present efficiencies in canal commands

The development of irrigation sector, like a few other development activities has its share of problems also. A number of irrigation systems, are operating much below their potential due to poor maintenance, problems of equity, waterlogging, lag in potential created and utilized etc., all leading to actual irrigation efficiencies being much less than the achievable values. This is not to say that problems of existing irrigation systems can be limited to those related to irrigation efficiency and equity. At times the water availability itself may be inadequate or may have become inadequate due to excessive upstream development. The cropping pattern have changed from those for which the system was planned. While all these problems need specific consideration, particular problem which is common to all the systems and required to be tackled is the low water use efficiency.

The irrigation efficiencies of 35-40 percent in surface water as generally obtained are considered to be low. The reasons which contribute towards low values of irrigation efficiencies can be summarized as under:-

i) A large number of major and medium projects could not be completed due to various reasons including thin spreading of resources. In many cases headworks were completed but the canal systems were only partially completed. With development of part command and abundant availability of water as planned for the project. The head reach farmers starts growing high water consuming crops practically on full size of their farms with irrigation intensities much higher than planned. They also tend to over irrigate and indulge in wasteful use of water. The problem is more acute in large system where full development of command takes 10-20 years. Even after completion of the project, the head reach farmers continue to draw more water in pretext of changed cropping pattern depriving tail reach farmers of their share of water. Some tail end channels, practically do not get any water, resulting in low water use efficiency.

ii) Excessive losses in conveyance and distribution systems are due to seepage, evaporation etc. Whereas the evaporation loss is less, as much as, 40-50 percent of water is lost in seepage through main canals, branches, distributaries, minors, water courses and field channels. It is observed that almost half of these losses occur in field channels.

iii) Design and operation of the conveyance and distribution systems, is in such a way that inequity and indiscipline prevail in the command. The systems are designed to run either at full discharge or at partial discharge. The cross regulators and head regulators are so designed, that off taking branch can draw full supply even when the flow in parent channel is having partial supply. In the secondary system, this leads to various manipulations in head reaches. The head branches take larger share of the parent channel and much higher shortages are passed on to the lower branches. So, the operation of the system is fundamentally dependent upon the two factors, i.e method of water allocation and method of distribution adopted for the system and water control within distribution system.

iv) Most of the irrigation systems are today facing twin issues of sub-optimal sector planning and financial management on one hand and inadequate maintenance of the system on the other hand. Efficient water management cannot be achieved unless the infrastructure for water conveyance and delivery system is in a reasonably good condition. Maintenance of irrigation system is generally neglected, which leads to weed growth, silting of canal system, breaches etc. Situation in some cases is seen to be so precarious, that even the head works & other regulatory structures start showing signs of distress. Infrastructure deterioration from inattentive and absent maintenance regime is one of the main reasons of wastage of water and lower value of irrigation efficiency.

v) The water rates being charged at present are low and the revenues are only a small fraction of the amount required for proper maintenance. This adversely affects the availability of resources with the State Governments for proper and regular maintenance of irrigation systems. This consequently leads to deterioration of system and is responsible for the poor quality of services.

vi) Another grey area is inordinate delay in completion of On-farm Development works (OFD works). Out of the irrigation potential of about 101 M. ha created so far, about 81 M. ha only is being utilized leaving a gap of 20 M. ha of unutilized potential. Though there are many factors which influence the utilization of created potential, the prime cause of under utilization is non-completion of field channels, land leveling and shaping, drainage channels etc.

vii) Other important factor leading to low value of efficiency is lack of involvement of beneficiaries. Farmers are real stake holders of water use. Though the process of formation of Water Users Associations (WUAs) and Participatory Irrigation Management (PIM) started in 1985, the beneficiaries are not involved sufficiently and effectively in the up-keep of the system and water management aspects. These works are considered to be the responsibility of irrigation department and is one of the important reasons of getting low efficiency of irrigation in many States.

viii) In initial phase of irrigation development, thrust was on for creation of irrigation infrastructure and no efforts were made for providing matching drainage facilities in the irrigation commands. This has resulted in problem of water logging and salinity in some of the irrigation commands. Seepage from conveyance system of the irrigation projects, excessive application of irrigation water to crops, lack of conjunctive use of surface and ground water, poor on farm water management, deficient maintenance etc only added to the problem. Working Group of Ministry of Water Resources (MOWR) in their report of 1991, estimated water logged area and salinity affected area in command of major and medium irrigation schemes as 2.46 and 3.3 M.ha respectively. Some waterlogged area is reclaimed but the progress of reclamation is very slow. In addition to waterlogged area, which has practically gone out of command and could not be used for crop production, other areas where sufficient drainage facilities for effective disposal of sub-surface water have not been provided, also lose fertility, leading to low yields.

ix) In spite of the fact that there is an acute shortage of water, no concerted efforts have been made to improve water application techniques in the field and age old irrigation practices continue to be in vogue. Most of the area in the country is irrigated by surface application methods such as basin, check basin, border strip, furrow irrigation etc. Except for furrow irrigation, adoption of other methods practically means flooding of the irrigation fields resulting in substantial loss of water. This happens as fields are generally not properly levelled or provided with correct slope for quick flow of water from one end to another. The application efficiency of these methods has been found to be only 30 to 50 percent as compared to attainable leve of 60 to 80 percent.

x) Development and management of water resources still remains with National and State Governments. The responsibility is spread amongst several institutions, some with overlapping jurisdiction. There is a distinct lack of coordination among various agencies involved. Research efforts in water management are being carried out by the Indian Council of Agricultural Research, Water and land Management Institutes of various States, various Agricultural Universities, other Central and State Research Centres etc. MOWR also funds the research schemes through INCID, INCH, INCOH etc. Though lot of information have been generated / collected by various agencies, there is no meaningful interaction and linkages between various agencies. The agencies involved in the extension services, fail to translate the research findings to actual field. There is lack of mass awareness programmes and farmers not realizing the scarcity of water continue to waste water.

1.2 Water use efficient technologies

Improving the use-efficiency of existing water resources will be crucial to relax the supply side constraints on future agricultural growth and to allow reallocation of water from agriculture to other uses. The development of technologies and management systems that enhance water-use efficiency warrants high priority. The identification, breeding and introduction of water efficient crops for dry land and saline environments are potentially an important aspect of achieving greater water-use efficiency. A large share of water to meet new demands must come by saving water from existing uses. As per one of the estimates, a 10% improvement in irrigation efficiency could conserve enough water to double the amount of water available for drinking. Further, at plausible sites, recycle / reuse of water has to be promoted to have more crops per drop of water.

Global climate change is likely to have a major differential impact on precipitation, water availability, crop water demand, erosion, salinization, droughts and floods in India. Shifts in the existing biodiversity and land use patterns are likely to occur due to climate change. The growing frequency and magnitude of the extreme climatic events warrants for researches on natural disasters as well as regional vulnerability. Among all natural disasters, floods are the most frequent, affecting annual average of 7.56 M ha and 33 million people in India. The post-flood contingent measures need to be more focused and targeted to minimize the agricultural loss. The drought prone area assessed in the country is of the order of 51.12 M ha. These areas should have soil-moisture conservation measures, water harvesting practices, evaporation losses minimization measures and development of ground water potential. The possibility of diverting surface water from surplus areas needs to be explored.

1.2.1 Measures for improving efficiency

There is a considerable scope for rationalizing irrigation demand and applying the right quantity of water at right time. Some of the important measures are as listed below:

i) Timely execution of projects

ii) Lining of conveyance system

iii) Operational and Maintenance

iv) Appropriate water price

v) Timely and adequate water supply

vi) Participation of stakeholders

vii) On-farm water management

viii) Technology upgradation

ix) Conjunctive use of water

x) Drainage as an integral part of irrigation project

xi) Policy changes

R & D efforts in irrigation agriculture require the attention to the following aspects:

- Development of data base on agricultural utilization.
- Saving in agricultural use, soil moisture conservation through use of mulches, improving water use efficiency, selective lining of canal.
- Conjunctive use of surface and ground water.
- Conjunctive use of multi source and multi quality waters.
- Economizing through micro irrigation systems.
- Environmental protection for water pollution, reuse of irrigation water.
- Developing policy guidelines for rationalising water pricing.
- Cropping for flood affected flood prone area.
- Biotechnology for developing salt/drought tolerant crops, low water requiring crops etc.
- Membrane technology for water treatment & desalinization at low cost.
- Improved water management.
- Participatory irrigation management.

1.3 Paradigm shift for integrate water management

A paradigm shift in the policies for irrigation development and management has been happening during the past two decades through participatory irrigation management (PIM) and irrigation management transfer (IMT) approach. The centralized control and management responsibility of the irrigation resources are being transferred to the local farmer groups or water users associations (WUAs) for better management. About 13.16 M ha of irrigated land has been covered under 56539 numbers of WUAs in the country. Recognizing the need for sound legal framework for PIM in the country, the Ministry brought out a model act which has been enacted by eight state governments, namely, Andhra Pradesh, Goa, Madhya Pradesh, Karnataka, Orissa, Rajasthan, Tamil Nadu and Kerala. The other states also need to work in this direction. Concerted efforts should be made to involve farmers progressively in various aspects of management of irrigation systems. Command area development programme should be taken up in all irrigation projects to bridge the gap between the potential created and actual utilization.

Groundwater played a major role in the success of green revolution and contributes 60% of the total irrigated area of the country. Over exploitation of groundwater has reached danger levels in Haryana, Punjab, Rajasthan and Tamil Nadu. The Punjab-Haryana region could lose its production potential in a few decades if current patterns of groundwater extraction and pollution, soil salinization and rice-wheat monoculture persist. Groundwater remains under developed in regions where surface water is adequate. A recent estimate reveals that in 15% of the blocks, the annual extraction of groundwater exceeds annual recharge. In 4% of the blocks, it is more than 90% of the recharge. Groundwater extraction in such blocks needs to be better regulated.

Conjunctive use of surface and groundwater is desirable to fulfill the irrigation requirements of crops by judiciously utilizing the water from both the sources. The optimal conjunctive use of the region's surface and ground water resources would help in minimizing the problem of waterlogging and groundwater mining. The conjunctive use also facilitates the use of highly saline groundwater which can't be otherwise use without appropriate dilution. Strengthening of knowledge base on geology and aquifer characteristics, hydrology of surface and groundwater, and existing surface and ground water facilities is required to develop appropriate conjunctive use system. Moreover, the quality of land and water must be sustained in the face of mounting pressure to degrade these resources through waterlogging, salinization, groundwater mining, and water pollution. Water erosion alone has contributed significantly to the degradation process. Temporal and spatial spread of degradation process, if not checked and reversed, would affect the future agriculture.

1.4 Virtual water

With the increase of food trade in coming years, the importance of virtual water at global level is likely to be felt more. In the water scarce areas, the transfer of virtual water embedded in the food being traded would become an important component of water management. Therefore, assessment of virtual water in terms of its value over space and time and its consideration at agricultural and water policy level is of paramount importance.

1.5 Future water requirements

The population crossed 1200 million and is expected between 1500 million and 1800 million by the year 2050. It is expected that the population will stabilise by 2050. The U.N. agencies have put the figure as 1640 million by then. The National Commission on Integrated Water Resources Development Plan (NCIWRDP) has assessed the water demand for irrigation sector considering low and high variant population of 1346 million and 1581 million as 628 BCM and 807 BCM respectively by 2050. Average food grain consumption at present is about 550 gm per capita per day whereas the corresponding figures in China and USA are 980 gm and 2850 gm respectively. With population growth at about 1.5 per cent per year, the food production should increase by about 2.6 percent annually. The area irrigated should also show an annual growth rate of about 3 percent to match the rising demand of foodgrain. NCIWRDP has, earlier expressed a view that per capita economic growth rate of 4.5 percent per year is a reasonable assumption. As such 284 kg of foodgrain per head per year or total of 382 M.T (low demand) and 449 MT (high demand) foograins will be required by the year 2050. For assessing the future water demand to meet this requirement of foodgrains, the Commission has assumed that cropping intensity, which at present is about 135 percent shall increase to 150-160 percent by 2050. Irrigated area is also likely to increase from about 40 percent to 53 percent of total cropped area by 2050.

The National Commission also looked into the possibility of increase in the food grain yields of rainfed and irrigated areas and opined that good probability exists for achieving food crop yields as given in Table 1.6. This is against present average yield of about 1.0 and 2.3 tonnes per ha for rainfed and irrigated agriculture respectively.

Table 1.6 : Food crop yield (t /ha) projections

Production System	Yield (t/ha)	
	2025	2050
Rainfed	1.25	1.5
Irrigated	3.4	4.0

Keeping the above projections in view, the commission has estimated that by 2050 the total irrigated area will have to be increased to 113 M ha and 146 M ha for low demand and high demand scenario for which water requirement will be of the order of 628 BCM and 807 BCM respectively.

Conclusion

Water forms the backbone for all the future endeavours to achieve the vision of food security. In the present day context, upscaling agricultural economic growth to more than 4% annually is the main challenge. Taking water technologies for better water management from lab to land is a formidable task to be addressed. Modernization / automation of irrigation system, precision irrigation, land reforms, corporate farming, cooperative farming, water and energy pricing, crop insurance, institutional mechanism for better governance, water rights are some of the key issues for bettering water management in agriculture. The projected food requirement demands a pronounced role for research, development and training in the water and agriculture sector.

It is evident that the water availability for agriculture is declining and to enhance agricultural production more water is needed. Therefore, concerted and holistic efforts are required in increasing the overall water use efficiency at system level which would be achieved through various measures like timely execution of projects, minimizing the losses, better operational efficiency through stake holders participation, implementation of on-farm water management technologies, conjunctive use of water and changes in irrigation policy. Simultaneously, the efforts of R&D institutions are required in development of water management technologies, suitable database development, economic studies of various irrigation systems, policy guidelines for on-farm water management and adoption of participatory irrigation management. The serious efforts of developmental agencies as well as research institutes are required to develop a suitable water prespective plan for various regions in the country for its implementation.

2.0 SOIL PHYSICAL PROPERTIES VIS-À-VIS SOIL-PLANT-WATER RELATIONSHIPS

V. K. Phogat, R. K. Pannu and Rajbir Singh

For designing, operating and managing any irrigation system, the basic concepts of soil physical properties, soil moisture constants, movement and retention water in very necessary. The soil acts as the basic substrate and serves not only as a medium for plant growth but also as a sink and recycles many waste products which might otherwise accumulate to pollute the environment. In addition, soil supports the buildings and provides materials for the construction of earthen structures such as dams and canal. Soil physical properties influence the movement, retention and availability of water in soil profile, therefore, these properties have to be understood in depth for deciding the efficient managing of the water resources. Similarly, soil-plant-water relationship should be clear to plan irrigation system to suit different crops grown on different soils.

2.1 Soil Profile

The most obvious part of any soil is its surface, through which the matter and energy are transported between the soil and the atmosphere. The conditions of soil surface affect the processes of radiation and heat exchange, water and solute movement and gaseous diffusion. Thus, soil surface is important but it does not describe the character of the soil as a whole. To characterize soil as a whole, it is necessary to examine the soil in depth. It is done by digging a vertical section of the soil from surface to the parent material, called a *soil profile* (Fig. 2.1.1).

The soil profile consisted of a succession of more or less distinct layers, in terms of physical, chemical and biological properties, is called the soil *horizons*. The surface layer or *A horizon* is the zone of major biological activities and is, therefore, generally high in organic matter and darker in colour than the lower horizons. This horizon is the most fertile zone of soil but also most vulnerable to erosion by water and wind. It is the *eluviated* horizon from which certain colloidal materials such as clay, oxides and carbonates are removed constantly by leaching action of water. A layer beneath the A-horizon, which contains less organic matter than A-horizon, is called the *B-horizon* (subsoil). It is the zone of *illuviation* where some of the colloidal materials that are leached from the A-horizon accumulate. The B-horizon is often thicker than the A-horizon. The pressure of the overlying soil

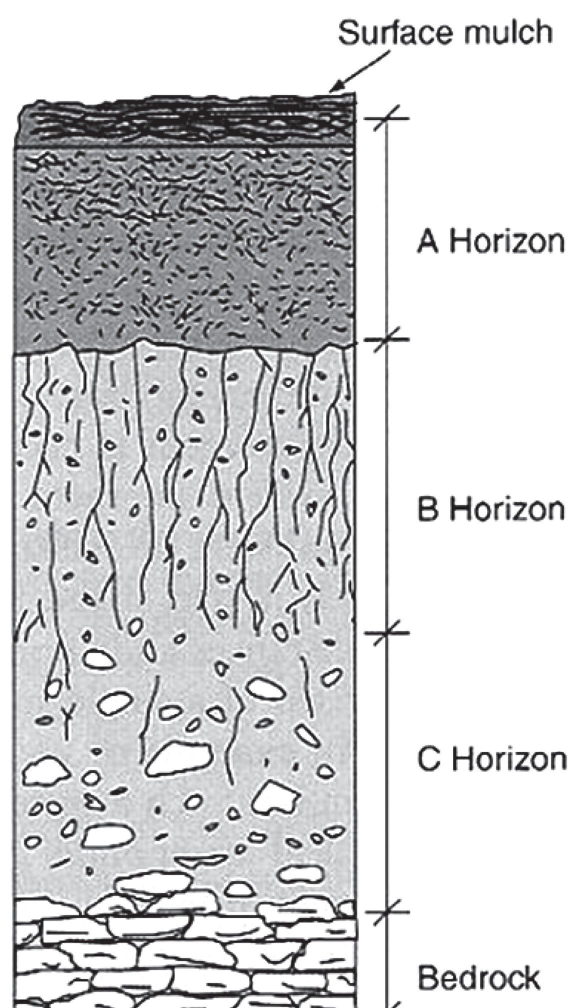

Fig. 2.1.1 Schematic representation of a hypothetical soil profile

tends to reduce the porosity of the deeper layers. In some cases, the dense B horizon may inhibit gas exchange, water drainage and root penetration. Directly below the B-horizon is the *C-horizon* which contains weathered rock or the soil's parent material. If the soil is formed from the bedrock *in situ*, the C horizon consists of a weathered and fragmented rock material. In other cases, the C-horizon may consist of alluvial, aeolian, or glacial deposits. In a young soil, the B-horizon is absent but in a developed matured soil, A- and B-horizons are more prominent, and at times, the C-horizon may disappear. In a recent alluvium, hardly any profile differentiation is apparent. The terminology to describe the horizons in a soil profile is given in Fig. 2.1.2.

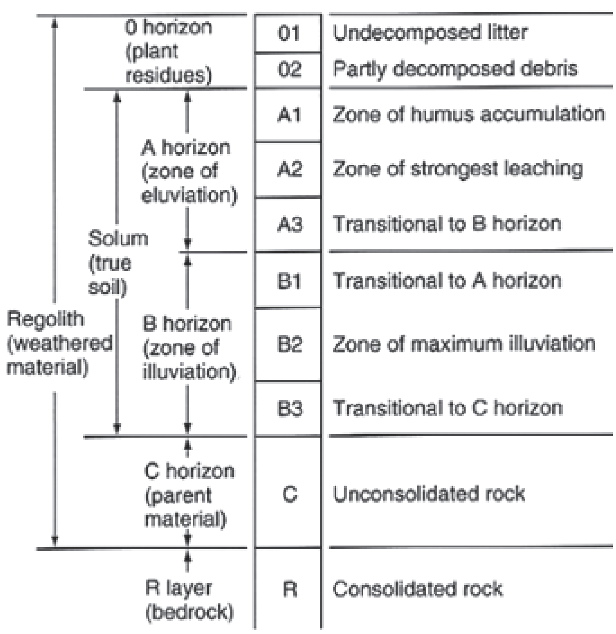

Fig. 2.1.2. Descriptive terminology for soil profile horizons

A soil, which contains adequate amount of various nutrients required by the plants in available form, not excessively acidic or alkaline and is free of toxic agents, can be considered to possess chemical fertility but such fertility does not by itself ensure the success of a crop. The suitability of a soil as a medium for plant growth depends upon the state and movement of water and air and also upon mechanical support of soil and its thermal regime. The soil must be loose, soft and friable to prevent root development without any mechanical obstruction. Therefore, for higher productivity, the soil in addition to chemical fertility should also possess physical fertility. The examples of soils, which are chemically but not physically fertile, are:

- A soil rich in all essential plant nutrients is a desert if water is absent.
- A fertile low lying land becomes worthless if flooded for a long time due to deficiency of oxygen.
- The nutrients and water of the sub-soil remain unapproachable to the crops if a dense plough layer restricts their root penetration.

2.1.1 Soil as a Dispersed Three Phase System

Soil is a dispersed three-phase system as it is made up of solids, liquids and gases. The solid phase composed of mineral particles and organic materials. It also contains amorphous compounds such as hydrated iron and aluminum oxides, and generally, the proportion of the amorphous material is small. Organic fraction of the solid phase is consisted of organic residues in different stages of their decomposition (undecomposed materials and well decomposed products) along with enormous varieties of millions of living as well as dead microorganisms. Solid phase forms matrix of the soil system and provides seat for most of the physico-chemical reactions, like ion-exchange, adsorption, etc. It shapes the pores which control the movement of air and water and penetration and development of roots in the soil.

Solid phase acts as an ultimate fertility sources and provides mechanical support to the plants. Organic matter helps in soil aggregation and largely responsible for loose and friable conditions of the soils. Apart from providing essential nutrients, it increases water holding capacity of the soil and available water. It is also the main source of energy for soil microorganisms.

Liquid phase is water in the soil, and the soil water always contains dissolved minerals. Therefore, it is also called as *soil solution*.

Nutrients get dissolved in water and become available to the plants. These nutrients move from soil to the root and from roots to the leaves through the medium of water, which meets the requirement of the plants and is important for all biochemical processes occurring in the plants. Water controls soil aeration, temperature of soil and plant and microbiological activities in the soil.

Gaseous phase is the soil air or soil atmosphere, which is not continuous as atmospheric air since it is located in soil pores separated by soil solids, and its composition varies from place to place in the soil. Soil air has higher moisture than the atmosphere, and the relative humidity approaches 100% at optimum moisture. Content of carbon dioxide is generally higher and that of oxygen lower than their contents in the atmosphere. Soil air provides oxygen for the respiration of roots and soil microorganisms.

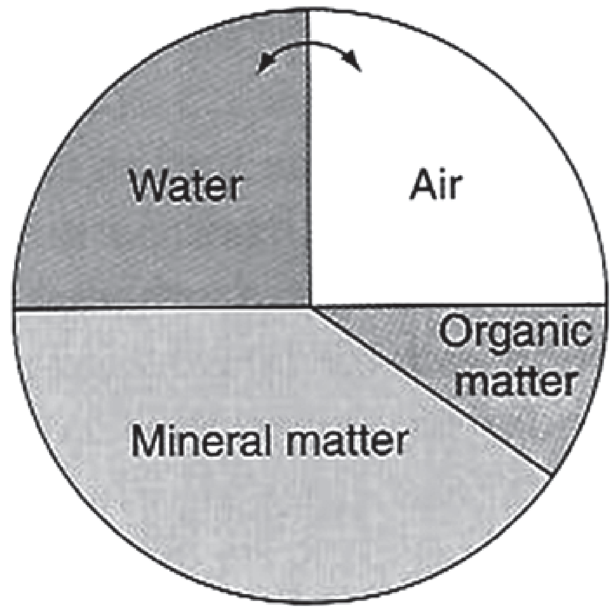

Fig. 2.1.3 Schematic volume composition of three phases in a medium textured soil at a condition optimal for plant growth

The relative proportion of three phases in the soil is not fixed but it varies continuously depending on weather, vegetation and management practices. At interface of two phases in the soil, many physical phenomena such as adsorption of water and nutrients**,** capillarity, ion-exchange, dispersion, flocculation, aggregation, swelling, shrinkage, heat of wetting, etc., occur. The hypothetical volume composition of three phases in a medium textured soil at a condition considered optimal for plant growth is presented in Fig. 2.1.3.

The solid matter constitutes 50% (45% mineral and 5% organic matter) of the soil volume and rest 50% is the pore volume which is equally shared by water and air. The water and air components can vary widely and are negatively related so that an increase in one is associated with a decrease in other.

2.2 Physical Properties of soil

2.2.1 Mechanical composition of soil : The term mechanical composition is often used interchangeably with soil texture, which is an expression of prominent size or size range of the soil particles, and it has both *qualitative* and *quantitative* meaning. Qualitatively, soil texture refers to the feel of soil whether it is coarse and gritty or fine and smooth when rubbed between thumb and finger. Quantitatively, soil texture refers to the relative proportions of different size groups or soil separates, specifically referred to as sand, silt and clay in a given soil.

The texture of a given soil is more or less a static property, hence, it is considered as a basic/ inherent property of a soil affecting almost all other soil properties.

2.2.1.1 Classification of soil particles : Soil particles may be classified on the basis of shape, density, chemical composition, or size but the classification based on shape, density and chemical composition is no longer in use. Only size of the particle is conveniently used to classify the soil particles. An essential criterion for determining soil texture is the upper limit of particle size, which is to be included in the definition of soil material. The conventional definition of *soil material/fine earth* includes particles <2 mm in diameter. Particles larger than 2 mm are generally referred to as *gravel* and still larger rock fragment, several centimeters in diameter, are called *stone* or *cobbles*, and if very large then they are called *boulders*.

Only soil material is normally considered in chemical and mechanical analysis of soils. All larger rocks, gravel, etc. are removed by screening the soil material through a 2 mm sieve. The components of fine earth are sand, silt and clay. The different particle size fractions are named and classified arbitrarily. Several conventional schemes exist for the classification of soil particles according to particle diameter ranges. Classifications of the International Society of Soil Science (ISSS) renamed as the International Union of Soil Sciences and the United States Department of Agriculture (USDA) are widely in use (Table 2.2.1).

Table 2.2.1 Classification of soil fractions according to particle diameter ranges

ISSS		USDA		European System	
Fraction	**Diameter**	**Fraction**	**Diameter**	**Fraction**	**Diameter**
Coarse sand	2–0.2	Very coarse sand	2–1	Coarse sand	2-0.6
Fine sand	0.2–0.02	Coarse sand	1–0.5	Medium sand	0.6-0.2
Silt	0.02–0.002	Medium sand	0.5–0.25	Fine sand	0.2-0.06
Clay	< 0.002	Fine sand	0.25–0.10	Coarse silt	0.06-0.02
		Very fine sand	0.10–0.05	Medium silt	0.02-0.006
		Silt	0.05–0.002	Fine silt	0.006-0.002
		Clay	< 0.002	Coarse clay	0.002-0.0006
				Medium clay	0.0006-0.0002
				Fine clay	<0.0002

The clay may be subdivided into coarse or non-colloidal clay of 0.002-0.0002 mm in diameter and fine or colloidal clay of <0.0002 mm in diameter.

2.2.1.2 Specific surface

Specific surface is an important property of soil particles and is defined as the surface area of particles per unit mass or per unit volume of soil particles. Most of the chemical reactions and physical processes, like adsorption of water, swelling, shrinkage, plasticity, soil strength, cation exchange capacity, availability of nutrients, etc., depend on the specific surface of particles, which increases as the size of the particle decreases. For same volume, the specific surface increases the times as the size of the particle decreases. Specific surface of soil particles, different clays and different textured soils is given in Table 2.2.2

Table 2.2.2 Specific surface of soil particles, clay minerals and different textured soils

Size fraction/ soil	Diameter (mm)	Specific surface (cm^2/g)	Clay mineral	Specific surface (m^2/g)
Coarse sand	2.0-0.2	45	Kaolinite	37-45
Fine sand	0.2-0.02	446	Illite	120-170
Silt	0.0-0.002	4458	Chlorite	130-180
Clay	10^{-4} -10^{-6}	1000 x 10^4	Montmorillonite	580-750
Sandy loam		$1x10^4$- $4x10^4$	Vermiculite	780-900
Loam		$50x10^4$- $100x10^4$		
Clay		$150x10^4$-$250x10^4$		

2.2.2 Textural class : The overall textural designation of a soil is called the *textural class*. It is normally determined on the basis of relative proportion of sand, silt and clay (weight basis). Soils with different proportions of sand, silt and clay are assigned to different classes as shown in *Textural triangle* (Fig. 2.2).

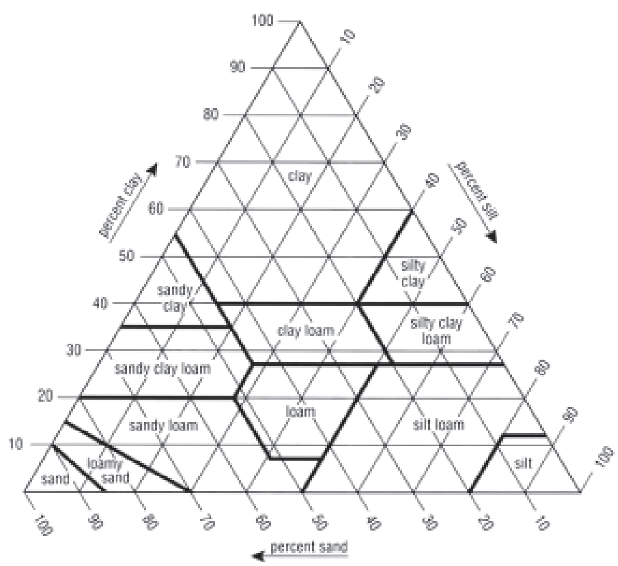

Fig. 2.2 Textural triangle (sand, silt and clay particle sizes of 2-0.02 mm, 0.02-0.002 mm and < 0.002 mm, respectively)

There are three well recognized broad primary textural groups of soils, namely sandy soils, loamy soils and clayey soils.

(a) Sandy soils

Soils in which the sand content is 70% or more and the clay content is 15% or less of the material by weight are characterized as sandy. Two specific textural classes are *sand* and *loamy sand*.

(b) Loamy soils

The loamy soil group contains seven sub-divisions, i.e., *sandy loam*, *loam*, *silt loam*, *silt*, *sandy clay loam*, *clay loam* and *silty clay loam*. To qualify for the modifier sandy or silt, a soil must have at least 40-50% of these separates, thus, a loam soil in which sand is dominant is classified as sandy loam.

An ideal loam soil is defined as a mixture of sand, silt and clay particles that exhibit the properties of these separates in equal proportions. This definition does not mean that the three separates are present in equal amounts. From agricultural point of view, loam soil is the most favorable as its capacity to retain water and nutrients is better than that of sand, while its drainage, aeration and tillage properties are more favorable than those of clay.

(c) Clayey soils

A soil to be designated as clayey must contain at least 35% of the clay separates. This group is further divided into three sub-divisions. If per cent of clay is 40 or more, class name is given either as *sandy clay*, *silty clay*, or *clay* depending upon the sand and silt contents as compared to 40% of clay. Sandy clay contains more sand than clay. Similarly, silt content of silt clay is usually more than the clay fraction.

i) Particle density

Particle density of a soil is the oven dry mass or weight of the soil per unit volume of soil solid only. It depends on chemical and mineralogical composition of the soil. In most mineral soils, it is in the range of 2.60 to 2.70 Mg m^{-3}, and for most purposes, an average value of 2.65 Mg m^{-3} is taken. The presence of iron oxides and of other heavy minerals increases, whereas, organic matter lowers the value of particle density.

ii) Bulk density

Bulk density of a soil is the oven dry mass of the soil per unit volume. If pores constitute half of the soil volume, the bulk density is half of the particle density. Therefore, the value of bulk density will range from 1.3 to 1.35 Mg m^{-3}. Bulk density of soil is influenced by soil texture, structure, moisture content, organic matter and land management practices. In coarse textured soils, it varies from 1.40 to 1.75 Mg m^{-3}, and in fine textured soils, it normally ranges from 1.10 to 1.40 Mg m^{-3}. Increase in organic matter content lowers the bulk density of soil, which normally decreases as the mineral soils become finer in texture. High bulk density indicates compactness of the soil. Bulk density is generally higher in lower depths in the soil profile due to lower organic matter content and higher overburden of the upper soil layers. In swelling soils, bulk density decreases with the increase in moisture content and *vice versa*. Bulk density is of greater importance than particle density in understanding the physical behavior of soils. It is used for calculating the weight of a furrow slice of soil in a given area.

iii) Porosity

Porosity is the volume occupied by pores per unit volume of soil and generally expressed as percentage. Its value lies between 30 and 60%. Porosity is less in coarse/light textured than in fine textured soils but size of individual pores is larger in coarse textured than in fine textured soils. In clayey soils, porosity is highly variable as the soil alternatively swells, shrinks, aggregates, disperses, compacts and cracks during wetting and drying. Porosity is related to bulk density and particle density of the soil and the relationship is expressed as under:

$$\text{Porosity (\%)} = \left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right) 100$$

Two types of pores- macro- and micro-pores occur in soils without any clear demarcation. Usually, pores larger than 0.06 mm in diameter are considered as macro-pores and those smaller than this are called as micro-pores or capillary pores. Macro-pores allow air and water movement readily, whereas, movement of water and air is restricted to some extent in micro-pores. Pore space directly controls the amount of water and air in the soil and indirectly influences the plant growth. Distribution of different sized pores rather than total pore space is more important for crop production. For optimum plant growth, the existence of approximately equal proportion of macro and micro-pores are needed, which influences aeration, permeability, drainage and water retention favorably. Porosity of a soil can be changed easily.

iv) Air-filled porosity

Air-filled porosity is the volume occupied by air per unit volume of soil and expressed as percentage. This is an important criterion of soil aeration. Air-filled porosity is related to the degree of saturation of soil.

v) Mass wetness (θ_g)

Mass wetness is the mass of water per unit mass of oven dried soil and often referred as the *gravimetric water content*. It is expressed as a fraction or percentage.

$$\text{Mass wetness } (\boldsymbol{\theta}_g) = \left(\frac{\text{Mass of water}}{\text{Mass of oven dried soil}}\right) 100$$

In mineral soils, gravimetric water content at saturation ranges from 0.25 to 0.60 (25-60%) depending on the bulk density. The saturated water content is usually taken as maximum water holding capacity of the soil and is generally higher in clayey than in sandy soils. In case of organic soils, such as peat and muck, the saturation water content on mass basis may exceed 100%.

vi) Volume wetness (θ_v)

Volume wetness is the ratio of total volume of water occupied in the pore spaces to the total volume of soil and expressed as a fraction or percentage.

$$\text{Volume wetness } (\theta_v) = \left(\frac{\text{Volume of water}}{\text{Total volume of soil}}\right) 100$$

Volumetric water content can be computed from the gravimetric water content by multiplying it with soil bulk density. At saturation, volumetric water content is equal to the porosity of soil. In sandy soils, the value of q_v at saturation point ranges from 40 to 50%, in medium textured soils, it is approximately 50%, and in clayey soils, it can be up to 60%. In clayey soil, the relative volume of water at saturation point can exceed the porosity of dry soil since clayey soil swells upon wetting.

The expression of water content on volumetric basis is more useful and convenient since volumetric water content is directly involved in calculating water flux, volume of water added to the soil by rain or through irrigation and volume of water extracted from the soil by the process of evaporation and transpiration by plants.

2.2.3 Influence of Soil Separates on Properties and Behaviour of Soils

The soil separates have profound influence on properties and behaviour of soils. Different soils contain different proportions of sand, silt and clay, and exhibit properties as determined by the dominant fraction. The comparative influence of soil separates on some properties and behavior of soils is presented in Table 2.2.3.

Table 2.2.3 : Comparative influence of soil separates on properties and behavior of soils

Property/behavior	Rating associated with soil separates		
	Sand	Silt	Clay
Feel	Gritty	Gritty	Plastic
Water holding capacity	Low	Medium to high	High
Plant available water	Low	Medium	High
Aeration	Good	Medium	Poor
Drainage	High	Slow to medium	Very slow
Organic matter decomposition	Rapid	Medium	Slow
Summer warming up	Rapid	Moderate	Slow
Compactability	Low	Medium	High
Wind erosion	Moderate (high in fine sand)	High	Low
Water erosion	Low (unless fine sand)	High	Low if aggregated
Shrinking-swelling	Very low	Low	Moderate to very high
Sealing	Poor	Poor	Good
Fertility	Poor	Medium to high	High
Buffering capacity	Low	Medium	High
Runoff	Low	Low-medium	Medium-high

In general, sandy soils have low water and nutrient holding capacity, low organic matter content, little or no swelling and shrinkage, poor sealing properties for ponds and dams, high leaching of nutrients and pollutants. The fine sands are easily blown by wind, while coarse sands resist erosion by water.

The medium textured soils dominating in silt content have medium to high water and nutrient holding capacity, moderate aeration, slow to medium drainage, medium to high organic matter content, usually good supply of plant nutrients and moderate leaching of pollutants and nutrients. These soils are easily blown by wind and susceptible to water erosion, easily compacted, have little swelling and shrinkage and are moderately difficult to till after rain.

A loam soil is often considered to be the optimal for plant growth. Its capacity to retain water and nutrients is better than that of sandy, while its drainage, aeration and tillage properties are often favorable than those of clayey.

The clayey soils have high water and nutrients holding capacity, poor aeration, very slow drainage unless cracked, high to medium organic matter content, medium to high shrinkage and good sealing properties. These soils resist wind erosion and aggregated clays also resist water erosion. They are easily compacted, and thus, retard leaching of nutrients and pollutants.

2.2.3 Soil structure

Soil structure is defined as the arrangement of primary and secondary particles into a certain structural pattern. This arrangement results in the formation of different sized soil pores. Therefore, sometimes, soil structure is also defined as the arrangement of various sized soil pores into a certain structural pattern.

Soil structure as such is not a plant growth factor, but practically, it influences all plant growth factors such as water supply, aeration, availability of plant nutrients, microbial activity, root penetration, etc. Soil structure is affected by soil management practices such as tillage, cultivation and application of fertilizers, manures, amendments (liming, gypsum) and irrigation. Aggregation decreases the detachability and transportability of soil particles by water or wind, and thus, reduces the runoff and soil erosion.

2.2.3.1 Desirable soil structure

The desirable soil structure is one that results in highest crop production. The quality of soil structure can be expressed in terms of pore size distribution, aggregation and permeability.

a) Pore-size distribution

Suitable proportion of large (>0.06 mm), medium (0.06-0.01 mm) and small (0.01-0.0002 mm) sized pores are needed for higher crop production. Large sized pores serve aeration and infiltration, medium sized pores water conduction, and small pores storage of plant available water, while the hygroscopic water is held on surface of the soil particles and within the lattices of the expanding clays. In areas where sufficient water is available from rain or irrigation, the water storage pores (small pores) are not so important but aeration pores (large pores) are greatly required. In regions of restricted rainfall (dry land areas), the storage pores are very important and sufficient large pores are needed to ensure adequate infiltration capacity.

b) Aggregation

The aggregation of a soil should be such that can provide the pore distribution as described above, and they should be stable enough to retain their identities in spite of rainfall impact or temporary submergence. Aggregates of sand and gravel size are preferred. If such aggregates are water stable, the soil is said to be in good tilth. Silt sized aggregates are undesirable as the resulting pores cannot be drained by gravity, and the dispersed clay represents the most unfavourable structure.

c) Permeability

Soil structure should be such that the infiltration capacity may be large, the percolation capacity medium and air exchange not excessive but sufficient.

d) Cohesiveness

It is desirable that the individual peds are highly cohesive since this will protect them from destruction by rain drop impact or submergence. Cohesiveness of soil changes with moisture content. Soil should be in friable condition but not too loose since very loose soil suffers from excessive aeration. It does not provide enough contact between roots and soil and does not provide the plants sufficient support. Massively compact soil restricts aeration and root proliferation.

2.3 Soil Moisture Constants

Knowledge of the amount of water held by the soil at various tensions provides information regarding the amount of water available to the plants, the water that can be stored by the soil before percolation starts and the amount of water needed for irrigation. The relationship between the amount of soil water and the energy with which it is held (soil water potential) is a continuous function, and the plot of relationship between the two for a given soil is known as the *soil moisture retention curve*. Water held at specific water potential values are called *soil moisture constants*. These constants have been proposed in attempts to characterize a soil by a single number and to compare the retention capacity of different soils.

i) Saturation

When all pores in the soil are completely filled with water, the soil is said to be at saturation. At saturation, water in the soil is at zero tension or suction and majority of its pores are filled with water. The maximum water holding capacity of a soil is desirable in pot culture experiments as it provides a simple means of determining useful moisture level to be maintained for good plant growth. With medium textured soils in pots, the good plant growth is obtained at moisture level corresponding to 50-70% of the maximum water holding capacity.

ii) Available water

The available water or plant available water signifies the water held by a soil between 1/3 and 15 bar suction, i.e., between field capacity and the wilting point. The available moisture holding capacities of soils are presented in Table 2.3.1.

iii) Air dried soil

The term air dry soil designates the moisture condition when soil is in equilibrium with the atmosphere. It corresponds to -31 to -1000 bar depending upon the degree of saturation and temperature of the atmosphere. It is not an equi-potential. Soil moisture constants and their corresponding soil water potential have been shown in Fig. 2.3.

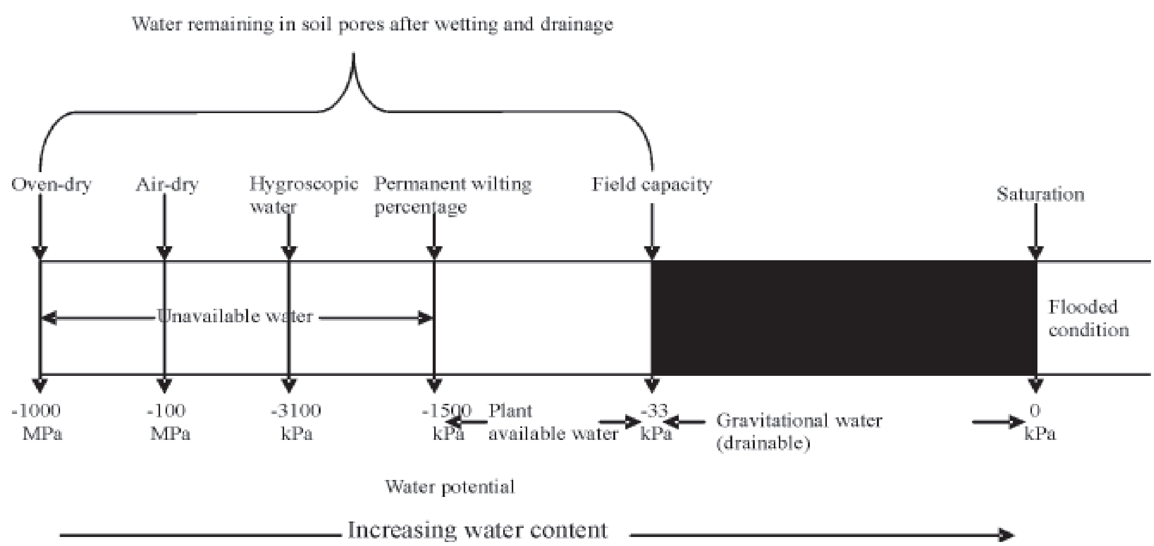

Fig. 2.3. Soil moisture constants and corresponding soil water potential

iv) Field capacity

When a saturated field soil is allowed to drain, soil moisture decreases with time. After 2 to 3 days, the moisture in surface layer attains a steady state. At this stage, the water retained in the soil is known as at field capacity. Thus, field capacity is defined as the amount of water retained in the soil after downward movement from a pre-saturated soil has materially ceased or practically zero. It is determined with the help of *pressure plate apparatus*. The matric potential corresponding to this moisture content is affected by soil texture, type of clay, organic matter, depth of wetting, the presence of impeding layers and evapo-transpiration. For these reasons, the concept of field capacity, being misleading, is generally abandoned by soil scientists. Generally, moisture percentage at 1/10 to 1/3 bar represents a measurable field capacity. Moisture percentage at 1/10 bar is more reasonable field capacity for coarse textured, while 1/3 bar for medium and fine textured soils. The field capacity is about 4% (by mass) in sandy soils, 45% in clayey soils and even up to 60% in some organic soils.

v) Wilting point

It refers to the soil moisture content at which plant roots can not extract water at a rate sufficient to meet the transpiration needs. At this moisture content, the plants lose cell turgidity and show symptoms of wilting. At this point, the plant can not regain turgidity even when placed in water saturated atmosphere. The matric potential corresponding to this moisture content is -15 bar (1 bar = 1000 cm of water column = 0.987 Atm) or pF of 4.18. Water retained by the soil at matric potential -15 bar can be estimated with the help of pressure plate apparatus. The wilting point is affected by both the plant species and the stage of plant growth. At wilting point, there is a layer of about 5-6 molecules of water around the particles which is an exceedingly thin. So, the soil structure has very little influence on moisture content at -15 bar and only texture plays the role. Concentration of salts in soil solution also has great influence on wilting point. Normally, the roots of a crop plant are extended to lower depths differing in moisture contents. Therefore, a plant can thrive in a soil which is dry at surface but has relatively higher moisture in lower depths.

Table 2.3.1 : Soil moisture constants and available water ranges of different soils

Soil texture	Field capacity		Permanent wilting point		Available moisture	
	(%)	(cm/m)	(%)	(cm/m)	(%)	(cm/m)
Sandy	9	15	4	7	5	8
	(6-12)*	(10-20)	(2-6)	(3-10)	(4-6)	(7-10)
Sandy loam	14	21	6	9	8	12
	(10-18)	(14-27)	(4-8)	(6-12)	(6-10)	(9-15)
Loam	22	31	10	14	12	17
	(18-26)	(25-36)	(8-12)	(11-13)	(10-14)	(14-19)
Clay loam	27	36	13	18	14	19
	(23-31)	(30-43)	(11-15)	(14-21)	(12-16)	(17-22)
Silty clay	31	40	15	20	16	21
	(27-35)	(34-46)	(13-17)	(16-23)	(14-18)	(18-23)
Clay	35	44	17	21	18	23
	(31-39)	(37-50)	15-19)	(18-25)	(16-20)	(19-26)

*Figures in parentheses are ranges

2.3.1 Water intake in soil

The movement of irrigation water from surface into and through the soil is called water intake. It is essentially an expression of infiltration and percolation.

i) Infiltration

Infiltration is the entry of water into the soil through its surface due to sorption and vertical flow through soil profile. The rate at which water enters into the soil is known as *infiltration rate*, i.e., volume of water entering into the soil per unit area per unit time. The process of infiltration is of a great practical importance as it determines the amount of runoff, helps in deciding the rate of irrigation to be applied and assesses the textural and structural conditions of soil surface and transmission characteristics of sub-surface soil layers.

Irrespective of soil texture, the infiltration rate reduces with time and attains a steady rate after a long lapse of time. The final steady rate is known as the *basic infiltration rate*. Infiltrability or infiltration capacity of soil is the maximum flux of water that enters the soil with free water ponded at the surface. The total amount / depth of water that infiltrates the soil in a given time is called as *cumulative infiltration*.

In addition to texture, the infiltration capacity also depends on vegetation (Table 2.3.2). The infiltration rate is classified as given in Table 2.3.3.

Table 2.3.2 : The effect of soil texture and vegetation on infiltration capacity

Texture	Infiltration capacity (mm/h)	
	Vegetated soil	Bare soil
Loamy sand	40-50	20-25
Loam	20-25	10-15
Silt loam	10-15	5-10
Clay loam	3-5	2-3

Table 2.3.3 : Classification of infiltration rate

Class description	Infiltration rate (mm/h)
Very rapid	>250
Rapid	125-250
Moderately rapid	60-125
Moderate	20-60
Moderately slow	5-20
Slow	1-5
Very slow	< 1

ii) Percolation

Percolation is the downward movement of water through the soil profile. It is same as the drainage. Percolation occurs predominantly in downward direction and infiltration can be considered as first stage of percolation. The downward flux of water below the maximum root zone depth is called *deep percolation*. It is unavoidable loss following irrigation which is more in coarser than in finer soils. Pressurized / micro-irrigation systems (sprinkler and drip) are very helpful in checking deep percolation loss as water application rate in these systems may be adjusted as per the hydraulic properties of soil and water requirement of the crops.

Percolation occurs when the soil water potential is greater than about 1 / 2 atmosphere as soil drier than this potential holds water with a force which is greater than the downward attraction force of gravity. Percolation is very important in soil development and land management. It removes the high salt content through leaching but removes valuable plant nutrients also. Since significant amount of water is lost through evaporation and transpiration processes, therefore, the amount of water that percolates through the soil decreases with depth. Further, during the active vegetative period, only small amount of water percolates from surface to the lower depths except in sandy soils. Classification of percolation rate is given in Table 2.3.4.

Table 2.3.4 : Classification of percolation rate

Class description	Percolation rate (mm/h)
Rapid	>150
Moderately rapid	50-150
Moderate	15-50
Moderately slow	5-15
Slow	1.25-5
Very slow	<1.25

iii) Seepage

Seepage is the downward and lateral movement of water into soil. Water seeps or leaks from a water source such as irrigation canal or a reservoir to the adjoining area. Such water may join the underground water table or may join the sub-surface flow to springs or streams or may appear as wet spot or seeps on the surface. Seepage rate depends on the wetted parameter of the reservoir or the canal and conductivity of the soil.

2.3.2 Water Retention by Soils

In an unsaturated soil, water is retained by the *forces of capillarity* and *adsorption*. The adsorption of water occurs through the hydration of dry soil matrix surface and exchangeable cations. Continued adsorption results in the formation of water rings at the points of contact of soil particles. With further intake of water, it gets into the soil pores where surface tension and radius of curvature of the air-water interface determine its distribution. The capillary concept is, therefore, often utilized to describe water retention in soil pores. In coarser soils, capillary action is more important than adsorption while the reverse is true in the finer soils. Water held by the soil is capable of movement and it is utilized by plants. When water supply is exhausted, soil gradually dries up from above to downwards.

2.3.3 Capillarity and Water Retention

The water rises in a capillary tube when it is partially immersed in water. If the tube is made of glass or quartz, water makes contact with the tube at an angle close to zero, and forms a concave air-water meniscus. Since the pressure at the water surface outside tube is the atmospheric pressure, water rises in the tube till the hydrostatic pressure of water column equals the pressure difference across the air-water meniscus. The hydrostatic pressure is actually equal to the height of water in the capillary tube, which is given by $\pi r^2 h \rho_w g$, where r is the radius of the capillary tube, h is the height of water, ρ_w is the density of water and g is the acceleration due to gravity. This downward force is balanced by the upward force due to surface tension which is estimated as $2\pi r\sigma\cos\theta$, where $2\pi r$ is the circumference of the capillary tube, σ is the surface tension and θ is the contact angle subtended by water with the glass tube.

At equilibrium the downward force will be balanced by the upward force as represented in the following equation :

$$\pi r^2 h \rho_w g = 2\pi r\sigma\cos\theta$$

From this equation, water height (h) can be determined by the following equation :

$$h = \frac{2\sigma\cos\theta}{r\rho_w g}$$

For water, θ being close to zero, cos θ may be taken as equal to unity and the above equation simplifies to the following equation:

$$h = \frac{2\sigma}{r\rho_w g} \quad \text{or} \quad h = \frac{4\sigma}{d\rho_w g}$$

where d is the diameter of capillary tube.

Considering $\theta = 0$, $\sigma = 72.75 \times 10^{-3}$ N m^{-1}, $\rho_w = 0.998$ Mg m^{-3} and $g = 9.81$ m s^{-2} at 20 °C, we get the simplified equation as:

$$h = \frac{0.297}{d} = \frac{0.3}{d}$$

Above equation can be used to estimate capillary or matric potential for a known pore size, or to calculate the diameter of the largest effective pore of a soil for which the capillary rise is known.

In soil, the capillary pores are not uniform in size. The variation in size of pores and the degree of saturation lead to air-water interfaces of varying radii of curvature, which also affect the matric potential by altering the pressure difference across the air-water interface. The relation of the curvature of an air-water interface to the pressure difference across the interface in given by the Laplace equation given below.

$$P_w - P_a = 2\sigma\left(\frac{1}{r_1} + \frac{1}{r_2}\right) = \frac{2\sigma}{r}$$

Where P_w and P_a are the pressure of water below and above air-water meniscus, respectively and r_1 and r_2 are the principal radii of curvature formed above and below the air-water meniscus. The mean radius of curvature r is positive if it lies within the water phase and negative if it lies in the gas phase.

2.4 Movement of Soil Water

Water is a highly dynamic component in soil system. It moves in all the three phases: solid, liquid and gaseous (vapour) phases. Under ordinary conditions, water movement in the soil does not occur in the form of ice or solid phase. Movement in solid phase is commonly occurring in the frozen soil where the formation of ice lenses makes the soil heave or swell and such movement occurs as part of a movement of the entire soil body. Movement in these soils is also believed to take place close to the clay surface. In a flooded or saturated soil, water moves in liquid phase, while in a partially dry or unsaturated soil, it moves in both liquid and vapour phases.

Liquid movement is of two types:

a) *Saturated flow:* When flow takes place under saturated conditions, flow is known as saturated flow. Most of the pores are filled with water and water in this condition is tension free. This occurs in the zone of groundwater and sometimes in the soil after heavy rains or during irrigation.

b) *Unsaturated flow:* When flow of water takes place under unsaturated condition, the flow is termed as unsaturated flow. Pores are partially filled with air and partially with water. The water is under tension.

Water vapour movement is of two types:

a) Diffusion: When water vapour move by diffusion as a result of vapour pressure (partial pressure) differences i.e. diffusion of water vapour.

The vapour pressure of soil moisture is affected by:

a. Moisture content—Vapour pressure increases with moisture content.

b. Temperature— Vapour pressure increases with temperature.

c. Soluble salts— Vapour pressure decrease with increase of soluble salt content.

b) Mass flow: When water vapor flow in a mass with the other gases of the system in response to difference in total pressure i.e. bodily movement of soil atmosphere. Mass flow can be caused by change in atmospheric pressure, change in soil temperature and pressure change cause by infiltration (compression) and by percolation (evacuation).

Mass flow of water vapour represents only a small portion of the entire water vapour movement in the soil.

In liquid and vapour phases, water movement is governed by the principles of fluid flow. In a flooded or saturated soil, water moves by gravity and the velocity of flow through soil pores increases with the height of water above it.

Poiseuille's Law states that flow of water through a narrow tube is directly proportional to the fourth power of its radius and pressure difference, and inversely proportional to the viscosity and length of tube and is given by the equation:

$$q = \frac{\pi r 4}{8\eta}\left(\frac{\Delta p}{L}\right)$$

where Δp is the pressure difference in dynes cm^2, r is the radius of tube in cm, L is the length of tube in cm and h is the coefficient of viscosity of the liquid in dynes-sec cm^2 (poise). This relation is true only when the flow is steady or streamline and pressure is constant along the cross-section of the tube.

Soil water movement will occur when there is a potential difference between different points in the soil system. The water moves from higher to lower potential.

All theories of flow of water in soils are based on early theories of fluid dynamics for flow of water through narrow capillaries or pipes. Early theories of fluid dynamics were based on the hypothetical concepts of a prefect fluid i.e. the fluid is frictionless and incompressible. In the flow of fluid, contacting layers can exhibit no shearing stress but only normal pressure. Such fluids do not in fact exist. In the flow of real fluids, adjacent layers do transmit tangential stresses (drag) and the existence of intermolecular attraction causes the fluid molecules in contact with a solid wall to adhere to it rather than slip over it. The flow of real fluid is associated with the properties of viscosity.

Saturated flow: When the soil pres are filled with water, the soil suction is negligible and the potential is made up of the gravitational and hydrostatic pressure terms. The theory of water movement in saturated soil is based on *Darcy's Law or its generalization, which states that the quantity of water crossing a unit cross-section of a soil in unit time is proportional to the hydraulic head gradient*.

$$v = -K\,i$$

Where v = flux velocity, K = hydraulic conductivity. This law was derived empirically in one dimension by Darcy.

Both types of flow are governed by Darcy's Law

Darcy's Law hold good under the following conditions:

- The fluid is incompressible, the medium is saturated, a steady state flow has been established,
- Temperature remains constant
- The flow is laminar.

In nature, the hydraulic head in most cases is such that the flow remains laminar. Hence, the law is considered valid in all soils except very sandy ones.

2.4.1 Soil Aeration

Soil aeration refers to the process of exchange of oxygen and carbon dioxide between the soil air and the atmospheric air. Soil aeration replenishes oxygen consumed during respiration of plant roots and microorganisms and prevents toxicity of carbon dioxide evolved during respiration (Fig. 2.4). Aeration porosity is used to describe aeration status of soil which is defined as the volume of pore space filled with air when soil is under a tension of 50 cm of water. At this tension, soil pores of sizes greater than 0.06 mm in diameter are filled with air.

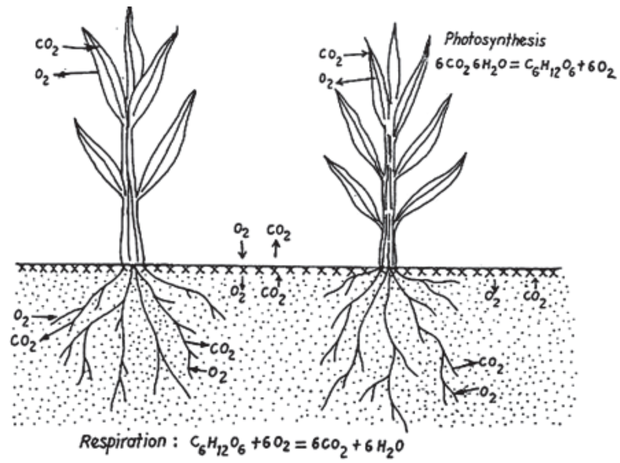

Fig. 2.4. Consumption of oxygen and production of carbon dioxide during respiration by roots and microbes

2.4.2 Characterization of Soil Aeration Status

Soil aeration status may be characterized by various methods including composition of soil air, air-filled porosity, carbon dioxide released, air-permeability, diffusion coefficient, redox-potential and oxygen diffusion rate. The oxygen diffusion rate (ODR) is the best method of measuring soil aeration. The ODR is the rate at which oxygen can replenish when it is used by respiring plant roots or by microorganisms. The instrument used to measure ODR is known as ODR meter. The instrument consists of a small platinum electrode and a standard calomel electrode. These electrodes are inserted into the soil to a desired depth. The calomel electrode is connected to the galvanometer which is connected to the positive terminal of an external source of direct current. Its negative terminal is connected to the platinum electrode. The out put electric current is related to the rate of oxygen flux at the electrode surface and given by the equation :

$$i \times 10^{-6} = nFA\,ö \qquad (1)$$

Where, i is the electric current in microamperes, n is the number of electron required for the reduction of one molecule of oxygen which is 4, F is the Faraday's constant, A is the surface area (cm^2) of platinum electrode and ö is the flux or ODR to the electrode surface in number of molecules of oxygen per second per cm^2. The ODR is calculated by equation (1) as:

Oxygen diffusion rate (ODR) =

$$= \frac{0.497\times10^{-8}\times i}{A} \text{g cm}^{-2}\text{min}^{-1}$$

The ODR has a critical importance to growing plants. Growth of most plants roots ceases when ODR drops to 20´10^{-8} g cm^{-2} min^{-1}. The growth of plant is normally satisfactory as long as the ODR remains about 30-40x0^{-8} g cm^{-2} min^{-1}. The requirement of ODR of some crops is given in Table 2.4.1.

Table 2.4.1 : Critical oxygen diffusion rate (ODR) for different crops

Crop	ODR (10^{-8} g cm^{-2} min^{-1})
Maize	30.0
Soybean	28.4
Wheat (unirrigated)	26.9
Wheat (irrigated)	26.3
Peas (Unirrigated)	32.9
Peas (irrigated)	39.5
Toria	22.9

The ODR decreases with the depth of soil and the decrease is sharp for the soils in which the concentration of oxygen is lower at soil surface. It also decreases as the moisture content increases.

2.5 Soil–Plant–Water Relationships

The judicious and efficient use of water for irrigation in agriculture needs thorough knowledge of soil-plant-water relationships. In soil-plant-atmosphere system, the integrated approach for water management helps in selection of suitable crops and varieties, improvement in crop yields and water use efficiency. The atmospheric demand for evapo-transpiration of water during the crop season depends on geographical location. Therefore, it is highly variable and area specific, and mainly determined by weather parameters such as temperature, relative humidity, radiation, rainfall, wind speed, etc.

Every plant process is affected directly or indirectly by the water supply. The metabolic activity of cells and plants is closely related to their water content. Water acts as a solvent in which gases, mineral and other solutes enter plant cells and move from cell to cell and tissue to tissue within the plant. Water is a reagent in many physiological processes including photosynthesis and hydrolytic such as hydrolysis of starch to sugar. Decreasing water content is accompanied by a loss of cell turgor and wilting, cessation of cell enlargement, closure of stomata, reduction of photosynthesis and interference with many basic metabolic processes. Eventually, continued dehydration causes disorganization of the protoplasm and death of most organisms.

Factors which influence the water relations of plants, and thus their growth and yield responses, includes: i) soil (soil moisture content, texture, structure, density, salinity, fertility, aeration, temperature and drainage), ii) plant (type of crop, density and depth of rooting, rate of root growth, aerodynamic roughness of the crop, drought tolerance etc.), iii) weather (sunshine, temperature, humidity, wind and rainfall) and iv) management factors (soil volume and plant spacing, soil fertility, and crop and soil management).

$$\frac{i\times60\times32\times10^{-6}}{4\times96500\times A}$$

2.5.1 Soil-Water Relations

Soil supplies water to plants and weather parameters controls the demand of water for various agro-physiological processes in the plants. Thus, soil-plant-water relationships are mainly related to the properties of soil and plants that affect the movement, retention and use of water. The rate of entry of water into the soil and its retention, movement and availability to plant roots are affected by the amount and size distribution of the soil pores. The amount of water present in soil is not very useful unless the soil water potential is known as far as the water availability to plants is concerned. The amount of water which may represent saturation in sandy soil might be below the permanent wilting point in a clay soil (Table 2.5.1). The available water capacity of medium textured soils is greater than light and heavy textured soils. Heavy textured soils have poor aeration under more wet conditions. Hence, in light and very heavy textured soils, shallow and frequent irrigations are more beneficial to avoid deep percolation and waterlogging.

Table 2.5.1 : Water content of different soils at -30 and -1500 kPa matric potentials

Soil type	Gravimetric moisture content (%)	
	- 30 kPa	-1500 kPa
Sand	4.6	1.6
Fine sandy loam	12.6	5.5
Loam	19.1	8.0
Clay loam	40.2	21.0
Clay	45.1	26.2

Apart from texture, soil structure also affects the amount and size distribution of pores in soils, thereby influences the movement and retention of water, soil aeration, and penetration and development of roots. Unlike soil texture, which is more or less constant, the structure is highly dynamic and may change in response to natural conditions, biological activities and management practices. In an ideal soil, the total pore space should almost be equally divided between non-capillary and capillary pores. Non-capillary helps in movement of water in the soil profile, penetration and development of roots, whereas, capillary pores are mainly responsible for retention of water in the soil and its availability to plant roots. Generally, sandy soils drain almost completely at low tension due to the presence of non-capillary pores (larger sized pores), but fine-textured clay still hold a considerable amount of moisture even at such high tension that plant growing in the soil may wilt due to the presence of large pore volume in capillary pores. When the tension is increased from -10 to -30 kPa in sandy soil, more than 50% of the available water is released. The energy of water (soil water potential) is decreased mainly due to the interaction of water and soil particle surface, and the solubility of salts in the soil.

The major force in driving water in saturated soil is gravity and naturally, most of it is directed down ward. Lateral movement also occurs mainly due to matric potential. In unsaturated soil, the movement of water is a function of soil moisture content. At moisture contents below field capacity, the unsaturated hydraulic conductivity (capillary conductivity) is so low that water movement is of little or no significance in relation to plant growth. Movement of unsaturated flow ceases at a lower tension in sand than in finer textured soils as the water films lose continuity sooner between the larger particles. The wetter the soil, the greater is the conductivity for water. In the 'moist range', the range of unsaturated flow in sand soil is less than loam followed by clay soil but a reverse is true under satu-rated flow. However, in the 'wet range' the unsaturated conductivity occurs in the same or similar order as saturated conductivity.

At a soil moisture potential of -1500 kPa, the continuity of the liquid films is broken and water moves only in vapour form. Diffusion of water vapour is caused by a vapour pressure gradient. The vapour pressure of soil moisture increases with the increase in soil moisture content and temperature, it decreases with the increase in soluble salt content. Water vapour movement is significant only in the 'moist range'. In the wet range vapour movement is negligible because there are few continuous open pores. In the 'dry range' water movement exists, but rate of movement is very low due to little water in the soil. The major force, direction and the rate of water movement in saturated, unsaturated and vapour flow is summarized in Table 2.5.2.

Table 2.5.2 : Saturated, unsaturated and vapour flow of water in soil

Particular	Saturated	Unsaturated	Vapour
Major force	Gravitational	Metric	Vapour pressure
Water form	Liquid	Liquid and vapour	Vapour
Major direction of flow	Downward	Lateral	All directions
Pore space	All pores filled	Micro pores filled	All pores empty
Rate of flow	Fast, (1-100 cm / day)	Slow, (0.01-0.00001 cm / day)	-
Vol. of water movement	Large, 375 m^3 / ha in 15 cm depth	Small, 100 m^3 / ha in 15 cm soil depth)	Negligible

Soil water potential ($Ø_{soil}$)

Water potential is a measure of the capacity of water at a point in an equilibrium (soil-water or plant water) system to do work as compared to the work capacity of pure free water at the same temperature and pressure. The principal forces which contribute to the soil water potential are those associated with soil matrix (matric potential, $Ø_m$), osmotic characteristics of the soil solution (osmotic potential, $ø_ð$), the total pressure (pressure potential, $ø_p$) and external force field (gravita-tional potential, $ø_g$). Thus, the soil water potential ($ø_{soil}$) comprise of :

$$Ø_{soil} = ø_m + ø_ð + ø_p + ø_g$$

In normal soils, the major component of soil water potential is associated with the soil structure and characteristics of the soil matrix ($ø_m$) while in salt affected soils, in addition to $ø_m$, osmotic forces associated with the soil solution also constitute a major component of $ø_ð$. Solutes lower the vapour pressure of the soil water and decrease its free energy or water potential (Table 2.5.3). The energy status of water is drastically reduced in highly saline conditions, particularly at low soil water content Therefore, in salt affected soils heavy and / or frequent irrigation is required to maintain low solute concentration in the root zone soil for proper growth of plants (Singh, 1993).

Table 2.5.3 : Components of $Ø_{soil}$ at low and high salinity levels in silty loam soil

Soil water content (v/v, %)	Low salinity			High salinity		
	Matric	Solute	Total	Matric	Solute	Total
37	-0.105	-0.100	-0.205	-0.105	-5.00	-5.10
20	-15.00	-0.185	-15.20	-15.00	-9.25	-24.25

Soil moisture is always being subjected to pressure gradients and vapour pressure differences cause it to move. Thus, soil moisture cannot be said to be constant at any pressure and the amount of available water varies in different soil textural groups (Table 2.5.4). For irrigation system design, the total available water is calculated for a soil depth based on the root system of a mature crop plant to be grown.

Table 2.5.4 : Range of available water holding capacity of soils

Soil type	Gravimetric moisture content (%)		Depth of available water (cm/m soil depth)
	Field capacity	Permanent wilting point	
Fine sand	3-5	1-3	2-4
Sandy loam	5-15	3-8	4-11
Silt loam	12-18	6-10	6-13
Clay loam	15-30	7-16	10-18
Clay	25-40	12-20	16-30

2.5.2 Plant-Water Relations

The total quantity of water required for the essential physiological func-tions of the plant is usually less than 5% of all the water absorbed. Most of the water entering the plant is lost in transpiration. However, failure to replace the water lost by transpiration results in the loss of turgidity, cessation of growth, and eventual death of the plant. The main areas of plant-water relationship are water absorption, water conduction and translocation, and water loss or transpiration. These processes are responsible for uptake of plant nutrient, creation of energy gradient and ultimately all the metabolic and physiological activities in the plant.

Plant water potential ($\O_l$)

The plant water potential or leaf water potential at any point in the system can be partitioned into:

$$\O_l = \o_{\eth} + \o_p + \o_m + \o_g + \o_i$$

Except in very dry tissue or in cells with small vacuoles, the matric potential ($\o_m$) is very small relative to osmotic potential ($\o_{\eth}$) and turgor potential ($\o_p$). The gravitational potential ($\o_g$) is usually very small for crop plants and is considered mainly in trees where a vertical change of 10 m affects the $\o_g$ by approximately 100 kPa. The $\o_i$ is the interaction of above explained components of total water potential is also very small in most of the crop species, hence it can be neglected and than :

$$\O_l = \o_{\eth} + \o_p$$

Assuming no change in cell volume the relationships can be:

$$\O_l = \o_{\eth} + \o_p$$

0 = - 20 + 20 bars, turgid

- 10 = - 20 + 10 bars, partially turgid

- 20 = - 20 + 0 bars, flaccid or wilted

2.5.2.1 Plant structure

Morphologically a plant consists of roots, stem and leaves. The leaves are born throughout the stem in all the plants and are mainly responsible for the loss of water. Similar variation in plant water relations among different species and between surfaces also exist. The internal structure of a typical leaf in Figure 2.5.1 shows that the surface has small pores surrounded by two cells. These pores are called stoma and the cells surrounding them are called guard cells.

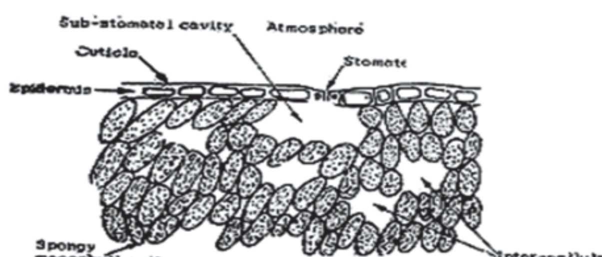

Fig. 2.5.1 Portion of a leaf cross-section adjacent to stomata.

The stomata regulate the loss of water as vapours and exchange of carbon dioxide in the leaf and other organs. The leaves maintain their continuity of structure with the stem which has conducting tissues called xylem, the main channels of water transport, and phloem. The stem maintains its continuity with the root, which eventually is in contact with the soil. The outer-most cell of the root usually gets elongated into a long hair which has its continuity with the remaining cells. Other epidermal cells are also capable of absorbing water but the root hair pro-vides the advantage of exploring more area because of its enlarged surface. Thus, a large number of root hairs draw moisture from their vicinity and supply water to the cortex.

2.5.2.2 Rooting characteristics and moisture use

The amount of soil moisture that is available to a plant is determined by the moisture characteristics of the soil, the depth to which the plant roots extend and the proliferation of the roots. Little can be done to alter soil moisture availability. Greater possibilities lie in changing the plant characteristics, enabling it to extend its rooting system deeper into the soil, thereby enlarging its reservoir of water. Plants vary genetically in their rooting characteristics (Table 2.5.5). Vegetable crops, such as onions and potatoes, have a sparse rooting system and are unable to use all the soil water within the root zone. Forage grasses, sorghum, maize and such other crops have very fibrous, dense roots. Lucerne has a deep root system. Perennial plant has already established root depth, and needs only to extend its small roots and root hairs to utilize the entire amount of available soil water.

Table 2.5.5 : Effective root zone depth of common crops in well drained soil

Shallow (60 cm)	Moderately deep(90 cm)	Deep (120 cm)	Very deep (180 cm)
Rice	Wheat	Maize	Sugarcane
Potato	Tobacco	Cotton	Citrus
Cauliflower	Castor	Sorghum	Coffee
Cabbage	Groundnut	Pearl millet	Apple
Lettuce	Muskmelon-	Soybean	Grapevine
Onion	Carrots, Chilli	Sugar beet	Safflower
	Pea, Bean	Tomato	Lucerne

Moisture extraction pattern within root zone: The moisture extraction pattern is the relative amounts of moisture extracted from different depths within the root zone. About 40% of the total moisture used is extracted from the 1st, 30% 2nd, 20% 3rd and only 10% from the last quarter of the root zone (Fig. 2.5.2). So to have a fair estimate of the soil moisture status, it should be measured at different depths within the root zone.

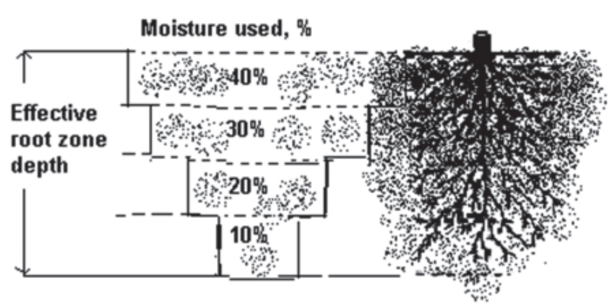

Fig. 2.5.2 Moisture-extraction pattern of plants under adequate soil moisture

2.5.2.3 Development of crop water deficit: The internal water balance or degree of turgidity of a plant depends on the relative rates of water absorption and water loss, which is influenced by the complex of atmospheric, soil and plant factors (Zhuang *et al*, 2000). Water stress causes changes in metabolism of plants, decreasing physiological processes, leaf area, cell size and inter-cellular volume and at certain critical stages of plant growth causes more injury than at other stages. During recovery from stress when the water deficit in the tissues is being replenished, losses from transpiration will be less than gains and the absorption lag will be -ve. During the transition period between the development of deficits in the morning and afternoon recovery period, the water potential of vascular and surrounding tissues approaches equilibrium, as does transpiration and water uptake *i. e.* there is little or no absorption lag by the roots (Ludlow and Muchow, 1990). All actively transpiring plants, therefore, experience some degree of short-term water deficits, regardless of how well they are supplied with water. In contrast to steady decline in soil water potential, the leaf exhibits marked diurnal fluctuations in water status as the evaporative demand varies during day and night (Ellsworth, 1999). The essential nature of water movement through the soil-plant-atmosphere systems, particularly the development of plant water deficits grown in soil allowed drying from a fully saturated to the point of wilting on a diurnal time scale is shown in Figure 2.5.3.

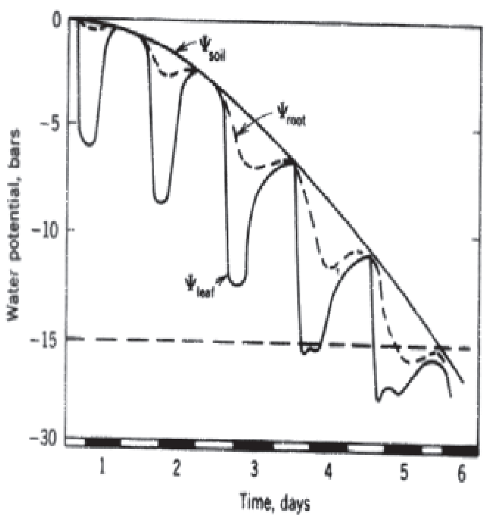

Fig. 2.5.3 Probable changes in $ø_{leaf}$ and $ø_{root}$ of a plant (Slatyer, 1967)

The rate of photosynthesis goes on decreasing with the progressive increase in moisture stress, reaching almost to compensation point at midday when $Ø_l = ø_{ð}$. The leaf attains zero turgor at this point, which causes wilting of leaves. The values $ø_l$ for CO_2 compensation point for several crops are summarized in table 2.5.6. Though the loss of leaf turgor is a major cause for stomatal closure but it is not a sole cause for stomatal response to water deficit (Turner, 1997). In controlling stomatal conductance in sorghum $ø_{soil}$ and $ø_p$ were equally important, but the $ø_{soil}$ in pearl millet and $ø_p$ in maize were the dominating factors in regulating the stomatal conductance (Singh and Singh, 1995).

2.5.3 Water Movement along Soil – Plant - Atmosphere System

The complete path of water from the soil→plant →atmos-phere forms a continuous system, which may be divided into four sequential processes. i) supply of liquid water to the root surface, ii) entry of water into the root, iii) passage of water in the conducting ele-ments and iv) movement of water vapour through and out of the leaves. The rate of water movement is proportional to the potential gradient and inversely proportional to the resistance to flow. The difference in total water potential in the soil-plant-atmosphere system could generate a driving force for water movement from the soil through the plant to atmosphere. On an average, the $ø_{soil}$ varies between - 0.1 to – 20, $ø_{leaf}$ between - 5.0 to - 50 and $ø_{atms}$ between - 1000 to - 2000 kPa (Bharmabe *et al*, 1999). If this continuum is broken, the driving force would automatically disappear.

Table 2.5.6 : Leaf water potential at which net photosynthesis is zero (Singh *et al*, 1991)

Crop	Cultivar	Growth stage	$ØØø_l$ (±2kPa)
Wheat	WH-147	Anthesis	- 42
Barley	BG-25	Anthesis	- 46
Chickpea	H-355	Pod initiation	- 30
Mustard	Parkash	Flowering	- 43
Pearl millet	BJ-I04	Heading	- 40
Cluster bean	FS-277	Pod initiation	- 30
Green gram	T-44	Flowering	- 16

Water movement in soil-plant atmosphere (SPA) is proportional to the driving force between evaporating surfaces and is inversely proportional to the various resistances in the pathway. Plants can extract water from the soil only when their water potential is lower than that in the soil. This potential difference or water potential gradient between the evaporating tissues of the plant and the soil water in the root zone increases with the evaporative demand and liquid flow resistances in the pathway.

The rate of water movement (flux) in soil-plant-atmosphere system :

$$\text{Flux} = \frac{Ø_{soil} - Ø_{root\ surface}}{r_{soil}} = \frac{Ø_{root\ surface} - Ø_{xylem}}{r_{root}} = \frac{Ø_{xylem} - Ø_{leaf}}{r_{xylem} + r_{leaf}} = \frac{Ø_{leaf} - Ø_{air}}{r_{leaf} + r_{air}}$$

Resistance to water movement in the soil (r_{soil}) is governed by its hydraulic conductivity, water content and path length. Water movement in the plant can be considered in two phases, i.e. the liquid phase from the root surface to the mesophyll cell, and the vapour phase from the surface of the leaf mesophyll cell to the stomatal pores. The resistances to flow are relatively low in the liquid phase, being highest in the roots (at the endodermis), intermediate in the leaves and lowest in the stems. In actively growing plant in a steady state in moist soil, the water potential at various points along the pathway are given in Table 2.5.7.

Table 2.5.7 : The water potential at different points in soil-plant-atmosphere system

Location	Potential (kPa)
Soil 1 cm from root	- 3
Soil adjacent to root	- 5
Xylem of root near ground surface	- 6
Xylem in leaf	- 7
Cell wall of leaf mesophyll cells	- 8
Air just inside stomata at 20°C and 95 % R.H.	- 69
Air just outside stomata at 20°C and 50 % R.H.	- 701
Air outside atmosphere at 20°C and 50 % R.H.	- 960

The transformation of water from the liquid to the gaseous phase requires energy, which comes from the solar radiation falling upon the leaf. There are several resistances to water movement from within the leaf to the external atmosphere but the most important are stomatal resistance and the resistance to diffusion through boundary layer of still air around the leaf.

a) Evaporation

Evaporation is a diffusive process by which water in the form of vapour is transferred from the underlying natural surfaces, such as open water, bare soil or vege-tative cover to the atmosphere. The essential requirements in evaporation process are: i) source of heat to vaporise the liquid water, and ii) presence of a gradient of concentration of water vapour between the evaporating surface and the surrounding air. The source of energy for evaporation may be solar energy, the air blowing over the surface or the underlying surface itself. The energy required for evaporation, regardless of the surface where evaporation is taking place is 540 calories per gram of water evaporated at 25^0C. Evapo-ration can, however, occur only when the vapour concentration at the evaporating surface exceeds that in the overlying air (Zhuang *et al*, 2000).-- Evaporation from the land surface is depends mainly on the degree of saturation of soil surface, temperature of air and soil, humidity and wind velocity. Several of these factors are greatly influenced by the vegetative cover. At high moisture contents, evaporation from land surfaces is nearly equal to that from free water surface. At lower moisture level, evaporation may decrease in proportion to the water content in the soil.

b) Transpiration

Transpiration is the process by which water vapour depart the living plant body and enters the atmosphere. It involves continuous movement of water from the soil into the roots, through the stem and out through the leaves to the atmosphere. The process includes *cuticular transpiration*, or direct evaporation into the atmosphere from moist membranes through the cuticle and *stomatal transpiration*, or outward diffusion into the atmosphere, through the stomata and lenticels. The rate of transpiration depends on the supply of energy to vaporise water, the water vapour pressure or concentration gradient in the atmosphere, which constitutes the driving force, and the resistances to diffusion in the vapour pathway. Transpiration is influenced by: i) climatic parameters viz., light intensity, atmospheric vapour pressure, temperature, and wind speed, ii) the plant features viz., the extent and efficiency of root systems in moisture absorption, the leaf area, leaf arrangement and structure, and stomatal behaviour and iii) the capacity of the soil to supply water plant roots (Bharambe *et al*, 2002).

Water use by crops or summation of evaporation and transpiration are combined into one term evapo-transpiration (ET), as it is difficult to separate these two losses in cropped fields. The term consumptive use is used to designate the losses due to evapo-transpiration and the water that is used by the plant for its metabolic activities. Since the water use in the actual metabolic processes is insignificant (less than 1 % of ET), the term consumptive use is generally taken equivalent to ET. Usually a close relationship exists between net incoming solar radiation and evapo-transpiration.

References

Bharmabe, P.R., Oza, S.R., Jadhav, G.S. and Shelke, D.K. 1999. Effect of irrigation layouts on soil plant water relationship and water use efficiency of safflower. Journal of Indian Society of Soil Science. 47: 396-400.

Bharmabe, P.R., Shelke, D.K., Oza, S.R., and Vaishnava, V.G. 2002. Effect of irrigation levels on spatial moisture distribution, soil plant water relationship and water use efficiency of cotton under drip irrigation. Journal of Indian Society of Soil Science. 50: 303-305.

Ellsworth,D.S. 1999. The CO_2 enrichment in a maturing pine forest: are CO_2 exchange and water status in canopy affected. Plant Cell and Environment. 22: 461-472.

Ludlow, M.M. and Muchow, R.C. 1990. A critical evaluation of traits for improving crop yield in water limited environments. Advances in Agronomy. 43: 107-153.

Singh, B.R. and Singh, D.P. 1995. Agronomic and physiological response of sorghum, maize and pearl millet to irrigation. Field Crops Research. 42: 57-67.

Singh, D.P. 1993. Soil plant atmospheric water relations and irrigation management. In: Important aspects of on-farm water management (Eds. D.P.Singh and H.C.Sharma).CCS Haryana Agricultural University, Hisar. pp 109-131.

Singh, P., Singh, D.P., Kumar, A. and Chaudhary, B.D. 1991. Pattern of soil water use in oilseed brassica and chickpea under dryland conditions. In: Recent advances in dryland agriculture. (Eds. Somani et.al). Scientific Press. Jodhpur. pp 167-173.

Slyater, R.O. 1967. Plant water relationship. Academic Press, New York. pp 366

Turner, N.C. 1997. Further progress in crop water relations. Advances in Agronomy. 58: 293-338.

Zhuang, J., Yu, G., Nakayama, K. and Urushisaki, T. 2000. Environmental dependence of sap flow of maize. Technical Bulletin of Faculty of Horticulture, Chiba University. Vol.54: 53-64.

3.0 WATER REQUIREMENT AND IRRIGATION SCHEDULING

Rajbir Singh, B.S. Yadav and Satyendra Kumar

Land and water are the basic natural resources in agriculture and efficient utilization of these resources in crop production is very important. The demands for these resources are continuously escalating due to increasing population. The drastic increase in population and improvement in standard of living and also increasing water demand towards industries, the water availability in agriculture sector with passage of time is declining at faster rate. Hence in agriculture sector, the available water can be utilized effectively for crop production by various approaches without further depletion.

3.1 Water requirement

Water requirement (WR) of a crop is the quantity of water required by crop at a given period of time for its normal growth under field conditions at a certain place which may be supplied by precipitation or by irrigation or by both Water is needed mainly to meet the demands of evaporation (E), transpiration (T) and metabolic needs of the plants, all together known as consumptive use (CU).

CU = E+ T + water needed for metabolic purposes

Water use in the metabolic activities of plant is negligible and often less than one percent of the quantity of water passing through the plant. Evapotranspiration is, therefore, considered as equal to consumptive use. Different losses like percolation, seepage, runoff etc., occur during transport and application of irrigation water. Water is needed for special operations such as land preparation, transplanting, leaching etc. Water requirement of a crop (WR), therefore, includes evapotranspiration, application losses and water needed for special purposes.

WR = ET + application losses + water for special purposes

The sources of WR are irrigation + effective rainfall (ER) + soil moisture depletion (SMD). Therefore, field irrigation requirement (IR) = WR–(ER + SMD).

Water requirement is a demand whereas the supply consists of contribution from irrigation water, effective rainfall (ER) and soil profile contribution including that from shallow water table. The water requirement may be assessed as:

WR (mm) = {Et_o x K_c (C, T, F) - ER (R, ET_a, S) +T_i} / E

where, WR = Gross water requirement; ET_o= Reference crop ET; K_c = Crop coefficient (C-crop type, T= stage of crop development, F= frequency of soil wetting), ER= Effective rainfall, R= rainfall, ET_a= actual ET, S= soil moisture storage factor),T_i = Technical irrigation (pre-irrigation), E= Irrigation efficiency

ET_a is based on assumption that it is directly related to ET_o. K_c is the proportion between ET_a and ET_o and is a function of crop and its growing stage. In the initial crop stage, when level of coverage is very small, the K_c is independent of the crop and is only a function of wetting frequency (F) and ET_o. ER is estimated by ET- RF ratio. Mean effective rainfall is a function of monthly RF, the actual ET (ETa) and the effective moisture storage in the soil (S).

3.1.1 Irrigation requirement

Irrigation requirement is the total amount of water applied to a field to supplement rainfall and soil profile contribution to meet the water needs of crops for optimum growth.

Irrigation requirement = WR – (ER + S)

The net irrigation requirement is the total amount of irrigation water just required to bring the soil moisture content in the root zone depth of the crops to field capacity. Thus the net irrigation requirement is the difference between field capacity and soil moisture content in the root zone before irrigation. Gross irrigation requirement is the total of net irrigation requirement and other losses such as conveyance, distribution and application.

a) Net irrigation requirement (NIR)

$$NIR = \frac{(M_{fc} - M_{bi})}{100} \times D_b \, D$$

Where, NIR = Net irrigation reqirement (cm)

M_{fc} = Moisture content at field capacity (%)

M_{bi} = Moisture content before irrigation (%)

D_b = Bulk density of the soil (g / cm^3)

D = Depth of soil (cm)

b) Gross irrigation requirement (GIR)

Gross irrigation requirement is the net irrigation requirement plus losses in water application and other losses. It is the total amount of water applied through irrigation.

$$GIR = \frac{\text{Net irrigation requirement}}{\text{Field efficiency of system}}$$

3.1.2 Water requirement of crops

The water requirement of crops during complete crop growth periods varies from soil types, duration of crops, evaporative demand of crops and management practices. The water requirement of the major crops, being grown in different location is given below for reference (Table 3.1).

Table 3.1 : Irrigation guide for important field crops

Crop	Irrigation scheduling criteria		Irrigation			Critical stage
	IW/CPE ratio	Others	Depth (cm)	Number	Requirement (cm)	
Rice		1-5DDPW	5±2	8-26	49-129	PI, flowering
Wheat	0.8-1.5(0.9)	For dwarf	4-7	4-8	30-52	CRI, Flowering
		For tall	7-8	3-4	25-30	Tillering , Flow.
Cotton	0.7-0.9		3-8	2-9	24-64	Flow., boll form.
Sugarcane	o.6-0.9	50 % DASM	6-10	5-20	60-200	Shoot elong. tillering
Sorghum	0.8-1.25	45-55%DASM	6-8	1-8	8-48	Flow., priomordial init.
Maize	0.75-1.2		5-8	3-6	24-48	Tasseling, silking
G. nut	0.4-0.9	50-75%DASM	5-8	2-8	15-50	Peg. ,pod filling
Sesamum	0.5-0.9	60-75% DASM	5-8	1-5	8-30	Flow. Seed setting
Gram	0.4-0.8	50-75%DASM	6-8	1-4	8-24	Flow., pod formation
Pigeon pea	0.25-0.9		6-8	1-4	8-30	Flow. initiation
Potato	1.0-1.2		3-6	6-9	30-45	Stolonisation, tuber formation
Sunflower	0.8-1.05	40-50%DASM	5-8	2-6	15-20 seed set.	Flow bud init.,
Soyabean	0.4-0.8		5-6	3-7	18-35 set.	Flow.init., pod
Greengram / black gram	0.6-0.9	80-300mm CPE	5-8	2-4	15-30	Flowering
Sugar beet	0.60	0.2 bar	4-5	8-10	40-50	Root init. and develop.
Jute		50-60%DASM	6-8	1-3	8-20	
Rapeseed, mustard	0.6-1.05	75%DASM	6-8	1-4	8-24	Flow. Initiation, pod. Form.

Source: Fifty Years of Agronomic Research In India (Edit. R.L.Yadav et al.1998), Publ. Indian Society of Agronomy, New Delhi

3.1.3 Factors affecting irrigation water requirements: The factors which affect evaporation and transpiration ultimately influence the irrigation water requirements of crops. Five main factors are **i) climatic** viz., temperature, relative humidity, sunshine and wind, **ii) soil** viz., texture, hydraulic conductivity, water holding capacity, bulk density, salt content and depth of soil, **iii) plant** viz., growing period of crop, crop coefficient (Kc), root depth, stress sensitivity, critical stage of the crop, cropping pattern; **iv) irrigation waters** viz., source, amount, quality and **v) management** viz., irrigation methods; cultural practices, fertilization, irrigation technologies, on-Farm irrigation efficiencies, and leaching and other special requirements.

3.2 Irrigation scheduling

Irrigation scheduling is a systematic method of deciding the quantity and timing of irrigation commensurate with crop needs, soil moisture holing capacity, water application procedure and the availability of water supplies. It helps the irrigator to decide on when and how much water to apply for maximizing crop yields and efficiency of water use. The basic objective of irrigation scheduling is to make available the correct amount of water for the biological processes of plants at appropriate time by applying the exact amount of water needed to replenish the soil moisture to the desired level. Irrigation scheduling becomes particularly sensitive under scarce water supplies where water shortage requires a refined timing of water application in order to minimize yield reductions.

Criteria most suitable for scheduling irrigations vary from one situation to another. Planning optimum irrigation schedules requires information on as to when and how much water stress occurs for a given set of conditions. Similarly, under saline conditions knowledge of water yield function and salt tolerance levels of plants is needed. Where water is scarcer or expensive, irrigation should be planned to maximize water productivity but where good land is scarcer than water, it be planned to obtain maximum production per unit of area. Several other factors such as: i) soil hydraulic properties, depth, salinity and nutrient status of root zone, ii) ground water level, iii) method of water application, vi) availability and quality of water vii) weather conditions, viii) plant characteristics and ix) other specific needs such as crop cooling, frost protection etc. must be considered. It should complement in favour of enhancing the efficiencies of other applied inputs. Its planning must be in such a way that the efficiencies of other applied inputs get enhanced.

3.2.1 Advantages of Irrigation Scheduling

- Enables the farmer to schedule water rotation among the various fields to minimize crop water stress and maximize yield.
- Helps to lower water losses and minimize waterlogging problems.
- Enhances the efficiencies of other applied inputs viz., fertilizers, pesticides, weedicides etc.
- Help to reduce energy and labour requirement by avoiding over-irrigation.
- Helps in maintaining soil health.
- Water saved can be used to irrigate additional area.
- Increase net profits by increasing crop yields and quality.

3.3 Irrigation Scheduling Criteria

All irrigation scheduling procedures consists of monitoring indicators that determine the need for irrigation. Various indicators are used to assess irrigation needs, including soil moisture measurement, plant indicators and climatological indices. Accordingly, the various approaches of irrigation scheduling may be classified as

- Soil water status approach
- Climatological approach
- Plant parameters' approach
- Simulation modeling approach

3.3.1 Soil water status approach

The amount of water to be applied on each irrigation depends upon the capacity of the soil to store and supply water. Soil may contain large amount of water but the water stored between field capacity (upper limit) and wilting point (lower limit) is the available water for plant growth. Three concepts relating soil water to plant response are in existence, each of these may apply under certain conditions. In the first concept soil water is considered equally available over the entire range between upper and lower limits. As per the second concept, the soil water availability gradually decreases from upper to the lower limit of available water. The third concept is based on the existence of critical soil moisture level within the available soil moisture range below which yield reduction is significant. The point at which this condition is reached depends on weather, plants and soil. Irrigation is, therefore, needed when this lowest limit of optimum water regime is reached and it is considered as the most opportune time for irrigation. Based on soil water status, irrigations can be planned by monitoring either soil water depletion or soil moisture tension.

i) Soil water depletion

Irrigations are scheduled based on depletion of available water from effective root zone of the crops. In this approach periodical determination of soil water content in the root zone is made to know the time when the available soil water depletion reached the critical level. For semi arid regions as encountered in northern India, the optimum allowable depletion of available moisture in the root zone for maximum yield of major crops is given in table 3.2.

Table 3.2 : Allowable water depletion in medium textured soils

Crop	Allowable water depletion (%) at different crop growth stages			
	Initial	Development	Mid	Late
Wheat (dwarf)	40-50	40-60	50-70	70-80
Wheat (tall)	45-55	50-65	55-70	70-80
Cotton	60-70	50-65	50-65	75-85
Mustard	50-60	50-60	50-70	60-80
Barley	50-60	55-65	65-75	70-80
Sorghum	40-50	40-60	50-60	65-75
Pearl millet	50-60	50-60	60-70	70-80
Chick pea	50-70	50-70	60-70	75-85
Pigeon pea	50-60	50-60	60-70	70-80
Cluster bean	50-60	50-60	60-70	70-80
Maize	40-50	40-60	50-60	65-75
Sugarcane	30-40	25-35	40-50	50-60
Sunflower	35-45	40-50	40-50	60-70
Groundnut	40-50	40-50	40-50	55-65
Greengram	40-50	45-55	50-60	65-75
Berseem	20-30	20-30	20-30	50-60

This approach is not very effective in the early stages of crop growth. Practical limitation encountered in implementing irrigation scheduling using this approach includes: periodic determination of root growth and soil water depletion. The moisture content in the soil profile can be determined by gravimetrically, electrical resistance blocks or by using neutron probe, time domain reflectometry (TDR) etc.

ii) Soil moisture tension

Plant response to soil moisture is better correlated with water tension than the water content in the soil. The use of the soil-water tension or potential to schedule irrigation overcomes much of the difficulty in applying results from one area to another. Figure 3.1 presents water-retention curves for several soils plotted in terms of percent available water removed (Richards and Marsh, 1961). Soil water potential can be determined by tensiometers or electrical resistance units.

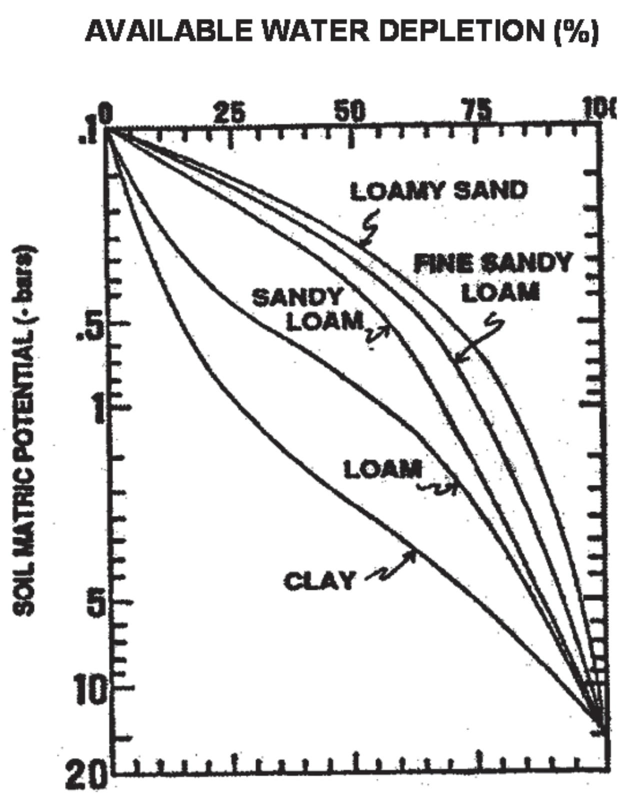

Fig. 3.1 Relation between available water depletion and soil moisture tension for different soils

Soil moisture tension may vary from soil surface to the bottom of root zone. It has been observed that, soil moisture tension measured at a depth of 15 to 30 cm is used as an indicator for scheduling irrigation. Optimum soil moisture tension to initiate irrigation varies for different crops (Table 3.3). Cotton, which is capable of tolerating water stress needs irrigation at much more soil moisture tension as compared to berseem, which very sensitive to water stress.

3.3.1.1 Soil water measurement

Soil water content can be determined by direct and indirect methods.

a) Direct method

In this method, the water is separated from the soil and the volume or mass of water is measured. The principles involved in this method are to remove water by oven dry method which is defined as thermo-gravimetric method. Before each irrigation, soil samples are taken from pre-determined soil depth in moisture boxes and dried in a hot air oven at 105 ^{0} C till constant weight is obtained . The gravimetric measurement of soil water content involves independent measurement i.e the wet mass , Mw; dry mass , Md; of the soil sample and the tare mass , Mt. They are used to calculate

$$W = \{ (Mw-Mt) / (Md-Mt) \}$$

When it is multiplied by 100 , this ratio becomes the percentage of water in soil sample on dry mass basis .

Disadvantage

In this method, the accuracy and reproducibility is dependent on the mass determination and on the dryness process. Soil is composed of mineral particles, organic matter, water, chemicals dissolved in water, volatile liquid, colloidal and non colloidal particles and gases; most of these can be removed from soil at different temperature so that depending on the drying temperature used in the process, different water content may be obtained.

Table 3.3 Optimum soil moisture tension to irrigated different crops

Crops	Suction (M Pa)	Depth of measurement (cm)	Crops	Suction (M Pa)	Depth of measurement (cm)
Wheat	1.00	20	Tomato	0.8	30
Rice (upland)	0.15	15	Potato	0.3	15
Sugarcane	0.70	20	Onion	0.65	15
Soybean	0.50	20	Peas	0.45	15
Maize	0.65	20	Ladies Finger	0.50	20
Cotton	1.5	30	Banana	0.30	30
Groundnut	0.60	15	Grapes	0.25	30
Lentil	0.50	20	Orange	0.60	30
Berseem	0.25	20	Tea	0.50	30

Precautions to be taken for obtaining accuracy of soil moisture

- Generally, at least duplicate soil sample s should be analyzed.
- While taking samples, evaporative losses of water must be prevented.
- Sample should be placed in sealed weighing container and weighed as soon as possible to minimize evaporation.
- When the soil samples are at or near saturation a lid with small hole must be used to cover the paper or glass container in order to avoid loss of sample from boiling.

i) Feel and appearance method : With experience, irrigator can judge soil water content by feel and appearance of the soil. Soil samples are taken with a probe or soil auger from each quarter of the root zone depth, formed into a ball, tossed into air and caught n one hand. From the description given in Table 3.4, available moisture percentage is estimated for soil of different textures. Considerable experience and judgment are necessary to estimate available soil moisture content in the sample within reasonable accuracy. This is a crude method but in the absence of any facility, this method can be used for estimation of soil moisture.

Table 3.4 Guide for judging the amount of available soil moisture for various soil texture and conditions

Available soil moisture	Coarse textured (loamy sand)	Moderately coarse (sandy loamy)	Medium texture (loamy and silt loamy)	Fine textured (clay loamy and silty clay loamy)
Filed capacity (100%)	On squeezing, no free water appears on soil, but wet outline is left on hand	Similar symptoms	Symptoms for al types of soils	Symptoms for al types of soils
75 to 100 percent	Tends to stick together slightly, sometimes forms a very weak ball under pressure	Forms weak ball, breaks easily, do not slick	Forms a ball, is very pliable, slicks readily	Easily ribbons out between fingers, has slick feelings

50 to 75 percent	Appears to be dry do not form a ball with pressure	Tends to form a ball under pressure but seldom holds together	Forms a ball somewhat plastic, sometimes slick slightly with pressure	Forms a ball, ribbons out between thumb and forefinger
25 to 50 percent	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 percent	Dry, loose, single grained flows through fingers	Dry, loose, flows through fingers	Powdery dry, sometimes slightly crusted but easily broken down into powdery conditions	Hard, baked, cracked, sometimes has loose crumbs on surface

b) Indirect method

Since the direct method of soil water content are often considered as the standard method, this method requires more time and destructive aspect of sample measurement. But in indirect measurement, it can be made electronically and frequently. Soil water content is estimated without disturbing soil profile by following methods :

(i) Neutron Thermolisation

The hydrogen nucleus of the water molecules has the property of scattering and slowing down the movement of neutrons. This property is used in neutron method for measuring water content in porous material. When the neutron probe is inserted in access tube, high energy which are emitted from radioactive source from probe collides with atomic nuclei which are emitted from radio-active sources with atomic nuclei which are present in nearby in the soil. Since hydrogen atom in water has same mass, they are very effective in slowing down the neutron. The slow down neutron reflected by the hydrogen in soil water are counted and the results are indicated through attached gauge. The equipment required to make measurement includes a neutron moisture meter, depth probe and meter consisting of fast neutron source (americium 241/beryillium). A detector for thermolised neutron, a protective shield is also used as the reference standard and the scale for counting. A soil auger for installing access tube, with a slightly smaller diameter from the tube to give tight fit thin wall tubing (aluminum, steel, or plastic) of the size consistent with the probe size to minimize error due to air gaps, calibration curve or parameters, radiation film badges leak test kit.

Radius of influence

In the bulk soil, the radius of the sphere of influence ranges from 16 cm at water saturation to about 70 cm at near zero water content (van Bavel et al., 1956). However the chemical composition of the soil changes the value of the parameters and lack of high resolution prevent the detection of sharp changes in water content particularly near the soil surface.

Precaution to be taken while operation

- The auger is used to execute the hole for installation of excess tube, which can minimize the air space around the tube.

- The tube should be closed at the bottom end by rubber stopper or an expansion plug.
- The top portion of the access tube should extend above soil surface and should also be closed by a rubber stopper.
- Safety rules supplied by the manufacturers should be followed to operate, transport and store the probe.
- Operator should wear radiation badge.
- If the surface probe is used, the soil surface should be smoothened out to eliminate air gaps between the soil and the bottom of the surface probe.

(ii) Time Domain Reflectometry (TDR)

The Time Domain Reflectometry measures the propagation of an electrical signal, which is independent on the dielectric constant of soil. The TDR measurement is independent of soil texture, temperature and salt content (Topp et. al., 1980). In TDR technique a step voltage pulse or signal is propagated along a transmission line. Parallel transmission line is usually used for measurement in soil. The parallel rods / wires serve as conductors and the soil, in which the rod are installed, serve as the dielectric medium. The pair of the rods acts as wave-guide and the signals is reflected from the end of the transmission line in the soil and returns back to the TDR receiver. The propagation velocity and the amplitude of the reflected signals are used in the measurement and analysis.

Precautions

The soil between and around the rod of the transmission line is most critical for the propagation of TDR pulse, and any disruption of soil, adversely influence the soil water content measurement. Air gaps around the rod / cracking should be sealed. Thus careful installation of the transmission line is most important

(iii) Soil water potential methods

In the soil profile, water is retained due to some energy force which is called soil water potential. This soil water potential indirectly gives status of soil water which can be measured by thermocouple psychrometers, tensiometer, resistance block and thermal dissipation sensors.

Thermocouple psychrometer

Thermocouple psychrometer determines the total water potential of the liquid phase of the soil by making measurement of vapour pressure difference in the vapour phase in equilibrium with liquid phase.

Tensiometer

Tensiometer measures the matric potential in the soil. The tensiometer consist of porous ceramic, high conductivity cup connected to pressure measuring devises through a small bore plastic or tube. The tesiometer is filled with de- aired water and can be inserted into a cored whole until a good contact is made with surrounding soil. After hydraulic equilibrium is achieved, the water in the tensiometer will be at same matric potential as present in soil.

Limitation of tensiometer

The tensiometer records moisture tension upto – 0.8 bar (80 j / kg). Generally most of the field crops are irrigated before this moisture tension reached and hence it can be used successfully.

(iv) Electrical Resistance Measurement

The principal behind electrical resistance is that the resistance to flow electricity through a porous media is a function of water content which is inversely related but directly related to capillary pressure. In electrical resistance block (gypsum) two electrodes are embedded in and buried in soil at desired depth and connected by insulated lead to a resistance bridge. The resistance in block is measured by inducing a current across the two electrodes and measured by simple ohm-meter. Thereafter the resistance block reading is calibrated with water content by gravimetric method regularly if the block is installed for a season or year.

(v) Thermal Dissipation Measurement

The rate of heat dissipation in a porous medium of low heat conductivity is good indicator to soil water content. Basically it depends on the fact that air is good thermal insulator with respect to water, so that air and the remaining water film become thinner replace water and the path length for heat conduction increases. This requires a larger temperature gradient to dissipate a given quantity of heat. Supplying and measuring the temperature rise at those points therefore measure the water content of porous material. Thus heat dissipation in porous medium can be used as an index of the amount of water present.

3.3.2 Climatological Approach

In climatological approach, crop evapotranspiration is basic important term as water requirement of crop is based on many climatic parameters. The soil moisture storage depletion is equivalent to actual evapotranspiration (ETc). When the computed value of cumulative ETc is equal to allowable amount of soil water depletion, irrigation is applied to replenish the water lost through ETc. Evapotranspiration / water use in a crop can be measured by studies in lysimeters. Alternatively, potential evapotranspiration (PET) of a crop can also be estimated by locally developed empirical formulae, energy balance equations and evaporation from open water surface.

i) Empirical formulae

Depending on the availability of different meteorological parameters, PET can be estimated by different formulae either empirical or based on certain aerodynamics and energy balance principles. The actual ET can be estimated by using PET and crop coefficients. Commonly used empirical formulae and required weather parameters are given in table 3.5.

Table 3.5 : Commonly used formulae for estimating potential/reference ET

Formulae	Required weather parameters	Adoptability
Thornthwaite	Mean monthly air temperature	Temperate continental climate where temperature and radiation are strongly correlated
Blaney-Criddle	Mean monthly air temperature and daylight hours	
Penman	Mean monthly air temperature, saturation vapour pressure, net radiation and wind velocity	Humid and arid regions with calm weather conditions
Modified Penman	Mean monthly air temperature, actual and saturation vapour pressure, net radiation and wind velocity	Almost all conditions, except high altitude
Penman-Monteith	Mean monthly air temperature, actual and saturation vapour pressure, net radiation and wind velocity	Recommended for all conditions

Computation of daily reference evapotraspiration, FAO56 PM (Allen et al., 1998)

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

Where,

ET_0 = reference evapotranspiration, mm day^{-1}

Δ = slope of vapour pressure curve (kPa $^0c^{-1}$)

R_n = net radiation ($MJm^{-2}day^{-1}$)

G = soil heat flux density ($MJm^{-2}day^{-1}$)

γ = psychrometric constant (0.0671 kPa $^0c^{-1}$)

T = mean daily temperature at 2 m height

U_2 = wind speed at 2 m height (m s^{-1})

e_s = saturation vapour pressure (kPa)

e_a = actual vapour pressure(kPa)

e_s-e_a = saturation vapour pressure deficit (kPa).

Modified Penman method (Doorenboss and Pruitt, 1977)

$$ET_0 = c\{W.R_n + (1-W).f(u).(e_a - e_d)\}$$

Where, C = adjustment factor for day and night wind speed and different relative humidity

W= weighing factor for altitude and temperature on radiation

Rn = net radiation in equivalent evaporation in mm day^{-1}

1-W = weighing factor for altitude and temperature effect on wind and humidity

f(u) = wind function or effect of wind on ETo and expressed in equivalent evaporation, mm day^{-1}

ea-ed = vapour pressure deficit in mbar

Hargreaves method, (Hargreaves and Samani, 1985)

Hargreaves (1985) method is often used to compute ET_0 through temperature data for daily / weekly or longer period for use in regional planning, reservoir operation studies where other climatic data are not available or the available data are questionable.

Where, R_a=extra terrestrial radiation (mm day^{-1})

TR = Tmax.-Tmin. (^{0} c)

TC = mean temperature (^{0} c)

Radiation method (Doorenboss and Pruitt, 1977)

$$ET_0 = c(W \times R_s)$$

Where, ET_0 = evapotranspiration mm day^{-1}

Rs = solar radiation in equivalent in mm day^{-1}

W= weighing factor which depend on temperature and altitude

c = adjustment factor which depends on mean RH and daytime wind estimate.

Blaney Criddle method (Doorenboss and Pruitt, 1977)

Where, T = mean daily temp.^{0}c

p = mean daily % of total annual day time hours for a given month and latitude

$$ET_0 = 0.0023 R_a (TC + 17.8) TR^{0.50}$$

$$ET_0 = c\{p(0.46T + 8)\}$$

$$ET_0 = E_{pan} \times K$$

c = adjustment factor which depend on minimum RH and sun shine hour and day time wind estimate

Pan evaporation method (Doorenboss and Pruitt, 1977)

Where, E pan = pan evaporation mm day^{-1} and Kp = pan coefficient

The Kp value depends upon wind speed, relative humidity and fetch distance.

To a certain extent, ET increases as the crop cover, height and density increases. Crops with deeper and extensive root system have higher ET. Crop coefficient, which is the ratio of actual and potential ET under no water stress conditions, is used to account the influence of different plant parameters on actual ET. The crop coefficients for each crop needs to be determined locally, lysimeter studies being the most appropriate method for its estimation. Typical values of crop coefficients for some selected crops are given in Table 3.6. Knowing the soil water reserve in the root zone, daily values of ETc are used to find the remaining available soil moisture storage.

Table 3.6 : Crop Coefficients for selected crops (Doorenbos and Pruitt, 1977)

Crop	Stage of crop growth (% of growth season)						
	0	20	40	60	80	90	100
Wheat	0.14	0.45	0.88	0.89	0.76	0.65	0.51
Maize	0.40	0.63	1.04	1.11	1.00	0.89	0.70
Sorghum	0.42	0.50	0.64	1.01	1.05	0.91	0.70
Cotton	0.22	0.26	0.95	1.07	0.85	0.62	0.40
Rice	1.00	1.07	1.13	1.22	1.16	1.10	0.86
Sugarcane	0.34	0.50	0.90	1.07	1.19	1.20	1.19
Groundnut	0.30	0.40	0.69	0.96	0.86	0.79	0.55

ii) Irrigation water (IW)/cumulative pan evaporation (CPE) ratio

Considering the strong relationship between the pan evaporation and crop ET, particularly in semi-arid tropics, the IW/CPE ratio has been suggested as a practical approach for irrigation scheduling. IW represents the fixed amount of irrigation water, and CPE is cumulative pan evaporation (USWB pan evaporation) minus effective rainfall, since previous irrigation. The first step in this approach is to find out the irrigation depth on the basis of permissible soil water depletion from the root zone for potential yield. The next step is to find a factor (known as IW/CPE ratio) which is to be multiplied with CPE to compute the depth of water depleted from the soil storage. Irrigation is applied as soon as CPE multiplied with IW/CPE ratio becomes equal to the irrigation depth. The optimum ratio of IW/CPE for major crops is given in Table 3.7.

Table 3.7 : Recommended values of IW/CPE for different crops

Crop	Irrigation depth (cm)	IW/CPE
Wheat (dwarf)	5-7	0.8 -1.0
Wheat (tall)	6-8	0.7-0.8
Barley	5-8	0.6-0.7
Summer maize	6-8	0.8-0.9
Winter maize	5-7	0.9-1.0
Pearlmillet	6-8	0.6-0.7
Sorghum	6-8	0.8-0.9
Cotton	8-10	0.5-0.75
Chickpea	6-8	0.4-0.5
Pigeonpea	6-8	0.5-0.7
Moongbean	6-8	0.4-0.6
Clusterbean	6-8	0.3-0.5
Mustard	6-8	0.4-0.5
Groundnut	6-8	0.7-0.8
Sunflower	6-8	0.6-0.8
Sugarcane	8-10	1.0-1.2

Irrigation schedule based on IW / CPE of 0.75 to 1.0 were observed to save 34% of water compared to the practice of applying 5 irrigations at 5 phenological stages of wheat. (Prihar *et al*,. 1976). This criterion can easily be adopted by Indian farmers but the lacunae of this criterion are the region specific and soil specific one.

3.3.3 Plant Parameters Approach

Many plant characters respond readily to water deficit. Thus, different plant indices may serve as a criterion for time of irrigation to crops, important ones for irrigation scheduling are summarized below:

i) Visual symptoms

Visual sign of plant wilting in response to water deficit viz., drooping, curling, rolling of leaves etc may be used as an indication of crops need for irrigation. Similarly, other plant criteria such as change in foliage colour, can also be used. Leaves of beans, cotton and peanuts become dark as the available soil water is depleted and moisture stress begins to affect the plant. Corn and sorghum leaves curl or change their angle of orientation when soil moisture decreases.

ii) Critical crop growth stage

Some physiological stages of crop growth are found to be more sensitive to water stress than other stages. The stages of the crop at which moisture stress affects the yield significantly are called critical growth stages. The critical growth stages in different crops have been identified and in order of decreasing sensitivity to water stress for major crops are given in Table 3.8 (Majumdar, 2000 and Singh and Sharma, 1993).

Table 3.8 : Critical growth stages for major crops in the semi-arid region.

Crop	Crop duration (days)	Critical stages for irrigation
Wheat (dwarf)	130-140	Crowing, flowering, jointing, milk and dough
Wheat (tall)	140-150	Tillering, heading and dough
Barley	125-135	Tillering, booting
Rice (dwarf)	130-140	Flowering, grain filling, tillering
Rice (Basmati)	140-150	Flowering, grain development
Summer maize	90-110	Tasseling and silking, and grain development
Winter maize	150-180	Tasseling, grain development
Pearlmillet	75-85	Heading
Sorghum	90-110	Flowering, seeding, grain filling
Cotton	150-180	Flowering and boll development
Chickpea	130-140	Preflowering and pod development
Pigeonpea	150-170	Flowering initiation, pod development
Moongbean	65-75	Flowering
Clusterbean	130-145	Branching and flowering
Mustard	140-150	Pre-flowering and pod development
Groundnut	110-135	Pegging, pod-setting and pod filling
Sunflower	100-120	Flowering, seed filling, late vegetative
Sugarcane	280-330	Tillering and grand growth

iii) Plant water contents and leaf water potential

The leaf water content (Ö_L) and leaf water potential (Ø_L) in most of the plants changes with variation in soil water availability. As the Ö_L or Ø_L drops below a certain criterion limit, specific to plant species and its growth stage, the physiological and growth phenomenon are adversely affected. Consequently these threshold values can serve as reliable indications for irrigating crops. For many plant species, stresses are mild when mid afternoon Ø_L depressions are not more than -12 bars; moderate if in the range of -12 to -16 bars and extreme if below -16 bars.

Plant water content measurement and methods:

Due to withhold of irrigation water plant shows symptoms of moisture stress. This moisture stress can be measured for relative leaf water content (RWC) or water saturation deficit (WSD). The energy status of water is usually expressed as the total leaf water potential.

a) Relative Water content

The water present in leaf before irrigation is determined by detaching 10-15 leaf segments and keeping in distilled water for 4-6 hrs. at 30± 1^0 C and 600-700 lux illumination after taking fresh weight of leaf segments. It is then surface dried by placing in between filter paper and then over dried at 70^0c for 24 hrs. Then dry weight is determined. The relative water content is calculated as

$$RWC = \frac{\text{Fresh Wt.} - \text{Oven dry Wt.}}{\text{Turgid Wt.} - \text{Oven dry Wt.}} x100$$

$$WSD = \frac{\text{Trgid Wt.} - \text{Fresh Wt.}}{\text{Turgid Wt.} - \text{Oven dry Wt.}} x100$$

WSD = 100-RWC

b) Pressure Chamber

To measure leaf water potential, pressure chamber technique is used. For this the leafy shoot is enclosed in a steel pressure chamber so that the cut end of stem protrudes. The pressure inside is then increased until xylem sap appears on the cut end. The pressure (with negative sign) is just sufficient to force xylem fluid to appear at the exposed cut end of the shoot is taken as the water potential of the leaf cell.

Precautions

(i) Ensure the accuracy of the pressure gauge (ii) Cut the stem or twig with sharp kharif(iii) Prevent transpiration loss. (iv) Do not increase the pressure too quickly.

c) Stomata Resistance

Under unlimited irrigation, water uptake from soil to the tip of leaf is very fast. As soil water content decreases, the resistance in soil water-plant continuum increase due to closure of stomata in leaf. This resistance is measured with the help of porometer. For field studies, the most popular instrument is steady state prorometer which is manufactured by LICOR and Delta t Devices. For irrigation scheduling, the resistance should recorded from top leaves instead of shaded and bottom leaves. Measurement of stomatal conductance/ resistance should be performed at any time of the day after evaporation of dew in the morning. To observe day to day changes due to changing soil water condition early afternoon is the most appropriate time of the day.

iv) Canopy temperature

The plant canopy temperature responds to air temperature and the relative transpiration rate. Leaves of a water stressed plant are warmer than a non-stressed plant, due to reduced evaporative (transpiration) cooling. The difference between the canopy temperature under actual condition, air temperature and the expected canopy temperature under non stressed and fully stressed condition is used to decide the timing of irrigation application. Canopy temperature can be measured with infrared thermometers (IRTs) or remote sensing sensors. Some of the shortcomings of the technique include: difficulty in measuring canopy temperature of row crops in early stages of development; it allows determination of irrigation timing but not amounts; sharp climatic changes may cause low canopy temperature even when soil water is limited. Alternatively, under such conditions, high canopy temperature may be observed when soil water is not limiting.

3.3.4 Simulation Modelling Approach

Simulation models are often used to simulate different water balance components for prevailing crop, climatic, soil and water supply conditions. These models can be used to evaluate or generate alternative irrigation schedules. Different water balance components are simulated on daily basis keeping full track of all inputs of water through rainfall, irrigation, capillary flux, withdrawal of water through runoff, crop evapo-transpiration and deep percolation.

The CROPWAT is a computer model for calculating of water, irrigation and scheme water supply for a crop and an area (FAO, 1992). The model has the options to calculate i) Reference ET (ETo), according to Penman-Monteith approach, ii) crop water requirement, effective rainfall and irrigation requirements, iii) irrigation schedules and iv) scheme water supply of an area. For the calculation of reference ETo, the weather parameters required are: monthly average minimum and maximum temperatures, relative humidity, sunshine hours and wind speed. The programme calculates the Radiation and ETo for each month. The crop water requirements are then calculated using the ETo, effective rainfall data, crop data and soil parameters.

The crop data required for various crop growth stages are:

i. **Length of individual growing stage**: Initial phase, development stage, mid- season and late stage.

ii. **Crop Coefficient** (Kc): For initial stage, mid-season and at harvest are to be given and Kc for development stage are interpolated.

iii. **Rooting depth**: The depths of soil water which can be used effectively by the crop for initial and at full development stages are required.

iv. **Allowable depletion level**: The critical moisture level where first drought stress occurs affecting ET and crop production and expressed as a fraction of total available soil moisture.

v. **Yield response factor**: For each growth stage to estimate yield reduction due to drought stress.

vi. **Soil data**: The data on soil required are total available soil moisture content, initial soil moisture depletion, maximum rooting depth and maximum rain infiltration rate.

After the input of these data for each crop and planting date the crop water requirement is calculated. Irrigation requirement and scheduling are determined by:

$$IR_{Req} = ET\ crop - P_{eff}$$

The irrigation scheduling programme provides the possibility to:

- Develop and plan indicative irrigation schedules adapted to field operational conditions;
- Evaluate field irrigation programmes in terms of efficiency of water use and yield production;
- Simulate field irrigation programme under water deficiency conditions, rainfed conditions, supplementary irrigation, etc.

There are eight options for irrigation scheduling

i. Each irrigation defined by user

ii. Irrigation at critical depletion (100% RAM)

iii. Irrigation below or above critical depletion (% RAM)

iv. Irrigation at fixed interval per stage

v. Irrigation at fixed depletion (mm)

vi. Irrigation at given ET crop reduction (%)

vii. Irrigation at given yield reduction (%)

This programme gives the irrigation calendar for the entire season, the efficiency of irrigation schedule, efficiency of rainfall, total and gross irrigation, and actual water use by crops, reduction in yield etc.

3.4 Frequency of Irrigation

Frequent irrigations with water application sufficient to meet the soil moisture deficit are usually more productive than heavier irrigations at long intervals. On the other hand, higher frequency of irrigations keeps surface soil moist for longer period leading to higher evaporation losses. The frequency of irrigations is affected by weather conditions, soil and crop characteristics and crop and water management practices (Table 3.9).

Table 3.9 : Representative available water holding capacity for various texture classes

Texture class	Available water holding capacity (cm/m)
Sand	4 -9
Loamy sand	6-12
Sandy loam	11-15
Fine sand loam	14-18
Loam and silt loam	17-23
Clay loam and silty clay loams	14-21
Silty clays and clays	13-18

Crop characteristics such as crop consumptive use rate, sensitivity to water stress and root characteristics also influence the frequency of irrigations. Crops with higher consumptive use rate (such as rice), varieties sensitive to water stress (such as dwarf wheat) and shallow rooted crops require more frequent irrigations

3.5 Depth of Irrigation

The net depth (d) of irrigation to be applied depends on the amount of water required to bring the soil water content to the field capacity of the soil. If the soil moisture content in the root zone just prior to irrigation is known, the net depth of water required can be estimated as:

$$d = \sum_{i=1}^{n} \frac{\theta_{fi} - \theta_{bi}}{100} \times \rho_i \times D_i$$

where, d is the net depth of water to be applied, θ_{fi} is the field capacity of i-th soil layer in percent by weight, θ_{bi} is the moisture content of i-th soil layer just before irrigation in percent by weight, ρ_i is the bulk density of the i-th soil layer, D_i is the depth of i-th soil layer and n is the number of soil layers in the root zone.

References

Doorenbos, J. and Pritt, W.O. 1977. Crop water requirements. Irrigation and Drainage Paper 24, FAO, Rome.

FAO. 1992. CROPWAT-A computer program for irrigation planning and management. FAO Irrigation and Drainage Paper 46.

Majumdar, D.K. 2000. Irrigation water management: principles and practices. Prentice-Hall of India Pvt. Ltd., New Delhi. 487 p.

Prihar, S.S., Khera, K.S., Sandhu, K.S. and Sandhu, B.S. 1976. Comparison of irrigation schedules based on pan evaporation growth stages in wheat. Agron. J. 68: 650-653.

Singh, D.P. and Sharma, H.C. 1993. Important aspects of on-farm water management. CCS HAU, Hisar.

4.0 CONCEPT OF IRRIGATION PERFORMANCE INDICATORS : IRRIGATION EFFICIENCIES AND WATER PRODUCTIVITY

Rajbir Singh and Ashwani Kumar

Globally, about 270 million hectares area is under irrigation accounting for two third of total water consumption, which is currently estimated at 4 billion m^3 yr^{-1}. Food production and food security are closely linked to water availability and water security in most of the developing countries. About 40 percent of foodgrain is produced from 20 percent arable irrigated land. In developing countries, the proportion of water going to irrigation is often ranging from 75–85 percent of total use and serious concern has focussed attention about the scarcity of water. Improving irrigation system and reducing irrigation water applications losses are thus of paramount importance. Water in the system is lost by percolation, run-off and the magnitude of these losses varies widely among irrigation projects. However, reducing irrigation water supply will cut off the field scale percolation rates and reducing irrigation water supply by improved conveyance and application efficiencies may cause decline of the groundwater table. One of the alternative solutions in water utilization is the framework of water accounting (Molden, 1997), which distinguishes different water use categories such as process depletion, non-process depletion, non-beneficial depletion, committed outflow and uncommitted outflow. The framework of performance indicators describes the various aspects of water management such as production, utilization, environment and economy (Kijne *et al*, 2003) and it needs to get more attention.

4.1 Performance indicators

The purpose of analysis of irrigation performance is to diagnose operational problems and suggest solutions and to identify potential changes in support of strategic planning. The exercise is useful for all stakeholders which include: irrigation and drainage service providers and water mangers, research agencies, farmers and other service recipients. Factors affecting the performance of irrigation are described below:

Agronomic	Crops, precipitation capture, evaporation, soil characteristics, cropping pattern
Engineering	Engineering systems that reduce losses, distribution uniformity
Management	Demand-scheduling, root zone threshold, system maintenance
Institutional	User participation, water pricing, training, legal steps

With increasing demand on the water resources, water use efficiency is becoming one of the key issues facing water managers. Efficiency concepts have been developed to determine how best the improvements can be made. Irrigation practices have to be evaluated from the time water leaves reservoir until it is utilized by the plants. Irrigation efficiency indicated how efficiently the available water supply is being used based on different methods of evaluation. The design and operation of the carrier system, the degree of land preparation, the method of irrigation and the management skill of the farmer are the factors which mainly influence irrigation efficiency.

4.1.1 Concept of Irrigation Efficiency

In engineering, dimensionless ratios of inputs and outputs are generally known as efficiencies. For example, the transmission efficiency of the electrical grid is the ratio of the energy received by consumers to the energy delivered into the grid from the power stations, similarly, the thermodynamic efficiency of a heating boiler is the heat energy absorbed by the water in the boiler divided by the heat energy generated by the fuel heating the boiler. In simple term, the mechanical efficiency of any device *per se* a bicycle, is the ratio of the energy transferred through the wheels to the road to the energy applied to the pedals by a person. These efficiencies clearly indicate that if there are less losses the efficiency is high and vice-versa.

In irrigation engineering, the concept of efficiency was evolved some 60 years ago. Israelsen (1950) did extensive field work during 1940s on measuring the quantities of water applied to the field and stored in root-zone soil of farm and thereby absorbed or transpired by plants. He defined irrigation efficiency as the ratio of the irrigation water consumed by the crops of an irrigation farm or scheme to the water diverted from a river or other natural water source into the farm or scheme canal or canals. In equation form, he defined irrigation efficiency (Ei) as

$$Ei = Wc / Wr$$

Where, Wc is irrigation water consumed by the crops and Wr is the water diverted from a river or other natural source (Israelsen, 1950). Essentially, irrigation efficiency as the ratio of water consumed by the intended purpose to that diverted. This basic approach to irrigation accounting remained fundamentally unchanged for over 40 years. Many researchers suggested many refinements. Hansen (1960) pointed out that if the water applied is less than the potential consumption by the crop, the water-application efficiency may approach 100%, but the irrigation practice and crop yield may be poor indicating that high efficiency was not reliably correlated to good performance. He proposed to disaggregate efficiency into a number of components, and proposed an overall concept of consumptive use efficiency. Jensen (1967) defined irrigation efficiency as the ratio of ET of irrigation water plus the water ‘‘necessary’’ for leaching on a steady-state basis to the volume of water diverted, stored, or pumped specifically for irrigation. Subsequently, Jensen (2002) has pointed out that this resulted in the numerator containing a consumptive component and a small non-consumptive component, making water balance calculations more complex. Bos and Nugteren (1974, 1982) published the results of a joint effort of the International Commission on Irrigation and Drainage (ICID), and the International Institute for Land Reclamation and Improvement (ILRI), Wageningen. The definitions of efficiency terms were refined in the 1982 edition. Distribution efficiency was defined as the ratio of the volume of water furnished to the fields to the volume of water delivered to the distribution system. Field application efficiency was defined as the ratio of the volume of irrigation water needed, and made available, for ET to the volume of water furnished to the fields. Combining these various figures at appropriate scales provided measures of efficiency at field, farm, tertiary, and scheme level.

Despite these variations and enhancements, Israelsen’s original definition of irrigation efficiency, i.e, water used by the crop to the water diverted, remained the basis of accounting in irrigation. Since the various losses in distribution and field application were essential knowledge to those designing the irrigation systems, this accounting basis was appropriate and relevant to that engineering purpose. High efficiency implied that a high proportion of the water available at the head of a scheme was being used for the design purpose of augmenting crop transpiration.

US Interagency Task Force, Irrigation Water Use and Management (Interagency TF, 1979) evaluated available literature and undertook detailed review of field data on irrigation efficiency and suggested in their report that any project dealing with irrigation efficiencies must define “efficiency” with a great deal of care. The report further suggested that it is frequently assumed that because irrigation efficiency is low, much irrigation water is wasted but this is not necessarily true.

As discussed above, the current nomenclature related to how irrigation interacts with hydrology – particularly the term efficiency– and produces confusing results for planners and policymakers. Even irrigation engineers use various terms interchangeably and without due regard to the clarity. Further, non-engineers have added many terminologies to the literature on the subject of irrigation efficiency. Therefore, first priority is to define terms that can be used unambiguously by planners, hydrologists, engineers and others, concerned with analysing water resources.

Given that the science of hydrology has been in place for many years, it provides the most tested framework, and whatever the irrigation profession finally opts for should be entirely consistent with hydrological analysis. Beyond the general framework, each speciality will have its own additional set of parameters of interest, but terminology for the basic parameters should be common. After in-depth consultations with many workers, Perry (2007) has suggested the following terms:

1. **Water use**: any deliberate application of water to a specified purpose. The term does not distinguish between uses that remove the water from further use (evaporation, transpiration, flows to sinks) and uses that have little quantitative impact on water availability (navigation, hydropower, most domestic uses).
2. **Withdrawal**: water abstracted from streams, groundwater or storage for any use – irrigation, domestic water supply, etc. Within withdrawals, following the recommendations of Willardson et al. (1994) and Allen et al. (1997), water would go to:

a. **Changes in storage** (positive or negative) – changes in storage include any flows to or from aquifers, in-system tanks, reservoirs, etc. The key characteristic of storage is that the water entering and leaving is essentially of the same quality.

b. **Consumed fraction** (evaporation and transpiration) comprising :

i. Beneficial consumption: Water evaporated or transpired for the intended purpose – for example evaporation from a cooling tower, transpiration from an irrigated crop.

ii. Non-beneficial consumption: Water evaporated or transpired for purposes other than the intended use – for example evaporation from water surfaces, riparian vegetation, waterlogged land.

c. **Non-consumed fraction**, comprising:

i. Recoverable fraction: water that can be captured and reused – for example, flows to drains that return to the river system and percolation from irrigated fields to aquifers; return flows from sewage systems.

ii. Non-recoverable fraction: water that is lost to further use – for example, flows to saline groundwater sinks, deep aquifers that are not economically exploitable, or flows to the sea.

An approach was developed by the International Commission on Irrigation and Drainage (ICID) and used the terms like overall project efficiency, which is suitable for all irrigation systems and subdivided this definition into three sub-components viz., conveyance efficiency, distribution efficiency and field application efficiency to track and account for water use from the point of supply through to the crops. Because of many factors that influence water efficiency form the source to the crop (capital investment, labour availability and skills, energy sue, weather, and the physical performance of irrigation system). Efficiency in the use of water for irrigation consists of various components and takes into account losses during storage, conveyance and application of the drained out water from one plot to other irrigation plot. CWC has proposed that water use efficiency for irrigation may be separated into i) Reservoir Efficiency W_R); Conveyance efficiency (W_C); On farm water application efficiency (W_F) and drainage efficiency W_D.

The product of the four types of efficiencies is the total efficiencies of water use for irrigation (W_P), which can be expressed functionally as:

$$W_P = W_R * W_C * W_F * W_D$$

Similar calculations on the weighted average (volume of water) basis will give a true picture of the efficiency of the basin (W_B) as a whole from all the major / medium projects of the basin. In addition to above, the Irrigation Potential Created (IPC) by a project and the Actual Potential Utilized (IPU) is also a indicator of the optimum water use, overuse or under use. A correlation of W_P with IPU / IPC is generally determined.

a) **Storage efficiency** is the ratio between the volume diverted for irrigation (Vd) and the volume entering a storage reservoir (Ve) for that purpose.

b) **Conveyance efficiency** is the ratio between the volume of water delivered to irrigation plots (Vp) and the volume diverted from the supply source (Vd).

c) **On Farm Application Efficiency** is the ration between the volume used by plants throughout the evapotranspiration process (Vu) and the volume that reaches the irrigation plots (Vp). It is important to point out that the volume used during the evapotranspiration process (Vu) is equal to the volume of evapotranspiration by plants minus the volume of effective rainfall.

The term irrigation efficiency which is expressed as ratio of Vr / Vp; where Vr is the volume of usable water stored in the exploration zone of the plants roots Vp is the volume received by the field.

i) Irrigation efficiency

Irrigation efficiency is the ratio usually expresses as percent of the volume of irrigation water transpired by plants, plus that evaporated from the soil, plus that necessary to regulate the salt concentration in the soil solution and that used by the plants in building plant tissues to the total volume of water diverted, stored or pumped for irrigation.

$$Ei = \frac{Wet + W1 - Re}{Wi} x100$$

Where :

Ei : Irrigation efficiency, percent

Wet : The volume of irrigation water per unit area of land transpired by plants, evaporated from the soil during the crop period (including field preparation and nursery)

W1 : The volume of irrigation water per unit area of land to regulate the salt content of the soil solution

Re : Effective rainfall

Wi : The volume of water per unit area of land that is stored in a reservoir or diverted for irrigation

Irrigation efficiency or overall efficiency indicates how efficiently or beneficially the available water supply is being used.

ii) Water conveyance efficiency

Losses that occur during conveyance of water from the reservoir outlet into the main canal and to the farm are excessive. These losses are due to seepage and evaporation in the canal network, water courses and field channels. Seepage losses are influenced by the nature and porosity of the soil, depth, turbidity, shape of the canal section and the ground water level. Weeds and aquatic plants along and in the water courses and field channel also use significant amount of water.

Water conveyance efficiency is the ration usually expressed as percent of the volume of water delivered by an open or closed conveyance system at the field to the volume of water delivered to the conveyance system at the supply source or reservoir outlet.

$$Ec = (W_f \ / \ W_d) \ X \ 100$$

Where

Ec = Water conveyance efficiency (percent)

W_f = Volume of water delivered by the conveyance system at the field

Wd = Volume of water delivered to the conveyance system at the supply source or reservoir

iii) Water application efficiency

Water application efficiency is the ratio, usually expressed as percent, of the volume of irrigation water used in evapotranspiration in a specified irrigation area plus that necessary to maintain a favourable salt content in the soil solution to the volume of water delivered to the area.

$$Ea = (W_s \ / \ W_f) \times 100$$

Where,

Ea = Water application efficiency (percent)

W_s = Volume of irigation water stored in root zone

W_f = Volume of water delivered to the filled

The common source of loss of irrigation water during application are: surface runoff, deep percolation below the root zone and evaporation. The aim should be to store in the root zone of the soil the maximum percent of water that is applied to the field consistent with good irrigation practice and economy. Irregular land surfaces, shallow soil underlain by gravel of high permeability, small irrigation streams, non-attendance on water during irrigation, long irrigation runs and excessive depth of application contribute to large losses and low efficiency.

The depth of water application in each irrigation is the dominant factor influencing efficiency of application. Land uniformity, irrigation methods, length of run, soil texture and permeability influence the depth of irrigation. As the depth of irrigation increases efficiency of application decreases. Where the depth of water application was 5 cm, the irrigation efficiency was 87 percent with 5-10 cm depth it was 55 percent and 10 – 15cm depth, it was 35 percent. In normal gravity irrigation, surface irrigation efficiency of application are in the range of 60 percent where as in a well designed sprinkler system it is approximately 75 percent and it is as high as 90 percent in drip irrigation system.

iv) Water storage efficiency

It is considered that irrigation with small quantities of water may lead to high water application efficiencies. The water storage efficiency refers to how completely the water needed prior to irrigation has been stored in the root zone during irrigation.

$$Es = \frac{Ws}{Wn} x100$$

Where,

Es = Water storage efficiency (percent)

Ws = Water stored in the root zone after irrigation

Wn = Water needed in the root zone prior to irrigation

Water storage efficiency assumes importance when water supplies are limited or when excessive time is required to secure adequate penetration of water into the soil. When salt problem is there, water storage should be kept high to maintain a favourable salt balance.

v) Water distribution efficiency

Uniform distribution of water over the entire field is necessary for high crop production per unit of water. The water distribution efficiency indicates the extent to which water is uniformly distributed along the run. The length of irrigation run in furrow or borders is decided to a large extent by the uniformity of water distribution for a given soil, size of stream and management practices.

$$Ed = 1 - \frac{y}{\bar{d}} x100$$

Where,

Ed = Water distribution efficiency percent)

$\bar{d}$ = Average depth of water stored along the run during irrigation

y = Average numerical duration from $\bar{d}$

vi) Project irrigation efficiency

Project irrigation efficiency is the percentage of irrigation water stored in the root zone of the soil and is available for consumptive use by the crop to the amount of water delivered as measured at the point of main source of supply. When the water is measured at the farm head gate (or well), it is called farm irrigation efficiency and when measured at the inlet ot he field than it is called field irrigation efficiency.

vii) Operational efficiency

It is the ratio of the actual project efficiency compared to the operational efficiency of an ideally designed and managed system using the same irrigation method and facilities. Low operational efficiencies indicate defective management or system design.

viii) Economical irrigation efficiency

It is the ratio of the total farm production (net or gross profit) attained under with the operating system, compared to the total production expected under ideally operated system under ideal conditions. Since this relates to input and output, it is a measure of the overall efficiency of the project.

ix) Water use efficiency

Agronomical speaking, water use efficiency (WUE) is the yield of marketable crop produced per unit of water use in evapotranspiration.

$$WUE = \frac{Y}{ET}$$

Where,

WUE = water use efficiency (kg / ha-mm)
Y = Marketable yield of the crop (kg / ha)
ET = Evapotranspiration (mm)

WUE is also known as crop water use efficiency (Ecu) if the water used for metabolic purpose of the crop (G) is also included with ET.

$$Ecu = \frac{Y}{G + ET}$$

Field water use efficiency (Eu) is the ratio of crop yield to the amount of water used in the field (WR) which includes G + ET + deep percolation (D).

$$Eu = \frac{Y}{G + ET + D} = \frac{Y}{WR}$$

4.1.2 Evaluation of irrigation efficiencies

A summary of the current efficiency with which water is used in irrigated agriculture is given in Table 4.1. A considerable amount of water is lost as evaporation and / or leakage during storage and transport of the water to the fields where the crops are grown. Bos (1985) has estimated that globally ~ 30% of irrigation water is lost in storage and conveyancing. Once the remaining (70%) water reaches the field where it is further lost as runoff and / or drainage. Postel (1993) has estimated the world wide irrigation efficiency, i.e. the amount of water evaporated compared to the amount of water delivered to the field, to be ~ 37%. This would mean 63% of the water delivered is lost as runoff and / or drainage. Broadly similar figures demonstrating the poor performance of most irrigation systems have also been published by the Food and Agriculture Organisation (e.g. see Barghouti, 1999). However, some of the water “lost” from an irrigated field may return to aquifers or streams from which it can be abstracted again, provided the necessary infrastructure is available and the water quality has not deteriorated beyond acceptable limits. If this is the case the efficiency of water use over large irrigated areas may be greater than the above global mean of field level irrigation efficiencies (Bouwer, 1992).

Water resources are, therefore, very inefficiently used in irrigated agriculture. The poor efficiencies of water resources are

Table 4.1. Estimates of WUE of irrigated agriculture in semi-arid area

WUE	Fraction of available water (%)
Storage and conveyance	30
Run-off and drainage	44
Evaporation (from soil to water)	8-13
Transpiration	13-18

Source: Wallace, 2000.

disappointing but there are plenty of scope for improvement. If properly utilized and managed, more food can be grown with existing water resources.

4.1.3 Confusion on WUE

The term water use efficiency (WUE) itself is confusing and is used in confused ways (Perry, 2007). In the context of irrigation, WUE is generally defined as the crop yield per unit of water. However, the term is frequently simply interchanged with irrigation efficiency, or is misquoted. Many researchers in literature use this term and confirm that the meaning of water use efficiency is not well agreed or applied in the context of irrigation. Thus term water use efficiency (WUE) is an unfortunate misnomer. Firstly, the water taken up by a plant canopy and transpired or lost in evaporation is only ‘‘used’’ in the very broadest sense – in reality only a very small part of the water taken up is actually utilised in the construction of carbohydrates or even in the composition of plant tissue. Furthermore, as usually defined, it is not even a true ‘‘efficiency’’, which is a term conventionally reserved for the dimensionless ratio between the output of a quantity and its input (Jones, 2004).

There are many benefits to improve water use efficiency, including environmental and economics. These include less stress on water resources, reduced losses of water and nutrients to groundwater and surface water resources, improving production and overall profits and allowing greater area to be irrigated with a given volume of water. Water use efficiency can be defined in many different ways by agriculturists, hydrologists and engineers. Efficient on-farm irrigation depends on water-use, energy use, labour and capital investment, and how these aspects relate to production and profitability, and there is no single definition that covers all these aspects of water use efficiency.

4.1.4 Improvement in water use efficiency

There is considerable scope for improving the efficiency and productivity of water utilisation. There are a wide range of options available for improving irrigation water use efficiency and productivity at the farm level (Table 4.2). Poor management is cited as the most frequent cause of inefficient water use on irrigation schemes and it is clear that few of the options listed in Table 4.2 will result in a significant increase in efficiency if overall management is of a low standard. Attempts to improve the efficiency of irrigation that are centred on a technological, agronomic or institutional quick fix are rarely successful.

Table 4.2. Option available for improving irrigation efficiency at farm level

Improvement category	Examples of options available
Agronomical improvements	Improved crop husbandry; introduction of high yielding varieties; adoption of cropping strategies that maximize cropped area during period of low ET and periods when recycling of water as rainfall is highest.
Technical improvements	Laser leveling of flood irrigation schemes to improve irrigation uniformaly; adoption of practices that increase effectiveness of rainfall; introduction of more efficient irrigation methods that reduce soil evaporation, improve uniformity and reduice drainage
Managerial improvements	Adoption of demand-based irrigation scheduling systems; use of deficit scheduling; better use and management of saline and waste water
Institutional improvements	Users involvement in scheme operation and maintenance; Introduction of water pricing and legal frameworks to provide incentives for efficient water user and disincentives for inefficient use; improved training and extension

Source: Batchelor (1999)

Although it is not possible to discuss all the options listed in Table 4.2 in detail, three of the options are of particular interest. Firstly, demand-based irrigation scheduling (such as tensiometer irrigation scheduling) is used frequently on irrigation trials but rarely used at the farm level. One reason for this has been the lack of cheap and reliable soil moisture sensors. However, it is possible that further development of dielectric soil moisture sensors can fulfil this need. Such sensors will facilitate irrigation applications that are matched closely to crop demand or even set at less than crop demand as in the case of deficit irrigation. Secondly, irrigation methods such as drip irrigation can be used extremely effectively to increase the yields, crop quality and water use efficiency of many crops. However, it should be recognised that these methods are relatively sensitive to management and maintenance. Poorly-managed surface and sprinkler irrigation systems continue to provide often low but acceptable crop yields whereas poorly-managed drip systems tend to fail catastrophically. Finally, there is potential for better use and management of poor quality irrigation water and areas prone to soil salination. Research and experience in recent years has demonstrated that waters of much higher salinity than those customarily classified as unsuitable for irrigation can, in fact, be used effectively for the production of crops given appropriate management and cropping strategies (Rhoades et al., 1992). In a review paper on irrigation with poor quality water, Oster (1994) states that the use of poor quality waters requires three changes from standard irrigation practice. These are: selection of appropriately salt-tolerant crops; improvements in water management and in some cases, the adoption of innovative irrigation technology; and, maintenance of soil-physical properties to assure soil tilth and adequate soil permeability to meet crop water and leaching requirements.

4.2 CONCEPT OF WATER PRODUCTIVITY (WP)

Water productivity is defined as crop production per unit amount of water used. Concept of water productivity in agricultural production systems is focused on producing more food with the same water resources or producing the same amount of food with less water resources. Initially, irrigation efficiency or water use efficiency was used to describe the performance of irrigation systems. In agronomic terms, *water use efficiency* is defined as the amount of organic matter produced by a plant divided by the amount of water used by the plant in producing it. However, the used terminology *water use efficiency* does not follow the classical concept of *efficiency*, which uses the same units for input and output. Therefore, International Water Management Institute has proposed a change of the nomenclature from *water use efficiency* to *water productivity*. Definitions of WP change with the background of the researcher or stakeholder involved. For example, obtaining more kilograms dry matter production per unit of transpiration is a key issue for plant breeders. At a basin scale, economists wish to maximize the economical value from water used. Water managers tend to be more concerned with the total water input. Rainfed farmers in arid areas are highly concerned with doing the most with limited rainfall. For irrigation farmers, and managers of irrigation systems, water supply is a managerial factor and they will evaluate their own WP on the basis of canal water supplies in relation to crop yield, rainfall, supplemental irrigation, or full irrigation supplies. Water productivity can be further defined in several ways according to the purpose, scale and domain of analysis (Table 4.3).

Water productivities (WP) are defined for different scales viz., the crop, the field and the regional scale. Water productivity (WP, kg of dry matter per m^3 of water) can be defined in different ways (To Phuc Tuong, 1999; Molden *et al.*, 1997, Zoebl (2006). The numerator may refer to different types of dry matter (DM), e.g. total DM or yield DM. The denominator may refer to different types of water, e.g. water transpired by

Table 4.3 : Stakeholders and definitions in the water productivity framework.

Stakeholder	Definition	Scale	Target
Plant physiologist	Dry matter / transpiration	Plant	Utilize light and water resources
Nutritionist	Calorie / transpiration	Field	Healthy food
Agronomist	Yield / evapotranspiration	Field	Sufficient food
Farmer	Yield / supply	Field	Maximize income
Irrigation engineer	Yield / irrigation supply	Irrigation scheme	Proper water allocation
Groundwater policy maker	Rs / groundwater extraction	Aquifer	Sustainable extraction
Basin policy maker	Rs / evapotranspiration	River Basin	Maximize profits

the crop, or water needed for the crop and for leaching salts from the soil or the total amount of water given to a region. The water productivity per unit of evapotranspiration (WPET) is the mass of crop production divided by the total mass of water transpired by the crop and lost from the soil. The water productivity per unit of irrigation (WPI) is the crop production divided by irrigation flow. The water productivity per unit of gross inflow (WPG) is the crop production divided by the rain plus irrigation flow. Water productivity with reference to evapotranspiration (WPET) takes into accounts only water evaporated or transpired and is therefore focused on plant behaviour whereas WPI and WPG include not only ET but also water used in other ways for crop products and water that is wasted. Water productivity of rice with reference to evapotranspiration WPET is higher (0.53 kg m^{-3}) under transplanting as compared to dry seeding (0.48 kg m^{-3}). The increment of global average water productivity of rice and other cereals is from 0.39 kg m^{-3} to 0.52 kg m^{-3} and 0.67 kg m^{-3} to 1.01 kg m^{-3} respectively from 1995 to 2025. Water productivity of irrigated crops is higher than that of rainfed crops in developing countries, is lower in developed countries.

4.2.1 Water productivity versus scale of references

The definition of water productivity is scale-dependent. Increasing water productivity is then the function of several components at different levels viz., plant, field, irrigation system and river-basin. An increase in production per unit of water diverted at one scale does not necessarily lead to an increase in productivity of water diverted at a larger scale. The classical irrigation efficiency decreases as the scale of the system increases. In India, the on-farm irrigation efficiency of most canal irrigation systems ranges from 30 to 40% whereas, the irrigation efficiency at basin level is as high as 70 to 80%. Basin water productivity takes into consideration beneficial depletion for multiple uses of water, including not only crop production but also uses by the non-agricultural sector, including the environment. Here, the problem lies in allocating the water among its multiple uses and users.

Plant scale water productivity will vary with plants according to its photosynthetic efficiency. The C_3 plants are the most common crop plants (wheat, barley, soybean, etc). Unfortunately, they are also the least efficient assimilators of carbon dioxide from the atmosphere. Therefore, they must keep their stomata open more than the other plants under the same atmospheric conditions and, hence, they have the lowest transpiration efficiency or water productivity (biomass per unit water transpired). Whereas, the C_4 plants (maize, sorghum, sugar cane, etc) have an enzyme that has twice the affinity for absorbing carbon dioxide as that in C_3 plants. C_3 plants also have photorespiration which occurs with photosynthesis in light and requires oxygen. This process does not occur in C_4 plants. Consequently, C_4 plants have 2-3 times higher transpiration efficiency or water productivity than C_3 plants. Further, the CAM plants (pineapple, agave, etc) have the ability to assimilate CO_2 during the night and store it in the form of organic acids. During the day the stored CO_2 is available for producing carbohydrates by photosynthesis. This enables CAM plants to close their stomata during the daytime, when transpiration is the highest, and open the stomata at night when it is lowest. CAM plants can attain a transpiration efficiency or water productivity as much as 10 times that of C_3 plants; however, their biomass production per unit land area is low.

At field level, WPET values under typical low land conditions range from 0.4 to 1.6 g kg^{-1} and WPIP values from 0.2 to 1.1 g kg^{-1}. In wheat, the WPET was 0.65 g kg^{-1} and WPIP was 0.8 g kg^{-1} in Indian condition. An experiment on the water productivity analysis from field to regional scale at Sirsa district, Haryana, concluded that at field scale, the average WPET (kg m^{-3}) was 1.39 for wheat, 0.94 for rice and 0.23 for cotton, and represents its average values for the climatic and growing conditions in Northwest India (Singh et al, 2006). Factors responsible for low values of WP include a high share (20 to 40%) of evaporation into ET for rice, percolation from fields and seepage losses (34 to 43% of the total canal inflow) from the conveyance system.

Finally, WP of different farm enterprises means getting more profit per drop of water. Producing more crops, livestock, fish and forest products per unit of agricultural water use holds a key to both food and environmental security. But, for society as a whole, concerned with a basin or country's water resource, this means getting more value per unit of water resource used. Researchers stated the importance of working out WP within agriculture, water use by fisheries, forests, livestock and field crops and concluded that analyzing each water use independently often leads to false conclusions because of these interactions.

4.2.2 Water accounting :

It involves classifying water balance components into water-use categories that reflect the consequences of human interventions in the hydrologic cycle. *Gross Inflow* is the total amount of water flowing in the water balance domain from precipitation, and surface and subsurface sources. *Net inflow* is gross inflow plus any changes in storage.

Water depletion is a use or removal of water from a water basin that can not be used again. Consumptive water for crops and ET from forests and evaporation from canals, surfaces and non-irrigated area are categorized into *depleted water*. Depleted water is classified into 3 parts, process, non-process and non-beneficial. Process *depletion* is the amount of water that is used to produce an intended good. For agriculture ET and water containing in the plants are process depleted water. *Non-process depletion* occurs when water is depleted by a natural use such as evaporation from forest cover or when diverted water depleted, but not by the intended process. *Non-beneficial depletion* occurs when no benefit or a negative benefit is derived from the depletion of water.

Committed water is that part of outflow that is allocated to other uses.

Uncommitted outflow is water that is neither depleted nor committed, is available for a use within a basin, but flows out due to lack of storage or operational measures. Uncommitted outflows can be classified as utilizable or non-utilizable. *Uncommitted outflow utilizable* is water that can be available if improvement of management with existing facilities can be achieved. *Uncommitted outflow non-utilizable* is water that can not be available without appropriate or sustainable improvement of facilities.

Available water is the net inflow less the amount of water set aside for committed uses and less non-utilizable uncommitted outflow.

4.2.2.1 Water accounting indicators : The WP can be measured in terms of quantity produced per unit of water. When the water is required for competing users in an irrigation scheme or basin, it has to be expressed in monetary terms. The water balance can be estimated at field, irrigation scheme and basin scales. While performance indicators are based on the water balance approach using inflows and outflows, non-agricultural water users and interaction with other users be considered. Fig. 4.1 shows flow of water at the field scale. On the right side, water is depleted by process of transpiration and evaporation.

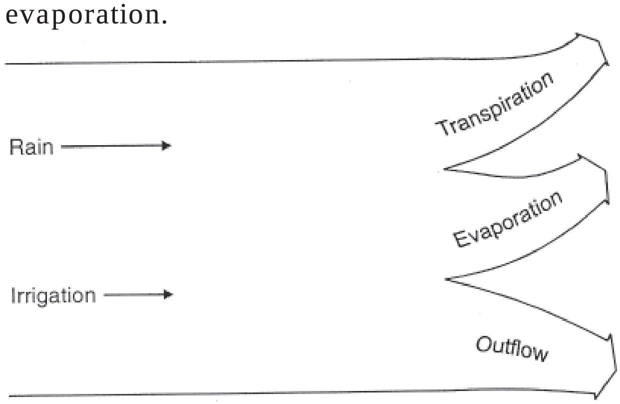

Fig. 4.1 Water accounting at field scale

The concept of water accounting is to present concepts and definition to account for water use, depletions and productivity. Some varieties of definitions, so-called "irrigation efficiency" has been used to evaluate irrigation water use. But these irrigation efficiencies do not take outflows into consideration. On the other hand, this water accounting approach take outflows into considerations. This approach is applicable on each level such as field, farm, irrigation system command and basin level. Of course, the domain should be defined not only area but also vertical range, for example, root zone or ground water level.

The accounting procedure can be considered at different spatial scales: basins, sub-basins, irrigation systems or fields. The water balance for a certain area can be described as and presented in Table 4.4.

Precipitation + Irrigation+ Capillary rise+ Soil water storage change= Transpiration + Evaporation + Surface runoff +Drainage + Percolation + Soil water storage change

Table 4.4 : Water balance components indicators of WP for field, irrigation scheme and basin scale

Performance indicators (kg/m^3)	Field	Irrigation scheme	Basin
$WP_{irrigated}$ =Productivity / irrigation	Irrigation	Irrigation	Not appropriate
WP_{inflow} =Productivity / net inflow	P + I + dS + Cap.	P + I + dS + Cap.	P + dS
$WP_{depleted}$ =Productivity / depletion	E + T or E + T + Drg. + Perc.+ R off	E + T or E + T + Drg. + Perc.+ R off	outflow
$WP_{process}$ = Productivity / process depletion	T	T	T

P = Precipitation, I = Irrigation, dS = Change in soil water storage, Cap. Capillary rise, E = Actual evaporation, T = Actual transpiration, Perc. = Percolation, Drg. = Drainage

Within the irrigation system irrigation infrastructure is water provided for crop transpiration, domestic and industrial uses, fish and livestock. In addition to the intended depletion, water is also depleted by evaporation from weeds, tress, fallow lands and water bodies. The analytical framework for water accounting in an irrigation system is shown in following Fig. 4.2.

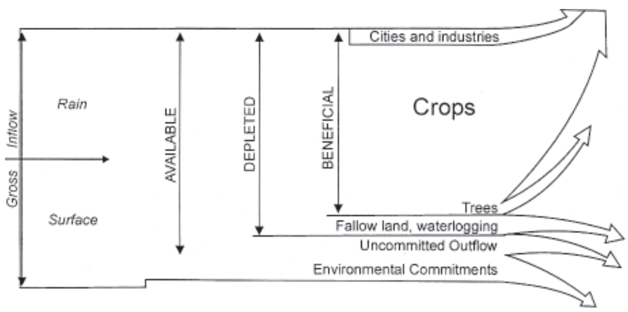

Fig. 4.2 Water accounting at irrigation project level

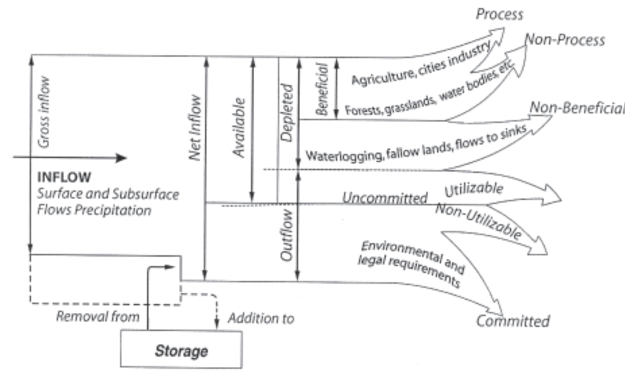

Fig. 4.3 Water accounting at basin scale

The following processes are involved in water accounting at the project level.

- Process depletion (by crops, cities, industries).
- Non-process but beneficial depletion, like evaporation by trees, wetlands within the system, or fisheries.
- Evaporative depletion of low or negative benefit, like evaporation from fallow land or from waterlogged areas (that do not have important wetland values).
- Flows that are directed by irrigation into sinks like seas or inland water bodies that do not add value, and could have been used within the irrigation system or elsewhere - this is considered as water depleted by irrigation
- Uncommitted flows, that are utilizable within the irrigation system or elsewhere
- Committed flows to meet environmental needs, or legal or traditional rights of downstream users.

As the scale of analysis increases more complexities are encountered (Fig. 4.3). Under such a situation the competition for water among different users increases. The understanding of basin scale processes are required to solve these problems. The solutions to these problems though, most often lie in action taken at local scales – irrigated and rainfed fields or within irrigation systems.

4.2.3 Water productivity at command scale

When water is distributed in an irrigation system at a major scale like this, the important processes include allocation, distribution, conflict resolution and drainage. Allocation and distribution of irrigation water are primarily for irrigation farmers besides meeting the non-agricultural demands like domestic, industrial, livestock and fisheries use.

For canal command areas, irrigation scheduling cannot be done on a micro-scale calculating the depth of irrigation required, frequency of irrigation and the duration of irrigation owing to a larger areal extent with different crops and a different system of irrigation supply throughout the season on a rotational basis. Here, irrigation scheduling refers to the quantum of water to be stored or diverted for meeting the overall command area crop and allied demands. The water productivity concept shall be redefined by way of incorporating the overall irrigation efficiency and the duty of water at storage, flow and field level. The base period over which irrigation flow is continuous through the canal network with suitable time rotations at outlets for distribution, also decide upon the productivity.

The overall productivity of this scale of reference depends ultimately on the total quantum of water released from storage over the base period, the area covered and the project yield. The storage duty includes the losses during conveyance, distribution and application over and above the field duty in a canal network project. The physical and economic water productivity under different canal system in Tamil Nadu is presented in Table 4.5.

Table 4.5 : Physical and economic water productivity under different canal irrigation systems with different scale of reference in Tamil Nadu

Scale of Reference	Total water used (m^3)	Output		Water Productivity	
		Physical (kg)	Economic (Rs)	Physical (kg/m^3)	Economic (Rs/m^3)
Parambikulam Aliyar Project					
Plant/crop level	0.013	0.0051	0.0312	0.39	2.40
Field level (0.4 ha)	3388.8	680	4160	0.20	1.23
Distributary level	1335283.7	185661	1135810	0.14	0.85
Lower Bhavani Project					
Plant/crop level	0.018	0.0131	0.029	0.73	1.61
Field level (0.4 ha)	5473.5	2200	7000	0.40	1.28
Distributary level	833824.4	213796	621952	0.26	0.75
Vaigai River Basin					
Plant/crop level	0.020	0.014	0.033	0.70	1.65
Field level (0.4 ha)	6931.25	1650	4390	0.24	0.63
Distributary level	2486534.4	396000	1053600	0.16	0.42
Tampiraparani River Basin					
Plant/crop level	0.028	0.017	0.068	0.60	2.43
Field level (0.4 ha)	7909.4	2100	7100	0.27	0.90
Distributary level	37647968.0	3549038	12066949.5	0.09	0.30

4.2.4 Ways of enhancing water productivity

Water productivity could be improved either by reducing the water losses that occur in various ways during water conveyance and irrigation practices or increasing the economic produce of the crop through efficient water management techniques. Principle factors that are influencing water losses and water productivity of a command area are the design and nature of construction of the water conveyance system, type of soil, extent of land preparation and grading, design of the field, choice of irrigation methods and skill of irrigators.

i) Enhancing water productivity at plant /crop level

Identification of traits and genes using conventional and molecular breeding techniques that have the following specific characters is required to improve the water productivity at individual plant level.

- Traits that reduce the non-transpirational uses of water in agriculture
- Traits that reduce the transpiration of water without affecting the productivity
- Traits that increases production without increasing transpiration
- Traits that tolerance to water logging, drought and salinity stress.
- Development of short duration varieties reducing the growing time from 5 months to 3.5 to 4 months will also resulting higher water saving.

ii) Enhancing water productivity at field /farm level

Water productivity at the field level can be improved through increasing the total output per unit cumulative water used, reducing the unproductive water outflows and depletions and making more effective use of rainfall. Its reduction at field /farm level is mainly due to the losses occurring by seepage in the supply channel, deep percolation and occasionally runoff occurring in fields. Improper land leveling and grading, faulty choice of irrigation methods, application of excess water, frequent irrigation and faulty design of fields are the major factors that cause low water productivity.

Water productivity of an agricultural ecosystem has been improved either by reducing the water losses that occur in various ways during water conveyance and irrigation practices or increasing the economic produce of the crop through efficient water management techniques

Water use can be minimized through various water conservation measures like:

- Proper land leveling and grading is a prerequisite for efficient water application.
- Lining of farm channels will reduce the water losses through seepage
- Reducing unproductive water outflows through the following ways will also be helpful viz., minimizing idle periods during land preparation, soil management to increase resistance to water flow (shallow tillage before land preparation to close cracks, puddling and soil compaction etc.) and water management to reduce hydrostatic pressure.
- Pipes may be laid for water conveyance in farms wherever feasible to cut the water conveyance losses.
- Crop productivity can be maximized through various measures like:
- Proper selection of irrigation methods according to crops, soil types, topography, climate and stream sizes are important to secure high water productivity.
- Introduction of water-saving irrigation techniques like drip and sprinkler will enhance the crop productivity. Institutional and Governmental policies will also promote the spread of these technologies, which could result in higher productivity.
- Improved agronomic practices, such as site-specific nutrient management, good weed management and proper land leveling can increase the crop yield significantly without affecting ET and therefore, may result in increased water productivity
- Adoption of water –saving irrigation technology in rice namely System of Rice Intensification (SRI), aerobic rice and dry-seeded rice techniques would increase the water productivity of rice.
- Optimum scheduling of irrigation is most important way of improving crop water productivity.

iii) Enhancing water productivity through multiple uses

The multiple uses of water i.e. using the available water sources for more than one uses/ production system is inevitable to produce more with less water. Multiple use systems, operated for domestic use, crop production, aquaculture, agroforestry and livestock, can improve water productivity and reduce poverty. However, intensification of multiple use of water in the catchment may affect downstream flow both in terms of quality and quanity. There is a need for proper understanding and economic evaluation of non-irrigation uses and to greater recognition of the linkages between water management activities and aquatic ecosystems.

iv) Enhancing water productivity at basin level

- Conveyance loss is the main cause of reduction in water productivity at basin level. It can be reduced by lining canals, waterways and channels with impervious materials like bricks or stone masonry or bitumen clay mixture and so on.
- Repairing of cracks, holes, burrows, erosion damages, leaks in water control structures should be done as a part of continuous maintenance.
- Weed growth should be checked in unlined canals and water ways etc. Integrated water

and land management will be much helpful in enhancing land and water productivity.

- Participatory irrigation management approach.

4.2.5 Future challenges and options

The scale and boundary of the area over which water productivity is calculated greatly affect its value. This is because of outflow losses by seepage, percolation and runoff at a specific location or field can be reused at another location within the area under consideration. Data on water productivity across scales are useful parameters to assess whether water outflows upstream are effectively reused downstream. The available informations suggest that water productivities at scale levels vary widely. The paucity of data on water productivity at scale levels higher than the field level is the major constraint.

In this context, increasing crop water productivity is a challenge at various levels which is briefly outlined hereunder:

- The first challenge is to continue to enhance the marketable yield of crops without increasing transpiration.
- The second challenge is at field, farm and system levels to reduce as much as possible all outflows that do not contribute to crop production.
- The third challenge is to increase the economic productivity of all sources of water, especially rainwater but also waste-water of various qualities and saline (ground) water.
- Interdisciplinary team work is warranted.

Hence, analysis of irrigation efficiency is important in canal irrigation systems as it is an improvement over the previously used physical measures. This measure provides information on how much water use could be decreased without altering the output produced and other inputs used. Comparison of irrigation efficiency and technical efficiency at farm level indicated that irrigation efficiency is lower than technical efficiency and the need for possibilities is reduction in water use with present situations. However use of modern water management technologies could improve the irrigation efficiencies considerably thus conforming the scope of introduction of modern irrigation technologies in canal irrigation systems.

References

Allen, R.G, Willardson, L.S, Frederiksen, H. 1997. Water use definitions and their use for assessing the impacts of water conservation. In Proceedings ICID Workshop on Sustainable Irrigation in Areas of Water Scarcity and Drought. Jager J.M, Vermes L.P, Ragab R (Eds), Oxford, England, 11–12 Sept.; 72–82.

Barghouti, S. 1999. Growing Challenges to Water Resources Management. Sustainable Development International, Launch Edition, Spring, 1999, pp. 43–52.

Batchelor, C. 1999. Improving water use efficiency as part of integrated catchment management. Agricultural Water Management 40: 249-263.

Bos, M.G. 1985. Summary of ICID definitions on irrigation efficiency. ICID Bull. 34.

Bos, M.G, Nugteren, J. 1974. On Irrigation Efficiencies, 1st edition. International Institute for Land Reclamation and Improvement : Wageningen,The Nether-lands; 95 pp.

Bos, M.G, Nugteren, J. 1982. On Irrigation Efficiencies, 3rd edition, International Institute for Land Reclamation and Improvement: Wageningen, The Netherlands; 142 pp.

Bouwer, A. 1992. Agricultural and municipal use of waste water. Water Sci. Technol. **26**, pp. 1583–1591.

Hansen, V.E. 1960. New concepts in irrigation efficiency. Transactions of the ASAE 3(1): 55–57, 61, 64.

Israelsen, O.W. 1950. Irrigation Principles and Practices. John Wiley and Sons, New York; 471 pp.

Jensen, M.E. 1967. Evaluating irrigation efficiency. Journal of Irrigation and Drainage, American Society of Civil Engineers 93(IR1): 83–98.

Jensen, M.E. 2002. Irrigation efficiency. 18th ICID Congress on Irrigation and Drainage, Montreal, Canada, 25 July 2002.

Jones, H. 2004. What is water use efficiency? In Water Use Efficiency in Plant Biology, Bacon M (ed.). Blackwell: Oxford, UK.

Kijne, J, Barker, R and Molden, D. 2003. Water productivity in agriculture: limits and oppurtunities for improvement. CABI Press, Wallingford, UK.

Molden, D. 1997. Accounting for water use and productivity. IWMI/SWIM Paper No. 1, InternationalWater Management Institute, Colombo, Sri Lanka.

Molden, D, Sakthivadivel, R. 1999. Water accounting to assess use and productivity of water. International Journal of Water Resources Development 15(1): 55–71.

Oster, J.D. 1994. Irrigation with poor quality. Agricultural Water Management 25: 271-297.

Perry, C. 2007. Efficient irrigation; inefficient communication; flawed recommendations. Irrigation and Drainage 56: 367-378.

Postel, S.L. 1993. Water and agriculture. In: Gleick, P.H. (Ed.), Water in Crisis: A Guide to the World's Fresh Water Resources. Oxford University Press, Oxford, pp. 56–66.

Rhoades, J.D. Kandiah, A and Mashali, A.M. 1992. The use of saline waters for crop production. Irrigation and Drainage Paper 28, FAO, Rome, p. 133.

Singh, R, Dam, J.C and Feddes, R.A. 2006. Water productivity analysis of irrigated crops in Sirsa district, India. Agricultural Water Management 82(3): 253-278.

To Phuc Tuong. 1999. Productive water use in rice production: Opportunities and limitations. Journal of Crop Production 2(2):241-264.

US Interagency Task Force. 1979. Irrigation Water Use and Management. US Govt. Printing Office: Washington DC, USA; 143 pp.

Wallace, J.S. 2000. Increasing agricultural water use efficiency to meet future food production. Agriculture, Ecosystems and Environment, 82: 105-119.

Willardson, L.S, Allen, R.G and Frederiksen, H. 1994. Eliminating Irrigation Efficiencies. USCID 13th Technical Conference, Denver, Colo., 19-22 October, 15 pp.

Zoebl, D. 2006. Is water productivity a useful concept in agricultural water management? Agricultural Water Management 84(3): 265-273.

5.0 METHODS OF SURFACE IRRIGATION AND MEASUREMENT OF IRRIGATION WATER

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Different methods are used to apply irrigation water to the crop depending on the source of supply of water, topography, quantity of water to be applied, crop and method of cultivation. These methods are classified as surface, sub-surface, overhead or sprinkler and drip irrigation methods. In surface methods of irrigation, water is applied directly to the soil surface from a channel or open ditch located at the upper reach of the field. The pressurized irrigation system like overhead or sprinkler and drip irrigation methods are described in different chapter separately.

Surface methods of irrigation are oldest and most commonly used methods of irrigation. Surface methods are followed as back as 4000 years. Even in developed countries like USA, 66 percent of irrigated area is under surface methods of irrigation and it is around more than 80 percent in most of the countries. Surface methods are most suitable for leveled lands or lands with slope less than 2-3 percent.

The most common methods of surface irrigation are flooding, check-basin, basin , border –strip and furrow methods. High efficiency in surface methods can be obtained if water distribution systems are properly constructed to provide adequate control of water to the fields and proper land shaping and leveling is done for uniform distribution of water over the field.

5.1 Methods of surface irrigation

5.1.1 Flooding

In this method, water is allowed form the channel into the field without much control on either side of the flow. It covers the entire field and moves almost unguided. The ideal size of each plot is 0.1 to 0.2 ha. The height of bund around the basin should be 15 cm for impounding and effective use of rainfall. Labour requirement for this method is minimum and large stream can be maintained in this method. Uneven distribution and low water application efficiency are the common drawbacks of the method.

5.1.2 Border-strip method

In this method, field is divided into number of strips by making bunds of around 15cm height. This method makes use of parallel ridges to guide a sheet of flowing water as it moves down the slop. The land is divided into a number of long parallel strips called borders that are separated by low ridges. The border strip has little or no cross slope but has a uniform gentle slop in the direction of irrigation. The essential feature of border irrigation is to provide uniform depth. Each strip is irrigated independently by turning in a stream sheet confined by the border ridges. The irrigation stream must be large enough to spread over the entire width between the border ridges without overtopping them. When the advantage water front either reaches the lower end, or a few minutes before or after that stream is turned off. The water temporarily stored in the border moves down the strip and infiltrates, thus completing irrigation. This method is suitable for field crops and medium to heavy textured soils. The length of the strip ranges from 30 to 300 m and width from 3 to 15 m depending upon stream size, soil type and slop of the field (Table 5.1) However, the most common sizes are 60 to 90m in length and 6 to 12m in width.

5.1.3 Check basin irrigation

Check basin irrigation is the most common method fo irrigation in India and in many countries. This is the simplest in principle of all method of irrigation. There are many variation in its use, but all involve dividing the field into smaller unit areas so that each has a nearly even surface. Bunds or ridges are constructed around the areas forming basins within which the irrigation water can be controlled. The basins are

Table 5.1 : Suggested size of borders and stream sizes for different soils and land slopes

Soil type	Slope (%)	Width (m)	Length(m)	Flow (l/s)
Sand	02 -0.4	12-30	60-90	10-15
	0.4-0.6	9-12	60-90	8-10
	0.6-1.0	6-9	75	5-9
Loamy sand	02 -0.4	12-30	75-150	7-10
	0.4-0.6	9-12	75-150	5-8
	0.6-1.0	6-9	75	3-6
Sandy loam	02 -0.4	12-30	90-250	5-7
	0.4-0.6	9-12	90-180	4-6
	0.6-1.0	6	90	2-4
Clay loam	0.2-0.4	12-30	180-300	3-4
	0.4-0.6	6-12	90-180	2-3
	0.6-1.0	6	90	1-2

filled to the desired depth and the water is retained until it infiltrates into the soil. When irrigating rice or ponding water for leaching of salts from the soil, the depth of water may be maintained for considerable period of time by allowing water to continue to flow into the basins.

The size of the check basin ranges from 4m x 3m to 6m x 5m depending on the stream size and soil texture. Bigger size streams of water need big check basins. Light textured soils need small sized check basins. The advantage of this method is that water can be applied uniformly. Even with small streams (2 l/s) irrigation can be applied effectively and efficiently. It is suitable for close growing crops like wheat, groundnut, pearlmillet, fingermillet etc. More labour are required for field layouts and irrigation. More land (about 5-8%) is wasted under channels and bunds.

In USA, large sized plots of over 5 hectares are perfectly leveled with the help of laser land leveler and large stream of 400-500 l/s are used to fill the basins. These large basins facilitate mechanized cultivation.

5.1.4 Basin method

Basin method is almost similar to check-basin method except that in this method entire field is irrigated wheras in basin method only basin around the tress are irrigated. This method is suitable for orchards. Basins are generally round in shape, occasionally square in shape. The basins are small when the trees are young and their size is increased with age of plant. Basins are connected with irrigation channel for supply of water.

5.1.5 Furrow method

In this method, small channels are formed along or across the slope of a field and water from open ditches are diverted into the furrows. Water infiltrates from the bottom and sides of the furrows moving downward and laterally to wet the soil. Furrow method of irrigation is adopted to crops grown with ridges and furrows. The size and shape of the furrow depends on the crop grown and spacing of the crop. Depending on the stream size, water infiltrates into the soil and spreads laterally as it flows through the furrows in smalls stream. Furrow length depends on soil texture and stream size (Table 5.2).

Table 5.2 : Length of furrows and streams sizes for different soils, land slopes and depth of water application

Furrow slope (%)	Furrow length (m)								
	Soil type								Maximum flow (l/s)
	Clay		Loam		Clay loam and Sandy loam		Loamy sand and sandy		
	Depth of water application (cm)								
	7.5	15	7.5	10	15	7.5	10	15	
0.05	300	400	120	270	400	60	90	150	12
0.10	340	440	180	340	440	90	120	190	6
0.20	370	470	220	370	470	120	190	250	3
0.30	400	500	280	400	500	150	220	280	2
0.50	400	500	280	370	470	120	190	250	1.2
1.00	280	400	250	300	370	90	150	220	0.6
1.50	250	340	220	280	340	80	120	190	0.4
2.00	220	270	180	250	300	60	90	150	0.3
Application depth (mm)	75	150	50	100	150	50	75	100	

This method is applicable in light to moderately heavy soils of 0.5 –2.5 cm / h infiltration rate, land slope of 0.3-0.6%, stream size of 2-10 l / s, suited to row crops and vegetable. It is good for crusting soil and provides better aeration and drainage but leaching is not possible. This method is best for cotton in which substantial amount of water is saved without any reduction in yield. The furrows can be made after each row or alternatively before or after first irrigation. Planting cotton in paired rows of 30-90 cm and making of furrows between the pairs saves another 15% of irrigation water. If flooding is practiced, than the width of borders should not be more then 5-8 m. and length should be 60-66 m. Making of furrows can be helpful in case heavy showers are received and temporary flooding occurs. The comparison of different methods of irrigation in cotton is shown in Table 5.3. Furrow irrigation is always better than border method and irrigation in alternate or paired rows gives higher water use efficiency. General specifications for surface methods for irrigation are given in Table 5.4.

Table 5.3 : Wetted area, irrigation water applied, profile water use, yield and WUE in cotton under different methods of irrigation

Irrigation methods	Wetted area, m^2/ha	Irrigation water applied, cm	Water use, cm	Seed cotton yield, kg/ha	W.U.E. Kg/ ha-cm
Border	10000	40.4	82.4	1960	26.1
Each furrow	6987	30.1	71.1	1980	32.0
Alternate furrow	4053	23.3	65.0	1900	35.7
Paired crop row	1003	24.4	63.7	2010	36.7

Table 5.4 : General specifications for surface method of irrigation

Item	Border	Check basin	Furrow
Soils	Most soils except coarse sands	Most soils	Most soils except sandy soils
Infiltration rate	Moderately low to moderately high	Moderate to low	Moderate to low
Slop (%)	0.20 – 1.0	No restriction	Minimum 0.05% upto 0.50% and even upto 2.0% in some cases
Stream size (l/s)	12-15	Large or small, basin size to be adjusted	0.3 to 2.5 common, maximum 12
Length (m)	60-300	Length : width (1.5-2.5 :1)	Usually 50-400. Spacing 45-60 cm depending on the crop. Depth of furrow : 7.5-12.5cm
Crops	Wheat, barley, legumes, fodder crops, close growing crops	Groundnut, vegetables, rice, fingermillet	Sugarcane, potato, cotton, sorghum, maize, chilli, vegetables

5.1.6 Corrugation

Corrugation irrigation consists of running water in small furrow, called corrugations which direct the flow down the slope. It is commonly used for irrigation non-cultivated, close growing crops such as small grains and for pasture growing on steep slopes. Corrugations may be used in conjunction with border irrigation on lands with relative flat slops to help in obtaining uniform coverage with water. The water is applied to small furrows, the main difference from regular furrow irrigation being that more, but smaller furrows are utilized and the crop rows are not necessarily related to the irrigation furrows.

5.1.7 Sub surface irrigation

In sub-irrigation water is applied below the ground surface by maintaining an artificial water table at some depth depending upon the soil texture and the depth of the plant roots. Water reaches the plant roots through capillary action. Water may be introduced through open ditches or underground pipelines such as tile drains or mole drains. The depth of open ditches or trenches vary from 30 to 100 cm and they are spaced about 15 to 30 m apart.

5.2 METHODS OF WATER MEASUREMENT

Water is the most valuable asset of irrigated agriculture. Systematic water measurements properly recorded interpreted and used, help in enhancing irrigation efficiency. In the absence of suitable measuring special facilities, there are possibilities of either under-irrigating the crops causing uneconomic returns, or over-irrigating resulting in wastage of valuable and scarce water and chances of crop damage. Accuracy in water measurement is, therefore, essential in the operation of a distribution system. Different units are used to measure irrigation water at rest and while flowing. Water from different sources on farms, is conveyed through open channels or pipelines. Water measuring methods are categorized as (i) volumetric, (ii) Area-velocity, and (iii) using measuring structures.

5.2.1 Volumetric method

This method is generally used to measure small discharges from pumps or other water lifting devices by collecting water in a container of known volume for a period of time. The method may also be well adopted to measure a stream discharging into a reservoir of sufficient capacity. The discharge rate is then calculated by noting the time for the reservoir to fill to a certain depth, or for the water surface to rise to a predetermined level Rate of flow is calculated by the formula as:

$$\text{Discharge rate} = \frac{\text{Volume of container (liters)}}{\text{Time (sec / m / h) to fill container}}$$

5.2.2 Area-velocity methods

It involves the measurement of velocity of water flow passing a point in an open channel. The flow rate is estimated by multiplying the cross-sectional area of the flow perpendicular to the direction of flow by the average velocity of water. The cross-sectional area is determined by direct measurements and the velocity of water may be determined by float method and current meter

$$Q = AV$$

Where,

Q = discharge rate, cm^3/s

A = cross-sectional area, cm^2

V = velocity of water, cm / s

i) Float method

The velocity of water is measured with the help of a float-block of wood or long-necked bottle partly filled with water in a straight clean section of the channel with fairly uniform cross section. The cross-sectional area of the stream is calculated by multiplying the mean width of the wetted part of the channel by the depth of wate. The velocity of water is the highest on the surface; therefore, a constant factor of 0.85 is used. The discharge of the stream may be estimated by:

$$Q = 0.85\ A\ V$$

Where,

Q = discharge, cm^3/s

A = mean cross section of the channel, cm^2

V = mean flow velocity, cm / s

ii) Current meter method

Current meter (Fig. 5.2.1) is suspended in a deep stream and the vanes that revolve by the movement of water in a stream and measure the velocity of water. The number of revolutions of the vane made by the flowing water in a given period is referred to a calibration chart to know the velocity of water. Discharge is estimated by multiplying the mean velocity of water by the cross-sectional area of the stream. Measurements are usually taken at 20% to 80% region of the stream depth to obtain an accurate estimate of the velocity in a vertical plane.

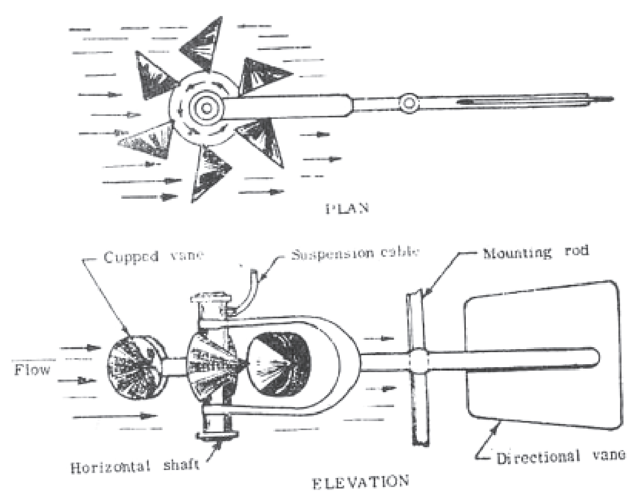

Fig. 5.2.1. Current meter

iii) Water meter

Water meter has multi blade propeller made of metal, plastic or rubber that rotates in a vertical plane. The meter is fitted in water line pipes. The propeller is geared to a totalizer with a counter that totals the flow in volumetric unit. Water meters are available for a range of sizes suiting the pipe sizes.

iv) Dethridge meter

The meter is simple and consists of an under-shot water wheel revolved by the moving water through a concrete pipe and is fitted at the outlet. It gives the direct measurement of the discharge in volumetric units and operates with small head loss. The accuracy of measurement is more than 95 per cent under normal situations.

v) Pipe method

This coordinate method is used to estimate discharges from flowing vertically or from pumping plants discharging horizontally (Fig. 5.2.2). The method presents difficulties in accurately measuring the coordinates of the jet and therefore is of limited use.

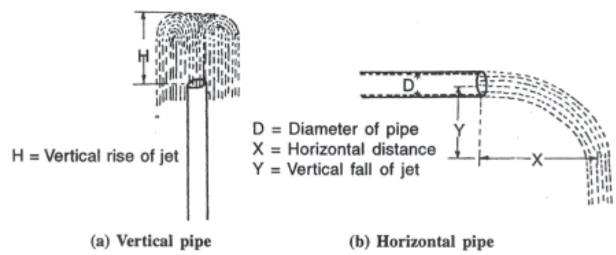

Fig. 5.2.2 Flow measurement through vertical and horizontal pipes

a) Flow from a vertical pipe

When water flows vertically out of an open pipe, the height to which it will rise above the pipe is proportional to the flow. When the height of the jet was less than 0.37D, where D is the inside diameter of the pipe, the flow is similar to the flow over a weir and can be expressed by the empirical equation:

$$Q = 3.1 \times 10^{-7} D^{2.5} H^{3.5}$$

When the height of the jet exceeds 1.4 D, the flow is comparable to jet flow and can be expressed by the empirical equation:

$$Q = 0.029\, D^{1.99} H^{0.53}$$

Where,

Q = flow in liters per second

D = inside diameter of pipe, cm

H = average height of rise of the center of the jet, cm

b) Flow from a horizontal pipe

The trajectory of a stream of water from a horizontal pipe can be used to estimate the discharge. X and Y coordinates are measured, X parallel and Y perpendicular to the pipe. The horizontal distance, X is from the end of the pipe to the middle point of the water jet where it falls vertically. The drop in height, Y of the water jet is the distance of the point from where it falls vertically from the centre of the pipe. The formula is derived using the equations :

$$Y = \frac{1}{2} gt^2 \qquad X = Vt \qquad Q = AV$$

$$Q = C' \sqrt{\frac{g}{2}} \frac{AX}{\sqrt{Y}} = 0.022\, CA \frac{X}{\sqrt{Y}}$$

Where,

Q = discharge, litre / second

C = coefficient of discharge (Table 5.2.1)

g = acceleration due to gravity, cm / sec^2

A = Cross-sectional area of water at the end of pipe, cm^2

X = Horizontal coordinate of the point measured from the water surface, cm

Y = vertical coordinate of the point measured from the water surface, cm

The coefficient of discharge C is very important and depends on the depth of flow in the pipe and X, Y coordinates. In case of partially flowing pipe, the depth of flow is denoted by d. Fig. 5.2.2 can be used to measure discharge for different inside diameters of fully flowing pipes (D). At a horizontal distance equal to 8D, vertical distance or fall of jet (Y) is measured.

5.2.3 Measuring Structures

The most common structures used for measurement of water in farm irrigation practices are – orifice, meter gate, weir and flumes

i) Orifices

An orifice is a simple opening, circular or rectangular in shape, in a wall made of steel or aluminum plates and placed across a channel to measure the flow rate (Anonymous 1997). The cross-sectional area of the orifice is small in relation to the stream cross section. Under free flow conditions, the flow from the orifice discharges entirely into air (Fig. 5.2.3). In submerged flow orifice, the downstream water level is above the top of the opening and the flow

Table 5.2.1 : Coefficient of discharge for measuring discharge from horizontal pipes

Flowing partially full at the end								
d/D	X/D							
	1.00	1.50	2.00	2.50	3.00	4.00	5.00	8.00
0.2	1.02	1.01	1.00					
0.3	1.11	1.06	1.03	1.02	1.01	1.00		
0.4	1.17	1.10	1.06	1.03	1.02	1.01	1.00	
0.5	1.22	1.13	1.07	1.04	1.03	1.01	1.01	1.00
0.6	1.26	1.15	1.09	1.05	1.03	1.02	1.01	1.00
0.7	1.30	1.17	1.10	1.06	1.04	1.02	1.01	1.00
0.8	1.33	1.18	1.11	1.07	1.04	1.02	1.01	1.00
Flowing completely full at the end								
Y/D	X/D							
	1.00	1.50	2.00	2.50	3.00	4.00	5.00	8.00
0.5	1.44	1.28	1.18	1.13	1.10	1.06	1.03	1.00
1.0	1.37	1.24	1.17	1.12	1.09	1.06	1.03	1.00
2.0		1.11	1.09	1.08	1.07	1.05	1.03	1.00
3.0			1.04	1.04	1.04	1.04	1.03	1.00
4.0			1.01	1.01	1.02	1.03	1.02	1.00
5.0			0.97	0.99	1.00	1.01	1.01	1.00

discharges into water. Free flow orifices plates can be used to measure comparatively small streams like in border strips, furrows or check basins (Michael 1992)

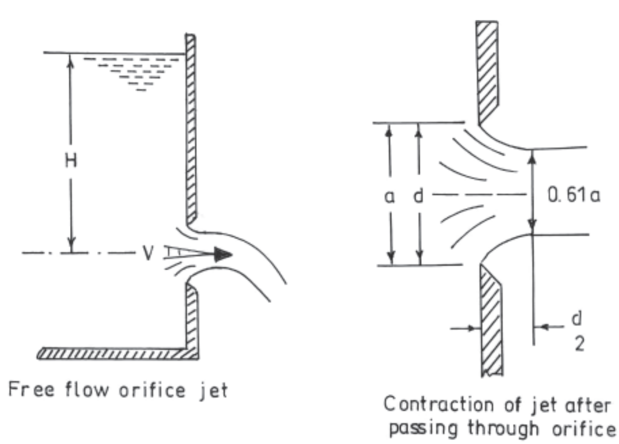

Fig. 5.2.3 Free flow through orifice

The discharge from an orifice is calculated by the formula,

$$Q = 61x10^{-5} \; A \; \sqrt{2gH}$$

Where,

Q = discharge, litre / sec

A = cross-sectional area of the orifice, cm^2

C = coefficient of discharge, usually found to be 0.61

g = acceleration due to gravity which is 981 cm / s^2

H = Depth of water over the centre of the orifice (on the upstream side) in case of free flow Orifice or the difference in elevation between the water surface at the upstream and downstream faces of the orifice plate in case of submerged orifice , cm

ii) Meter gate

It is a modified submerged orifice with an adjustable dimension and are used to control the water flowing from one channel to another. A flow rate is a function of the head and the degree of gate opening as measured by the displacement of the gate stem.

iii) Weirs

The term, weir is used to denote a notch in a wall built across an irrigation channel. It may be rectangular, trapezoidal or triangular. Water is allowed to flow over it for measurement in an irrigation channel. Weirs are very simple devices that can profitably be used to measure even small water supplies and are of two types- sharp crested and broad crested. The discharge through a weir is proportional to the head on the crest depends on condition of the crest, contraction, velocity of approaching stream and elevation of the water surface downstream of the weir.

$$Q = CLH^{m}$$

Where,

Q = discharge

C = coefficient dependent on nature of crest and approach conditions

L = length of crest

H= head n crest

m = an exponent depending on weir opening

Table 5.2.2 : Discharge through V-notch in relation to hight of water over V-notch (cm)

Height of water over V-notch, cm	Discharge, litre/sec	Height of water over V-notch, cm	Discharge, litre/sec	Height of water over V-notch, cm	Discharge, litre/sec
4.0	0.45	12.5	7.8	21.0	28.3
4.5	0.60	13.0	8.6	21.5	30.3
5.0	0.80	13.5	9.5	22.0	31.0
5.5	1.0	14.0	10.5	22.5	34.0
6.0	1.2	14.5	11.3	23.0	35.7
6.5	1.5	15.0	12.3	23.5	38.2
7.0	1.8	15.5	13.3	24.0	40.0
7.5	2.2	16.0	14.5	24.5	42.7
8.0	2.5	16.5	15.6	25.0	44.5
8.5	2.8	17.0	16.7	25.5	46.7
9.0	3.4	17.5	18.3	26.0	48.8
9.5	3.9	18.0	19.4	26.5	51.0
10.0	4.5	18.5	21.7	27.0	53.8
10.5	5.1	19.0	22.3	27.5	56.3
11.0	5.7	19.5	23.5	28.0	58.7
11.5	6.3	20.0	25.5	29.0	64.5
12.0	7.1	20.5	27.0	30.0	69.4

The accuracy in water measurement, simplicity and ease of construction, non-obstruction by floating material and durability are some of advantages of using weirs. But it requires considerable fall of water surface making their use in areas having level land impracticable. Deposition of gravel, sand and silt above the weir affects accurate measurements. A weir when properly constructed and installed is one of the simplest and most accurate methods of measuring water. The accuracy may vary from 80 to 85 per cent.

iv) Flumes

Flumes are shaped, open channel flow sections that force flow to accelerate. Acceleration is produced by converging the side walls, raising the bottom or combination of both (Clemmens *et al.* 1993). Flumes range in size 2.5 cm to 15 m used in ditches and large canals. Parshall flumes and cut throat flumes are the most commonly used flumes for discharge measurement at the farms.

a) Parshall flume

It is an important device for measuring water in irrigation channels or canals by measuring the loss of head of a stream passing through the flume. It can be used to measure streams of varying sizes from a very small one to a very large one. Parshall flume consists of three sections viz., i) converging or upstream section, ii) throat or middle section, and iii) diverging or downstream section (Fig. 5.2.4). Converging section has a level floor with vertical walls converging to the throat. Throat section has parallel walls and a floor inclined downward at a slope of 9 vertical to 24 horizontal. Diverging section has a floor inclined upward at a slope of one vertical to six horizontal

Width of throat, cm	Free flow limit, H_b / H_a
2.5 to 7.5	0.5
15 to 22.5	0.6
30 to 240	0.7

and wall diverging towards the outlet. A graduated scale is fixed in a stilling well constructed in the converging section (H_a) to measure the head of water over the floor of this section and to calculate the stream size. Another scale is fixed in the other stilling well at the beginning of the divergent section (H_b) to measure the head at that section for necessary correction for submerged flow. Discharges through the flume may be either free flow or submerged flow.

The size of flume is decided by the size of throat. Flumes are built of wood, steel sheet, concrete blocks or concrete and bricks. A heavy metal sheet may be used for a smaller flume. Standard

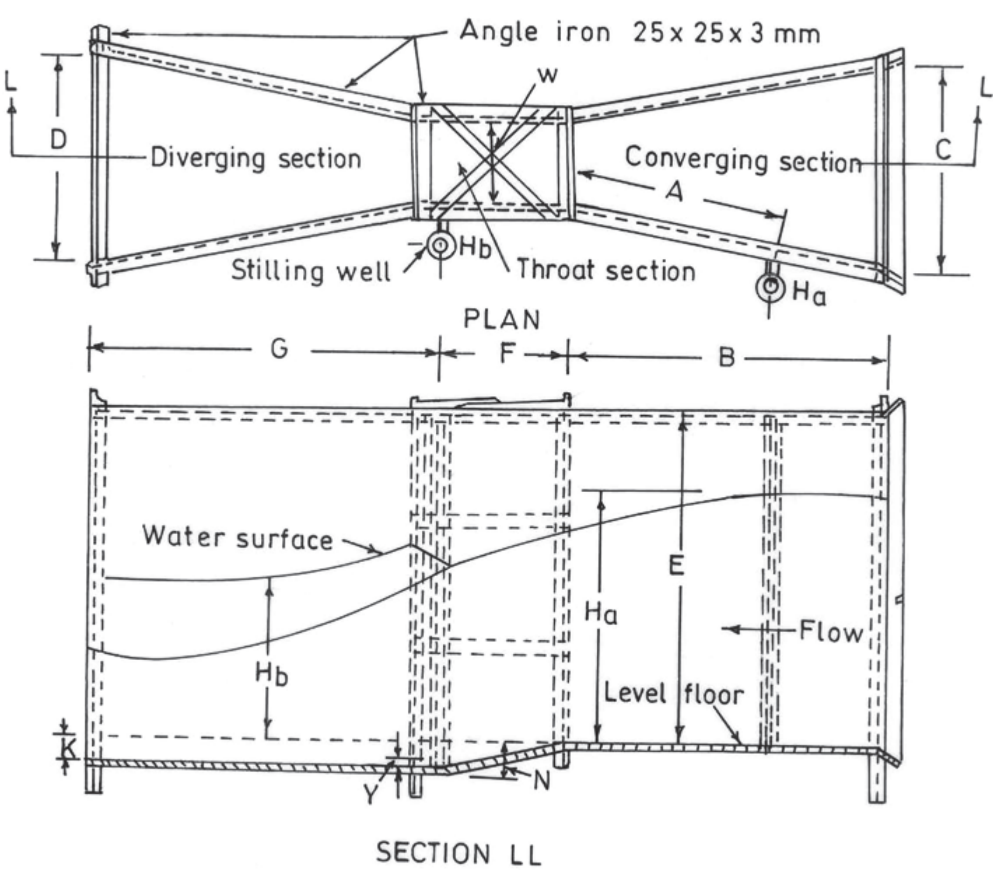

Fig. 5.2.4 Parshall flume showing different components

dimensions of Parshall flumes and discharges can be referred in any standard book for irrigation and water engineering.

The limitations are: i) it is costlier and more difficult to construct than weirs, ii) protection of the channel immediately down the flume against the channel bed erosion occurs and iii) it cannot be readily combined with a turnout.

For successful operation, the flume should be of correct size carefully. The probable maximum and minimum flows and the allowable head are required to be estimated. Maximum allowable flow on the grade of the channel and the freeboard at the place where installed. The freeboard is the upward distance from the normal water surface in the channel to the top of banks. Flumes should have a free flow possible.

b) Cutthroat flume

The cutthroat flume is an improvement over the Parshall flume and has only two sections, viz., converging and diverging and no throat section (Fig. 5.2.5). The flume has a flat bottom, vertical walls and a zero length throat section. It may have both free flow and submerged flow. Under free flow condition, critical depth of flow occurs near the flume neck or flume throat, which is the junction of the converging and diverging sections. The ratio of incoming flow depth (h_a) to the flume length shout be less than 0.4. The flume length may be from 45 cm to 3 m at neck width may vary from 2.5 cm to 1.8 m. The flume should be a

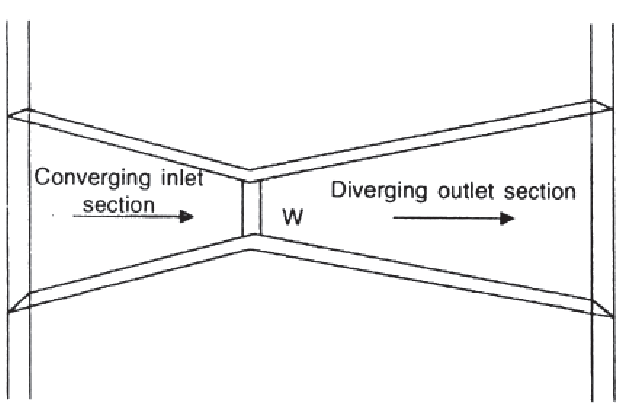

Fig. 5.2.5 Cut throat flume

straight section of the channel. It is desirable to operate it under free flow conditions.

The discharge through a cutthroat flume under free flow conditions is:

$$Q = C_1 h_a^{n_1}$$

Where,

Q = flow rate, ft^3/sec

C_1 = free flow coefficient, which is the value of Q when h_a is 1.0 foot which is the slope of the free flow rating curve

h_a = head at the converging section, ft

n_1= exponent whose value depends on flume length. L

The value of n_1 is a constant for all cut throat flumes of the same length regardless of their throat width, W. The value of n_1 can be obtained for any flume length between 1.5 feet and 9 feet by plotting Q and h_a on logarithmic paper and reading the intercept and slope and the discharge may be $Q = 1.09\ h_a^{1.825}$

When the flow depth exceeds the critical depth, the flow becomes submerged. For finding out the discharges, flow depths both at the converging section (h_a) and the diverging sections (h_b) are considered. The submergence, S is expressed as the ratio, often expressed as a percentage, of the down stream depth (h_b) the upstream depth (h_a).

References

Anonymous. 1997. Water Measurement Manual 1997.U.S. Department of Interior, Bureau of Reclamation,, Washington, U.S. A.

Clemmens, A. J., Bos, M.S. and Replogle, J.A. 1993. Flume-Design and Calibration of long throated Measuring Flumes 1993. ILRI Publication 54, Wageningen, the Netherlands, pp. 123.

Majumdar, D.K. 2000. Irrigation Water Management-Principles and Practice. Prentice Hall of India Pvt. Ltd., New Delhi, pp. 487.

Michael, A.M. 1992. Irrigation - Theory and Practice. Vikas Publishing House Pvt. Ltd., New Delhi, pp. 801.

6.0 ON-FARM DEVELOPMENT FOR ENHANCING WATER APPLICATION EFFICIENCY

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Water is a precious natural resource which should be used judiciously. However, in an irrigation system, water is lost by evaporation, transpiration by weeds and seepage in reservoirs and carrier systems. Water is also lost by deep percolation beyond root zone in fields, and also by runoff at the end of borders and furrows. The magnitude of these loses varies widely among irrigation projects because of the different physiographic features, water control and conveyance structures and management practices.

6.1 Losses in unlined canals

The actual quantity of water used by the crops through transpiration and loss from the cropped field due to evaporation during the crop period was only 38.5% of supply at the head of the canal. In no irrigation project in India the total losses in the canal distribution system and field has been less than 50% of the head discharge. A review of 90 irrigation projects of the world indicated generally low irrigation efficiencies, with only 20-40% of the water diverted from the reservoir being effectively used by the crop, while in India, the irrigation efficiency is around 10-20%. The losses of irrigation water in unlined canal distributary system in north India are given in Table 6.1.

Table 6.1 : Losses of irrigation water in unlined canal distribution systems and in the field

Source of loss	% of supplies at canal head		
	Seepage	Evaporation	Total
Main canal and branches	13.6	3.4	17.0
Distributories (10% of supply at distributor)	6.4	1.6	8.0
Field water courses (27% of supply at outlet head)	16.0	4.0	20.0
Losses from field during application (30% of supply reaching the head)	13.2	3.3	16.5
Total	49.2	12.3	61.5

In any irrigation project the total losses in the canal distribution system and field has not been less than 50% of the head discharge. Studies conducted in Nagarjuna Sagar Project have revealed that only 40-60% of water released from the reservoir reaches the field and only 20-40% is used by the crops. The main components of water losses in an irrigation system are: (a) water losses in storage-10 to 20% (b) water losses in conveyance systems -25 to 40% (c) water losses in operation 10 to 30% and (d) water losses in application 45 to 70%. Irrigation efficiency is considered to be as low as 10-20% in some projects in India. It is estimated that 11 million ha-m of water is contributed to ground water recharge annually through seepage from canal system and the return flow from irrigation. An overall irrigation efficiency of 40-50% for a project can be considered to be high and this can be achieved only by the adoption of improved irrigation and drainage practices based on scientific land and water management principles. In view of these heavy losses, it is necessary to find out where and how improvement can be made which will result in more efficient use of irrigation water.

6.2 On-Farm development

The objective of On-Farm development is to develop a proper water distribution system and to obtain maximum crop production per unit of water from a unit land in unit time. Ungated outlets, huge outlets, badly constructed and poorly maintained outlets, field channels, field to field irrigation lead to enormous wastage of water. Suitable gated outlets, junction boxes to divide the size of stream , use of water application control devices such as syphons, spiles, canvas dam etc., increases field application efficiency. The important aspects of wasteful use of irrigation water at farmers level are as follow:

- Field to field irrigation in the absence of field channels
- Escape of water to drains during transit from outlet to field
- Improper field Leveling result into surface run-off
- Over irrigation particularly during night

6.2.1 Components of On-Farm development

On-Farm development consists mainly the fol1owing items of work under the pipe outlets

A. Community items

- Formation of field channels providing water to each survey number
- Internal irrigation channels within each survey number, if the extent is large
- Drop structures and distribution boxes in field channels and drains
- Crossing on field channels and drains wherever required

B. Items on individual farmers holding

- Providing bunds to form plots in the holding.
- Land shaping to a planned grade for cultivation of light irrigated crops
- Land Leveling
- Efficient water-use on the farmer's field.

6.2.3 Field Channels

The foremost requirement is the construction of a net work of field channels of acceptable standards and their maintenance for proper distribution of water. The topographical configuration of land holdings are primary considerations in the design and layout of field channels. Scattered and fragmented holdings cause considerable problems. Consolidation of holdings will help but it has become almost impossible to accomplish under our present social and economic conditions. The field channels are usually aligned along field boundaries except the plots are of bigger size when it is unavoidable to align them through the plot. It is advantageous to align field channels to reduce seepage losses.

6.2.3.1 Capacity of Field Channel

The capacity of field channel depends on how large an area is to be irrigated, how often and how much water is to be coveyed for each conveyance.

$$\text{Capacity of channel (l/s)} = \frac{A \times d \times 27.8}{F \times H}$$

Where, A = Area to be irrigated (ha or acre)

d = depth of water to be sent through the channel (cm)

F = Number of days over which irrigation will be spread

H = Number of hours of irrigation per day

Generally, the natural slope of the land determines the slope of the bed of the field channel. The permissible velocities for various soils which do not cause erosion or silting are given in table 6.2. The entire length of the field channel should have the same carrying capacity equivalent to the flow at the pipe outlet.

Table 6.2 : Permissible velocities for field channels

Type of soil	Maximum velocity (cm/s)
Loam, sandy loam, silt loam	60
Clay loam	65
Clay	70

6.2.3.2 Lay-out of field channel

The field channel system should be laid out so as to provide atleast one outlet for each individual farmer. Where convenient and to minimise the length of farm channels, additional outlets may be provided permitting diversion directly to the field channel bordering a holding. However each outlet from the field channel as far as possible should be a permanent gate structure with accompanying check structure if necessary to command the outlet. The field channel has to be provided with drop structures and distribution boxes to ensure diversion at full capacity at each outlet. The field channels as-far as possible should be in the cutting. The alignment of the field channel is determined by both topographic and cadastral considerations. As far as possible it should follow field boundaries. The upstream one quarter to one third of the field channel should be aligned directly on the main ridge to the extent possible.

Irrigation channels are generally constructed along the line of the land and if the slope is steep soil erosion takes place. Drops and chutes are constructed to flatten channel grades, reduce velocity of water and soil erosion. In steep slops, chutes are more economical than a series of drop structures. Similarly, water application control devices are necessary for easy and proper application of irrigation water. Good control of water will reduce the labour required to irrigate and will help to make the best use of the water supply without wastage.

6.2.3.3 Lining of field channels

In canal irrigation as well as irrigation through tube well or ponds, the water reaches the plant in its final lap through water courses or field channels. These channels are generally small earthen channels running along the borders of the fields. The loss due to seepage and evaporation which can occur in the water courses / field channels can be staggeringly high. Width of water courses and velocity of flow is generally quite low. Earlier, the water courses were maintained by cultivators and the tariff system was based on area irrigated and not the volume of water used. The cultivator, therefore, had hardly any interest in the efficiency of water course. However, recently, the enormous losses of water in field channels has attracted the attention of irrigation authorities and considerable efforts are being made to construct lined water courses which would reduce water losses. Construction of field course channels has been taken up on a large scale under the command area development in many major and minor irrigation projects. Since, CADA authorities as well as minor irrigation departments are going to handle water course lining it would be easier to introduce modern, economical and technically feasible lining method on extensive scale.

6.2.3.4 Lining material

Six experimental field channels were designed for discharge varies between 28 and 56 lps based on the criteria of best hydraulic section for both trapezoidal and rectangular shapes. Five different lining materials were: cement pointed brick lining (1:1 side slope), low density polyethylene (L.D.P.E.) overlaid with 15 cm soil cover (1.5 : 1 and 2 : 1 side slopes), and with 15 cm soil cover on the bottom (rectangular section) and the sixth channel was kept unlined (control). The steady state seepage rates observed in these six channels (channels 1 to 6) were 1.350, 0.057, 0.121, 0.011, 0.031 and 3.228 $cm^3 / cm^2 / h$ respectively (Kumar and Singh, 2010). Based on their studies, it was recommended that earthen irrigation channels should be lined with 150 micron LDPE film overlaid by soil cover at 2:1 side slope

6.3 Proper farm layout, appropriate irrigation method and provision of drainage

Size of irrigation stream, depth of irrigation, soil infiltration rate, land slope, method of irrigation and crop to be irrigated are the factors which decide the size of the individual farm plots to secure uniform water application without wastage or loss of nutrients. The length of the field should not exceed 90 m where as the width should not be less than 15 m. Similarly, there are standard dimensions of basins; furrows, border strips etc., to suit the soil type, slope, stream size, crop to be irrigated etc. The detail of each method is described in detail in Chapter 5. Proper land shaping with rational layout of form boundaries and land slopes permit more controlled use of water and increases water use efficiency. The slope of the plots varies from 0.05% to 0.5% depending upon soil type and other factors. In addition for proper water management, field drains have to be laid out for removal of surface water during heavy rainfall or removal of excess irrigation water due to over irrigation or seepage from an adjacent channel as well as percolation of irrigation water from the fields. Drains have to be laid out at the lower end of each block or farm to convey water to a collector drain which in turn should discharge into a natural drainage course at the nearest convenient point. Spacing and layout of collector drains depends on size of individual blocks, topography, soil and location of outfall into natural drainage. The design of farm drainage system has been discussed in Chapter-9.

6.4 FIELD LEVELING – KEY TO ENHANCE WATER APPLICATION EFFICIENCY

Surface method of irrigation need level plots or field with a planned grade for efficient application of irrigation water. It is not uncommon to find uneven lands with boulders, mounds, depression, gullis, shrub, jungle and outcrop of rocks. When such land is to be irrigated, land development is essential. The most important land development at farmers field is land leveling. Low spots in a field allow concentration of water and cause waterlogging whereas high spots do not receive enough moisture for plant growth. It is difficult to control water in an uneven field. Unevenness of the soil surface has a major impact on the germination, stand and yield of crops through nutrient water interaction and salt and soil moisture distribution pattern. Excessive slope leads to accelerated erosion. Leveling of land permits easy control and uniform application of irrigation water. If the field or plot is well leveled, erosion is reduced, time for irrigation is saved and crop yield is also increased due to uniform moisture in the entire field. Efficiency of use of irrigation water is, therefore, increased due to proper leveling of land.

6.4.1 Methods and equipments for leveling

Mostly farmers rely on animal power or small mechanized equipment which an individual can own and operate. As the farmers irrigate their fields, they observe the locations of high and low spots on the field. Then as he prepares the fields between plantings, he tries to move soil from the high spots to the low ones. Over a period of several years, individual fields are smoothed enough to be watered fairly well. Conventionally, farmers use plankers drawn by draft animals or by small tractors. However, farmers in Punjab, Haryana and Uttar Pradesh use tractor operated iron scrappers or leveling boards. Traditional land leveling includes field survey, staking and designing the field, calculation of cuts and fills and then using a scraper and a land plan to even the land. Despite all these labor-intensive efforts, desired accuracy is not achieved. Thus traditional methods of leveling are not only more cumbersome and time consuming but donot achieve a precise land leveling. Very often most rice farmers level their fields under ponded water conditions and check level by ponding water. Thus in the process of a having good leveling in fields, a considerable amount of water is wasted (Rickman, 2002). It is a common knowledge that most of the farmers apply irrigation water until all the parcels are fully wetted and covered with a thin sheet of water. Studies have indicated that a significant (20-25%) amount of irrigation water is lost during its application at the farm due to poor farm designing and unevenness of the fields (Rickman, 2002). This problem is more pronounced in the case of rice fields. Unevenness of fields leads to inefficient use of irrigation water and also delays tillage and crop establishment options. Fields that are not level have uneven crop stands, increased weed burdens and uneven maturing of crops.

New equipment is continually being introduced which provides the capability for more precise land Leveling operations. One of the most significant advances has been the adaptation of laser control in land Leveling equipment. The equipment has made level basin irrigation particularly attractive since the final field grade can be very precise. Comparisons with less precise techniques have clearly shown that laser-levelled fields achieve better irrigation and production performance. The advent of the laser-controlled land Leveling equipment has marked one of the most significant advances in surface irrigation technology. The precision improves irrigation uniformity and efficiency and as a result the productivity of water and land. The improved productivity has shown to pay economic dividends that easily exceed the cost of the Leveling. Laser-guided equipment is being demonstrated and tested in different part of the country and this technology has become very popular among farmers particularly in plains of Northern part of the country. Farmers recognize this and therefore devote considerable attention and resources in leveling their fields properly.

6.4.2 Laser land leveling and layout

The extent of laser leveling in South Asia is currently extremely small, compared with 50-80% leveling in many advanced countries (Rickman, 2002; Jat *et al*, 2006). Land leveling can reduce evaporation and percolation losses from wheat by enabling faster irrigation times and by eliminating depressions and therefore ponding of water in depressions. This also reduces waterlogging problems, especially on heavy textured soils. Laser leveling in Pakistan resulted in average wheat irrigation water savings of 25% in comparison with non-lasered fields while increasing yield by 20- 35% and reducing labour and land preparation costs (Jat *et al*, 2006). Land leveling also reduces the depth of water required to cover the highest parts of the field and for ponding for weed control in rice. Rickman (2002) found that rice yields in rainfed lowland laser-leveled fields were 24% higher than in non-lasered fields in Cambodia, and that yield increased with the uniformity of leveling.

Laser-controlled precision land leveling helps to:

- Save irrigation water
- Increase cultivable area by 3 to 5% approximately
- Improve crop establishment
- Improve uniformity of crop maturity
- Increase water application efficiency up to 50%
- Increase crop yields
- Facilitate management of saline environments
- Reduce weed problems and improve weed control efficiency

6.4.3 Laser land leveling

The introduction of laser leveling in the 1970's produced a silent revolution that has raised potential of surface irrigation efficiency to the levels of sprinkler and drip irrigation (Erie and Dedrick 1979). Laser-controlled land Leveling equipment grades fields to contour the land for different irrigation practices. With sprinklers, a perfectly level field conserves water by reducing runoff and allowing uniform distribution of water. Furrow irrigation systems need a slight but uniform slope to use water most efficiently. Before starting the laser land leveling process, the field should be ploughed and a topographic survey be carried out. One of the measures to improve irrigation efficiency is zero-grade Leveling for crop production. Zero-slope fields can be flushed or drained more quickly. Level fields allow for a more uniform flood depth, using less water. Benefits from precision leveling of land extend for many years, although some minor land smoothing may be required from time to time due to field operations and weather conditions.

6.4.3.1 Components of laser land leveling system

The laser leveler involves the use of laser (transmitter), that emits a rapidly rotating beam parallel to the required field plane, which is picked up by a sensor (receiving unit) fitted to a tractor towards the scraper unit. The signal received is converted into cut and fill level adjustment and the corresponding changes in the scraper level are carried out automatically by a hydraulic control system. The scraper guidance is fully automatic; the elements of operator error are removed allowing consistently accurate land leveling. The set-up consists of two units. The Laser transmitter, which is mounted on a high platform. It rapidly rotates, sending the laser light in a circle like a lighthouse except that the light is a laser, so it remains in a very narrow beam. The mounting has an automatic leveler built into it, so when it's set to all zeros, the laser's circle of light is perfectly level. A laser-controlled land leveling system consists of the following five major components: (i)Drag bucket; (ii) Laser transmitter; (iii) Laser receiver; (iv) Control box and (v) Hydraulic system

i) Drag bucket

The drag bucket can be either 3-point linkage mounted on or pulled by a tractor. This system is preferred as it is easier to connect the tractor's hydraulic system to an external hydraulic ram than to connect the internal control system used by the 3-point-linkage system. Bucket dimensions and capacity will vary according to the available power source and field conditions.

ii) Laser transmitter

The laser transmitter mounts on a tripod, which allows the laser beam to sweep above the field. Several tractors with laser unit and drag bucket can work from one transmitter with guidance from laser receiver.

iii) Laser receiver

The laser receiver is a multi-directional receiver that detects the position of the laser reference plane and transmits this signal to the control box. The receiver is mounted on a manual or electric mast attached to the drag bucket. It is mounted on the scraper. A set of controls allow the laser receiver to control the height of the bucket on the scraper.

iv) Control box

The control box accepts and processes signals from the machine mounted receiver. It displays these signals to indicate the drag buckets position relative to the finished grade.

v) Hydraulic control system

The hydraulic system of the tractor is used to supply oil to raise and lower the leveling bucket. The oil supplied by the tractor's hydraulic pump is normally delivered at 2000-3000 psi. As the hydraulic pump is a positive displacement pump and always pumps more oil than required, a pressure relief valve is needed in the system to return the excess oil to the tractor reservoir. If this relief valve is not large enough or malfunctions, damage can be caused to the tractors hydraulic pump.

6.4.3.2 Operational aspects of laser land leveller

Laser-controlled grading technology is currently the best method to grade a field. The system includes a laser-transmitting unit that emits an infrared beam of light that can travel up to 700m in a perfectly straight line. The second part of the laser system is a receiver that senses the infrared beam of light and converts it to an electrical signal. The electrical signal is directed by a control box to activate an electric hydraulic valve. Several times a second, this hydraulic valve raises and lowers the blade of a grader to keep it following the infrared beam. Laser leveling of a field is accomplished with a dual slope laser that automatically controls the blade of the land leveler to precisely grade the surface to eliminate all undulations tending to hold water. Laser transmitters create a reference plane over the work area by rotating the laser beam 360 degrees. The receiving system detects the beam and automatically guides the machine to maintain proper grade.

6.4.3.3 Steps in laser land Leveling

i) **Ploughing of field:** Ploughing of a field should start from the center outwards. It is preferable to plough the field when the soil is slightly moist, because if the soil is ploughed dry a significant increase in tractor power is required and large clod sizes may remain. If the soil is very dry, a one-way disc or mould board plough may be used. Disc harrow implements are ideal for second workings. All surface residues need to be cut up or removed to facilitate the transport of soil.

ii) **Topographic survey:** After ploughing, a topographic survey can be conducted to record the high and low spots in the field. Adjust the individual positioning of the tripod legs until the base plate is level. Attach the laser transmitter to the base plate. If the laser is not well leveled, adjust the individual screws on the base of the transmitter to get the level indicator (bubble) at the center. Most lasers will not rotate unless the transmitter is leveled. When transmitter is leveled, attach the receiver to the pole and activate the alarm to take field observations. All measurements should be recorded in a field book. The mean height of the field is calculated by taking the sum of all the readings and dividing by the number of readings taken. It is advisable to take the reading at a regular interval of 15 m x 15 m to achieve greater precision in land leveling.

iii) Steps in the process of leveling of field : Following steps are taken for precise levelling of the field

Step1	Set the average elevation value of the field in the control box
Step 2	The laser-controlled bucket should be positioned at a point that represents the mean height of the field
Step 3	The cutting blade should be set slightly above ground level (1.0-2.0 cm).
Step 4	The tractor should then be driven in a circular direction from the high areas to the lower areas in the field.
Step 5	To maximize working efficiency, as soon as the bucket is near filled with soil the operator should turn and drive towards the lower area. Similarly as soon as the bucket is near empty the tractor should be turned and driven back to the higher areas
Step 6	When the whole field has been covered in the circular manner, the tractor and bucket should then do a final leveling pass in long runs from the high end of the field to the lower end
Step 7	The field should then be re-surveyed to make sure that the desired level of precision has been attained

iv) Tillage practices to maintain the level of field after Leveling

Traditional tillage practices often move the soil in one direction — outward from the center of the field. Over time, such soil movement creates an uneven soil surface resulting in a low spot in the centre of the field. The center of the field often remains wetter and tillage operations will often be delayed with high incidence of weeds. After leveling, the field should be ploughed beginning from the center and working out toward the field boundary. Initially, a single pass should be made in the centre of the field to move the soil to the right. The tractor is then repositioned at the end of the first run so as to plough the second run outwards from the furrow created. The third plough run then moves the previous ploughed soil back into the depression in the center of the field. The fourth run then refills the remaining furrow leaving the center of the field level. The field should then be ploughed on either side of the land until a margin equal to the width of the headland is left. The remainder of the field is then ploughed in a continuous pattern with the final run leaving a drainage furrow beside the bund.

6.4.4 Impact of laser leveling

Laser leveling of agricultural land is a recent technology development in India. Precise leveling by laser leveler has the potential to enhance water and other precious inputs without deleterious effect of environment. Popularisation of this technology among farmers in a participatory mode on a comprehensive scale, therefore, needs appropriately focused attention on priority basis along with requisite support from researchers and planners. Laser leveling is evidently one of the ways by which we can address these issues of conservation agriculture to a great extent. The results reported by different works and agencies are quite encouraging. The major effects on different aspect are summarized below:

i) Increase in cultivable area

Smoothness of the land surface permits larger plot sizes for irrigation. This helps in saving precious land, and also adds additional land after removal of extra bunds and channels. Plot sizes in different villages have increased from 33 to 80% when laser leveled as compared to original plot sizes. The plot size for the wheat crop increased from 50 m x 12 m (before leveling) to 50 m x 20 m (after laser leveling) whereas in rice crop plot size increased from 50m x 25m to 50mx 50m (Rajput and Patel, 2003). In another investigation, it was found that 2 to 3% addition in the cultivable area is possible due to laser land leveling (Khan,1986). Rickman (2002) had also reported that about 5 to 7% cultivable area could be increased due to precision land leveling. Increasing field size from 0.1 ha to 0.5 ha results in the increase of the farming area from 5 to 7 percent. This increase in farming area gives the farmer the option to reshape the farming area that can reduce operating time by 10 to 15 percent (Rickman, 2002). Another study conducted under USAID project at the farmers' fields in western Uttar Pradesh, revealed that about 3 to 6% additional land areas could be brought under cultivation in canal and tube well irrigated areas respectively, however, the area increase varies from field to field depending on plot size and divisions (Table 6.3 and 6.4).

Table 6.3 : Effect of laser land leveling on plot size for wheat and rice

Village	Field No.	Wheat		Rice	
		Polt size (mxm)		Polt size (mxm)	
		Before levelling	After levelling	Before levelling	After levelling
Lakhan	516	50x12	50x20	50x25	50x50
	456	30x12	50x12	50x10	50x25
	745	25x14	45x14	40x15	60x25
Masanta	364	60x11	60x20	60x15	80x25

ii) Saving in irrigation water

A significant reduction in total water use in wheat as well as rice was recorded due to precision land leveling compared to traditional land leveling. The total water use in wheat and rice in laser leveled field was reduced to 49.5% and 31.7%, respectively (Jat *et al.* 2003, 2005). The estimated total water use of wheat crop was 5270 m^3 ha^{-1} and 3525 m^3 ha^{-1} in traditionally leveled field and laser leveled fields respectively. In raised bed

Table 6.4 : Estimated additional area which can be brought under cultivation by precision land leveling in selected farmers' fields in western Uttar Pradesh

Parameters	Traditional land levelling		Laser land levelling	
	Canal irrigated	Tube well irrigated	Canal irrigated	Tube well irrigated
Basin size (mxm)	40x30	30x20	50x50	40x30
Basin area (m^2)	1200	600	2500	1200
Area under bund & channel (m^2 ha^{-1})	600	1200	300	600
Additional area brought under cultivation (%)	-	-	3	6

planted wheat, about 26% water can be saved through laser land leveling. In rice, total water use was estimated as 6950 m^3 ha^{-1} and 9150 m^3 ha^{-1} under precision land leveling and traditional land leveling respectively. From other on-farm investigations on wheat in villages Masauta and Lakhan, 338 to 808 m^3 ha^{-1} saving in total water use was found (Rajput and Patel, 2003). Studies conducted by RWC and PDCSR, Modipuram at the 71 farmers' fields of western Uttar Pradesh revealed that more than 61 farmers saved about 5-10 ha-cm water in wheat crop and about 10-15 ha-cm water in transplanted rice crop (Jat *et al*, 2006) . Tyagi (1984) reported the application depth values of 3.9 and 9.7 cm at leveling index (LI) of 0.75 cm. and 6.75 cm, respectively in wheat crop under sodic soils of Haryana. Further, the distribution efficiency obtained with various depths of application (4 to 12 cm) showed that distribution was more uniform (> 90%) in plots with an average LI of 0.75 cm and poor (< 50%) in plots with an average LI of 6.75 cm. However, with increasing depth of water application, the distribution improved in poorly leveled plots as well.

iii) Improvement in irrigation and nutrient-use efficiency

The foremost objective of laser land leveling is to improve application and distribution efficiencies of irrigation which ultimately leads to higher water productivity. The distribution efficiency of applied water in wheat in sandy loam soil was significantly higher under precision land Leveling compared to traditional leveling (Jat *et al*. 2003, Jat *et al* 2006). The application and distribution efficiencies of applied water were improved significantly under precision land leveling compared to traditional leveling (Sattar *et al*. 2003 and Rajput *et al*. 2004). Laser land Leveling facilitate uniform application of water under irrigated condition create an opportunity for uniform distribution of nutrients. The uptake of applied nutrients in a sandy loam soil increased significantly under precision land leveling compared to traditional land leveling. A significant increase in the uptake efficiency as well as apparent recovery fraction of the applied N, P and K in a typic*Ustochrept* in rice was observed due to precision land leveling (Pal *et al.* 2003). Choudhary *et al.* (2002) observed higher fertilizer use efficiency in wheat in fields under laser land leveling compared to conventional leveling. In on-farm investigations carried out at 71 locations in western Uttar Pradesh, significant improvement in nitrogen-use efficiency in rice-wheat cropping system was recorded and increase in NUE were found from 45.11 to 48.37 and 34.71 to 36.90 kg grain kg^{-1} applied nitrogen in rice and wheat, respectively.

iv) Enhancement of water productivity

In an on-station investigation at PDCSR, Modipuram, a significant reduction in water use, and marked improvement in water productivity in rice-wheat cropping system was recorded due to precision land leveling compared to traditional leveling. It was recorded that with similar fertility levels and land configurations, the water productivity of rice and wheat increased from 0.55 and 0.82 to 0.91 and 1.31 kg grain m^3 water, respectivel (Jat *et al.* 2005). Raised bed planting further improved the productivity of wheat in laser leveled fields. On-farm investigations, carried out under USAID project in Meerut, Baghpat, Muzaffarnagar and Ghaziabad districts of western Uttar Pradesh in a rice-wheat cropping system, revealed significant improvement in water productivity of rice and wheat under laser land leveling compared to traditional land leveling. Field trials were conducted in rice season to evaluate the interactive effects of rice planting methods and land leveling on 16 farmers' fields inWestern Uttar Pradesh. Results indicated that precision land leveling improves the yield and water productivity of rice grown as puddled transplanted or unpuddled direct seeded rice. The total saving in irrigation water in DSR rice over the puddled transplanted rice was nearly 25cm-ha shared equally between direct seeding and precision land leveling. The descriptive statistical analysis of 71 locations revealed that the coefficient of variation in water productivity decreased in rice and wheat from 10.84% and 8.97% to 9.72% and 7.89% respectively due to precision land leveling. Further, the average irrigation water productivity of rice and wheat was increased from 0.49 and 1.02 to 0.61 and 1.22 kg grain m^{-3} water. With the use of precision land leveling, significant increase in water-use efficiency of seed cotton was observed from 36.9 to 63.1% (Sattar *et al.* 2003). The increase in WUE was attributed to less requirement of irrigation under precision leveling (54.80 cm) as compared to traditional leveling (74.65 cm). Choudhary *et al.* (2002) also reported higher water use efficiency (1.67) under precision leveling compared to conventional leveling (1.10) under on-farm investigations.

v) Increase in crop yield

A considerable increase in yield of crops is possible due to laser land leveling. Results of an experiment carried out at PDCSR, Modipuram showed a perceptible yield advantage of laser land leveling over traditional leveling (Jat *et al.* 2006). They reported that the grain yield of wheat increased from 4.3 t ha^{-1} under traditional Leveling to 4.6 t ha^{-1} through precision leveling. The improvement in yield of wheat under laser land leveling was associated with overall improvement in the growth and yield attributing characters of the crop due to better environment for the development of the plants under well-leveled field. In another investigation at Modipuram, Pal *et al.* (2003) reported a significant improvement in growth and yield of upland paddy due to precision land leveling compared to traditional land leveling. Farmers' participatory research under USAID project in western Uttar Pradesh revealed a marked yield improvement in rice-wheat cropping system due the laser land leveling. The average yield levels of rice and wheat respectively, being recorded 4.84 and 5.53 t ha^{-1} under laser land leveling were markedly superior to traditional land leveling being 4.51 and 5.21 t ha^{-1} (Table 6.5). Further, the coefficient of variation in yield of rice (9.58%) and wheat (7.86%) between farmers was decreased with laser land leveling compared to traditional land leveling being 10.24 and 8.82%, respectively.

Findings of a long-term study (Rickman, 2002) showed 24% increase in yield of rice due to precision land leveling over traditional land Leveling at the same level of variety and fertilizer use. Further, a strong correlation was found between the levelness of the land and crop yield. Sattar *et al.* (2003) reported a reduction in the yield of seed cotton up to 20.1% on traditionally leveled (TL) fields compared to precision leveling (PL) maily due to (i) low plant population in TL, (ii) greater variation in plant height from average plant height (tallness and shortness of the plants within the TL field declined fruit bearing capacity of the plants), and (iii) late crop maturity or prolonged vegetative growth due to excessive water applied to the TL fields. Choudhary *et al.* (2002) demonstrated the effect of laser land leveling on the productivity of wheat sown on different dates. In general, as the time of sowing

Table 6.5 : Water productivity of rice-wheat cropping system due to land leveling in western Uttar Pradesh

Parameters	Grain yield (t ha^{-1})*			
	Rice		Wheat	
	Laser leveling	Traditional leveling	Laser leveling	Traditional leveling
Minimum	3.90	3.50	4.60	4.20
Maximum	5.70	5.44	6.21	6.12
Average	4.84	4.51	5.53	5.21
CV (%)	9.58	10.24	7.86	8.82
Water productivity (kg grain m^{3} water)*				
Minimum	0.49	0.38	1.00	0.83
Maximum	0.73	0.60	1.38	1.18
Average	0.61	0.49	1.22	1.02
CV (%)	9.72	10.8	7.89	8.97

*Data is mean of 71 farmers

delayed, the yield decreased. But, the marginal decrease in the yield due to delayed seeding (from 1st to 2nd and 2nd to 3rd date of seeding) was much higher in traditionally sown wheat (774.5 and 1425.5 kg ha^{-1}) compared to seeding under laser land leveling (346 and 581 kg ha^{-1}). Tyagi (1984) reported that the yields were higher by 50% in precision-leveled plots compared to traditional leveled plots. In a similar study Khepar (1982) observed a decrease of 270 kg ha^{-1} for each unit increase in topographic index from 0.5 to 2.82 cm. Recently, Jat *et al*, (2009) reported 6 percent increase in system yield of rice-wheat rotation with a saving of 15 percent in water use and net returns of about 143 US$ in laser land leveling compared to traditional leveling (Table 6.6).

Field demonstrations with precision land leveling were conducted in the districts of Bathinda, Mansa and Muktsar by, Regional Research Station, Bathinda in rice (PAU-201), *Bt* Cotton hybrid (RCH-134) and chilli (CH-1), wheat (PBW 343), potato (Kufri Bahar) and cauliflower (Punjab Katki) during 2008-09. The results are presented in Table 6.7 indicated that during *kharif*, there was 6.5, 10.5 and 14.6 per cent increase in yield and 21.4, 20 and 25 per cent saving in water in rice, cotton and chilli, respectively with laser leveling compared to conventional method of leveling. The laser land leveling resulted in an additional monetary benefit of 4.8 per cent (Rs. 2055/-) per hectare without any additional cost of cultivation in rice. Similarly, there was additional benefit of 10.4 per cent (Rs. 5820/-) per hectare over the conventional method at the same cost of cultivation in cotton. Interestingly, in chilli, the additional monetary benefit was 21.6 per cent (Rs. 13080/-) per hectare over conventional method.

During *rabi*, the mean wheat yield increase was 8.0 % with 31.4 % water saving over the conventional technology. Tthe laser leveling increased the tuber yield and curd yield by 10 percent where as the saving in water was to the tune of 20 percent both in potato and cauliflower compared to conventional leveling. Though there was no monetary benefit with this technology in

Table 6.6 : Effect of levelling on grain yield, water productivity and net returns of Rice-Wheat System

Parameters	Land leveling	Rice	Wheat	RW system
Grain yield (t ha^{-1})	PLL	6.42	4.69	11.11
	TL	6.15	4.32	10.47
Total water use (cm ha^{-1})	PLL	155.5	32.5	187.0
	TL	179.0	36.0	215.0
Water productivity (kg grain m^3 water)	PLL	0.29	1.13	0.43
	TL	0.25	0.95	0.36
Cost of production(US$ ha^{-1})	PLL	590	374	955
	TL	593	387	978
Net returns (US$ ha^{-1})	PLL	385	788	1173
	TL	336	694	1030

PLL : precision land leveling; TL: Traditional leveling (Source: Jat *et al*, 2009)

wheat, however, additional monetary benefit of 13.1 and 10.4 percent was obserbed in potato and cauliflower respectively (Table 6.7). It can, therefore, be concluded that precision leveling is the most effective technique to improve productivity of surface irrigated crops

Table 6.7 : Effect of Laser land leveling on water saving, yield and monetary benefits in different crops during 2008-09 in Punjab

Parameters	CT	PLL	Benefits in quantity	Percent increase	Remarks
Rice					
Water use(m^3/ha)	15750	12375	3375	21.4	Uniform distribution of
Yield(kg/ha)	8178	8708	530	6.5	water, better plant stand
Monetary benefits (Rs/ha)	42484	44539	2055	4.8	with laser leveling
Cotton					
Water use(m^3/ha)	3750	3000	750	20.0	Uniform distribution of
Yield(kg/ha)	2875	3178	303	10.5	water, better germination
Monetary benefits (Rs/ha)	56120	61940	5820	10.4	with laser leveling
Chilli					
Water use(m^3/ha)	8250	6000	2250	25.0	Uniform distribution of
Yield(kg/ha)	17800	20400	2600	14.6	water, better plant stand
Monetary benefits (Rs/ha)	60454	75534	13080	21.6	with laser leveling
Wheat					
Water use(m^3/ha)	4375	3000	1375	31.4	Uniform distribution of
Yield(kg/ha)	5148	5560	412	8.0	water, better germination
Monetary benefits (Rs/ha)	28899	28098	-	-	with laser leveling
Potato					
Water use(m^3/ha)	6000	4800	1200	20.0	Uniform distribution of
Yield(kg/ha)	25000	27500	2500	10.0	water, better germination
Monetary benefits (Rs/ha)	42095	47595	5500	13.1	with laser leveling
Cauliflower					
Water use(m^3/ha)	6000	4800	1200	20.0	Uniform distribution of
Yield(kg/ha)	16200	17900	1700	10.5	water, better plant stand
Monetary benefits (Rs/ha)	63118	69693	6575	10.4	with laser leveling

CT : Conventional leveling; PLL: Precision Laser Leveling

vi) Environmental benefits of laser land leveling

Laser land leveling can certainly minimize yield variability at farm level, optimize input-output relation and save resources like soil, water and energy. If adopted on a large scale, the laser leveling would help in improving the quantity and quality of ground water because of improved water productivity and less accumulation and deep percolation of water-soluble pesticides and chemicals, especially nitrate. It is estimated that adoption of precision land leveling system to just two million hectare of area under rice-wheat system could save 1.5 million hectare-meter of irrigation water and improve crop yields amounting to US$ 500 million in three years. Rickman (2002) reported 10-15% reduction in operating time of agricultural machinery in the laser-leveled fields as compared to traditional leveling. Laser leveling thus may prove to be an important technology in reducing the consumption of fossil fuel for various farming operations, which will bring a direct tangible and intangible benefit to farmers. It is estimated that extension of laser assisted precision land leveling system to just two million hectares of area under rice-wheat system could save diesel up to 200 million liters (equal to US $1400 million) and reduce GHG emissions equivalent to 500 million kg.

In spite of several direct and indirect benefits derived from laser land leveling technology, it is yet to become a popular farming practice in our country. For accelerating its popularisation and large-scale adoption, it requires a number of well-considered and synchronized research, extension in participatory mode and policy initiatives keeping in view the long-term sustainability of our production systems. A judicious blending of appropriate research and policy strategies in conjunction with various resource conservation technology options have the necessary potential to bring about a significant change in agricultural production scenario of country.

References :

Choudhary, M.A, Mushtaq, A, Gill, M, Kahlown, A and Hobbs, P.R. 2002. Evaluation of resource conservation technologies in ricewheat system of Pakistan. In: *Proceedings of the International workshop on developing an action program for farm level impact in rice-wheat system of Indo-Gangetic plains*, 25-27 September 2000, New Delhi, India. Rice-wheat Consortium Paper Series 14, New Delhi, India. Ricewheat Consortium for the Indo-Gangetic Plains. 148 pp.

Erie, L.J and Decrick, A.R. 1979. Level basin irrigation: A method for conserving with and Labor. USDA Farmers' Bulletin 2261, 23.

Jat, M.L, Pal, S.S, Subba Rao, A.V.M. and Sharma, S.K. 2003. Improving resource use efficiency in wheat through laser land leveling in an *ustochrept* of Indo-Gangetic plain. In: *National Seminar onDevelopments in Soil Science, 68th Annual Convention of the Indian Society of Soil Science*, November 4-8,2003, CSAUAT, Kanpur (UP).

Jat, M.L, Sharma, S.K and Gupta, R.K, Sirohi, K and Chandana, P. 2005. Laser land leveling: the precursor technology for resource conservation in irrigated ecosystem of India. In: Conservation Agriculture-status and prospects (Eds., Abrol, I.P., Gupta, Raj K. and Malik, R.K.), CASA, New Delhi, p. 145-154.

Jat M.L., Chandna, P, Gupta, R.K, Sharma, S.K. and Gill, M.A. 2006. Laser Land Leveling: A Precursor Technology for Resource Conservation. Rice-Wheat Consortium Technical Bulletin Series 7.New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains. pp 48.

Jat, M.L. Gathala, M.K, Ladha, J.K, Saharawat Y.S, Jat, A.S. Kumar, V, Sharma, S.K, Kumar, V and Gupta, R. 2009. Evaluation of precision land leveling and double zero-till systems in the rice–wheat rotation: Water use, productivity, profitability and soil physical properties. Soil and Tillage Research**,** 105 (1): 112-121.

Khan, B.M. 1986. Overview of water management in Pakistan. *Proceedings of Regional seminar for SAARC member countries on farm water management*. Govt. of Pakistan. P. 8.

Khepar, S.D., Chaturvedi, M.C. and Sinha, B.K. 1982. Effect of precise leveling on the increase of crop yield and related economic decision. Journal of Agricultural Engineering. 19(4): 23-30.

Kumar, A and Singh, Rajbir. 2010. Plastic lining for water storage structues. Technical Bulletin No. 50. DWM, Bhubaneswar.

Pal, S.S., Jat, M.L. and Subba Rao, AVM. 2003. Laser land leveling for improving water productivity in rice-wheat system. PDCSR Newsletter.

Rajput, T.B.S. and Patel, N. 2003. *Laser land leveler se khet samatal karayiye, pani bachayiye aur paidavar badhayiye*. Folder (Hindi). Water Technology Centre, Indian Agricultural research Institute, Pusa New Delhi.

Rajput, T.B.S., Patel, N. and Agrawal, G. 2004. Laser Leveling- A tool to increase irrigation efficiency at field level. J. Agril. Eng. 41(1): 20-25.

Rickman, J.F., 2002. Manual for laser land leveling, Rice-Wheat Consortium Technical Bulletin Series 5. New Delhi-110 012, India: Rice-Wheat Consortium for the Indo-Gangetic Plains. pp.24.

Sattar, A., Khan. F.H. and Tahir, A.R. 2003. Impact of precision land leveling on water saving and drainage requirement. *J. AMA*. 34: 39- 41.

Tyagi, N.K. 1984. Effect of land surface uniformity on irrigation quality and economic parameters in sodic soils under reclamation, *Irrigation Sci.* 5: 151-166.

7.0 OPTIMUM UTILISATION OF IRRIGATION WATER FOR ENHANCED LAND AND WATER PRODUCTIVITY

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Water is a scarce and expensive resource and it is, therefore, necessary to use this resource most efficiently. In big and medium irrigation projects, the water is transported to large distances and on the way to the field a large portion of it is lost mainly due to seepage from the system, evaporation from the open water surface. It has been estimated that under semi-arid and medium to light textured soil conditions, the net utilization is only 30% of the total water delivered when the entire system is unlined. When the whole system is lined than the net utilization has increased to 50% (Table 7.1). World over, on an average, only 45% of the total delivered water is used by the crop (Fig. 7.1).

Table 7.1 : Losses (%) and net utilization of irrigation water under different irrigation system

Systems	Canals	Distri-butories	Field water courses	Field losses	Total losses	Net utilization
Entire system unlined	15	7	22	27	71	29
Only canals lined	4	7	25	30	66	34
Canal and distributory lined	4	2	26	32	64	36
Whole system lined	4	2	6	42	54	46
Whole system lined and sprinkler method	4	2	6	6	18	82

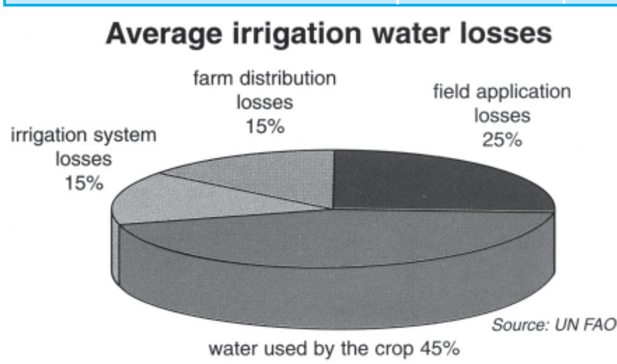

Fig. 7.1 Average irrigation water losses

7.1 Optimum utilisation of irrigation water

Optimum utilisation of irrigation water means the using of irrigation water for achieving maximum crop production without excessive losses in the distribution system and application losses in the field. Maximum crop production should be obtained from a unit of land, per unit of water in a unit time. For optimum utilisation of irrigation water, the supply of water to the farmer should be dependable, timely and adequate. Reducing losses in the field and applying correct quantity of water based on crop water requirements will be of little value if the design and operation of the irrigation system is not geared for meeting the actual field requirements to ensure delivery of the proper quantities of water to the field at the right time.

7.2 Improvements to the irrigation system

In the operation of an irrigation system, water level control and water flow control are two most important functions. These are achieved by means of appropriate hydraulic structures and their operation. The operation of these structures is now done manually. In major irrigation systems in the country, outlets are ungated, outlet sizes are either too large or inadequate to meet the crop water requirements; water courses are either absent and field to field irrigation is practiced or water courses are constructed badly and poorly maintained leading to enormous wastage of water. In south India, water flows are continuous and variable and so regulated from the reservoir to the outlet. In this process large number of gate controls are provided and become unmanageable. Because of large number of such operations are to be done manually, they are not being operated in the manner they are designed and intended to be operated. In view of this, water regulation is inefficient and the farmers tamper the gate controls and draw water far in excess of their allocation.

The effective solution of tackling this problem is to reduce the number of gates to a manageable number and shifting the last control from pipe outlet to distributory head. If this is done, the flow above this point will be continuous, variable and regulated. Below this point proportional dividers can be provide which supply water to each off take in proportion to the area irrigated by it. The flows will be at full supply level of the channel, when the control is 'on' and flow completely closed when contro1 is 'off'. In view of this, the tendency of the farmers to tamper with the sluices, over draw and wastage of water is avoided. Another alternative is to provide structures. This will reduce considerably human involvement in the operation of the canal system. If gates are not provided, it is necessary to control the water levels in the main and branch canals (conveyance system) and in the distributories and minors (distribution system). In the conveyance system, water levels are maintained by regulation and in the distribution system by running the canals full whenever they are open. It means that the main and branch canals run continuously with regulation flows to maintain constant levels and in distributories and minors run intermittently with flow whenever open and completely empty when 'off'. The main system receives the water from the head regulator. Based on requirements of irrigation water, flows are regulated at the head regulator and the depth of flow in the canal depends on the quantity of water released. At low flows, water depth in the canal may be low far supply to distributory off takes. Control structures are, therefore, necessary. The common control structures to control water level are the cross-regulators and duckbill weir.

Distributories receive water from the main system through offtake sluices. The off-take sluice at the head of a distributory is a rguIating structure because the flow is regulated at this point and operated for 'on' and 'off' supplies in distributories. They are normally operated on an intermittent basis. From the distributory, proportional distribution of water takes place through ungated structures such as proportional distributor, open flume, tail cluster, ungated pipe outlet, orifice semi-module etc. All the minor and water courses receive flows proportional to the area served. Water flows are controlled by off-take sluice and proportional division structures. Operation of the structures is needed only at the cross regulator and off-take sluice and in exceptional cases the duckbill weir.

The measurement of flow is a key aspect of an irrigation system. The flows in the irrigation system have to be measured regularly at various locations in canals during the irrigation season. Too much flow drawn in the upstream outlets may result in less water being available to tail enders, damage canals and create drainage problems. The purpose of flow measurement is to monitor flows in canals i.e. to know if the flows in different parts of the system are as scheduled, to know the total quantity of water delivered to the system over a period of time; to set gates at off-take sluices and to modify and adjust operation of the system.

Too little flow in the canal may lead to unequal distribution of water and interference from the water users. To maintain correct flow and its monitoring, measurements of flow in the main canal and distributories periodically is essential. For this purpose, the two commonly used methods are (i) flow measurement with structures and low measurement with stage discharge curve (ii) the second method requires only a gauge for measuring water depth from which discharge can be found. Any irrigation system provided with facilities for water level control, water flow control and for monitoring flows in canals will help to deliver the exact quantity of water required for the crop and avoids wastage of water.

7.3 Lining the carrier system

Percolation and seepage are two main losses in conveyance system as described earlier. The other losses in the distribution system are through evaporation, weed consumption, operational and accidental losses. Rapid changes in water demand pattern which cannot be met in time by adjusting releases form head works or by effective redistribution with in the system results in non-productive release into drain channels through escapes and this is purely an operational loss. Spillage by overtopping of canal bank, breaches, incorrect or unresponsive gate setting especially during night irrigation are accidental losses. For operational and accidental losses, allowance of 10- 15% in fully lined distribution system and higher percentage in unlined system is provided.

The methods to reduce conveyance losses are by lining the bed and sides of canal, eradication of weeds, reduction of wastage from escapes and tail ends. If the financial resources do not permit lining the entire length of the conveyance system, lining may be limited to selected canal reaches identified to be heavy in seepage losses or which are vulnerable for breaching.

7.3.1 Plastic film as lining material

The use of plastic films as a lining material has offered tremendous scope as lining material which provide an impervious lining thus prevent water losses due to seepage (Anonymous, 1982). The performance of these films as lining material has been found very satisfactory. These linings using Poly Vnyl Chloride (PVC) and Low DensityPolyethylene (LDPE) film have been tried experi-mentally. Out of all the types tested so far, LDPE film appears to be the best whereas, PVC lining has several limitations. It cannot be manufactured in wide width and, further, the stability of this film is hampered by the migration of plasticizers, which are essential for ex-truding flexible PVC film. In India, where plastic materials are always sold on weight basis, PVC film becomes too expensive compared to LDPE film. Due to its higher specific gravity, PVC film gives 40% less film for a given weight compared to LDPE film. LDPE film lining which had been tried on an experimental basis for the past several years is now extensively used in states like West Bengal, Gujarat, Rajasthan, Madhya Pradesh, Punjab, Haryana and the irrigation departments of other states (Singh and Kumar, 2007; Kumar et al, 2008; Kumar and Singh, 2010). The experience indicates that lining with plastic films is a convenient and economical proposition.

7.3.2 Role of plastic film (Agri-film) in canal lining

The use of plastic films (Agri-film) as a lining material was introduced in India as far back as 1959 in canal system. More than 10000-km length of canals in different irrigation projects has been lined with LDPE films (Anonymous, 1985). This prevents water losses due to percolation and there is tremendous scope in the years to come. Basically, Agri-film is a tough, wide width black low-density polyethylene (LDPE) film tailor made for lining applications. Agri-film is manufactured by blown film extrusion technique from virgin Indothene grade 22F A002 and has excellent mechanical properties which meets 1SI specification of LDPE films as per IS: 2508-1984. Agrifilm has got excellent water barrier properties, very good blend of physical properties like tensile-impact strength coupled with good weatherability and chemical resistance properties.

Numerous studies conducted abroad and in India shows that plastic material is quite effective in lining the canal system. The plastic material of polyethylene or poly vinyl chloride (PVC) is widely adopted in lining of canals. Heat welding of polyethylene and PVC is possible by heated metal plates, hot gas welding and sonic welding. Polyethylene and PVC are two crystalline polymers that are used as liners for water conservation. Polyethylene provides the low temperature flexibility and toughness needed for most liner applications. The most desirable water barrier characteristics of plastic film are mentioned below:

- Effective means of water barrier to reduce seepage
- Resistance to deterioration by soil micro organisms, climatic parameters (heat, air, sunlight, wind) and subgrade movement
- Resistance to weatherability, mechanical puncture and worm attack
- Ease of installation and transportability with respect to the use at the site
- Less maintenance requirement and better economic feasibilityproperties.

7.3.3 Research findings of lining with Agri-film

LDPE film has been found to be cheap, promising and effective method for minimizing seepage losses. LDPE film layer minimizes damage to water bodies due to burrowing animals. For small water bodies like small canal, the construction is also quick and polyethylene film can be laid even in running canals during closure periods of rotation. The breaches which were frequent in these canals either due to rodents or due to soil characteristics have been practically eliminated after lining. There is no effect on canal lining due to alternative wet and dry conditions. Rodents generally bore holes after closure of canals. But in case of vertically laid polyethylene film, the nibbling even parts of film are minimum. Even if the hole is dug by rodents and the film pierced, the breach does not get widened easily as the hole gets plugged by the sliding earth.

Long-term experiments have been conducted at Irrigation and Power Research Institute (IPRI), Amritsar with LDPE film (Anonymous, 1985). The permeability of LDPE film was determined in permeability cylinders at a head of 3.65 meter, and the permeability was found to be practically nil for 100 micron (400 gauge, 0.1 mm) LDPE film even after 12 years of lining. The laboratory experiments were extended to semi field scale where LDPE films of 400 gauge and 250 gauge were embedded in channels at Doburji Distributary under a cover of 30 cm thick layer of local soil and sides were lined with 3.75 cm thick masonry laid in 1:3 cement sand mortar. The steady value of seepage varied from 0.95 to 1.37 cusecs per million square feet of wetted perimeter. Jalandhar distributary with a bed width of five feet and full supply water depth of 5 feet was selected for carrying out full field scale experiments of the combination type of lining. The section of the canal was brought to 1:1 slope and lined with LDPE film in the bed and rigid lining was laid in the sides. To monitor seepage losses, piezometers were installed in the back fill of the lined reach of the Jalandhar distributary. Observations of water level were taken at regular intervals with the help of these piezometers and no seepage was observed. The film has been visually examined by removing the soil or tile cover at different sites and has been found intact. At places where there is animal traffic, the hoofs of the animals have not affected the film, as it was protected under 30 cm soil cover. It has been observed that the indent of the hoof is hardly 7 cm deep and even repeated indent are not deeper than 10 cm. LDPE film laid 27 years ago on the Doburji distributary near Amritsar has been found as fresh as a new specimen (Anonymous, 1985). It is also not affected by the submerged aquatic weeds when laid on the bed. The soft weed-roots do not penetrate deep at 30 cm thick soil cover is sufficient to protect the film from getting punctured. Similarly, the Central Water Commission reported almost impermeability of LDPE Agrifilm after a period of more than one decade (Anonymous, 1985). Similarly, the results of accelerated laboratory tests have shown that the service life of black film of 200 micron thick film is between 40 to 50 years when used as water-proof lining material (Anonymous, 1982).

In brief, use of LDPE film as lining material has beyond doubt, made impetuous impact on saving water from seepage losses. It has made lining practicable successful in many arid and extremely cold countries. Some of the countries that have made extensive use of polyethylene film for lining of the irrigation schemes and water reservoirs are Iraq, Sudan, Russia, U.S.A, Canada, Romania, Spain, Nigeria and Pakistan etc. Above facts offer ample evidences for the usefulness of Agri-film lining on a large scale. It may, however, be desirable that the specification can be more critically gone into by the expert committee and the same finalized to suit the different parameters and areas where lining of channels is the programme for conservation of water. Apart from the lining of channels, it would be of great advantage to provide a buried layer of polyethylene with soil cover in unlined reaches of the canal, distributaries and minors where very often breaches take place.

7.4 Better operational planning

Irrigation system operation is the process of releasing, conveying and diverting water in the canal systems to ensure pre-determined flows at prescribed times for specified duration at all designated points of delivery. The operation plan takes into account the water available in the reservoir at the beginning of each crop season and spells out the starting date of release of water, the mode of supplies i.e. whether intermittent or continuous, the detailed schedule of releases and the closing date of release of water. The operation plan should be prepared with active participation and involvement of farmer's representatives so that it may be implemented without any resistance from the farmers to plan their crop production operation properly. This will reduce wastage and better utilisation of irrigation water.

7.4.1 Systematic canal operation

The object of systematic canal operation is to ensure equitable distribution of available flows at the heads of all off-takes on a distributory. A schedule of canal operation has to be prepared in advance. For instance, a distributory may be divided into seven reaches each covering one or more, off-takes whose total discharge is about a seventh of the designed 'discharge of the distributory. One-seventh of the total discharge can be saved on each day by closing the off-take in each reach far 24 hours in succession in a week. This water can be made available to tail-enders. This will result in saving water besides not having dry tail-enders problem.

7.4.2 Response to rainfall in canal operations

Canal operations should respond meticulously to rainfall in the command area for efficient use of storage water in the reservoir. The demand of crops for water is met in the wet season by both rainfall in the command area and water stored in the reservoir. Water requirement of crops is worked out using one of the empirical methods suggested by FAO. The most common method used is Modified Penman method. While assessing the water requirements of crops during the wet season for preparing the operation plan, effective rainfall worked out from the data of average rainfall over a period of past 20 years is deducted from the water requirements of crops worked out by the 'Modified Penman method' or other empirical methods. But in real time situations, the pattern and amount of rainfall varies influencing the scheduled deliveries. When rainfall is in excess, the scheduled irrigations are skipped and when rainfall is deficient unscheduled deliveries have to be made. This will ensure maximum utilisation of rainfall as well as protecting the crops from water stress or from excess water.

7.5 Cropping pattern in command areas

Cropping pattern means the proportion of area under different crop at a particular period of time. A change in cropping pattern means change in the proportion of area under different crops. The irrigation departments have been planning irrigation projects on the basis of a designed cropping pattern to give a favourable benefit-cost ratio. In any command area of irrigation projects, the current cropping systems are the result of past and present decisions of individual farmers or farming communities. These decisions are usually based on experience, tradition, expected profit, personal preferences and available resources.

7.5.1 Factors influencing cropping patterns

A wide range of factors such as soil, rainfall, temperature, altitude,availability of inputs (irrigation water, high yielding varieties, fertilizers, pesticides), length of growing season, market demand and prices for farm products, availability of credit, socio-economic status of farmers, expertise of farmers, comparative economics of alternate crops, benefit-cost ratio etc., have bearing on individual farmer's decisions to grow any particular crop. Cropping pattern should therefore, be viewed as a dynamic rather than a static concept.

Climate : Climatic conditions, especially rainfall and temperature influence cropping pattern. The period of commencement of monsoon rains is very important as time of sowing of the crop is dependent on rainfall. Due to diversity in climate and soil conditions, different cropping patterns are adopted in different areas.

Soils : Each type of soil gives high yield of certain crops and not others. In alluvial soils all types of crops can be grown. Sandy soils are not suitable for growing rice and sugarcane. Laterite soils are more suitable for growing coffee, tea, rubber etc. In crops that are climatically suitable, their water requirements have to be considered in relation to both water supply and the efficiency of water utilisation in crop production.

Economics : Cropping pattern is influenced by the prevailing price for the farm products in the market, yield per hectare and the relative profitability per hectare. The prices influence the average area under crops in two ways. Variation in price among products of different crops leads to shift in area between crops. The maintenance of stable level of prices for a crop provides a better incentive to a producer to increases the output than what a higher level of price does.

Economic Status of Farmer : Farmers who are economically sound adopt a cropping pattern which is most profitable with high input intensity, while a farmer who is economically weaker adopts a cropping pattern which is less risky and with low input requirements. Availability of timely and adequate credit also influences cropping pattern. .

Time of Sowing : Timely sowing of a crop gives high yield besides reduced incidence of pests and diseases. Delayed sowings reduce yields and expose the crop for higher incidence of pests and diseases. The crop to be grown, is dependent on the availability of irrigation water for sowing during the crop season.

7.5.2 Project planning

The cropping pattern, which includes choice of crops, crop varieties, crop rotation, and cropping intensity and the efficiency with which production resources can be utilised is essential input in overall project planning. The cropping pattern selected has to match the overall available soil and water resources. For the selected crops, not only the water requirements have to be considered in relation to water supply available but also the efficiency of water utilisation in crop production. The most suitable cropping pattern and several other alternate profitable cropping patterns have to be considered at the time of project planning and designing for introducing flexibility into the system and attaining the most efficient use of available water supply and the distribution system. Similarly, the most suitable cropping pattern has to be decided well before the commencement of each sowing season for most efficient project operation. Maximum profitable production (with favourable benefit-cost ratio) should be obtained from a unit of land, per unit water, in a unit time.

7.6 Rotation supply of irrigation water (*Warabandi system*)

Without proper distribution and management of available irrigation water resources, it may not be possible to ensure maximum economically and socially desired returns. If proper distribution of irrigation water is not done by any agency/ authority, excessive use of water by head-reach and influential farmers is common thus depriving the legitimate right of those at the tail end of an outlet command.

7.6.1 Concept of *Warabandi*

Warabandi is nothing but rotational supply of irrigation water system and in vogue for over a century in north-western states of India and in Pakistan. The cardinal principle in this system is that available water, whatever be the quantum, is allocated to farmers in equal proportion to their holdings. The principal management objective in *Warabandi* is to simultaneously achieve high efficiency of water by imposing water scarcity on each and every farmer. This acts as a deterrent to wasteful practices and results in maximum production per unit of available water, though it may not be the maximum production per unit of land irrigated. This system has its focus on equity and provides ample safeguards for the farmers at the tail end of the conveyance system.

7.6.2 Distribution System

Water from the source, which may be a river or a reservoir, is carried by a main canal. The main canal feeds two or more branch canals which operate by rotation and may or may not be able to run full supply. This is primary distribution system and runs throughout the irrigation season with varying supply. Branch canal supply water to a large number of distributories, which must run full supply by rotation. This is the secondary distribution system. Distributaries supply water to water courses through ungated, fixed discharge outlets. An outlet is the measuring structure through which water is admitted from disrtributory to farmers' water course. Water course run full supply when the distributory is running and the water is allocated between farmers on a water course by a time roster. The management of the secondary and tritiary distribution system under *Warabandi* is the distinguishing feature from other systems of water distribution.

Each unit of culturable command area is allocated a certain rate of flow of water which is termed as water allowance. Its value is a compromise between demand and supply. The carrying capacity of the distributaries and water course is designed on the basis of this allowance. Water allowance and capacity factor donot ensure irrigation for 100 percent of the culturable command area. The ratio which the resultant irrigated area would bear to the total culturable command area is known as intensity of irrigation. The intensity of irrigation is used for monitoring the actual performance of the system and its various constituents.

Most of our irrigation projects have not visualised problems of equitable water distribution and thus made no provision for enough control and regularising devices in irrigation net work. Additional structures and improvements like strong embankments, cross regulators, drop structures, gates, distribution boxes and measuring devices have to be provided if *warabandi* system is to be adopted.

An advantage of rotational irrigation is possibility of a more effective use of rainfall. For the introduction of *warabandi*, proper maintenance of canals and carrying capacity of canals at full supply level (FSL) in middle reaches as well as at tail end reaches is a pre-requisite. Thus Warabandi will be successful only to the extent that the farmers at the chak willingly accept the regulation of water. There has to be a concerted effort to make the system a success.

7.6.3 Farmers participation in *Warabandi*

The present system of water management does not provide for collective efforts in self governance by the users. In most of the irrigation projects, farmers involvement is limited. Usually a meeting of the farmers of localised area is convened at the commencement of the crop season for fixing the date of release of water into the canal from the reservoir. The operation and control of water up to the outlet level is done by the irrigation department officials. The problem of irrigation water theft in upper reaches and thereby creating water scarcity in the lower reaches are solely due to lack of understanding and cooperation among the farmers. The objective of any irrigation project can be achieved only when efficiency in use of irrigation water is ensured at sluice level and on the actual field. The ability of farmers to properly mange the water to get the maximum yield has a big say on the efficiency of the project. Therefore, there is urgent need to bring farmers into group action and involving them in the planning of water management strategy, accommodating all their genuine needs will make them voluntarily work for the success of the system. Hence, for an effective mechanism of managing the water efficiently and effectively is to involve participation of farmers for water distribution right from the stage of release of water from reservoir and also make them responsible for maintenance of the irrigation system. Participation of farmers in irrigation water management implies a significant role for them in decision making.

7.6.4 Pricing of water

The present system of levying irrigation water rates on the basis of crop area irrigated rather than on volume of water received in the field is leading to excessive and inefficient use and wastage of water. The ideal practice would be to levy irrigation water rates on the volume of water delivered in the field so as to act as a disincentive to over irrigation. If this is not done, determining the quantity of water supply in *warabandhi* system based on outlet discharge and time allowed for irrigation can be adopted to charge water rates.

7.6.5 Water budgeting

Maintaining a consolidated account of receipt of river flows and release into canal system at the reservoir, and supplies made to branch canal, distributaries, minors and field channels will help to know the wastage of water. Seasonal operational plans should be drawn for allocating water for both seasons. Similarly, weekly irrigation schedules should be prepared allocating water to different water to different off-take. Water levels at various off-takes are measured daily and discharge recorded for the week and month. The deliveries planned to be released and the deliveries actually made are compared. It will be known whether the delivery of water is as planned or in excess. If it is in excess, schedules can be revised so that less water is drawn in the next week and adjusting irrigation schedule by skipping irrigations in non-critical periods of the crops. Thus water budgeting can help in ensuring the supply of water more efficiently and effectively.

7.7 Integrated irrigation water management

The process of water management in an irrigation system includes an integrated development of sub-systems such as watershed, reservoir intake, conveyance, regulation, measurement, effective use of rainfall, application of appropriate quantities for crop use and effective drainage from command area. For efficient use of irrigation water simultaneous development of all the components of an irrigation system is essential. Further, active involvement of farmers in the management of irrigation water will ensure the objectives of increased utilization of created potential, equitable distribution of water at the farm level and increased production on sustainable basis.

7.8 Operation research

Research progrmme should be relevant to farmers needs. Operational research is most needed at present. It should not only be a function of needs as perceived by farmers who are ultimate beneficiaries of the irrigation system, but should also respond to the project limitations and to the concerns of the irrigation department who manages it. For this purpose it is necessary to

- Diagnose operational constraints for improving management and use of water
- Measure the impact of changes in water management on cropping pattern and consequently on the timing of farm oprations
- Establish crop growth and yield responses to different levels of water supply over the full growing period for specific crops and crop sequences
- Monitor and record factors influencing the supply of water which could disturb and change the underlying assumptions for designing water delivery schedule

The occurrence of frequency and distribution of local rainfall, water table fluctuations, residual moisture, crop input-output relations and on farm water management have to be studied.

The operational research should cover the entire command area of a canal irrigation system or total command area of a tank or well command. There will be considerable variability in irrigation water management in the command area and the crop management practices. This variability existing in the command should be used to establish correlations between certain water management situations and farmers' output. Improved water and crop management practices can be introduced simultaneously for purposes of comparison in the entire command of a distributor or minor. Farmers respond to differerent situations can also be studied. Farm management factor can be introduced as an independant variable and can be rated to scale to get an indication how farmers endowed with the same resources utilize these resources to obtain farm output. The aim of the diagnostic and gap analysis is to determine the major field deterimants under the actual farming and water supply situation. The constraints affecting adoption of recommended technologies and farmer innovations in the field of irrigation should be taken into consideration for better understanding the system. Further, the contribution of ground water to meeting crop water requirements, either from wells or by direct consumption through capillary rise, has to be studied for both canal and tank commands.

Pressurized irrigation systems like sprinkler and drip methods can be best substitutes for surface irrigation methods. There is great need to try these methods under various situations and workout cost-benefit ratios. The economic and financial consequences of water management systems and their effect on subsequent cropping patterns, yields and farm incomes should be monitored. Special efforts should be made for active and enthusiastic participation of farmers in the implementation of the operation programme.

7.8.1 Extension and Training

Extension efforts in irrigated agriculture are mainly focussed on recommendations of crops, varieties, fertiliser application, crop protection etc. Very little attention is paid to soil water relationships, methods of field preparation, layout of irrigation response to variable water supply conditions, synergistic packages of level of irrigation, plant population and fertilisers etc. Concepts of integrated management of soils, water, crops, soil fertility, plant protection etc., has to be developed by the extension staff.

With the expansion of the irrigation programme, the need for training technical personnel both in method of construction and efficient management of the irrigation system has assumed importance. The command area personnel have to be trained in operation and maintenance for improved water management. Water and Land Management Institute (WALMI) and Irrigation Management and Training Institutes (IMTI) have been established for this purpose in several states.

7.9 Knowledge Gap and Researchable Issues on Water Management

i) **Creation of data base:** The detailed monthly / weekly data on command / region basis on availability and utilization of water from various sources of water i.e., canal, ground and rainfall on long term basis is lacking. The relevant information on soil, cropping pattern, water table, etc. should also be monitored and integrated. A sound data base is an essential requisite in water resource management. Dependable data, based on agro-climatic conditions of a regions, are needed on water resources availability, temporal release of water and reliability of water supply from reservoirs, ground water status in terms of recharge, extraction and quality, areas under irrigation and quality of irrigation service, use of waste / recycled waters, water use pattern, efficiency constraints, water induced environmental socio-economic and institutional aspects. Periodic monitoring, analysis, documentation and dissemination of this information will help in proper water resource utilization, framing policy guidelines and planning management strategies. The GIS is the modern tool to store and manipulate spatial information. Natural resources like water and soil etc. always have a spatial dimension overriding them. Therefore, GIS is an essential requirement for efficient and quality water resources research.

ii) **Development of irrigation schedule and cropping pattern for the potential water table rising areas**: In the canal irrigated areas and where the ground water exploitation due to its poor quality is low, the water table is showing a rising trend. Obviously, the areas having water table within critical limit are likely to be increased. For these areas there is a need to develop irrigation schedules for economically viable cropping pattern which require less input of canal irrigation water. This will help in arresting the further rise in water table, water-logging and secondary soil salinization for long term sustainable agriculture.

iii. **Mismatch between irrigation demand and supply of canal irrigation water**: In most of the command areas, the supply does not match as per the requirement of the areas which is highly variable and uncertain in space and time. On long term basis, this creates hydrological imbalances in the area. The excess water during rainy season may be diverted to falling water table areas for recharging the ground water. Moreover, uninsured water availability leads to high wastage of irrigation water. The cropping pattern can also not be planned in advance under such situations. Under such conditions, the supply of water on probability basis will ensure judicious use. There is need to determine the optimum level of probability i.e., 60-80% for planning purpose.

iv. **Integrated use of rain, canal and ground waters:** Integrated management of surface, ground and rain water resources is not practised owing to availability of canal water at cheaper rates and costlier exploitation of ground water.

v. **Artificial recharge of ground water in falling water table areas:** During rainy season, excess surface water, both from rainfall and canal, is available, which causes water-logging in some areas. If this water is diverted properly for recharging the ground water, the falling water table can be arrested on the one hand and the water logging problem can be avoided on the other.

vi. **Diversification of land use in favour of high value crops:** To achieve high crop yields require high input cost and its management, growing of conventional crops is becoming less and less profitable. There exists a huge scope for fruits and vegetables and other non conventional crops. Switching over to such crops can be more profitable under somewhat controlled conditions of crop growth. There is thus need to develop appropriate water management technology for these diversified crops.

vii. **Water management technology for the reuse of waste waters:** The waste waters include industrial effluent, sewage water and good quality drainage waters. The consumption of water by urban population and industries is increasing day by day and these waters can be recycled and can be safely used for irrigation purpose, as in case of developed countries. A technology, suited to our conditions, need to be developed for the safe use of such waters.

viii. **Drip fertigation:** It is a well known fact that the efficiency of irrigation water and fertiliser is less than 50% when applied through conventional methods of irrigation. Increasing the efficiency of these two factors holds the key for long term profitable agriculture. This can be substantially increased to the level of 90% under pressurized system of irrigation. However, as installation and management of micro irrigation system including drip, sprinkler and micro-sprinkler require a high investment, at this stage it can be adopted in high value crops, which require a favourable marketing infrastructure. The industries can play a significant role in adoption for this technology by providing, high quality system, post sale services, storage and processing of harvested crops. By adopting the technology of controlled application of water, fertilizers and pesticides the pollution hazards to the environment can be minimized.

ix. **Development of irrigation Atlas**: Irrigation Atlas containing all the relevant information about the water can be prepared on the each of the agro-ecological regions of the state.

x. **Development and validation of crop growth and water use models:** There is need to focus more attention on the development of crop growth and water use models. These models can be validated keeping in view our agro-climatic and socio-economic conditions. This will help the researchers, to put less effort on experimentations, the planners and the farmers for working out a long term strategy for efficient use of water.

References

Anonymous. 1982. Proceedings of Seminar on The use of plastics for lining of water conveyance systems in irrigated agriculture. Ministry of Irrigation, Government of India, New Delhi.

Anonymous. 1985. A Manual on Canal and Reservoir Lining with Agri-film. Indian Petrochemical Corporation Limited, New Delhi.

Kumar, A and Singh Rajbir. 2010. Plastic Lining for Water Storage Structures. Technical Bulletin No. 50, Directorate of Water Management, Chandersekharpur, Bhubaneswar-751 023, India, page: 34.

Kumar, S., Singh, Rajbir, Bhatnagar, P.R., Gupta, R.K and Nangare, D.D. 2008. Microirrigation in conjuction with service reservoir in canal command. Technical Bulletin APA/Pub/03/2008, CIPHET, Abohar.

Michael, A.M. 1992. Irrigation-Theory and Practice. Vikas Publishing House Pvt. Ltd., New Delhi.

Reddi, G.H.S and Reddy, T.Y. 1999. Efficient use of irrigation water. Kalyani Publishers, New Delhi.

Singh, Rajbir and Kumar, S. 2007. Plastic Films in Efficient Water Management. (Ed). K.K. Singh *et al.* Kalyani Publisher (Pvt) Ltd, Ludhiana.

8.0 ENHANCING WATER USE EFFICIENCY THROUGH PRESSURIZED IRRIGATION SYSTEM IN CANAL COMMAND

Satyendra Kumar, Rajbir Singh and Ashwani Kumar

The water use efficiency under conventional flood method of irrigation, which is predominantly practised in Indian agriculture, is very low due to substantial conveyance and distribution losses. Recognizing the fast decline of irrigation water potential and increasing demand for water from different sectors, a number of demand management strategies and programmes have been introduced to save water and increase the existing water use efficiency in Indian agriculture. One such method introduced relatively recently in Indian agriculture is pressurized irrigation system, which includes both drip and sprinkler method of irrigation. Since, these methods need water under pressure, they are classified as pressurized irrigation system. Pressurized irrigation system is proved to be an efficient method in saving water and increasing water use efficiency as compared to the conventional surface method of irrigation, where water use efficiency is only about 35-40 percent.

One of the main reasons for adopting pressurized irrigation system in crop cultivation is to save water and increase the efficiency of water use. Over centuries all over the world, irrigation water has been predominantly applied for crops using flood / gravity method. Generally, under conventional (flood / gravity) method of irrigation, water is supplied through unlined canal and field channels for crops where controllability of water is not easily possible and therefore, conveyance and distribution losses are substantial. Unlike conventional method of irrigation, both sprinkler and drip irrigation supply water to crop using pipe network along with drippers, emitters and nozzles. As a result of supplying water directly to the crop or to the field, the conveyance and distribution losses are found to be completely absent under pressurized irrigation system. Estimates carried out at different research stations under different methods of irrigation reveal the comparative efficiency of irrigation under different methods (Table 8.1). While the conveyance efficiency under surface method of irrigation is estimated to be only in the range of 40-50 percent in canal and 60-70 percent in well, the same is estimated to be 100 percent in both sprinkler and drip method of irrigation. As mentioned earlier, the higher level of conveyance efficiency under pressurized irrigation system is mainly because of application of water by pipe network, where seepage and other leakages are also completely absent. A less than 50 percent of conveyance efficiency in surface irrigation method suggests that by converting all the surface method of irrigation into micro-irrigation, we would be able to double the irrigated area without constructing any new irrigation projects.

Table 8.1 : Irrigation efficiencies (%) under different methods of irrigation

Irrigation efficiency (%)	Methods of irrigation		
	Surface	Pressurized irrigation systems	
		Sprinkler	Drip
Conveyance Efficiency	40-50 (canal) 60-70 (tube well)	100	100
Application Efficiency	60-70	70-80	90
Surface water moisture evaporation	30-40	30-40	20-25
Overall Efficiency	30-35	50-60	80-90

Application efficiency refers to water use at the farm level. Estimates suggests that there are wide variation here too in the level of efficiency. Water can be applied at a required quantity and time under pressurized irrigation system and therefore, the application efficiency is always higher under pressurized irrigation system as compared to conventional surface irrigation method. The overall application efficiency is estimated to be 60-70 percent in surface irrigation, whereas the same comes to 70-80 percent for sprinkler and 90 percent for drip irrigation method. Because of flooding of water under surface irrigation method, large quantity of water is wasted in the form of evaporation and seepage losses and thus, the application efficiency is always lower. Since water is applied directly to the root zone of the crop at a required quantity by drip method of irrigation, the application efficiency is above 90 percent. The application efficiency is estimated to be relatively lower under sprinkler irrigation as compared to drip method because of two reasons. First, sprinkler irrigation is often affected by wind interference which ultimately reduces the efficiency. Second, unlike drip method, sprinkler supplies water to whole of cropped area and therefore, water losses would obviously be higher.

Unlike application efficiency, there are no variations between surface method and sprinkler method of irrigation in the case of surface water moisture evaporation. In both surface and sprinkler method, it is estimated to be the same, varying from 30 to 40 percent (Table 8.1). In the case of drip, the surface water moisture evaporation is only 20-25 percent. Drip method of irrigation does not allow water to spread beyond the root zone of the crop and therefore, the water moisture evaporation is very less in drip irrigation. Because of very high level of conveyance and application efficiency and low water moisture evaporation, the overall water use efficiency is very high (80-90 percent) under drip method of irrigation as compared to sprinkler (50-60 percent) and surface method of irrigation (30-35 percent). Therefore, drip irrigation appears to be the most efficient method of irrigation in terms of absolute use of water for crop cultivation. Drip irrigation method also appears to be efficient method in terms of moisture availability to crops

8.1 SPRINKLER IRRIGATION SYSTEM

Available information suggests that sprinkler was introduced in India during the mid-fifties for plantation crops like coffee and tea. During mid-seventies, progressive farmers in Narmada valley in MP, southern part of Haryana and north east part of Rajasthan started using sprinkler particularly during summer to avoid the shortage of water (INCID, 1998). Over the years, the adoption of sprinkler system penetrated into larger area in states like Haryana, Rajasthan, MP, Maharashtra and Karnataka. However, detailed and accurate statistics are lacking for sprinkler irrigation but the present estimate indicate that gross area under sprinkler irrigation has increased from 0.23 mha in 1985 to 0.67 mha in 1998. According to the latest information compiled by the National Committee on Plasticulture Applications in Horticulture (NCPAH), the total area under sprinkler in the country is estimated to have increased to 2.45 Mha.

The spread of sprinkler irrigation is also not the same across the states. State-wise area under sprinkler irrigation shows that it is mainly concentrated in Central and northern part of the country. Up to 2008, states like Haryana (0.51 Mha), Rajasthan (0.70 Mha), West Bengal (0.15 Mha) and Maharashtra (0.21 Mha) together accounted for about 70 percent of India's total sprinkler irrigated area. The reasons for large adoption of sprinkler irrigation are different for different states. Though MP receives medium rainfall, factors like unpredictable rainfall and long dry spells during the summer encouraged the farmers to adopt sprinkler irrigation for crops like soybean in various part of the state. In the case of Haryana, the soil condition, topography and the climates that are prevailing in the south western part of the state especially in districts of Bhiwani, Mahindergarh, Rothak, Sirsa and Hisar have prompted the adoption of sprinkler irrigation. Similarly, favourable cropping pattern and water scarcity during the summer season are found to be the main reasons for the relatively higher adoption of sprinkler irrigation in Rajasthan (INCID, 1998).

8.1.1 Sprinkler irrigation in canal command areas

For economic and efficient use of water, it is necessary to use the sprinkler irrigation system. This can be used not only in groundwater application but also in canal water application. The irrigation department in Haryana launched the installation of during late seventies and eighty on the existing canal network. The installation of sprinkler system in canal network is first of its kind in the country and has shown a success story. During 1978 and 1981, 131 sprinkler sets were installed in the Lift Command, Bhakra Command and Western Jamuna Canal (WJC) areas. The area selected for experimental sprinkler irrigation was chronically deficit in water. These sets were installed in lift canal command areas for irrigation of lands of undulating terrain where extension of irrigation by normal method of construction of water course was not feasible. In the canal command areas of established Western Jamuna Canal and Bhakra Canal system, these sets were installed to extend irrigation to high lands which were identified as non-command areas within the gross area of command. Typically the command areas of the distributary and minors in which these sprinklers are installed are divided into groups and the regulation of irrigation supply is made in 8 days rotation. The periodicity of the rotation is dependent upon the available supplies for pre determined rotational programme and aims to ensure equitable distribution of water. Generally, the system runs for 16 days out of 24 days in *kharif* and 8 days out of 24 days in *rabi*.

Large number of farmers of these areas has adopted sprinkler system during eighty and nineties and number of sets owned by farmers has increased to more than 15,000. About 18% of the area is reported to be sandy soil and the sprinkler system is ideal for these areas. The Haryana irrigation department installed more than 200 community sprinkler sets (each irrigating about 40 hectares) on canal system (Jui canal, Jui feeder and Sewani canal commands). During eighties, sprinkler irrigation system was introduced in Rajasthan. Initially, aluminum pipe based sprinkler systems were adapted by the farmers in Sikar, Jhunjunu, Nagaur districts. Later on HDPE pipes based sprinkler system were introduced. Sprinkler system was also introduced in canal irrigated areas of Bikaner and Kota.

Sprinkler system of irrigation has tremendous scope for irrigation in different command area of major and medium projects in different agro-ecological regions. Gravity flow system of irrigation is the common method of irrigation in all the command areas of irrigation project in India. Where supplies are planned for dry crops like millets and pulses, it would be economically rewarding if sprinkler irrigation can be introduced in these areas. The area available under this category is estimated to be about 10 m ha based on the assumption that at least 50 % of the 20 Mha under CAD schemes (Anonymous, 1998) will be under irrigated low duty crops like coarse cereals, millets, pulses and oil seed crops. This would also substantially contribute to higher levels of production on sustainable basis.

8.1.2 Type of sprinkler system and components

Sprinkler system are classified into following two major types of the arrangement for spraying irrigation water.

a) Rotating head or revolving system
b) Perforated pipe system

a) Rotating head

Small size nozzles are placed on riser pipes fixed at uniform intervals along the length of the lateral pipe and the lateral pipes are usually laid on the ground surface. They may also be mounted on posts above the crop height and rotated through

900, to irrigate a rectangular strip. In rotating type sprinklers, the most common device to rotate the sprinkler heads is with a small hammer activated by the thrust of water striking against a vane connected to it.

Rotating head system can further be divided into three categories:

i) Conventional system/small rotary sprinklers

ii) Boom type and self propelled sprinkler system

iii) Mobile rain gun/large rotary sprinkler

b) Perforated pipe system

Perforated pipe system consisted of drilled holes or nozzles along the length of the lateral pipe through which water is sprayed under pressures. This system is usually designed for relatively low operating pressure (<1.5 kg/cm^2). The application rate ranges from 1.25 to 5 cm per hour for various pressures and spacings. There are three types of spraying systems:i)Stationary; ii) Oscillating and iii) Rotating

8.1.2.1 Classification based on portability

Based on portability, sprinkler systems are classified into following types

(i) Portable system : A portable system has portable main lines, laterals and pumping plant.

(ii) Semi portable system: A semi portable system is similar to a portable system except that the location of water source and pumping plant is fixed.

(iii) Semi permanent system: A semi permanent system has portable lateral lines, permanent main lines and sub mains and a stationery water source and pumping plant.

(iv) Solid set system: A solid set system has enough laterals to eliminate their movement. The laterals are positions in the field early in the crop season and remain for the season.

(v) Permanent system: A fully permanent system consists of permanently laid mains, sub mains and laterals and a stationery water source and pumping plant.

8.1.2.2 Components of sprinkler system

A typical sprinkler irrigation system usually consists of following parts or components.

Components	Approximate cost of component of the total sprinkler system (%)
Pipe network: mains, sub mains and laterals	70
Couplers	15
Sprinkler head	7
Accessories like valves, bends, plugs, risers and fittings	8
In addition, the pumping and control unit costs about 40% of this total cost	

a) Pipe networks

The pipe network comprises of three types: main, sub main and laterals. Main pipe lines carry water from the pumping plant to different parts of the field. Sub main lines are provided to take water from the main to laterals. The lateral pipe lines then carry the water from main or sub main pipe line to the sprinklers. Sprinklers on a lateral pipe line may vary in number from one to thirty. The main pipe lines can be laid either as permanent, semi-permanent or portable ones. However, the lateral pipes are always laid as portable ones. Permanent pipes are made of steel, asbestos, cement, plastic or wrapped aluminium. They are commonly buried at about 45 to 60 cm below ground level so as to be out of the way of farming operations. Portable pipe lines are usually made of aluminium or plastic (HDPE) and are generally equipped with quick coupling devices. These can be shifted quickly to enable farming operation.

b) Couplers

A coupler provided connection between two pipes and between pipes and fittings. Couplers should i)provide flexible connection; ii)not leak at the joint under pressure; iii)automatically drain at no pressure; iv) be simple and easy to couple and uncouple and v) be light, non-corrosive and durable.

c) Sprinkler head or sprinkler

Sprinkler may be rotating or fixed type. The components of a rotating sprinkler can be adapted for a wide range of application rate and spacings. They are effective with pressure of above 1.5 to 4 kg/cm^2 at the sprinkler nozzle. Fixed type sprinklers are commonly used to irrigate small lawns and gardens. A recent variation of the fixed type sprinkler is the 'pop-up' sprinkler. In this, the sprinkler unit poops up out of a casing when put to use and sinks down into the casing when not in use. This facilitates safety of the unit from being damaged. Perforated lateral pipes are also sometimes used as sprinklers. They require less pressure than rotating sprinklers. They also release more water per unit of time than rotating sprinklers. Their use should be restricted to soils that have high intake rates.

d) Other accessories/fittings

To operate sprinkler system some fittings are essentially required while some are optional. Some of the important fittings / accessories used in sprinkler systems are bends, tee, reducers, elbows, hydrants, risers, plugs and crosses and butterfly values. These are fabricated either from aluminium or HDPE, as the case may be depending upon the material of the pipe to suit the standard size of pipe. While drawing a bill of materials a designer should provide suitable couplers with all fittings.

e) Pump and control unit

To operate the sprinkler system sufficient pressure is required to distribute water under pressure to the fields. The pumping plant usually consists of a centrifugal or a turbine pump, a driving unit, a suction line and a foot value for the centrifugal system. Centrifugal pump is generally used when the distance from pump inlet to the water surface is less than eight meters. Normally centrifugal pumps are used to lift water from irrigation ditches, drainage canals, lakes, ponds, river channels or shallow wells. If the distance to the water surface is more than eight meters or if the water level is fluctuating widely, the use of a turbine pump is recommended. The driving unit may be either an electric motor or an internal combustion engine.

Different types of pumps with desired characteristics, including monoblocks for sprinkler irrigation system are manufactured in India. Therefore, the farmers can select the pump sets depending upon the soil, crop, slopes and discharge available and the pumping water level.

f) Water meter

This is used to measure the volume of water to be delivered. In India, though irrigation water is normally not measured and users pay according to the area irrigated; this is necessary to operate the system to give the required quantity of water.

g) Pressure gauge

It is used to measure and monitor the pressure under which the sprinkler is working in order to deliver the water uniformly. A portable gauge-pack with a pitot tube enables an operator to read the sprinkler pressure at the sprinkler nozzle which is in use.

h) Connectors

Flanges, couplings and nipples are used for facilitating proper connection to the pump and suction delivery pipes.

i) Fertilizer applicators

Soluble chemical fertilizers can be injected into the sprinkler system and applied to the crop. The equipment for fertiliser application is relatively cheap and simple and can be fabricated locally. The fertilizer applicator consists of a sealed fertilizer tank with necessary tubings and connections. A venturi injector can be arranged in the main line, which creates the differential pressure suction and allows the fertilizer solution to flow in the main water line.

8.1.3 Design of sprinkler system

The objective of the design of sprinkler system is to obtain a system that provides satisfactorily uniform application of water with a minimum annual operation and maintenance cost. The design procedure should take into consideration crop requirements, existing soil type, climate, water quality and quantity, topography and shape of the field, irrigation facility, labour, economics and future expansion considerations.

8.1.3.1 Principles of design

a) Inventory of the area

The first step in the design of sprinkler systems is to make the resource inventory of the area. This consists in obtaining information about the available land, water and equipments. A topographical map of the area to be irrigated should be prepared. The soil type in the area under consideration should be known. Information about the source of water, quality and its availability during the entire year should be collected. The water available should be of sufficient quantity and its quality should be satisfactory for irrigation. Amount of sediment present in the water is an important consideration in sprinkler system design. The type of sprinkler equipment available and its specifications are necessary in the proper selection of the equipment.

b) Depth of irrigation

The quantity of water to be applied and the period of irrigation depends upon the crops, climate and soil. The proposed crops, their water requirements along with the water holding capacities of the soils of the area should be known. The depth of irrigation required (d, cm) is determined using the relationship:

Gross depth of irrigation (d) = $D*d_m*s / E_a$

Where,

D = Effective root zone depth of soil to be brought to field capacity, cm

d_m=Difference in moisture content between field capacity and the moisture content before irrigation in percentage on dry weight basis

s = Specific gravity of soil

E_a = Irrigation application efficiency

c) Irrigation interval (days)

The irrigation interval (F) presented in days is expressed as below:

$$F(days)=\frac{Depth\ of\ irrigation(cm)}{Peak\ rate\ of\ daily\ consumptive\ use(cm/day)}$$

d) Effect of wind

To achieve uniform sprinkling of water, it is necessary to overlap water spread of sprinklers. The overlap increases with the increase in wind velocity. The design of sprinkler overlap under different wind conditions is presented in Table 8.1.2. The actual spacing, however, shall be guided by the standard sizes of pipe available in the market. Pipe sizes of 6 m (full size) and 3 m (half size) are generally available in the market.

Table 8.1.2 : Maximum spacing of sprinklers under different wind conditions

Average wind speed	Overlap (%)	Spacing
No wind	35	65% of the diameter of the water spread area of a sprinkler head
0 to 6.5 km / ha	40	60% of the diameter of the water spread area of a sprinkler head
6.5 to 13 km / hr	50	50% of the diameter of the water spread area of a sprinkler head
Above 13 km / hr	70	30% of the diameter of the water spread area of a sprinkler head

e) Application rate for different soils and surface slopes

The discharge of the sprinkler system would vary with the characteristics of the soil and its surface slope. The following information may be used to decide on water application rates for different soils and surface slopes (Table 8.1.3).

Table 8.1.3 : Maximum application rate (lph) of sprinkler for different soils and surface slops

Soil texture and profile	Slope (%)			
	0.5	5-8	8-12	12-16
Coarse sandy soil for 2 m depth	5.0	3.7	2.5	2.3
Coarse sandy soil over more compact soils	3.7	2.5	2.0	1.0
Light sand loams to 2 m	2.5	2.0	1.5	1.0
Light sand loams over more compact soils	2.0	1.3	1.0	0.8
Silt loam to 2 m	1.3	1.0	0.8	0.5
Silt loam over more compact soils	0.8	0.6	0.4	0.3
Clay loam	0.4	0.4	0.2	0.1

f) Selection of sprinkler nozzle

The sprinkler nozzle which gives application rate equal to or less than the infiltration rate of the soil is normally selected. The specifications of the sprinkler nozzle shall include model of sprinkler nozzle, nozzle size, diameter of throw, application rate and discharge of the nozzle.

g) Spacing of sprinkler nozzles

The spacing of sprinkler nozzle will depend upon nozzle size diameter of throw and wind directions. The value of maximum sprinkler nozzle spacing as a fraction of diameter of throw is given in table 8.1.4.

Table 8.1.4 : Maximum allowable sprinkler nozzle spacing as a fraction of diameter of throw under condition of wind

Wind velocity (km/hr)	Nozzle spacing (m)
0 – 6.5	0.6 x diameter of throw
6.5 – 13.0	0.5 x diameter of throw
13 or above	0.3 x diameter of throw

8.1.3.2. Capacity of the system

The capacity of sprinkler system or the capacity of the pump to be used depends upon the area to be irrigated, the depth of water applied at each irrigation, the time allowed to apply this water and the application efficiency. The capacity is given by the formula

$$Q = \frac{A \times D \times 27.8}{F \times H \times E}$$

Where,

Q = Pump capacity (lps)

A = Area (ha) of the field to be irrigated

D = Depth of application (cm)

F = Irrigation interval (days)

H = Duration of operation (h / day)

E = Field application efficiency (fraction) and conversion factor of 27.8

The optimum water application rate is determined by soil type, slope of land and crop. Rate of application should bot exceed intake rate of soil. For almost level soil (slope less than 2 percent) and moderate infiltration rate, the maximum application rate is 1.5 cm / hr.

8.1.3.3 System layout

Topography, field lay out and locations of water source are the important factors that influence the system layout. When there is choice, the water source and pumping unit have to be located to minimize pipe and pumping cost. Wells should be located as close to the centre of the irrigated area as possible. Lateral are placed across the slop to minimize the variation of pressure along the laterals. When it is necessary to run laterals up and down the major slope, it is preferably for water to flow downslope rather than upslope. When water must flow-up hill, laterals need to be shortened unless pressure of flow regulators are used. Whenever possible, lateral should be located at right angles to the prevailing wind direction. If wind direction and slope are in opposite direction, precedence is given to slope and laterals are kept across the slope. Layout of mainline and sub main is done according to lateral layout. When laterals run across prominent land slope, mainlines and sub mains are placed along the slope. When it is necessary to run laterals along the slop, mainlines are located on upper side of ridge of the field so as to avoid aligning the lateral uphill. It is also desirable to locate mainlines so that laterals may operate on either side of them.

Classification of sprinklers and their adaptability

Parameters	Type of Sprinklers						
	Low pressure 0.35-1 kg/cm²	**Moderate pressure 1-2 kg/cm²**	**Intermediate pressure 2-4 kg/cm²**	**High pressure 3.5-7 kg/cm²**	**Hydraulic or giant 5.6-8.4 kg/cm²**	**Under tree low angle 7-3.5 kg/cm²**	**Perforated pipe 0.28-14 kg/cm²**
General characteristics	Special thrust springs or reaction-type arms	Usually single nozzle oscillating or long-arm dual- nozzle design	Either single or dual nozzle design	Either single or dual nozzle design	One large nozzle with smaller supplemental nozzles to fill in pattern gaps. Small nozzle rotates the sprinkler	Designed to keep stream trajectories below fruit and foliage by lowering the nozzle angle	Portable irrigation with pipe with lines of small perforations in upper third of pipe perimeter.
Rang of wetted diameters	6 to 15 m	18 to 24 m	23 to 37 m	33 to 70 m	60 to 120 m	12 to 27 m	Rectangular strips 3 to 15 m
Recommended minimum application rate	1.0 cm / hr.	0.50 cm / hr.	0.62 cm / hr.	1.25 cm / hr.	1.6 cm / hr.	0.83 cm / hr.	1.25 cm / hr.
Jet characteristics (assuming proper pressure-nozzle size relations)	Water drops are large due to low pressure	Water drops are fairly well broken	Water drops are well broken over entire wetted diameter	Water drops are well broken over entire wetted diameter	Water drops are extremely well broken	Water drops are fairly well broken	Water large due to low pressure
Moisture distribution pattern (assuming proper spacing and pressure relations)	Fair	Fair to good at upper limits of pressure range	Very good where wind	Good except calm air. velocities exceed 6 km per hour	Acceptable in Diamond Severely distorted by wind	Fairly good is rectangular patterns recommended where laterals are spaced more than one tree inter space	Good. Pattern
Adaptations and limitations	Smaller acreages. Confined to soils with intake rates exceeding 3 cm per hour and to good ground cover on medium-to coarse-texture soils	Primarily for under tree. Can be used for field crops and vegetables	For all field crops and most irrigable soils well adapted to over tree sprinkling in orchards and groves and to tobacco shades	Same as for intermediate pressure sprinklers except where wind is excessive	Adaptable to close-growing crops that provide a good ground cover. For rapid coverage and for odd-shaped areas. Limited to soils with high intake rates	For all orchards or citrus groves. In orchards where wind will distort over tree sprinkler patterns. In orchards where available pressure is not sufficient for operation of over tree sprinklers	For low-growing crops only. Limited to soils with relatively high intake rates. Best adapted to small areas of high value crops. Low operating pressure permits use of gravity or municipal supply.

(*Source* : Hurd, 1969)

Irrigated area is subdivided into sets or units and each unit is irrigated separately. One cycle of irrigation is completed when all units are irrigated. Set length is the time required to apply the desired water to a set. The number of laterals required for a set can be calculated from the equation:

$$N = N_{1p} / N_s$$

$$N_s = W(II) \ / \ H$$

$$H = T_{sl} + T_m$$

Where,

N = Number of laterals operating on a set

N_{ip} = Number of lateral positions in the irrigated area

N_s = Number of sets

II = Irrigation interval (days)

W =Working hours per day

H = Hours between successive irrigation of a set position

T_{sl} = Set length (hr)

T_m = Time needed to move the set from one position to another in irrigated area

8.1.3.4 Nozzle discharge

The capacity of individual sprinkler is calculated using the equation

$$q = I \frac{S_1 \, x \, S_2}{360}$$

Where

Q = Required average discharge of individual sprinker (m^3/hr)

S_1 = Spacing between sprinkler (m)

S_2= Spacing between laterals or lateral position (m)

l= Rate of application (mm/hr)

An optimum arrangement of the mains and laterals is made based on land slope and irrigation interval. Then the spacing and discharge of sprinklers are determined by trial and error method. For example, if the field has to be irrigated once in seven days and the laterals is required to be moved four times a day, then 28 moves are required with one lateral and 14 moves with the two laterals to irrigate the entire field.

8.1.3.5 Size of lateral

The diameter of the lateral pipes has to be minimum for economy and ease in handling, consistence with good sprinkler performance. A pressure variation of about 20 percent between the first and last sprinkler nozzle on a lateral is permissible in design. A 20 percent difference in pressure results in 10 percent variation in discharge of a nozzle. The quantity of water flowing at the beginning of the lateral becomes less at each successive outlet. Therefore, the friction losses in a sprinkler lateral gradually reduce as water moves away from the mainline. To determine the pressure loss in a lateral, the friction loss is first computed as in a lateral pipe line without multiple outlets. Computation can be made by the use of Scobey's formula:

$$H_f = 2.59 K_s \frac{LV^{1.9}}{D^{1.1}}$$

Where,

H_f = Friction loss in the line (m/1000m)

K_s = Coefficient of retardation based on the pipe material

L = Pipe length (m)
V = Velocity of flow (m/s)
D = Diameter of pipe (m)

Friction losses computed based on Scobey's formula are presented in Table 8.1.6. The friction loss is then multiplied by a factor (F) based on the number of outlets or sprinklers (N) in the lateral. The empirical equation for computing the F factor is

$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{m-1}{6N^2}$$

Where

m = 1.0 of velocity exponent in Scoby's formula
N = Number of outlets in the line
F = Factor values are calculated and presented in Table 8.1.5.

Table 8.1.5 : Scoby's pipe friction coefficient (K_s)

Type of pipe material	K_s
Asbestos-cement plastic	0.32
Cement-lined cast iron, dipped and wrapped steel	0.36
Unprotected steel (new), alminium pipe with couplings	0.40
Slightly used steel	0.44
15-year old steel or iron	0.48
Rough interior	0.54
Very rough interior	0.60

Table 8.1.6 : Friction loss (m/100m) in lateral pipeline of portable aluminum pipe with coupling of 9m length (based on Scobey's formula)

Flow (l/s)	Diameter of pipe (cm)				
	5.0 cm (K_s = 0.34)	7.5 cm (K_s = 0.33)	10.0 cm (K_s = 0.32)	12.5 cm (K_s = 0.32)	15 cm (K_s = 0.32)
(1)	(2)	(3)	(4)	(5)	
1.26	0.32				
1.89	2.53				
2.52	4.49	0.56	0.130		
3.15	6.85	0.86	0.198		
3.79	9.67	1.21	0.280		
4.42	12.90	1.63	0.376	0.122	
5.05	16.70	2.10	0.484	0.157	
5.68	20.80	2.63	0.605	0.196	
6.31	25.40	3.20	0.738	0.240	0.099
7.57		4.54	1.04	0.339	0.140
8.83		6.09	1.40	0.454	0.188
10.10		7.85	1.80	0.590	0.242
11.36		9.82	2.26	0.733	0.302
12.62		12.00	2.76	0.896	0.370
13.88		14.4	3.30	1.07	0.443
15.14		16.9	3.90	1.26	0.522
16.41		19.7	4.54	1.47	0.608
18.93		25.9	5.96	1.93	0.700
22.72		36.6	8.40	2.74	0.798
23.98		40.9	9.36	3.03	0.846
25.24		44.7	10.30	3.34	0.904
26.50			11.30	3.66	1.02
27.76			12.3	4.0	1.13
29.03			13.4	4.35	1.26
30.29			14.6	4.72	1.38
31.55			15.8	5.10	1.51

34.70			18.9	6.12	1.66
37.86			22.2	7.22	1.80
41.00			25.9	8.40	1.95
44.17			29.8	9.68	2.12
47.32			33.8	11.0	2.52
50.48				12.5	2.98
53.63				14.0	3.46
56.79				15.6	3.99
59.94				17.3	4.54
63.10				19.0	5.15

8.1.3.6 Pressure in the lateral

The sprinkler pressure refers to the average pressure in the middle of the laterals. There is a loss of pressure in laterals due to friction loss. About 75 percent of total friction loss occurs in the first half of the line and 25 percent in second half. The pressure of the last sprinkler is obtained by subtracting the pressure equivalent of 25 percent of lateral loss from the average design pressure. For finding the pressure in the first sprinkler, an equivalent of 75 percent of the lateral loss is added to the average design pressure along the lateral. The maximum and minimum pressures on sprinkler heads on a lateral are thus determined. These pressures should be within the permissible pressure range of sprinkler, specified by the manufacturer.

8.1.3.7 Selection of size of main line, lateral line and calculation of friction head loss: The sizes of main line and lateral line are selected as per the discharges carried through them and the friction loss corresponding to these discharges.

Discharge through lateral line (q)

q = sprinkler nozzle discharge x number of sprinkler nozzle in one lateral line

Discharge through main line, Q (total discharge of sprinkler system)

Q = Sum of the discharge through all the lateral operating at any time

The size of diameter of pipelines is selected by generally a trial and error procedure, by striking a balance between the cost of pipe and friction losses. Standard tables and charts are referred to for estimating friction losses for the given discharge, size, length of pipeline and number of nozzles used in the line. The step by step procedure is given below:

Step 1 Select a given size of pipe diameter

Step 2 Assume the flow in the pipe through the entire length without sprinklers/nozzles and determine the friction loss

Step 3 Multiply the friction loss as in step 2 above by the correction factor (Table) obtained corresponding to the number of sprinkler on the lateral line

Step 4 To step 3 above, add the elevation difference if the lateral goes uphill of subtract if it goes downhill

Step 5 Check whether the head loss computed in step 4 is within the allowable limit of 20 percent of operating head. If it is within the limit, the size of the pipe diameter selected in step1 above is acceptable. Otherwise another value for the diameter of the pipe is selected and the step 1 through step 5 is repeated. When the value of head loss as obtained in step 4 is far less than the allowable value, than a smaller size of pipe, from among the available sizes, is considered. Otherwise, larger size is adopted

Table 8.1.7 : Correction factor of F for computing friction loss in a pipeline with multiple outlets

Number of outlets	Value of F	Number of outlets	Value of F
1	1.000	16	0.377
2	0.634	17	0.375
3	0.528	18	0.373
4	0.480	19	0.372
5	0.451	20	0.371
6	0.433	21	0.370
7	0.419	22	0.369
8	0.410	23	0.368
9	0.402	24	0.367
10	0.396	25	0.366
11	0.392	26	0.365
12	0.388	27	0.364
13	0.384	28	0.363
14	0.381	29	0.362
15	0.379	30	0.360

The friction loss in lateral lines can also be calculated with the help of Hazen William equation (for plastic pipe) and Scobey's formula (for aluminum pipes). The friction loss calculated for lateral lines should be corrected with correction factor for multiple outlets (Table 8.1.7). An allowance pressure variation of 20 percent results in 10 percent loss / reduction in nozzle discharge, which is an acceptable norm of design.

8.1.3.8 Size of pumping unit

The size of pumping unit depends on the total discharge carried through the system and total pressure head.

Total pressure head (H,m) = $H_f + H_o + H_s + H_r$

Where,

H_f = Pressure head drop due to friction in lateral line + pressure head drop due to friction in main line + pressure head changes due to elevation of land surface ± friction head loss through fittings such as bend, joints etc., m

H_o = Operating pressure head required at nozzle, m

H_s = Total static head, m

H_r = Height of riser, m

The required water horse power is calculated as:

WHP = Q*H / 75

Where,

Q = Total discharge, lps

H = Total head, m

The horse power of the pump, HP is given by

HP = WHP / E_p x E_m

Where,

E_p = Efficiency of pump

E_m = Efficiency of motor

8.2 MICRO IRRIGATION SYSTEMS (MIS)

Micro-irrigation is the universal term for drip, tickle or micro spray irrigation system. It is a growing technology, which has the potential to enhance crop productivity, conserves soil, water and fertilizer resources while also protecting the environment. Micro-irrigation is able to manage high water potential continuously and minimize fluctuation in soil water contents in the effective root zone and holds the promise of increasing crop yields and quality of produce. It also provides opportunity of judicious use of water, fertilizer and other inputs, and requires less energy for irrigation. Thus, microirrigation has wide adaptability in the regions where water supply is limited and scares.

Microirrigation is being used extensively for widely spaced row crops, with plastics or organic mulched crops, orchards, gardens, greenhouses and nurseries. It is adaptable with almost all type of crop and almost all type of land. Microirrigation systems have shown their utility for problematic soils and even poor quality water can be utilized which otherwise not possible with other irrigation methods. It can also be installed as either a surface or subsurface water application system. Types of micro irrigation differ based on the emission devices. The most important benefits of micro-irrigation is summed up below :

Table 8.2.1 : Water use efficiency with microirrigation system

Crop	Yield increase (%)	Water saving (%)	Increase in water use efficiency (%)
Water melon	88	36	195
Pomegranate	45	45	167
Sugarcane	33	56	204
Tomato	50	31	119
Banana	52	45	176
Chilly	45	63	291
Grapes	23	48	136
Groundnut	91	36	197
Sweet lime	50	61	289

Source **: INCID (1994), Drip in India, New Delhi**

Saving of water : The high water application efficiency in micro irrigation offers opportunity to use available water judiciously, effectively and efficiently (Table 8.2.1). An application efficiency of 90% could easily be achieved for drip irrigation as compared to 60-80% for sprinkler and 40-60% for surface irrigation.

Fertilizer economy : The crop response to the fertilizer is better in the presence of proper moisture in the soil. Drip irrigation offers the opportunity of using fertilizer with irrigation water (fertigation). Fertigation enables users to put the fertilizers in plant root zone in desired frequency, amount and concentration at appropriate time. Various research studies conducted in different parts of the world have proved that supplying liquid / soluble fertilizers through drip system can lead to 40-60% savings in fertilizer application without affecting the yield and a much higher application efficiency compared to the conventional methods. This is in addition to the savings in water applied which could be anywhere from 50 to 70 per cent, besides improvement in quality of produce being added advantages.

8.2.1 MICRO IRRIGATION IN CANAL COMMAND

Farmers of canal-irrigated areas are even more reluctant to adopt this technology because of lack of information and additional investment required to ensure regular water supply for operation of the system. In summer, canal is usually closed for 2-3 weeks for cleaning and repair or due to shortage of water at heads etc. The authorities distribute water among the farmers and the turn for canal water supply hardly comes once in a week. The situation at the tail of canal is more severe as water supply is more erratic. Construction of a water storage reservoir of sufficient capacity is required to maintain the water supply during canal off periods to operate the microirrigation system. Since, water scarcity is increasing day by day, the farmers need to be convinced to adopt micro irrigation system in order to utilize efficiently and effectively the limited water resource available for the irrigation.

8.2.2 Secondary reservoir for storage of canal water

Water management assumes paramount importance to reduce the wastage of water, increase water use efficiency and ensure equitable distribution. Unscientific and injudicious use of canal water resulted in heavy conveyance and water application losses, and cause water logging and salinity in canal command. Besides this, canal water supply is not regular throughout the year. Further, the authorities distribute water among the farmers and the turn for canal water supply hardly comes once in a week. The situation at the tail of canal is more severe as water supply is more erratic. Construction of a water storage reservoir of sufficient capacity is required to maintain the water supply during canal off-periods for higher water productivity. Secondary reservoirs are storage structures (ponds) located in irrigated areas that allow farmers to store a part of canal water and use judiciously. Some time, during lean period or in rainy season when canal water is not needed for irrigation can also be stored in secondary reservoir for using during critical periods. Similarly, in period of scarcity, even underground water can also be used by mixing with canal water. Storage of canal water in service reservoir (pond) and judicious utilization of stored water provide an excellent opportunity to enhance the water productivity and save water to enable bringing more area under cultivation in canal command. Hence, service reservoir can be an integral component of irrigation system in canal command to provide ensured irrigation for higher productivity. Further, introduction of microirrigation in these areas can further improve the water productivity by growing high value crops from the stored precious water. In South-west Punjab, Western Haryana and Northern Rajasthan, where canal water is being used for irrigation, the technology of secondary service reservoir is gaining popularity and many farmers are constructed secondary reserior (ponds) for storage of canal water.

8.2.3 Components of drip irrigation System

A typical drip irrigation system and different components of the system are shown in Fig 1 and 2. Components of microirrigation system are:

- ❖ Water source
- ❖ Filter
- ❖ Fertiligation unit
- ❖ Main and submain pipes
- ❖ Lateral pipes
- ❖ Emitters

a) Water Source : For the present case, the water source is a service reservoir, which is fed by water flow from canal distributary / minor or water course. The water from the reservoir is pumped to main line to create necessary pressure head to operate the system.

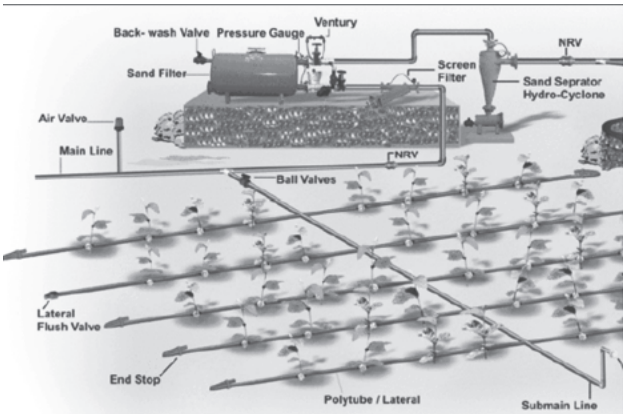

Fig. 1. Typical drip irrigation system

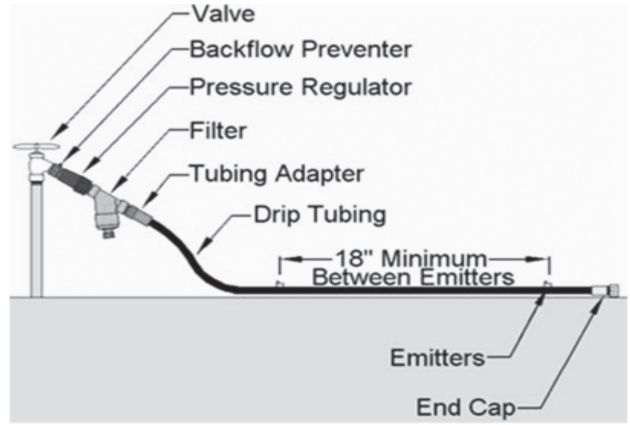

Fig 2 Different components of the micro irrigation system

b) Filter : Filters are used to minimize or prevent inflow of possible suspended material in the water to the pipeline and dripper network. The types of filters are: Sand filter, Media filter, or Screen filter. Screen filters are popular because they are relatively less expensive, easy to install and take up less space than a media filter. Screen filters can be used as primary or secondary filter and can be operated either manually or by automatic controls. Screen filters usually work well with low to moderate loading of inorganic contaminants and where virtually no organic or chemical contaminants are present.

c) Main and sub-main pipe : Rigid PVC and HDPE pipes are used as main pipe to minimize corrosion and clogging. The main pipe is generally laid underground and supply water to sub-main pipes. Diameter of main and sub main pipes depend on the water requirement of crop and size of the fields. Both main and sub main lines are provided with flush valve at the outlets to occasionally flush the pipes to remove sediments from the pipes. Normally, pipes of 65 mm diameter and above with a pressure rating of 4 to 10 kg/cm^2 are recommended for main pipes. Rigid PVC, HDPE or low-density polyethylene (LDPE) is used as sub main pipe. Pipes having an outer diameter ranging from 32 mm to 75 mm with a pressure rating of 6.0 kg/cm^2 are used as sub main pipe.

d) Lateral pipe : Laterals are the pipes on which drippers are connected or drippers are made part of lateral e.g. for inline drippers. Lateral lines are usually made of linear low-density polyethylene (LLDPE) ranging from 10 mm to 20 mm diameter with wall thickness varying from 1 to 3 mm with a pressure ratings of 2.5 kg/cm^2. Lateral pipes should be flexible, non-corrodible and resistant to solar radiation. LLDPE gives better protection against ultra violet rays and longer life than LDPE. Each lateral is connected to either the main or a sub main pipe. Water flow in each lateral depends upon the number of drippers on that lateral and the pressure head provided.

e) Emitters : Emitters are the devices that are used to apply the required amount of water uniformly from the lateral to the root zone of the plants. The drippers on the basis of their application are classified into three types namely, point source, line source and disc source.

i) ***Point source drippers*** discharge water from individual or multiple outlets. They are widely used for fruit crops.

ii) Line source drippers are used primarily on small fruits, vegetables or other closely spaced crops.

iii) Disc source drippers include micro sprinklers, micro sprayers and bubblers, which can be used for close-growing crops and small fruit plants.

f) Fittings and accessories

PVC pipes can be joined using PVC resin and HDPE pipes can be joined using heat butt-welding. Polyethylene tubing are normally not cementable, and are connected with barbed or compression fittings. Common PVC fittings are elbows, reducer, tees, straight connector, end cap and gate valve. Accessories include gate valve, tee, joiner, elbow, end caps and grommet takeoff etc. All these components are available in 4, 10, 12, 16 and 20 mm sizes. These takeouts/starter and rubber grommet are used for taking out laterals lines from sub-main, connector, bend and end caps are used in drip laterals.

8.2.4 Design of drip system

8.2.4.1 Estimation of Water and Power Requirement

Knowledge about the irrigation scheduling i.e. amount and time of water application is important to realize the benefits of drip irrigation system and saving of water with better yield and quality of produce. For this, crop water requirement is to be estimated which needs to be supplemented through irrigation.

Table 8.2.2: Crop coefficients of selected crop

Crop	Crop coefficient
Beans, green	0.90
Cabbage	0.80
Corn, sweet	0.95
Onion, dry	0.90
Onion, green	0.80
Pea	0.95
Peper	0.80
Watermelon	0.85
Citrus, Kinnow	0.60
Grapes	0.70
Pecans, almonds, apricots, plums, peaches, pomegranate	0.75
Walnuts, apples	0.85
Melons, peanuts, lettuce	0.95
Carrots, beans	1.00
Cotton, potato, tomato, peas	1.00
Corn, sugar-beet	1.10

8.2.4.2 Irrigation scheduling

Water requirement of crops (WR) is a function of nature of plant, area covered by the plant and potential evapotranspiration rate. Irrigation water requirement has to be calculated for each plant and thereafter for the whole plot based on plant population for different seasons. The daily water requirement for fully grown plant can be calculated as

$$V = E_p.K_p.K_c.C_c.A \quad (1)$$

Net volume of irrigation to be applied is given by

$$V_n = V - R_e.A \quad (2)$$

If V_n is negative, then V_n=0. Total time of drip irrigation application to meet the water requirement is estimated as

$$T = \frac{V_n}{q} \quad (3)$$

Where, V is the Water requirement (L/day/plant); E_p is the Evaporation from Class A pan (mm/day); K_p is the pan factor; K_c is the Crop factor as given in Table 8.2.2; C_c is the Canopy factor (Cc=1 for closed spaced field crops, Cc= wetted area/plant); A is the area covered by each plant (m^2); R_e is the effective rainfall (mm); and q is the emitter discharge (L/h).

However, water application may be decided as daily, alternate day or any other frequency as recommended for the location for a given crop in a particular month, the time of operation of the system is estimated using eq (3) by multiplying T by irrigation interval (days).

8.2.4.3 Design of laterals, main

Normally, pump is used to create the pressure head required to operate the system. In an efficient drip irrigation system all the drippers (or orifices) are considered to deliver the same volume of water in a given irrigation time. The dripper flow variation caused by water pressure and head loss due to the friction in the pipes can be controlled by hydraulic design.

Flow in different components:

Flow carried by laterals, $Q_l = q.n_e.n_p$ (4)

Flow carried by submain, $Q_{sm} = Q_l.n_l$ (5)

Flow carried by main, $Q_m = Q_{sm}.n_{sm}$ (6)

Where n is the numbers of units, and subscripts e, p, l, sm, and m are used for emitters, emitters per plant, lateral, submain and main, respectively.

The friction head loss in pipes (h_f) in m, can be estimated by using the following formula

$$h_f = \left[78900 \frac{Q^{1.75}}{D^{4.75}} \right] L.F_d \quad (7)$$

where L is length of pipe (m); Q is discharge (L/s); F_d is factor for multiple outlet (Table 8.2.3); D is diameter of pipe.

Total friction head drop can be calculated as

$$H_f = h_{fm} + h_{fsm} + h_{fl} \quad (8)$$

Where h_{fm} is friction loss in main (m); h_{fsm} is friction head loss in sub-mains (m); and h_{fl} is friction head loss of laterals (m).

Total Pumping Head can be calculated as

$$H = H_f + H_e + H_s \quad (9)$$

Table 8.2.3 Correction factor (F) for friction losses with multiple outlets

Outlets number	Correction factor, F_d
1	1.00
2	0.63
4	0.48
6	0.43
8	0.41
12	0.39
16	0.38
20	0.37
>20	0.36

Where H_e is the operating pressure head required at the dripper (m); and H_s is suction head (m)

8.2.4.4 Slection of pump

The capacity of pump required to create required pressure head (H) is estimated in HP as

$$H.P. = \frac{H.d_m}{75.\eta} \quad (10)$$

Where d_m is the discharge for mainline (L/s); and h is the pump overall efficiency in (fraction).

The design of lateral pipe involves selection of pipe for a given length, which can deliver required quantity of water to the plant. In designing the lateral, the discharge and operating pressure at drippers are required to be known and accordingly, the allowable head can be determines by the same formula as the main line. However, the following criterion needs to be fulfilled while designing the system.

1. The head loss in the lateral between the first and last emitter should be within 10 per cent of the head available at the first emitter.
2. The friction head loss in the mainline should not exceed 1m / 100m length of the mainline. Friction head loss for various discharges is given in Table 8.2.4.

Table 8.2.4 : Friction head losses in Meters per 100 m Pipe Length

Flow	Inside diameter (mm)						
(L/s)	**9.2**	**11.7**	**12.7**	**13.9**	**15.8**	**18.0**	**19.0**
200	10.2	5.2	2.5	1.7	0.8	0.4	0.3
400	39.0	18.0	8.6	5.7	2.7	1.6	1.1
600		39.0	18.0	13.0	5.9	3.2	2.5
800			30.0	21.0	10.0	5.5	4.1
1000			42.0	30.0	16.0	8.3	6.2
1200			45.0	21.0	11.0	8.8	6.4
1400				56.0	28.0	16.0	11.0
1600					36.0	20.0	15.0
1800					45.0	25.0	19.0
2000					54.0	30.0	23.0

8.2.5 Example of design of a drip system

1.) A Farmer propose to install drip irrigation system for a new pomegranate plantation on a 1 ha plot.

Given : Area – 1.0 ha (100 x 100 m^2) of nearly flat land;

Water source – farm pond with water level 5m below ground level;

Crop – Pomegranate at 4m x 3m spacing in dry hot climate (peak pan evaporation 8.58 mm / day) in sandy loam soil (Table 8.2.5).

Crop co-efficient for pomegranate, Kc = 0.75; Pan co-efficient, Kp = 0.75; Cc = 0.48

No. of plants (n_p) = 10000 / (4x3)= 833

Estimation of water requirements

For the designing of an irrigation system, water requirement is determined with the peak value of evapotranspiration.

V = 8.58 x 0.75 x 0.75 x 0.48 x 12 = 27.80 L / day or say 28 L / day per plant

Irrigation requirement per day for 1 ha

Vp = V x 833 = 28 x 833 = 23324 L / day / ha

Capacity of service reservoir

Assuming water application efficiency, h = 90%

Hence, actual irrigation water requirement = 23324 / 0.90 = 25916 = 25.91 m^3 / day / ha

Since farmer gets his turn once in a week, hence, the weekly water requirement = 25.91 x 7 = 181.37 say 181 m^3

Considering for canal closer for longer periods, dead storage need, and other factors, the volume needs to be multiplied with safety factor. A value of safety factor as 2 may conveniently be assumed for the present case. Assuming 10% evaporation losses, the total volume of water to be stored in service reservoir = 181 x 2 x (1+10 / 100) =398 m^3 or 400 m^3.

If reservoir is proposed to be constructed with trapezoidal section (3:1) of square shape and depth is restricted to 2 m because of high ground water table and poor quality

The surface area of the pond = 400 / 2 = 200 m^2

Number of emitters

Water requirement per plant is 28 L / day. If we use emitter of 4 L / s discharge and four emitters around each plant, then the number of emitters required for 1 ha = 833 x 4 = 3332

Time of emitter operations = $\frac{28}{4 \times 4}$ = 1.75 hr or one hour 45 min.

System capacity

Mainline Capacity (flow rate) = $\frac{3332 \times 4}{3600}$ = 3.70 lps

Lateral

For one hectare area, 50 laterals, 25 on each side of the main pipe will be laid having a length of 49 m each.

Capacity of each lateral = $\frac{3.70}{50}$ = 0.074 lps

Table 8.2.5 Montly average pan evaporation (for Abohar, Punjab)

Month of the year	Pan evaporation (mm)
January	1.16
February	2.50
March	4.36
April	6.01
May	8.58
June	8.30
July	4.96
August	4.52
September	4.81
October	4.81
November	2.87
December	1.21

Diameter of lateral

Length of each lateral, L = 49 m

Flow rate of each lateral, Q= 0.074 lps

Lateral is a multiple out let pipe with 16 outlet

Hence F_d = 0.38

Head loss due to friction (by using equitation (3)

Let the diameter of lateral pipe (D) = 12 mm

$H_f = 789000 \times 49 \times (0.074)^{1.75} \times 12^{-4.75} \times 0.38 = 1.15$ m

Elevation head = 0 (flat)

Total head loss = 1.15 +0 = 1.15 m

Total head loss in a lateral is 1.15 m (this is greater than 10%) of normal operating pressure in the laterals i.e. 1 kg/cm^2 or 10 m of water head. Hence, the 12 mm size of the pipe is not acceptable.

Therefore, take bigger diameter,

Since, the next higher size available in the market is 16 mm

Let assume the lateral Diameter (D) is 16 mm for design.

Head loss due to friction in 16 mm lateral (by using equitation (3)

$H_f = 789000 \times 49 \times (0.074)^{1.75} \times 16^{-4.75} \times 0.38 = 0.29$ m

Elevation head = 0 (flat)

Total head loss = 0.29 +0 = 0.29 m

Total head loss in a lateral is 0.29 m (this is less than 10%) of normal operating pressure in the laterals i.e. 1 kg/cm^2 or 10 m of water head. Hence, the 16 mm size of the lateral pipe is acceptable.

Diameter of main pipe

Let the diameter of main pipe be 50 mm.

Length of main pipe = 100 m

Main is also multi out let pipe with 50 outlets (50 laterals on either side) and hence

F_d = 0.36

Hence, head loss in pipe due to friction (by using equitation (3)

$H_f = 789000 \times (3.70)^{1.75} \times (50)^{-4.75} \times 100 \times 0.36 = 2.38$m

Elevation head = 0

Total head loss in main pipe = 2.38 + 0 = 2.38 m (this is greater than 10% of normal operating pressure.

Therefore, the pipe of 50 mm diameter is not acceptable for use as a main pipe.

Since, the next higher size available in the market is 63 mm

Let assume the main diameter (D) is 63 mm for design.

Head loss due to friction in 63 mm pipe (by using equitation (3)

$H_f = 789000 \times (3.70)^{1.75} \times (63)^{-4.75} \times 100 \times 0.36 = 2.38$m

Elevation head = 0

Total head loss in main pipe = 0.80 + 0 = 0.80 m (this is less than 10% of normal operating pressure.

Therefore, the pipe of 63 mm diameter is acceptable as a main pipe.

Size of pumping unit:

i) Suction head – 5 m

ii) Head loss in fiting and accessories = 2m

iii) Head required for operation = 10 m

iv) Friction loss in lateral pipes = 0.29 x 50 = 14.50 m

v) Friction loss in main pipes = 0.80

Total friction loss = 15.30 m

Total head = (5+2+10+15.30) = 32.30 m

Let the overall efficiency of pump

E = 60% (Electric pump)

$$HP = \frac{3.70 \times 32.30}{75 \times 0.60} = 2.65 \text{ say } 3.0 \text{ hp}$$

Details about designing of drip irrigation system for 1 ha pomegranate orchard

Sr. No.	Components	Specification
1.	Capacity of water storage tank	400 m^3
2.	Pumping unit	3.0 hp (H=35m)
3.	Sand filter (6.48 m3/hr)	16.0 m^3/h
4.	Screen filter (6.48 m3/hr)	16 m^3/hr
5.	Pressure gauge 0-2 kg/cm^2	2 nos
6.	Gate valve	63 mm, 3 Nos
7.	Main pipe	63 mm diameter, PVC, 100 m long
8.	Laterals	16 mm diameter, LLDPE, 2500 m
9.	Laterals for loop around the plant	12 mm diameter, LLDPE, 3270 m
10.	Drippers	4.0 lph, 3333 nos
11.	Fittings (Tee, Bend, connector, end cap, grommet, air release valve & thresh valve)	As per requirements

2) A Farmer propose to install drip irrigation system for a new *kinnow* plantation on a 1 ha plot

Basic data available is:

Area = 1 ha (100 x 100 m^2)

Topography = nearly flat

Water to be pumped from a farm pond and water level in the pond in 5 m below the level of the farm

Crop = *Kinnow*

Spacing = 6 m x 6 m

Climate = dry hot

Soil type = Sandy loam

Pan evaporation (peak) = 8.58 mm

Crop co-efficient for kinnow, Kc = 0.6 (Table 1)

Pan co-efficient, Kp = 0.75

Lateral spacing = 6 m

Cc = 0.56

No. of plants (np) = 278

Design procedure is same as in example 1.

The Detail requirement for adopting drip irrigation system in 1 ha *kinnow* orchard is as follow

Sr. No.	Components	Specification
1.	Capacity of water storage tank	371 m^3
2.	Pumping unit	2.0 hp (H=35m)
3.	Sand filter	10.0 m^3/h
4.	Screen filter	10 m^3/hr
5.	Pressure gauge 0-2 kg/cm^2	2 nos
6.	Gate valve	63 mm, 3 Nos
7.	Main pipe	63 mm diameter, PVC, 100 m long
8.	Laterals	16 mm diameter, LLDPE, 1670 m
9.	Laterals for loop around the plant	12 mm diameter, LLDPE, 1390 m
10.	Drippers	8.0 lph, 834 nos
11.	Fittings (Tee, Bend, connector, end cap, grommet, air release valve & thresh valve)	As per requirements

9.0 DRAINAGE SYSTEM FOR WATERLOGGED SALINE SOILS IN CANAL COMMANDS

M.J. Kaledhonkar and Satyendra Kumar

Irrigation induced waterlogging and soil salinity problems are generally observed in irrigation commands of large irrigation projects in many states of India as result of over irrigation, flat topography with lack of natural outlet or heavy nature of soil impeding natural drainage. These problems adversely affect the production and productivity as well as threaten the sustainability of irrigated agriculture. It has been estimated that 8.5 million ha land has been affected by salinity and alkalinity (Singh, 1996). As per revised estimate the salt soils are estimated as 6.73 M ha. The alluvial soils of Indo-Gangetic plains of north- west India are very deep and the topography is flat. The climate is semi-arid to arid. Waterlogging and secondary salinisation problems are extending steadily over the years in various irrigation basins of these plains. About 0.7 to 1.0 million ha semi –arid part of Punjab, Haryana, North- western Rajastan and Western Uttar Pradesh is affected by these problems and affected area is increasing alarmingly (IPTRID, 1993). It is also observed that large areas in Gangetic plain of north India suffer from critical and semi-critical waterlogging. Waterlogging is called as critical, if watertable fluctuates between 0- 2 m below ground surface. It is treated as semi-critical, if fluctuates between 2-3 m below ground surface. Critical and semi-critical waterlogged areas, in the Gangetic plains of Uttar Pradesh, are 3.3 and 4.6 million ha, respectively (Rai, 2003). Waterlogging and soil salinity problems are also reported in irrigation commands in states of Maharashtra, Karnataka, Andhra Pradesh Madhya Pradesh and Gujarat due to heavy nature of soils, which have low permeability values. These problems are also reported in non-command areas of these states due to cultivation of sugar cane crop with lift irrigation schemes.

Drainage is the artificial removal of water in excess of the quantity required for the crop. Drainage includes removal of excess surface and subsurface water in the root zone. Irrigation and drainage go together and are not mutually exclusive. Irrigation system aims at supplying optimum quantities of water throughout the crop period. Drainage system aims at removing excess quantity of water in a short time. Often, both may be required together to assure sustained and high level of production of crops. In the planning of most of the existing irrigation projects in our country, provision was not made for adequate drainage in the command areas. Water table built up steadily due to high seepage and percolation losses, consistent over irrigation, spillage from canal systems and not using groundwater. Waterlogging and salinisation have thrown considerable acreage in the command area out of production. The importance of providing adequate drainage in command area of projects needs no emphasis.

Most of the saline soils in irrigation commands are underlain by poor quality ground waters. Studies have shown that in these circumstances vertical drainage by tube well have limited application. Subsurface (horizontal) drainage appears as promising under these situations as the drainage effluent disposal problem is minimized. A subsurface drainage system constitutes the laterals, the collectors and the main drains. The following subsections provide details related drainage investigations, design criteria, envelope material and installation, operation and maintenance of subsurface drainage system. The post drainage management aspects are also covered in details.

9.1 Drainage Investigations

The pre-drainage investigations can be conducted at three levels i.e. the reconnaissance, the semi-detailed and detailed surveys of the area. The reconnaissance survey helps in determining the technical and economic feasibility of the proposed project. The semi-detailed survey corresponds to the level of feasibility studies, which enable to decide the optimal plan, for execution. A detailed survey involves the collection of all relevant field data (Such as topographical map, Temporal ground water table depth and quality information, Spatial groundwater composition, Soil details, Cropping pattern, Irrigation sources and methods of irrigation, Sources of excess water, soil hydrological characteristics (hydraulic conductivity, drainable pore space, infiltration rate) that allows an effective design of the drainage system. The brief details of expected output of these surveys are given in Table 9.1.

Table 9.1 : Types of drainage investigations

Type of drainage investigation	Expected output
Reconnaissance	Identification of need for drainage; Mapping/inventory of existing/available survey information (Scale 1:50,000 to 1:250,000); Identification of additional investigation to be carried out.
Semi-detailed	Preliminary plan of the future drainage system(Scale 1:10,000 to 1:25,000); survey Rough estimate (to an accuracy of 10 to 20%) of the costs.
Detailed survey	Recommended drainage techniques and their layout (Scale 1:2500 to 1:5000); Construction plans and specifications

9.1.1 Drainage Criteria

The agricultural drainage criteria is defined as the state to which the original waterlogging on or in the soil is to be reduced by a drainage system so that the maximum agricultural benefit of the system is attained. When designing a system for a particular area, the drainage engineer must use certain criteria to determine whether or not water is in excess. Drainage engineer, besides agricultural drainage criteria, should also employ:

- Technical drainage criteria (for the minimization of the cost of system while maintaining the agricultural criteria),
- Environmental criteria (for the minimization of the environmental damage), and
- Economic drainage criteria (for the maximization of the net benefits)

9.1.2 Subsurface Drainage Coefficient

It is the depth excess water in cm to be drained off from a given area in 24 hours. It is the most important parameter that decides the lateral drain spacing, size of the laterals and collectors and capacity of the pump to dispose off the drainage effluent. The drainage coefficient for some of the sites in India has been observed to be in the range of 1-5 mm (Table 9.2) and guidelines on type of climate are given in Table 9.3. Drainage coefficient can be estimated any area by studying the groundwater balance.

9.2 Design of Subsurface Drainage System

a) Depth of laterals

Depth and spacing of laterals should be planned according to agricultural drainage criteria. The drain depth is also decided by the selected construction method, the available machinery and drain specifications. Drains need to be installed at depths, where chances of damage due to agricultural operations are less. Drain depth is decided on the basis of depth to water table for proper aeration in the root zone, cost of system, presence of unstable or impermeable layers, soil texture and strata permeability, land topography, minimum soil grade and outlet conditions. To protect the pipes against damage due to passage of heavy machinery, the minimum drain depths

Table 9.2 : Subsurface drainage coefficients from different locations (as observed from test plots)

Site	Rainfall (mm)	Rate Recommended (mm day^{-1})	Range (mm day^{-1})
Chambal (Rajasthan)	850*	3.0	2.5 - 3.5
Sampla (Haryana)	600	2.5	2.0 - 3.0
Hisar (Haryana)	400	2.0	1.5 - 2.5
Dabhou (Gujarat)	800	4.0	3.0 - 5.0
Mundlana (Haryana)	500	5.0	5.0 - -
Kailanakhas (Haryana)	500	6.8	5.0 - 7.0
Muraj (Gujarat)	500	2.8	2.0 - 4.0

* Variation in the range of 600-1400 mm. Source: Gupta and Gupta (1997)

Table 9.3 : Guidelines on drainage coefficient for subsurface drainage

Climatic conditions	Range (mm day^{-1})	Optimum value (mm)
Arid	1-2	1
Semi-arid	1-3	2
Sub-humid	2-5	3

have been recommended which vary from one soil type to another (Table 9.4).

Table 9.4 : Subsurface drainage coefficients from different locations (as observed from test plots)

Soil type	Minimum soil cover (cm)
Mineral	60
Deep peat and muck	120
Organic	75

To achieve this depth to water table at the mid-point of the two laterals, depending upon the soil type and hydraulic characteristic, drain depth should be kept in the range of 125-150 cm. The general guidelines for drain depths on the basis of outlet are given in Table 9.5. Apparently, these recommendations take care of minimum soil cover required against breakage of pipes.

On the basis of experience at CSSRI, Karnal, it is recommended that drains should not be laid less than 1.5 m depth from ground surface.

Table 9.5 : Guidelines on drain depth

Outlet conditions	Depth of the drains	Optimum depth (m)
Gravity	0.9-1.2	1.1
Pumped	1.2-1.8	1.5

Otherwise drains get damaged due to agricultural operations. On the basis of desirable minimum average water table depths for various types of uses, shallow drains (1.2 m – 1.8 m) can be successfully used to maintain water table at desirable depths. Guidelines for optimum depth to water table for various crops and soil types are given in Table 9.6.

On the basis of this discussion in the Indian context, shallow drains (depth 1.2 – 1.5 m) could be cost effective in reclamation and management of saline soils.

b) Spacing of lateral drains

Assuming the steady state drainage criteria and depth of laterals, spacing between the laterals can be computed using Hooghout's formula.

Table 9.6 : Guidelines for optimum depth to water table for various crops

Crop	Soil type	Water table depth (m)
Irrigated annual crops	Loamy, sandy loam, silt loam	0.6 -0.8
Perennial crops	Clay loam, clay silt	0.8 – 1.0

***Average seasonal depth = 1.0 m**

(1)

where

q = drain discharge (m / d) or unit flow rate through plane (m^2 / d); k = hydraulic conductivity of the soil (m / d); d = depth to impervious layer (m); H = height of watertable at midway between the drains (m); S = drain spacing (m)

Equation (1) can be written as:

$$q = \frac{8kdH}{S^2} + \frac{4kH^2}{S^2} \qquad (2)$$

If drains are located on the impervious layer (i.e. d=0), the first term of Equation (2) becomes negligible. In case of d >>H, the second term of Equation (2) becomes negligible. If d>>H, an imaginary impervious layer above real one can be assumed. The imaginary layer decreases the thickness of layer through which water flows towards the drains. It is assumed that such imaginary impervious layer exists at equivalent depth (de). Hence Equation (2) becomes:

$$q = \frac{8k_b d_e H}{S^2} + \frac{4k_t H^2}{S^2} \qquad (3)$$

where

K_t = Hydraulic conductivity of the layer above drain level (m / d)

K_b = Hydraulic conductivity of the layer below drain level (m / d)

The Equation (3) can be solved through iteration. However, nomographs are also available, which value of de can be read easily.

c) Guidelines on lateral drain spacing and grade

While these equations can be used to design a drainage system for site-specific conditions, design guidelines have been prepared on the basis of field experiences (Table 9.7) and guidelines for grade are given in Table 9.8.

Table 9.7 : Guidelines on lateral drain spacing

Soil texture	Spacing of drains (m)
Light textured	100-150
Medium textured	50-100
Heavy textured	
including vertisols	30-50

Table 9.8 : Minimum grade for pipe drains

Drain size (mm)	Grade (%)
100	0.10
125	0.07
150	0.05

q

d) Sizes of lateral, collector and main drain

The areas that can be drained with different slopes and different diameters of pipes can be computed with a capacity limitation of 60% for pipes less than 100 mm in diameter and 75% for pipes for more than 100 mm diameter (due to silt deposition, pipe deflection, etc.) with following Equation (4) and (5).

$Q = q*A = 2.0 * 10^6 * d^{2.67} * i^{0.5}$

if d < = 100 mm (4)

$Q = q*A = 2.5 * 10^6 * d^{2.67} * i^{0.5}$

if d > 100 mm (5)

where

Q = drainage volume (m^3 / d); A = drainable area (m^2) ; q = drainage coefficient (m / d); d = internal diameter of the pipe (m); i = slope of lateral line (m / m)

9.2.1 Drain Envelope Material

A drain envelope is porous material placed around a perforated pipe drain to perform different functions such as filter, hydraulic and mechanical and bedding functions.

- Filter function prevents or limits the movement of soil particles into drainpipe, where they may settle and eventually clog the drainpipe.
- Hydraulic function provides a porous medium of relatively high permeability around the pipe to reduce entrance resistance at or near the drain openings.
- Mechanical function provides passive mechanical support to the pipe in order to prevent excess deflection and damage to the pipe due to soil load. Bedding function, which is only accomplished by use of a gravel envelope, provides a stable base to support the pipe in order to vertical displacement due to soil load during and after construction.

i) Types of envelope material

Based on the material used he following types of envelopes can be distinguished.

• Granular envelopes	Gravel or sand gravel combinations
• Organic envelopes	Organic materials such as peat or top soil, building paper, hay straw, cloth burlap, corn cobs, leather, wood chips, wire coir or coconut fibre, etc.
• Fabric (synthetic) envelopes	Woven and non-woven materials

ii) Layout of Subsurface Drainage System

Drainage systems could be laid out in the field in a number of ways. The basic principles of designing a layout are :

- The mains should be put along natural drainage line.
- Main and laterals should be, as far as possible, placed in straight lines.
- Laterals should be given the greatest fall possible by running them down the slope except in cases of intercepting seepage water.
- Laterals should be in long lengths rather than short ones in order to eliminate double drainage due to the mains and laterals.
- The land should be equally drained.
- The number of outlets should be the minimum.

Layout can be classified as random, herringbone, gridiron and interceptor. Combinations of two or more of these types are frequently required to complete drainage of whole area.

9.2.2 Drainage Structures

Manhole: The manhole or sedimentation basin is any type of structure that provides for sediment accumulation, thus reducing deposition in the tile. The manhole should be cleaned at regular interval.

Junction boxes: Junction boxes are used where two or more mains or submains join or where several laterals join at different elevations. A sediment basin should be integral part of the junction box.

Surface inlets: In some heavy soils water tends to collect at low spots and it may be desirable to provide surface inlet to water to get into drain through manhole or junction box through silt basin.

Blind inlets: In case blind inlets, small section of drain is constructed by backfilling by stone / gravel. The collected water at low spot passes through backfilled material to drain.

Structure for outlet protection: Generally metal pipes are provided at outlet end, where it discharges into drain. The flap gate is provided from top to avoid backwater entry into drain.

EXAMPLE OF ESTIMATION OF DRAINAGE COEFFICIENT FOR SUBSURFACE DRAINAGE

Location : Hisar

A procedure to decide the drainage criteria is explained here with the help of data of drainage Project at Hisar (Haryana) to reclaim waterlogged saline soils. Rainfall data of Hisar station for monsoon months (July, August and September) are analyzed for determining 1, 2, 3 and 4-day duration maximum rainfall for different return periods. The results of analysis of 30 years (1950 to 1979) rainfall data for the months of July, August and September are presented in Table.

It can be observed that most likely duration and depth (on 10-year return period basis) for Hisar is 3 days and 129 mm, respectively. It is assumed that 80% of amount of such storm may reach to ground water. It means that 103 mm of effective rainfall will give rise of 103 cm of water by considering drainable porosity of 0.1. It may increase the water table level from 150 cm below ground surface to 50 cm below ground surface. Still the water level remains safe for crops tolerant to water logging. Thus, it eliminates need of rapid removal of water.

Drainage system is required to remove the recharge contributions of rainwater and deep percolation losses from the applied irrigation water. For this purposes the recharge from rainstorms of July, August and September have been considered. The average annual rainfall for these months at Hisar is about 336 mm. For Hisar area the contribution to groundwater has been assumed to be 20% of the total rainfall of the period. The expected deep percolation losses from irrigation applications of 132 mm of canal water for same months are taken at 35%. With these assumptions the recharge from rainfall and deep percolation losses would be 67.2 and 46.2 mm. Neglecting subsurface inflow and capillary rise from watertable during dry periods, the drainage coefficient would be 1.26 mm/day i.e. 1.5 mm/day. This drainage coefficient is used in design of subsurface drainage system.

i) Determination of drain spacing for drainage

Hooghout's formula i.e. equation (1) as explained earlier is to be used for calculation of drain spacing. Instead of d, Equivalent depth is to be used.

Rainfall depths of different durations at various return periods at Hisar

Duration (days)	Rainfall depth, mm Return periods, years		
	5	10	20
1	63	83	108
2	87	113	138
3	99	129	153
4	103	133	163

Available data of site of study are as below:

q = drain discharge (m/d) = 0.0015 m/day

(Drain discharge is taken equal to drainage coefficient of 1.5 mm/day)

k = hydraulic conductivity of the soil (m/d) = 0.5 m/day

de = equivalent depth to impervious layer (m) = 2.66 m (determined using monograph)

The depth of impervious layer was taken as 4.5 m as in some profiles the soil changed from loamy sand to silt loam in the depth range of 4.5 to 5m and equivalent depth was estimated as 2.66 m from monograph.

H = height of water table at midway between the drains (m) = 0.75 m

The drain spacing (S) in m was determined putting above data in Equation (1). Spacing between the drains was determined as 77.9 m. For field installation, drain spacing of 75 m was adopted.

ii) Determination of sizes of lateral, collector and main drain

For this project, though drainage coefficient, , was calculated as 1.5 mm/day, it could rise up to 3.0 mm/day when water table reaches to 0.5 m depth below ground level. The areas that can be drained with different slopes and different diameters of pipes is computed with a capacity limitation of 60% for pipes less than 100 mm in diameter and 75% for pipes for more than 100 mm diameter (due to silt deposition, pipe deflection, etc.) by using Equation (4) and (5) already explained in text. The detail of corrugated pipe, lateral drain calculated for the project under different slope is given below in Table.

Capacity of corrugated pipe lateral drain for the project of Hisar

Internal diameter (mm)	Q (m3/day)		Drainage area (ha)		Max. length at 75m spacing between laterals (m)	
	Slope (%)		Slope (%)		Slope (%)	
	0.1	0.15	0.1	0.15	0.1	0.15
75	62.7	76.5	2.1	2.5	278	339
100	135.2	164.8	4.5	5.5	599	730
125	306.7	374.0	10.2	12.5	1359	1659
150	498.8	608.5	16.6	20.3	2212	2699

Drainage sump: Drainage sump is the open well, where all collectors bring water. Sump is located lowest point in the area. Drainage water is pumped from sump at regular interval to maintain certain water table depth in drainage area. Pumped water from drain is disposed into surface drain or into evaporation pond if natural outlet is not available. In water logged areas with sandy soils, quick sand may interfere with the installations of sump. To overcome the problem, it is suggested to de-water the area around the sump while sinking the structure.

Evaporation pond: The inland basin between Indus and Gangetic basins has no natural outlet and evaporation pond appears to be as interim option for management of saline drainage effluent. An evaporation pond is generally constructed as pumped outlet for storage, evaporation or possible reuse of drainage water.

9.3 Installation of Subsurface Drainage System

The installation of subsurface drainage system begins with construction of outlet. In absence natural outlet, pumped outlet is constructed. The installation of collectors and laterals follows the construction of outlet. Excavation of trenches, lying of lateral pipes along with filter material and immediate back filling of trenches are done to avoid any problem in event of rainfall. Proper slopes of collectors and laterals are required for gravity flow of water. Manholes (RCC pipe 2.5 m length and 0.6m diameter) can be installed and collectors and laterals are connected to manholes at 20-30cm above their bottom levels so that manholes act as sediment trap. Installation could be considered as successful when all the laterals and collectors start functioning in case of sufficient rainfall or irrigation.

9.3.1 Operation of Subsurface Drainage System

In case of gravity outlet based subsurface drainage system, the system works automatically. In case of pumped outlet, pumping of drainage effluent is very much necessary for effective leaching and consequent reclamation of the waterlogged saline lands. The operation of subsurface drainage system enhances leaching process. The subsurface drainage controls water table, reduces salinity and improves the crop yields by providing better conditions at root zone for growth of crops.

9.3.2 Maintenance of Subsurface Drainage System

Pipe drain systems may fail for several reasons; some of these are mentioned below :

S.N.	Problem	Causes
1	Improper design	Size of pipe too small; Soil cover over pipes not deep enough; Not enough surface inlets, catch basin and outlets; Improper design of envelopes
2	Poor maintenance	Line filled with silt from openings; Watershed out catch basins and surface inlets; Root growth; Tile not kept open; Erosion at the pipe outlet

3	Poor construction	Poor joints; Bottom not shaped to fit the pipe; Uneven grade; Improper backfilling; Poor junctions to laterals; Poor alignment; Improper laying in sandy soil, quick sand, or muck
4	Poor quality material	Poor quality pipe and envelope material
	Other causes	Sealed joints; Interference and breakage by animals

Efficient and well-maintained subsurface drainage system will effectively control the water table. Regular maintenance is absolutely necessary if the system is to perform properly.

9.4 Post Drainage Management

A package of post-drainage (after installation of system) management of waterlogged saline soils consists components such as land grading; construction of *bund* (field dykes) and surface drainage; horizontal subsurface drainage to control water table; leaching; selection of crops and cropping sequence; improved cultural practices. The first two components of reclamation package are related pre-installation and installation activities of drainage system. However, remaining components are essentially post drainage activities. Performance of post drainage activities depend on pre-drainage activities.

9.4.1 Leaching

The application of the excess good quality water to pass through the root zone with the aim of pushing the salts below the root zone is defined as leaching. Leaching maintains salt balance in the reclaimed or irrigated lands so that crops do not suffer due to excess salts at any time in future.

9.4.2 Bunds along with subsurface drainage for uniform leaching

Uniform leaching can be achieved by proper land leveling. It also helps in applying the shallow irrigation. Strong *bunds* are needed to conserve the rainfall within the reclaimed lands. To ensure uniformity of leaching through subsurface drainage system, smaller plots with temporary *bunds* within the designed layout could be constructed.

9.4.3 Amount of water required for leaching

The actual amount of water required under practical leaching, however, depends mainly upon the following factors such as initial salt initially in the profile, desired level of salt in the root zone, soil texture, type of salts, reclamation soil depth, efficiency of the drainage system, method of leaching, Usually, thumb rules are applied to decide amount of water required for leaching (Table 9.9).

Table 9.9 : Leaching requirements of soils for one time reclamation

Soil type	Leaching requirement (cm cm^{-1} of soil depth)	Water requirement to leach 60 cm of soil profile (cm)
Coarse textured	0.5 – 0.6	30-36
Medium textures	0.6 – 0.8	36-48
Heavy textured	0.8 – 1.0	48-60

Note: The above requirement is to leach down 80% of the salts initially present.

9.4.3.1 Leaching for salt balance

The long-term viability of irrigated agriculture requires that amount of salts brought into the soil must not be allowed to accumulate beyond certain limit. The drainage water that percolates beyond the root zone should remove salts added beyond this limit. Thus leaching requirement is given as:

$$LR = EC_i / EC_d \quad (5)$$

Here EC_i and EC_d are the electrical conductivity of the irrigation and drainage water, respectively. The LR is the theoretically average requirement of water for leaching, and LF (Leaching Fraction) is the actual fraction of the applied water that passes through the root zone.

9.4.4 Selection of crops and cropping sequences

Since complete reclamation is not attained in the initial years, tolerant or semi-tolerant crops that can withstand expected salinity levels are preferred in the early phase of reclamation (Table 9.10).

Table 9.10 : Crop groups based on response to salt stress

Sensitive Group		Resistant Group	
Highly sensitive	**Medium sensitive**	**Medium tolerant**	**Highly tolerant**
Lentil	Radish	Spinach	Barley
Mash	Cow pea	Sugarcane	Rice (transplanted)
Chickpea	Broad bean	Indian mustard	Cotton
Beans	Vetch	Rice (direct sowing)	Sugar beet
Peas	Cabbage	Wheat	Turnip
Carrot	Cauliflower	Pearl millet	Tobacco
Onion	Cucumber	Oats	Safflower
Lemon	Gourds	Alfalfa	Taramira
Orange	Tomato	Blue panic grass	Karnal grass
Grape	Sweet potato	Para grass	Date palm
Peach	Sorghum	Rhodes grass	Ber
Plum	Minor millets	Sudan grass	Mesquite
Pear	Maize	Guava	Casuarina
Apple	Clover, *berseem*	Pomegranate	Tamarix
		Acacia	Salvadora

The recommended cropping sequences for saline soils are:

- Pearl millet-barley; Pearl millet-wheat; Pearl millet-mustard
- Sorghum-wheat or barley; Sorghum-mustard
- Cluster bean-wheat or barley
- Cotton-wheat or barley

9.4.5 Improved cultural practices

Improved cultural practices for salinity management includes following important components.

- Pre-sowing irrigation
- Deep tillage and inversion
- Establishing good crop stand
- Chemical treatment of seeds
- Sowing / Planting Practices
- Nutrient Management
- Irrigation water management
- Alternate Land Use
- Grasses for saline soils
- Afforestation of saline soils

9.4.6 Effect of Irrigation Efficiencies on Watertable

The process of supplying irrigation water to agricultural fields is usually split into three parts namely conveyance, distribution and field application and there is separate efficiency for each part. The overall efficiency considers all three efficiencies. If overall irrigation efficiency is below 60%, the groundwater level rises and

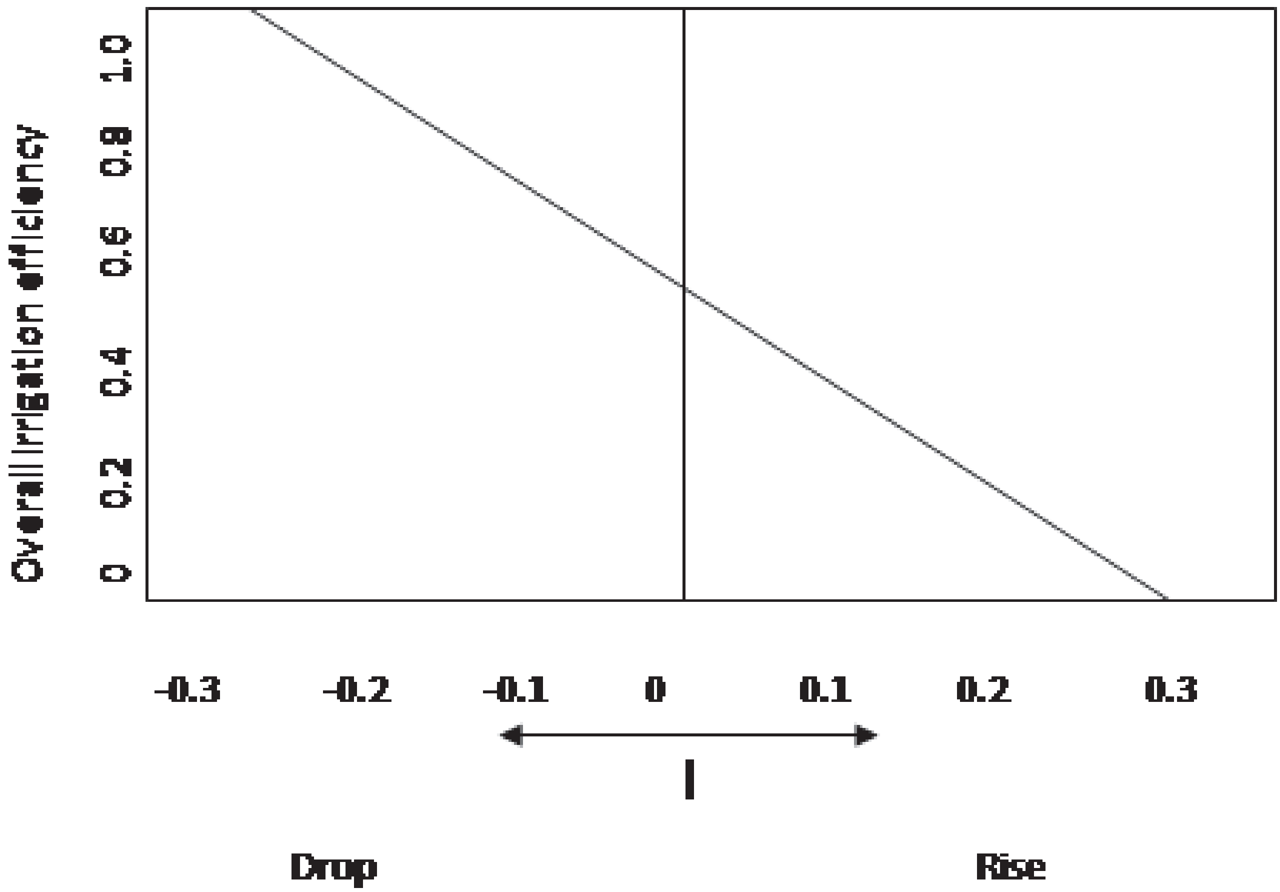

Fig. 9.1. Relation between overall irrigation efficiency of canal water and groundwater fluctuation, monthly averages

vice-versa (Fig. 9.1). Thus overall efficiency can be used as a management indicator to control the groundwater depth below the soil surface. The control of watertable is essential to limit capillary rise, which is responsible for re-salinisation.

9.5 Controlled Drainage

Capillary rise in drainage area is generally avoided during the reclamation period by maintaining the downward flux. Capillary movement increases the soil salinisation, if groundwater quality is poor. However, it can be used in beneficial way provided soil has reclaimed and groundwater quality does not pose any threat of soil salinisation. In such situation, capillary movement of groundwater in root zone is promoted by blocking lateral drains to reduce the irrigation water requirements of the crops. In Indian scenario, other form of controlled drainage is also observed, where farmers block the lateral drains during paddy crop to reduce the leaching and ultimately irrigation water requirement.

9.6 Effectiveness of Subsurface Drainage System

The performance of subsurface drainage system is evaluated on the basis of its ability to control waterlogging, soil salinity and improving crop yields. After reduction in soil salinity and improvement in drainage water quality, excessive draining is avoided as water soluble fertilizers are also leached out with drainage water. The controlled drainage is more effective in post reclamation period.

Conclusions

Provision of subsurface drainage and post drainage management are very important for successful reclamation of waterlogged saline soils in canal commands. Effective and uniform leaching is required to maintain favourable salt balance at root zone. The overall irrigation efficiency of drainage project area should be according to leaching requirement, water table fluctuations and crops to be grown. Selection of crops and cultural practices should be according to soil salinity. Water table and soil salinity data in the drainage area should be used for further improvement in post drainage water management and design assumptions.

References

CSSRI, 2004. Reclamation and Management of Salt Affected Soil Affected Soils. Central Soil Salinity Research Institute, Karnal 160p.

Gupta, S.K and Gupta, I.C. 1997. Crop Production in Waterlogged Saline Lands. Scientific Publishers. Jodhpur, 239p.

ILRI, 1994. Drainage Principles and Applications. Publication 16, (Ed. H.P. Ritzema), ILRI, Wageningen, 1125p.

IPTRID, 1993. Proposal for Technology Research in Irrigation and Drainage, World Bank, Washington D.C. 113p.

Personal communication. 2003. Dr. D. Rai, Ground Water Department, Uttar Pradesh.

Singh, N.T. 1996. Land degradation and remedial measures with reference to salinity, alkalinity, waterlogging and acidity. In: Natural Resources Management for Sustainable Agriculture and Environment (Deb, D.L. Ed.) Angkor Publication, New Delhi, pp. 442.

10.0 CONJUNCTIVE USE OF SALINE/ SODIC WATER IN CANAL COMMANDS

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The ground water surveys in India indicate that different states use poor quality water in the range of 32 to 84% of the total ground water development. Groundwater of arid regions is largely saline and in semi-arid regions it is sodic in nature. These groundwater resources are used solely or in conjunction with canal water for irrigation purpose. Indiscriminate use of the poor quality waters for irrigation deteriorates productivity of soils through salinity, sodicity and toxic effects. In addition to reduced productivity, it deteriorates the quality of produce and also limits the choice of cultivable crops. No systematic attempts have been made so far in the country to arrive at the estimate of poor quality ground water resources. However, some predictions about use of poor quality water in various states are given in Table 10.1. It is approximated that the total area underlain with the saline ground water (EC>4 dS m^{-1}) is 193438 km^2 with the annual replenishable recharge of 11765 million m^3 Yr^{-1}, leaving aside minor patches (CGWB, 1997).

Table 10.1 : Use of Poor quality groundwater in different states

State	Utilizable groundwater (M ha-m Yr^{-1})	Net draft	Groundwater Development (%)	Poor quality water use (M ha-m Yr^{-1})	Saline groundwater area >4 dSm-1(km^2) (M ha-m Yr^{-1})
Punjab	1.47	1.67	98	0.68	3058
Haryana	0.86	0.72	76	0.47	11438
Uttar Pradesh	6.31	2.98	42	1.42	1362
Rajasthan	0.95	0.77	73	0.65	141036
Bihar	2.06	0.82	36	NA	NA
W. Bengal	1.77	0.63	32	NA	NA
Delhi	0.01	0.01	120	NA	140
Gujarat	1.56	0.85	49	0.26	24300
Karnataka	1.24	0.45	33	0.17	8804
Tamil Nadu	2.02	1.40	63	NA	3300
Madhya Pradesh	2.66	0.73	25	0.20	NA
Maharashtra	2.29	0.88	35	NA	NA
Andhra Pradesh	2.70	0.78	26	0.25	NA
India	32.63	13.50	37		193438

(Source: Minhas et al., 2004)

Poor quality alkali water zones occur in parts of Agra, Mathura, Aligarh, Mainpuri, Etah, Ballia and several districts of U.P. and parts of Haryana, Punjab and Rajastan. Low to medium RSC waters occupy about 47% area of Punjab. Highly alkali waters are found in Parts of Amritsar, Southern Ludhiana, Ropar, Patiala, Ferozpur, Bhatinda, Faridkot and Sangrur districts covering 25% of total area of the state. In Haryana alkali waters are found in Bhiwani, Mahendragarh, Gurgaon, Kaithal, Kurukshetra, Ambala, Karnal and Panipat districts covering almost 21% of the total area of the state. Saline area occupies another 36% area in Haryana. In parts of Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu poor quality sodic and saline waters are observed in the pockets. Many of these areas have black cotton soils. In east coast, areas between Krishna and Godavari rivers have brackish groundwaters. In coastal areas of Sunderban Delta, the groundwater is saline. Scientific use of these waters enhances availability of water resources for irrigation as well as reduces negative impacts on soil and agricultural produce.

10.1 Classification of Irrigation Water

Irrigation water is classified based on electrical conductivity (EC), sodium adsorption ration (SAR) and residual sodium carbonate (RSC). However, from management point of view, the groundwater in different agro-ecological regions can be grouped into three classes *i.e.* (a) good, (b) saline and (c) alkali/sodic. Depending on the degree of restriction, each of the two poor quality water classes has been further grouped into three homogenous subgroups (Table 10.2).

Table 10.2 : Classification of poor quality ground water

Water Quality	ECiw (dS m^{-1})	SARiw ($mmol^{-1}$)^{½}	RSC(meq l^{-1})
a. Good	<2	<10	<2.5
b. Saline			
i. Marginally saline	2-4	< 10	<2.5
ii. Saline	>4	< 10	<2.5
iii. High-SAR saline	>4	>10	<2.5
c. Alkali waters			
i. Marginal alkali	<4	<10	2.5-4.0
ii. Alkali	<4	<10	>4.0
iii. Highly alkali	Variable	>10	>4.0

10.2 Water Quality Guidelines for Management of Saline Groundwaters

It has been established that the success with poor quality water irrigation can only be achieved if factors such as rainfall, climate, depth to water table and water quality, soils and crops are integrated with appropriate crop and irrigation management practices. The available management options mainly include the irrigation, crop, chemical and other cultural practices but there seems to be no single management measure to control salinity and sodicity of irrigated soil, but several practices interact and should be considered in an integrated manner. The guidelines for use of saline groundwaters are given below (Table 10.3).

Table 10.3 : Guidelines for use of saline water (RSC < 2.5 meq/1)

Soil texture (% clay)	Crop tolerance	Upper limits of ECiw (dS/m) in rainfall regions		
		350 mm	350-550 mm	550-750 mm
Fine (> 30)	S	1.0	1.0	1.5
	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Moderately Fine(20-30)	S	1.5	2.0	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Moderately Coarse(10-20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse(< 10)	S	- -	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

S, ST and T denote sensitive, semi-tolerant and tolerant crops

10.3 Management Technologies for Use of Saline Groundwaters

Some of management options have been described as below.

- Selection of semi-tolerant to tolerant crops and crops with low water requirements
- Use of crop cultivars having tolerance to salinity (Table 10.4)
- Proper selection of crop sequence
- Avoiding saline water use during initial growth stages

Table 10.4 : Promising cultivars for saline environment

Crop	Cultivars
Wheat	Raj 2325, Raj 2560, Raj 3077, WH 157
P. millet	MH269, 331, 427, HHB-60
Mustard	CS416,CS330,-1, Pusa Bold
Cotton	DHY 286, CPD 404, G 17060, GA, JK276-10-5, GDH 9
Safflower	HUS 305, A-1, Bhima
Sorghum	SPV-475, 881, 678, 669, CSH 11
Barley	Ratna, RL345, RD103, 137, K169

10.4 Nutrient management for saline environment

- Additional doses of nitrogenous fertilizers are recommended to compensate for volatilization losses occurring under saline environments
- Soils irrigated with chloride rich waters respond to higher phosphate application, because the chloride ions reduce availability of soil phosphorus to plants. The requirement of the crop for phosphoric fertilizers is, therefore, enhanced and nearly

50 per cent more phosphorus than the recommended dose under normal conditions should be added, provided the soil tests low in available P.

- For sulphate rich waters, no additional application of phosphate fertilizers is required and the dose recommended under normal conditions may be applied.
- For micro-nutrients such as zinc, the recommended doses based on soil test values should be applied.
- Farmyard manure (FYM): FYM and other organic materials have not only the nutritive value, but play an important role in structural improvements, which further influences leaching of salts and reduce their accumulation in the root zone. The other advantages of these materials in saline water irrigated soils are in terms of reducing the volatilization losses and enhancing nitrogen-use efficiency and the retention of nutrients in organic forms for longer periods also guards against their leaching and other losses. Therefore, the addition of FYM and other organic / green manure should be made to the maximum possible extent.

10.5 Conjunctive Use of Canal and Saline Groundwater

In saline groundwater areas, conjunctive use practice can ensure judicious use of canal water, which is available in limited quantities along with saline ground water. Under such situation, two options are available with the users. Dilution or mixing of available poor quality water with good water in such proportions that resultant EC is acceptable for the range of crops to be grown in a given area. The salinity of resulting water can be easily calculated from their respective volumes and salinities.

The management options for use of saline groundwater for irrigation, mentioned in the earlier section, are also applicable for conjunctive use of canal and saline water to maintain the productivity levels. If canal water (CW) is available during initial crop growth stages, maximum possible irrigations are to be given by canal water before switching to saline water (SW). Suppose wheat crop requires 4 irrigations. The 2CW: 2SW mode can be a good option as root zone salinity under this mode remains low for almost two months (during initial crop growing period). Then CW: SW alternate mode ensures low salinity for initial month. The mix (1:1) mode might be preferable over SW: CW option. It is obvious that 2SW: 2CW would get the least preference. Though the amount of salt load added under different conjunctive use modes is same, temporal changes in root zone salinity are different. Therefore, selection of proper mode of conjunctive use is required for suitable salinity management at the root zone for optimum crop yields. The preference order for conjunctive water use for wheat crop requiring 4 irrigations can be 2CW: 2SW; CW: SW alternate mode; Mix (1CW:1SW) mode and SW: CW alternate mode (Kaledhonkar and Keshari, 2006). The relative yield of crop generally remains highest for 2CW: 2SW and lowest for SW: CW mode. This assumption is violated, in case there is high salinity at time of germination and crop stand gets affected due to salinity. The conjunctive use preference order prepared for use of canal and saline groundwater also holds true for conjunctive use canal and alkali groundwater. The relative yields under different conjunctive water use practices, with reference to canal water irrigation, are given in the Table 10.5.

Some important suggestions for management of conjunctive use practices are listed below:

- Analysis of saline water to evaluate its use potential
- Selection of crops / crop varieties that can produce satisfactory yields with saline water irrigation
- Selection of tree species / medicinal plants in adverse condition

Table 10.5 : Effect of various cyclic modes of post-plant irrigations with canal water and saline water on mean relative (%) yields of wheat and succeeding pearl millet and sorghum crops

Mode of water application	Wheat	Pearl millet	Sorghum fodder
4 CW	100	100	100
CW: SW (alternate)	94.4	97.0	91.8
SW: CW (alternate)	91.3	95.5	91.1
2 CW + 2 SW	94.3	96.4	92.8
2 SW + 2 CW	88.2	94.9	91.1
1 CW + 3 SW	83.6	91.9	87.2
4 SW	73.7	85.0	78.7

CW - Canal water; SW - Saline water

- Pre-sowing irrigation by good quality water so that germination and seedling emergence is not affected
- Adequate leaching of accumulated salts
- Alternating the area/ area switching i.e. irrigate the selected area with saline water for 3-4 years and than switch to next area
- Improved cultural and nutrient management practices/

10.6 Water Quality Guidelines for Management of Sodic Groundwaters

Based on field experience and results from different saline and sodic water use experiments, CSSRI, Karnal in consultation with Scientist from HAU, Hisar and PAU, Ludhiana has prepared some guidelines for efficient utilization of sodic waters. These guidelines emphasize on long-term influence of water quality on crop production, soil conditions and farm management with assumption that all rainwater received in field is being conserved for leaching and de-adsorption of Na^+ from upper root zone (Table 10.6).

Special considerations

- Gypsum application is necessary for sensitive crops if saline water (SAR > 20 and / or Mg: Ca ratio > 3 and rich in silica) induces water stagnation in rainy season.
- Fallowing in rainy season under high salinity (SAR > 20) is helpful for low rainfall areas.

Table 10.6 : Sodic Groundwaters with RSC > 2.5 meq L-1 and ECiw < 4.0dSm-1

Soil texture (% clay)	Upper limits of SAR (m mol L-1)$^{1/2}$	RSCmeq L^{-1}	Remarks
Fine(>30)	10	2.5-3.5	Limits pertain to kharif fallow – rabi crop rotation when annual rainfall is 350 –550 mm
Moderately fine(20-30)	10	3.5-5.0	When water has Na < 75%, Ca+Mg >25% or rainfall >550mm, the upper limit of RSC becomes safe
Moderately coarse (10-20)	15	5.0-7.5	For double cropping, RSC neutralization with gypsum is essential based on quantity of water used during rabi season. Grow low water requiring crops during kharif.
Coarse (<10)	20	7.5-10.0	

- Fertilization with additional phosphorus is beneficial especially when $C1:SO_4$ ratio in waters is > 2.0.
- Canal water should be used preferably at early growth stages including pre-sowing irrigation in conjunctive use mode.
- Putting 20% extra seed rate and a quick post-sowing irrigation (within 2-3 days) will help in better germination.
- Accumulation of B, F, NO_3, Fe, Si, Se and heavy metals beyond critical limits with irrigation is toxic.
- Expert advice prior to use of such water is essential.

Textural criteria should be applicable for all soil layers down to at least 1.5 m depth. In areas, where ground water table reaches within 1.5 m at any time of the year or a hard subsoil layer is present in the root zone, the limits of the next finer textural class should be used

10.7 Management Technologies for Use of Sodic Groundwaters

Water quality researches over past few decades have enabled development of technological options to cope up with the problems of sodic water use. Possibilities have now emerged to safely use the water otherwise designated unfit. These options are as below:

- Selection of crops (Table 10.7) cropping patterns and crop varieties (Table 10.8) that produce satisfactory yields under the existing or predicted conditions of sodicity.
- Appropriate irrigation scheduling and conjunctive use options with canal water; rain water management and leaching strategies to maintain a high level of soil moisture and low level of salts and exchangeable sodium in the rhizosphere.
- Use of land management practices to increase the uniformity of water

Table 10.7 : Relative tolerance to sodicity of soils

ESP	Crops
10-15	Safflower, Mash, Peas, Lentil, Pigeon-pea, Urd-bean, Banana
16-20	Bengal gram, Soybean, Papaya, Maize, Citrus
20-25	Groundnut, Cowpea, Onion, Pearl-millet, Guava, Bel, Grapes
25-30	Linseed, Garlic, Guar, Palmarosa, Lemon grass, Sorghum, Cotton
30-50	Mustard, Wheat, Sunflower, Ber, Karonda, Phalsa, Vetiver, Sorghum, Berseem
50-60	Barley, Sesbania, Paragrass, Rhoades grass
60-71	Rice, Sugarbeat, Karnal grass

Table 10.8 : CSSRI recommended crop varieties for cultivation in sodic soils

Crop	pH	Varieties
Rice	9.8-10.2	CSR 10
	9.4-9.8	CSR 10, CSR 13, CSR23, CSR 27, CSR 30, CSR 36
Wheat	9.2 - 9.3	KRL-1-4, KRL-19, WH 157, Raj. 3077
Mustard	Up to 9.3	Pusa bold, Varuna, Kranti, CS-52, CS-54, CS-56
Barley	Up to 9.3	CSB 1, CSB 2, CSB 3, DL 200, DL 348. Ratna, BH 97, AZAD
Chickpea	Up to 9.0	Karnal chana 1

distribution, infiltration and salt leaching besides the optimal use of chemical amendments like agricultural grade gypsum and acidic pyrite at proper time and mode of their application with judicious use of organic materials and chemical fertilizers. The gypsum can be directly applied before rice crop in soil top layer or can be used in gypsum bed for passing sodic groundwater.

The other guidelines pertinent to selecting crops suitable for sodic waters are:

- Fields should be kept fallow during *kharif* in low rainfall areas (< 400 mm) where good quality water is not available. However, only tolerant and semi-tolerant crops like barley, wheat and mustard should be grown during rabi.
- Jower-wheat, guar-wheat, pearl millet-wheat and cotton-wheat rotations can be successfully grown in areas having rainfall > 400 mm/annum provided that sowing of kharif crops is done with rain or good quality water and only 2 to 3 sodic water irrigations can be applied to kharif crops.
- In rice-wheat belt of alluvial plains having rainfall 600 mm, rice-wheat, rice-mustard, sorghum mustard, and *dhaincha* (GM)-wheat rotations can be successfully practiced with gypsum application.
- Sodic water should not be used for summer crops in the months of April to June.

10.8 Nutrient management for sodic environment

Since sodic waters cause a rise in soil pH that leads to greater nitrogen losses through volatilization and denitrification, extra nitrogen may have to be added to meet the requirement of the crops. Similarly, the availability of zinc and iron is also low due to their precipitation as hydroxides and carbonates. Some other beneficial tips as regards fertilizer use are.

- Application of 25% extra nitrogen is needed as compared to the normal conditions.
- Zinc sulphate @ 25 kg ha should be added, particularly to the *rabi* crop.
- Phosphorus, potassium and other limiting nutrients may also be applied on the basis of soil values.
- Some sodic waters may be rich in nutrients like nitrogen, potassium and sulphur such waters should be analyzed and the fertilizer dose of concerned nutrient reduced accordingly as per their composition in such water.

10.9 Conjunctive Use of Canal and Sodic (Alkali) Groundwater

In case of irrigation by sodic waters, the conjunctive use strategy should either minimize the precipitation of calcium or maximize the dissolution of precipitated calcium. This is particularly relevant to the areas, where canal water supplies are either un-assured or less than required, and farmers often pump sodic groundwater for crop production. For the efficient use of waters of different qualities, good quality waters can be used for sensitive crops and sodic waters for tolerant crops. The most appropriate practice, however, can be the conjunctive use of these waters by: i) blending in supply network, making appropriate water quality available for each crop irrespective of soil conditions; ii) alternate use of sodic and canal water according to availability and crop needs; and iii) switching these water sources during the growing season according to critical stages of crop growth. The blending of sodic water and canal water is done in such proportion so that final RSC is maintained below the threshold limit of the crop to be grown. The alternate use is preferable and has operational advantages. Effect of conjunctive use of sodic groundwater and canal water on soil properties and crop yields is given in Table 10.9.

Table 10.9 : Effect of cyclic use of sodic and canal waters on soil properties and crop yields

Water quality/mode	Adj SAR*	pH	ESP	RIR	Average yield (Mg/ha)	
					Rice	Wheat
Canal water (CW)	0.3	8.2	4	100	6.78	5.43
Sodic water (SW)	22.0	9.7	46	14	4.17	3.08
2CW-ISW	8.9	8.8	13	72	6.67	5.22
1CW-ISW	12.8	9.2	18	59	6.30	5.72
1CW-2SW	18.5	9.3	22	34	5.72	4.85

After accounting for 828 and 434 cm of irrigation and rainwater, respectively

Compiled from Bajwa and Josan (1989)

10.10 Policy Issues related to Sustainable Development of Saline and Sodic Water Resources under Conjunctive Use Policy

- Conserve the available fresh water resources and make the judicious use of fresh water along with saline / sodic water
- Exploit full potential of surface / canal water system by improving the overall efficiency
- Exploitation of fresh groundwater in coastal areas should be kept within permissible limit to avoid seawater intrusion.
- Improve groundwater potential through recharge
- Develop institutional support for participation, development and optimal utilization of poor quality ground waters
- Demand management through pricing
- Diversification of agriculture
- Incentives for water saving and adoption of improved technologies
- Awareness and capacity building
- Involve women and children in water management
- Educate the farmers about water scarcity, judicious use of water and side effects / losses due to salinity / sodicity
- Legislative measures
- Need to create an environment for sustainability of system: use of green manuring, FYM, salinity / sodicity tolerant crop varieties to be promoted

References

Bajwa, M.S and Josan, A.S. 1989. Prediction of sustained sodic irrigation effects on soil sodium saturation and crop yields. *Agricultural Water Management*. 16: 227-228.

Kaledhonkar, M.J and Keshari, A.K., 2006. Modelling the effects of saline water use in agriculture. Irrigation & Drainage, 55(2): 177-190.

Minhas, P.S., Sharma, D.R. and Chauhan, C.P.S. 2004. Management of saline and alkali waters for irrigation. In Advances of Sodic Land Recommendation. p121- 62.*International Conference on Sustainable management of Sodic Lands held at Lucknow*. Feb, 9-14, 2004.

11.0 PARTICIPATORY IRRIGATION MANAGEMENT (PIM) FOR OPTIMUM UTILIZATION OF IRRIGATION WATER

Souvik Ghosh, Rajbir Singh and Parbhakar Nanda

Irrigation facilities are created by the Government at huge cost for supplying water to the farmers for raising crops so as to increase agricultural production. The major and medium irrigation projects are planned, constructed, managed, operated and maintained by the Irrigation Departments, wherein certain procedures and rules are evolved and followed in respect of opening canals, frequency of supply and distribution of water to the farmers and closing of canals. Creation of such facilities resulted in ushering the green revolution in seventies in production of food grains and also employment generation in the country there by improving the socio-economic condition of Indian farmer. However, optimized management of irrigation water is the key element for sustainable development of agriculture and livestock. Since management of water for irrigation is highly location specific, depending upon agro-ecological and socio-economic conditions, type of irrigation project and land use pattern, it differ from project to project and region to region in the country.

11.1 Need for Participatory Irrigation Management (PIM)

The optimum benefits from irrigation water are not obtained as it was expected. There is considerable wastage of water and over irrigation in upper reaches of the command area with consequent non-availability of water to the tail end farmers which is a common feature. The canal is designed for 24 hrs irrigation water supply; however, the farmers are accustomed for day time irrigation water supply. Consequently one third of water delivered at the outlet is wasted during night time. Injudicious use of irrigation water has resulted into huge losses in the command and consequently many irrigation schemes are operating sub-optimally. The project irrigation efficiency of major projects is less than 35%. The average yield of fooodgains is about 2.5 t / ha under irrigation where as it should be at least 4.5 t / ha.

Another problem in canal command is drainage. In the planning of most of the existing irrigation projects in our country, provision was not made for adequate drainage in the command areas. Water table has built up steadily due to high seepage and percolation losses, consistent over irrigation, spillage from canal system and not using ground water. Water logging and salinization have thrown considerably acreage in the command area out of production. About 6.73 M ha land has degraded due to water logging, soil salinity and alkalinity by the end of 10th plan.

There are deficiencies in the design, operation and maintenance of the irrigation system. This is mainly due to assuming unrealistic duties for crops, assuming low seepage losses in the distribution system, inadequate maintenance of the system etc. By and large, the indiscipline of the users is the main reason for tail-end fields in localized ayacut not receiving water. Further, in order to irrigate their lands in shortest possible time, the farmers do not hesitate to damage the sluices or cause breaches in canals. This calls for a holistic approach for efficient irrigation management so that more and more area can be added under irrigation command which is possible only when performance of irrigation system and management of irrigation is improved with proper crop planning, increased cropping intensity and share of food grains in gross cropped area. To achieve this, farmers' active participation in irrigation water management is most essential as the farmers are the ultimate users of irrigation water and their participation will ensure successful operation, maintenance of the irrigation system and collection of water rates.

11.2 Concept of PIM

As a result of the debate over non-performance of publicly supplied irrigation system in early 90s, PIM has been advocated as a solution. On the concept of peoples management of developmental infrastructures that requires local solution to local problems affecting them, the National Water Policy of Government of India of 1987 and 2002 stressed on farmers participation in irrigation management. Accordingly, several states (like Maharastra, Madhya Pradesh, Gujarat, Andhra Pradesh, Orissa, etc) in India have been implementing the participatory irrigation management programmes and transferring the irrigation management to water user association (WUA) / Pani Panchayat (water council) with a view to providing equitable, timely and assured irrigation. This programme envisages making farmers to participate in the water resources planning and management and to hand over the system to the farmers for which suitable legislation has already been done.

A paradigm shift in the policies for irrigation development and management has been happening during the past two decades through PIM. The centralized control and management responsibility of the irrigation resources are being transferred to the local farmer groups or water users associations (WUAs) for better management. About 13.16 M ha of irrigated land

State-wise position of WUAs and area covered by them

Sl. No.	Name of State	Number of WUAs formed	Area covered (*000 ha)
1.	Andhra Pradesh	10800	4169.00
2.	Arunachal Pradesh	39	9.02
3.	Assam	720	47.04
4.	Bihar	46	147.76
5.	Chattisgarh	1324	1244.56
6.	Goa	57	7.01
7.	Gujarat	576	96.68
8.	Haryana	2800	200.00
9.	Himachal Pradesh	876	35.00
10.	J & K	1*	1.00*
11.	Jharkhand	NA	NA
12.	Karnataka	2515	1295.19
13.	Kerala	4126	255.27
14.	Madhya Pradesh	1687	1691.80
15.	Maharashtra	1539	667.00
16.	Manipur	73	49.27
17.	Meghalaya	123	16.45
18.	Mizoram	NA	NA
19.	Nagaland	23	3.15
20.	Orissa	16196	1537.92
21.	Punjab	957	116.95
22.	Rajasthan	506	619.65
23.	Sikkim	NA	NA
24.	Tamil Nadu	1310	787.96
25.	Tripura	NA	NA
26.	Uttar Pradesh	245	121.21
27.	Uttaranchal	NA	NA
28.	West Bengal	10000**	37.00**
	Total	56539	13155.89

*** Under verification; Under MI, RIDF scheme**

(Source: Ministry of Water Resources, Govt. of India, Year: 2007)

has been covered under 56539 numbers of WUAs in the country till the end of 10th five year plan.

Irrigation is state subject in India and its management is being done by the State Irrigation Departments but the involvement of farmers/ group of farmers directly or indirectly may not be denied. The private sector management/ contract management approach is not popular particularly in major or medium irrigation projects but in case of tube well irrigation it may not be denied. In India, farmers were managing irrigation projects but after independence the management of irrigation was taken over by the Irrigation Departments. It is now realized that the PIM through involvement of farmers is the only answer; however, the introduction of PIM is very slow.

Any farmers' managed system with full O & M and regulatory control is rarely found in the country. The appropriate approach may be a Joint Management System, wherein the O & M and regulation with ownership of the system may continue to remain with Irrigation Department till farmers are fully trained for taking over the system. The formal group of farmers called Water Users' Association (WUA) may carry out all other functions relating to management of irrigation in their operational area. The participation of farmers in department managed activities and the department participation in farmers managed activities should be ensured till the performance of WUAs becomes satisfactory.

Various approaches may be adopted suiting to the local condition or type of project. But it is important to understand the functions for management of irrigation, which are summarized as under:

- Operation and maintenance of all irrigation systems and structures viz., head works, main, secondary, minor, tertiary and drainage systems
- Regulation/rostering of main and secondary system
- Equitable distribution of irrigation water amongst users
- Fixation and recovery of water rates
- Improvement in water use efficiency
- Maintenance of drainage system and prevention of water pollution
- Reduction in conveyance, distribution and field application losses
- Economic use of water
- Conjunctive use of surface and ground water
- Payment of land and water rates to the Department as applicable through the approach adopted in the transfer agreement
- To develop a suitable cropping pattern, improve cropping intensity and agricultural production
- Conflict resolution
- Administrative and financial functions

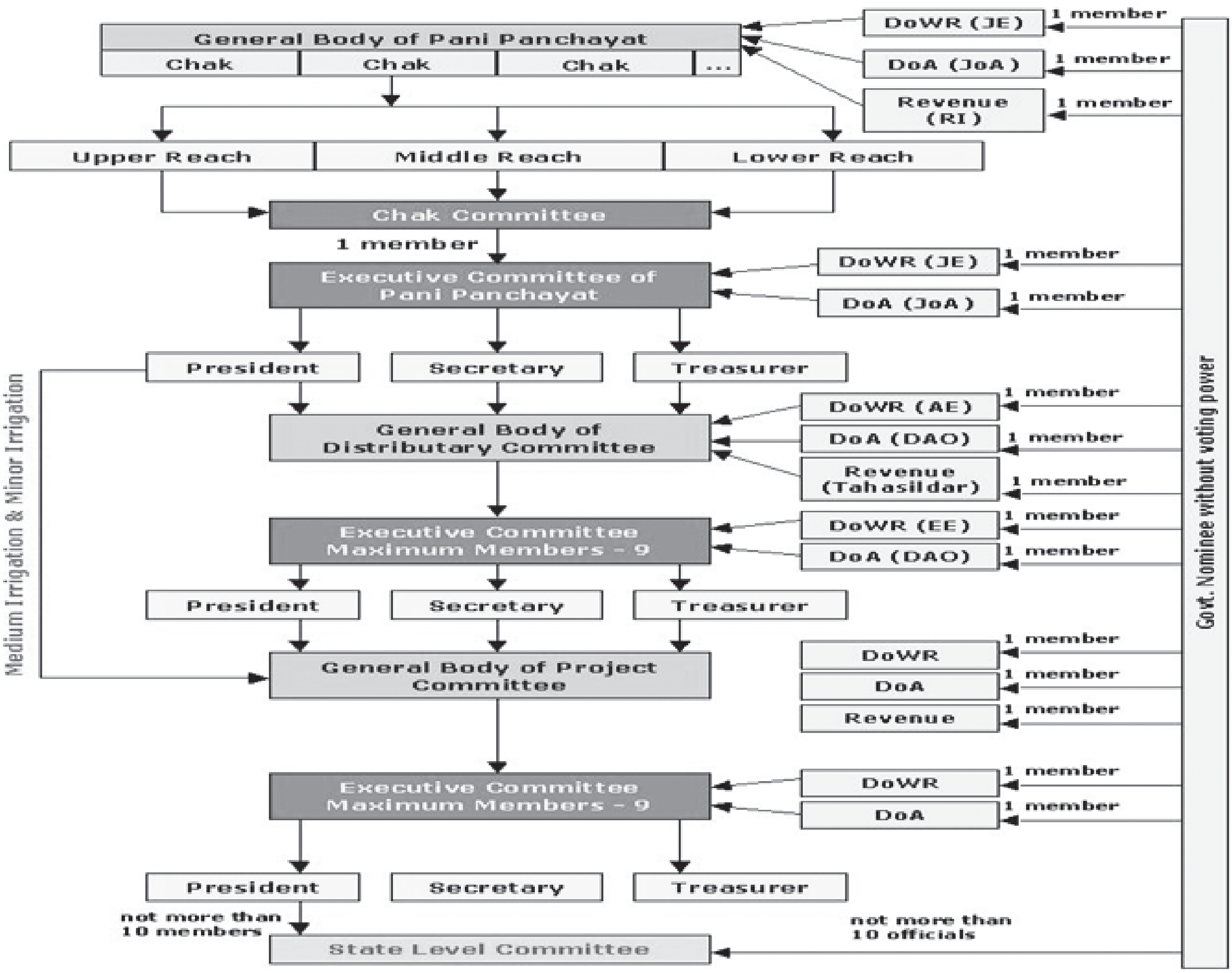
11.3 Structural Arrangements for PIM

11.3.1 Structure of WUA

The structural arrangements of WUA / Pani Panchayat (Fig. 11.1) indicate the involvement of both irrigation and agriculture department to facilitate proper planning of irrigation and agriculture in the irrigation command.

There is no uniform procedure to form WUAs. Its structural development, size and organization may be at the convenience of farmers and the irrigation department. It is usually advocated that the size of a WUA may be in between 500 to 750 ha on a hydraulic unit preferably a minor covering one or more villages.

A minor irrigation project may be managed by one WUA-a single tier system. The medium irrigation project may be managed by a two-tier system, having WUAs' at minor level and Apex body at project level. In a major Irrigation project, it may a three-tier system, the WUA at minor level, a federation or a Distributary Committee at branch canal / distributary level and apex body at project level. In all cases mentioned above, WUA would be the only registered body.



Chak : Outlet, Pani Panchayat : WUA, DoWR : Department of Water Resources

DoA : Department of Agriculture, RI : Revenue Inspector , JE : Junior Engineer, AE : Assistant Engineer

E.E : Executive Engineer, JoA : Junior Agricultre Officer, DAO : District Agriculture Officer

Fig. 11.1 : Structural arrangements for PIM

All farmers in the operational area of the WUA may become its members. The WUA will also have a managing committee, which may consist of a president, vice president, treasurer and a secretary in addition to at least five members. State Irrigation, Agriculture, CAD and Revenue Departments may also nominate one officer from each department to be included in the managing committee. They will help managing committee in its functioning. There may be two methods to elect the managing committee.

The WUA will have its by-laws defined as regulations of the society, which may be summarized as follows:

- Objective of water users association
- Definition of the member
- Size of the water users' association
- Functions to be carried out by the WUA
- Managing committee-size, function and legal powers

- Responsibilities and rights of the WUA
- Responsibilities and rights of the members
- Details of the general body
- Election procedure of the managing committee
- The structure of the WUA and its internal management
- Conducting meeting of the general body and managing committee
- Amendment of by-laws
- Liquidation of WUA

In addition of the by-laws, another important legal document is the Transfer Agreement or the Memorandum of understanding between the WUA and the Irrigation Department, wherever necessary. This agreement contains the terms and conditions of transfer of the system and will clearly spell out the duties and responsibilities of Irrigation department and WUA. Handing over of the system, method of its operation and supply of irrigation water in bulk at agreed time and quantities in different crop seasons would be included in the agreement.

The transfer agreement / MOU will clearly define the area of operation of WUA, the details of the irrigation system its present condition and the existing structures with their technical details. The plan map delineating the area of operation, irrigation distribution network and location of structures is to be attached with the transfer agreement. Technical details like longitudinal and the cross section of the system is also to be attached with the document. It will also specify the procedure to be adopted for the management of irrigation in the operation area.

There will be a legal provision of termination of agreement but the procedure would be defined in detail in the transfer agreement. The agreement would be valid for a specified period but having been satisfied with the performance; the agreement may be renewed for a further mutually agreed period. The grounds for termination of agreement should be clearly mentioned in the agreement.

11.3.1.1 Structure of Distributory Committee

The WUAs at minor level may be federated at the distributory level to co-ordinate the functions of WUAs. The federation may be called a distributory committee. The presidents of all WUAs may be the members of the distributory committee and these members may elect their president. The state departments may also nominate their officers to the distributory committee.

11.3.1.2 Apex Body

The distributory committees of the project may be further federated into the project level committee called apex body. The main function of the apex body would be to suggest improvement in the O & M of the irrigation system, environment of the area and rationalization of water supply to the users other than irrigation. The Presidents of the distributory committee may be the members of the apex body. These members may elect their president.

11.3.2 Legal framework for PIM

Recognizing the need for sound legal framework for PIM in the country, the Ministry brought out a model act which has been enacted by eight state governments, namely, Andhra Pradesh, Goa, Madhya Pradesh, Karnataka, Orissa, Rajasthan, Tamil Nadu and Kerala. The other states also need to work in this direction. Concerted efforts should be made to involve farmers progressively in various aspects of management of irrigation systems.

11.3.3 Constraints in Implementation of PIM

It is now well established that the irrigation potential created in 1960s could not be fully utilised because the management of irrigation was done by the irrigation agencies which could not pay adequate attention. It was strongly felt that the only answer for managing the irrigation efficiently, involvement of farmers is unavoidable as they are the end-users. In almost all states PIM is being implemented in one form or the other but following are the constraints being observed in its implementation

- Lack of awareness
- Absence of clear-cut policy in implementation of PIM

State-wise position of enactment / amendment of Act

Sl. No.	Name of State	Position of issue/ amendment of Irrigation Act
1.	Andhra Pradesh	Enacted 'Andhra Pradesh Farmers' Management of Irrigation System Act, March 1997.
2.	Assam	The Assam Irrigation Water Users Act, 2004
3.	Bihar	The Bihar Irrigation, Flood Management and Drainage Rules, 2003. under the Bihar Irrigation Act, 1997
4.	Chhattisgarh	Enacted 'Chhattisgarh Sinchai Prabandhan Me Krishkon Ki Bhagidari Adhiniyam, 2006.
5.	Goa	Enacted 'Goa Command Area Development Act 1997' (Goa Act 27 of 1997).
6.	Gujarat	Gujrat Water Users Participation Management Act. 2007
7.	Karnataka	Promulgated an Ordinance on 7th June 2000 for amendment of the existing Karnataka Irrigation Act 1957.
8.	Kerala	Enacted 'The Kerala Irrigation and Water Conservation Act', 2003.
9.	Madhya Pradesh	Enacted 'Madhya Pradesh Sinchi Prabandhan Me Krishkon Ki Bhagidari Adhiniyam', 1999, during September 1999.
10.	Maharashtra	The Maharashtra Management of Irrigation System by Farmers Act 2005.
11.	Orissa	Enacted 'The Orissa Pani Panchayat Act', 2002 and Orissa Pani Panchayat Rule 2003
12.	Rajasthan	Passed the Rajasthan Sinchai Pranali Ke Prabandh Me Krishkon Ki Sahabhagita Adhiniyam, 2000
13.	Tamil Nadu	Enacted the 'Tamil Nadu Farmers' Management of Irrigation System Act. 2000.

(Source: Ministry of Water Resources, Govt. of India, Year: 2007)

- Lack of legal support.
- Financial support
- Rehabilitation of irrigation systems.
- Socio-economic factor.
- Resistance from Irrigation Agency.
- Attitude of big and head reach farmers.
- Lack of leadership.
- Inadequate number of NGOs to assist in implementation of PIM
- No incentive to the farmers initially.
- Lack of political will.

11.4 PARTICIPATORY IRRIGATION MANAGEMENT: A CASE STUDY OF HARYANA

Haryana has played a great role to bring the 'Green Revolution' in India and is second to Punjab for its contribution to the national pool of food grains. The state is ideally suited for PIM due to number of factors such as consolidated holdings, well defined equitable distribution system for irrigation water, geographically small area, a well-developed and efficient irrigation infrastructure, an old and established irrigation agency and last but not the least well-aware stakeholders. It has only been conceptualized during the last two years and launched as a major program also. The state is also in the process of planning reforms in water sector and the issue of PIM is on the top of the agenda. The State is reaching its limits of agricultural expansion and scope for further development of irrigated agriculture is very limited. The condition of irrigation infrastructure, existing since long, is also deteriorating due to lack of adequate maintenance. Economical use and conservation of water, improving efficiency in conveyance system and diversification of crop to less water consuming crops are some of the possible solutions for this difficult situation. Therefore, a partnership needs to be evolved with water users as all the possible solutions relate only to them. The forum of water users' association (WUA) can be very effectively utilized underlining the urgency of PIM with proactive role of stakeholders in irrigation management.

11.4.1 PIM in Haryana

Participation of stakeholders in irrigation management essentially consists of two major components - equitable distribution of irrigation water for all users and efficient management of infrastructure.

a) *Warabandi*- equitable distribution of water: According to Canal & Drainage Act (1974), there is a provision for equitable distribution of irrigation water called *Warabandi* i.e., water-turn in Haryana, After the *Warabandi* is fixed, notified and published, it is practically implemented in field by the shareholders by mutual consent.

b) Management issues: The second aspect of PIM is the management of irrigation infrastructure which includes planning, design, construction and O & M. During the construction stage, shareholders are given the responsibility to keep vigil on quality of work, which they generally assume readily and perform well. This aspect has resulted in an overall improvement in the quality of works.

c) Maintenance of watercourses: There are number of provisions in the Act starting from the mandatory maintenance of the watercourse by the stakeholders and the government will not bear the cost of maintenance of watercourses. Practically also stakeholders have been maintaining the watercourses till state's intervention by way of lining of watercourses. Therefore, historically the participation of stakeholders at watercourse level has been quite successful.

11.4.2 Model Bye-laws

In the year 1998, the state government approved Model Bye-Laws (To be adopted by a WUA at the time of forming of WUA with appropriate suitable amendments) and Draft MOU (To be signed at the time of turning over management to WUA on completion of modernization or rehabilitation of a watercourse), for effective implementation of the program in the state. These bye-laws brought a uniform code in all the WUAs and the MOU practically transferred rights to the stakeholders.

11.4.3 Guidelines for PIM

The comprehensive guidelines issued by the government in August 2000 contain general outline of the WUA, rules, regulations, duties, functions, resources etc,. A procedure for formation of WUA has been suggested in the guidelines, which is based on the social, economical, political and practical aspects of the state. The guidelines also lay down the roles and responsibility of officers / officials of service agency. It was felt that HID should be in the lead role for transfer of irrigation management as HSMITC was engaged in modernization & rehabilitation of watercourses.

11.4.4 Core Group on PIM

In order to accelerate and coordinate the program, a Core Group on PIM was formed in Haryana Irrigation Department, which had members of all the implementing agencies such as HSMITC, HAD, HIRMI. The results of implementation of PIM at primary level have been quite encouraging and a framework is being prepared for transferring the management at secondary level i.e. Distributary level to stakeholders.

11.4.5 Legal Status of WUA

There are two issues regarding legal status of WUAs- the provisions which enable the state to entrust the entire management to stakeholders without any legal complications, and the ownership right of the WUAs so far as the watercourse is concerned. In this model, WUA will have the ownership of watercourse and all other related works jointly with other farmers. It implies that WUA is a legal entity (duly registered), has mandatory obligation for management of watercourse and acquires ownership right apart from number of other rights on signing of MOU between the state and WUA. The working details of this model are as under: -

- When a scheme for modernization of watercourse is taken up, consultations are held with the stakeholders for their views and suggestions.
- Public hearing of all the stakeholders is held to decide all the features of the scheme such as alignment, length etc.
- WUA is formed there and then by consensus and is got registered under Indian Societies Act by the managing committee of WUA.
- On decision of the scheme, design and detailed estimate is prepared by the agency and there is another consultation with the WUA so that detailed design is explained.
- WUA among itself constitutes a committee to supervise the construction work.
- WUA is made aware of every aspect of construction including quality control aspects by the agency.
- Supervision committee regularly supervises the work and checks the quality of work, duly recording its observations in the official records. WUA thus become quality control managers.
- Once the scheme is completed, WUA, agency staff carries out a joint 'Walk-through' for inspection and hydraulic test of the watercourse.
- Upon satisfactory result of the walk-through, MOU is signed between WUA and agency effecting the transfer of the watercourse to WUA.
- Funds are collected by WUA generally at the rate of Rs. 20 per acre of holding but in some cases Rs. 100 is also collected.
- These funds are being utilized by some WUAs for maintenance and routine repair.
- Field staff is given training and general awareness about the concept of PIM by HIRMI frequently and recently, a mass training program for all line staff at all district headquarters was organized.
- Field training to WUA is being imparted by line staff apart from workshops being organized by HIRMI.
- Three tier-monitoring infrastructure for PIM has been put in place and the job of this infrastructure is to foster PIM program, monitor the process and suggest improvements in the program.

11.4.6 Impact of PIM

An impact study conducted at 66 watercourses where WUAs were functional after lining of watercourse and 18 outlets where there was no WUA. The comparison of functional WUA and non-existence of WUA, the studies establishes the fact that the Haryana model is not only workable but also exclusive to its own circumstances and needs. The following conclusions have been drawn:

i) Functional WUA

- The condition of watercourses where no WUA exists was very poor as compared to those watercourses, where WUAs are in place.
- WUAs are fully involved in construction activities and are performing the role of quality control managers and has brought in improved quality of construction.
- The level of awareness has gone up and with active partnership, an incipient sense of ownership has also been noticed.
- Tail enders got benefited.
- No conflicts have been reported on distribution of water.
- Desilting, deweeding and cleaning functions have been adopted by WUAs as their primary functions.
- The process of walkthrough, decision-making and identification as a hydrological group are there to take cognizance.
- Most of the watercourses were badly damaged and severely silted.

ii) Non-existent WUA

- In 70 % cases water was not reaching the tail ends while in 30 % cases, it was in meagre quantity.
- There was no involvement of farmers groups and they expected the government to take care of maintenance.
- The level of maintenance ranged from extremely poor to no maintenance.
- The comparison of both the studies establishes the fact that the Haryana model is not only workable but also exclusive to its own circumstances and needs.

11.4.7 Missing links in Haryana model

i) Financial sustainability: WUA is working on its contribution of share money from members and no other source has either been identified or fixed. It is true that the share money if collected in time and made an annual feature will be enough for routine maintenance work. But for long-term sustainability, a definite source of revenue needs to be identified.

ii) Assessment, collection and sharing of revenue: The present practice is assessment of irrigated area by Canal Patwari (Irrigation Booking Clerk) and prepares the charges due from the shareholders of a particular watercourse. The revenue so accrued is collected by the district collector through a separate infrastructure. Though there are provisions for exercise of a control but the system can be simplified and made more transparent with active involvement of WUAs.

iii) Democratic process of WUAs: The elections of WUAs office bearers are by consensus and nomination in the present set up. Consensus and unanimity are the essence of democracy but there is scope for domination of WUAs by powerful social groups and suppression of weaker or disadvantaged groups in the present arrangement.

iv) Powers to WUAs for penal action: All the penal provisions for offences relating to water, its application, use, management etc. have vested the powers with the HID officers. WUAs can apply motivation, persuasion, social pressure etc. to work as a control mechanism. Now this is a missing link, which can become a stumbling block in the long run.

v) Conflict resolution mechanism: The WUAs in the saddle for irrigation management, lack of conflict resolution mechanism. A system has to be put in place to provide for an effective conflict resolution mechanism vested in WUAs. This will help in establishing the usefulness of WUAs in the social context also.

11.4.8 Suggestions for Better Functioning of WUA

The state has the definite advantage of consolidated command areas, a well-developed irrigation infrastructure, long-established mechanism for equitable distribution of irrigation water, a sound agricultural know-how and statutory provisions to take the lead in the field of PIM. A detailed analysis of the model and impediments clearly indicate the need for some solution and strategy. The PIM program needs to be made sustainable at the inception only and a little push will take this program ahead. The following suggestions are given for the positive improvement in the PIM program in Haryana:

i) Political patronage: Political patronage for ownership of the program and spreading the message across will provide necessary impetus to the program. PIM will have a better mass appeal, when elected representatives promote it.

ii) Institutional options: Second important issue is institutional. The need is to make the Haryana Irrigation Department fully responsible for WUAs right from the beginning, fostering and nurturing it all along till it becomes self sustainable.

iii) Share of stakeholders in investment: Stakes can be made feasible by a suitable design in the form of share in the initial investment, which can be nominal and a percentage and can possibly be made initial capital for WUAs for O & M activities later on.

iv) Financial sustainability: Financial sustainability needs to be developed by entrusting the job of realization of revenue and a cut in it and a percentage in the revenue realized for O & M works.

v) Democratic process: A democratic process for WUAs will have to be provided by means of elections of WUAs.

vi) Penal powers to WUAs: The WUAs must be provided with penal powers for offences such as wastage or theft of water, non-contribution in the affairs of WUA, neglect of maintenance aspect, damage to property, obstruction of irrigation or drainage system etc

vii) Conflict resolution mechanism: It essential to devise a suitable conflict resolution mechanism vested with WUAs. This will become an effective tool for making the entity of WUAs more acceptable, as the conflicts are bound to increase in the initial stages.

viii) Agricultural extension: There is an urgent need for developing an institutional arrangement for providing agricultural know-how at the level of WUA by providing awareness, training and workshops.

ix) PIM at distributary level: For IMT at secondary, a mass awareness program and a comprehensive training program needs to be developed and implemented at distributary level. Detailed statewide public consultation must be taken up before designing and implementing structure for secondary level IMT. Use of media and other modes need to be designed and launched. Need-based training program for PIM within the framework of Haryana model will go a long way in launching this program as a major initiative for one of the major reforms in water sector.

11.5 PARTICIPATORY IRRIGATION MANAGEMENT – A CASE STUDY OF ORISSA

Conforming to the policy guidelines of National water Policy (1987) and State Water Policy of Orissa (1994), the government of Orissa with a view to providing equitable, timely and assured irrigation has introduced the concept of *Pani panchayat* for PIM. PIM was introduced in the state during 1995 on pilot basis in four projects with the assistance of World Bank. Due to positive response from farmers at large, during 2000, the programme was named "Pani Panchayat" and was extended to all commands of major, medium, minor and lifts irrigation projects. This programme envisages making farmers to participate in the water resources planning and management and to hand over the system to the farmers for which suitable legislation has already been done. The Orissa *Pani panchayat* Act-2002 and Orissa *Pani panchayat*

Rules-2003 are concrete steps in this direction (DoWR, Govt. of Orissa, 2004). The Pani Panchayat is registered under Society Registration Act, 1860 and recognized by Orissa Pani Panchayat Act, 2002 and Orissa Pani Panchayat Rules, 2003. The geographical extent of the participatory irrigation management programme covers the entire State comprising of about 17.79 lakh hectares of irrigation command under different irrigation systems (Table 11.1).

Table 11.1 : Status of *Pani panchayats* under PIM programme in Orissa till March 2009

Projects	Total target		Formed		Handed over	
	Number	Area covered (L ha)	Number	Area covered (L ha)	Number	Area covered (L ha)
Major and medium	2562	11.25	2358	10.35	1324	5.71
Minor (flow)	1883	3.28	1883	3.26	1883	3.26
Minor (lift)	14174	3.16	13705	3.07	13681	3.06
Total	18619	17.79	17946	16.68	16888	12.03

Source: Annual Report (2006-07), Department of Water Resources. Govt. of Orissa

Pani Panchayat is an association of all persons owing land within a hydraulically delineated portion of the command area ranging in size approximately from 300-600 hectare in case of major / medium / minor irrigation project. In case of lift irrigation or minor flow irrigation project, the area is limited to the project command area where the area is less than 300 hectare. In the present concept of PIM, the responsibility of O&M of the reservoir, dam, sluices, spill way, distribution networks (primary and secondary) rests with the Department of Water Resources (DoWR), whereas the responsibility of the O&M of the tertiary system (below minor / sub-minor) is with the Pani Panchayat. The rights and responsibilities of the Pani Panchayat will be governed by an agreement between the Pani Panchayat and the Department of Water Resources.

11.5.1 Objective

The principle aim of the Pani Panchayat / Water Use Association is to maintain the canals, receive water in bulk from Water Resources Department and distribute the water among themselves efficiently by adopting suitable cropping programme and rotational use of water.

11.5.2 Key activities

- O&M of minors and sub-minors
- Equitable distribution and management of irrigation water
- Promote economy in the use of water
- Assist the government in the preparation of demand and collection of water rates
- Resolve disputes, if any, between the members and water users in its area of operation and raise resources for O&M
- Distribution of seeds, pesticides, fertilizers and other agricultural inputs
- Actively participate in all agricultural demonstration programmes within its boundary.

11.5.3 Funding pattern

Total funding pattern is managed by state government of Orissa. Pani Panchayat will have a bank account of its own. A Pani Panchayat of a major, medium or minor irrigation project will ordinarily be provided with grant-in-aid equal to the number of hectares within its boundary multiplied by Rs. 35 every year. The grant-in-aid will be admissible after all the farmers within the boundary become members of the Pani Panchayat. No grant-in-aid will be paid where farmers are exempted from payment of water rate. When water rates are revised in future, appropriate enhancement of the amount of grant-in-aid will be considered.

11.5.4 Strengthening PIM through Biju Krushak Vikash Yojana

To strengthen Pani Panchayat and to give a boost to extension of irrigation network, the Government of Orissa launched an innovative scheme, known as BKVY, in 2001-02. Under the scheme, stress has been laid on attracting people's participation in planning and implementation of small irrigation projects by revival of derelict irrigation systems as well as construction of new projects. Under this scheme, the operation and maintenance of the project is taken up by the Pani Panchayat which collects appropriate user charges from the beneficiaries.

11.5.4.1 Objective

- To encourage user-initiative and participation in construction and management of new and derelict lift and flow irrigation projects.
- To stimulate mobilization of the farmers to make them self-reliant.
- To strengthen and expand the irrigation infrastructure to accelerate the rate of growth of income, output and employment in the rural areas, and to remove regional imbalance in irrigation coverage.

11.5.4.2 Funding pattern: The assistance will be limited to 80 percentages of the estimated capital cost and contribution of Pani Panchayat shall be 20 percentages of the cost. In case of tribal sub-plan areas and KBK (Koraput, Blangir, Kalahandi) districts, the assistance may be raised to 90 percent of the capital cost. The Pani Panchayat may contribute its share either in cash or in terms of labour or in the form of land etc. The farmers will not pay water tax to the government. The Pani Panchayat will fix the water tax and collect it from the users, and deposit in the bank account of Pani Panchayat. To safeguard against the natural calamity, government provides necessary assistance as per the provisions of relief code.

11.5.4.3 Target group: A group of at least seven farmers with cultivable land of minimum 4 ha and willing to form a Pani Panchayat can go for a lift or flow irrigation project. Priority is given to small marginal farmers, women farmers, SC / ST / OBC farmers and farmers of areas without irrigation facilities.

11.5.4.4 Procedure for application: The beneficiaries of the programmes will form a Pani Panchayat by registering as per the Society Registration Act, 1860. This body will submit the project proposal to the collector in the prescribed format giving details of water source, list of users, the appropriate *ayacut* area, village, Gram Panchayat, block, tehsil and district. After receipt of the application the collector sends the application to the surveying agencies as detailed below for study of technical feasibility. Responsibility of lift irrigation projects lies with Executive Engineer, Orissa Lift Irrigation Corporation (OLIC) or District Manager, OAIC while that in case of Minor irrigation projects with command area less than 40 ha is under District Rural Development Agency (DRDA) / ITDA / Soil conservation. Minor flow irrigation projects with command area more than 40 ha are under Executive Engineer, Minor Irrigation. If the project is found suitable after survey, proposals are sent by the collector to the Water Resource Department indicating a priority order. A state level screening committee accepts or rejects the proposal after due scrutiny within one month. Then, financial assistance for execution of the project is released to the concerned executive agencies in a phased manner as per the estimate of the project.

11.5.5 Impact of PIM

PIM has been implemented in the state of Orissa since 1995-96 with funding from various agencies, where the differential functioning and effectiveness of WUAs under different types of irrigation system are observed. Farmers perceived adequacy of irrigation water and overall performance of minor irrigation system relatively better in Orissa. The impact of rehabilitation and irrigation management transfer to the farmers group is found positive with respect to cultivated area, cropping intensity, irrigated area, irrigation intensity, crop diversification and crop productivity in the sampled minor irrigation systems (Koska in Nayagarh district, Devijhar in Ganjam district and Analaberini in Dhenkanal district) in Orissa. There is a major shift from paddy to non paddy crops in *kharif* that might be the result of assured water availability and trainings received by the farmers from different agencies during the process of PIM. During *rabi* season, pulses like green gram, horse gram, black gram and bengal gram; oilseeds like sunflower and groundnut and vegetables like pointed gourd and brinjal are grown by the farmers that led to a reduction in fallow area.

11.6 Sustainability of PIM

Water Users' Associations like any other organization may sustain only when

- The earning is more than the expenditure funds available as and when required
- It has some reserve fund at its disposal
- Ensured supply of irrigation water from the system
- Effective operation plan of the project
- Equitable distribution of water
- Improvement in recovery of water charges from the farmers
- Recovery of water charges for using other source of water in the operational area
- Honesty, dedication and sacrifice
- Willingness of the farmers and irrigation agency to make it a success

Conclusion

Farmer's involvement in irrigation is not new in India. Many irrigation works were constructed and managed by the farmers. During the 19th century, a number of modern irrigation schemes were implemented by various departmental agencies without the involvement of farmers. The irrigation department is left with the only option to implement PIM, if they want to improve the performance of irrigation. All state governments have to frame their policy considering the type of irrigation projects and the socio-economic status of farmers. For the sustainability of the farmer groups, adequate administrative financial and legal provisions would be necessary. To observe the performance of the farmers managed system, it would be essential to have a monitoring committee. The objectives and the functions are to be evaluated in the light of the performance indicators like increase in irrigated area and the agricultural production. Improvement in the economic condition of the farmers would be another indicator. The most ideal situation may be when the demand of taking over of management of irrigation system comes strongly from the farmers.

12.0 ON-FARM WATER MANAGEMENT FOR ENHANCED WATER USE EFFICIENCY

RAJBIR SINGH AND PARBHAKAR NANDA

The success of the physical development of water resources for irrigation is well recognized for its significant contribution in attaining all round agricultural development, but at the same time, it has created problems of secondary soil salinization leading to degradation of eco-systems due to adoption of unscientific water management practices. Significant improvement in efficiency of irrigation and water use is required for prevention and alleviation of these problems for which technological innovations and their adoptions are important ingredients. There has been a growing realization by the planners and irrigation development and management agencies for adoption of innovative technologies of water management on variant aspects for improving the efficiency of irrigation water which may lead to sustainable agricultural production.

There is a growing awareness of the scarcity value of water under the conditions of increasing water demand from agricultural, domestic and industrial sectors. Scope of expanding water supplies through development of new water resources is limited since suitable dam sites are fewer, development cost are prohibitive and environmental concerns are too strong. This has led to the realization that saving in the use of water is the best option for expanding water supply.

12.1 AICRP on Water Management

After independence, the major irrigation projects were taken up to increase the irrigated area so that the food production can be improved. After commissioning of the major projects like Bhakra, Hirakud and Tungabhadra etc, need of scientific use of irrigation water was apprehended for judicious use for higher productivity. In view of this, conceptualization of systematic and scientific research was realized to generate data on different aspects of water management and to develop practices and systems for efficient use of irrigation water commensurate with increased agricultural production and sustained soil productivity. Looking into above, national level coordinated research project was initiated in late sixties in major commands. The All India Coordinated Project on Water Management was sanctioned by the Indian Council of Agricultural Research (ICAR) during 1967 with three centres for three major river valley projects viz. Bhakra, Hirakud and Tungabhadra to conduct research on different aspects of water management. During the 4th Five Year Plan, the Coordinated Project on Soil Salinity, Irrigation, Drainage, Soil Science and Water Management (sanctioned during the later part of Third Five Year Plan) was merged with it expanding the jurisdiction of the new project namely "AICRP on Water Management and Soil Salinity" to 16 centres. During 5th Fivr Year Plan, the sphere of the AICRP on Water Management and Soil Salinity project was further extended to 23 centres by merging it with another Fourth Plan Project "AICRP on New Cropping Patterns and Water Use in selected Irrigation Commands". In the 6th Five Year Plan (1980-85), the ICAR sanctioned the All India Coordinated Research Project on Water Management for operation at 34 centres by merging with it the on-going "Coordinated Project for Research on Water Management in High Rainfall Areas and Temperate Hill Zones" with 7 centres; addition of 8 new centres in hitherto uncovered irrigation commands; and transfer of four centres (which had emphasis on soil salinity and saline water) to the "Coordinated Project on Management of Salt Affected Soils and Use of Saline Water in Agriculture". In the 7th Five Year Plan (1985-90), the project was elevated to the level of Project Directorate, however, due to financial constraints and poor performance, nine centres were discontinued during Seventh Year Plan period. The sanctioned Project Directorate was established at Rahuri, Distt. Ahmednagar (Maharashtra) in October 1990. Thus during the 8th Five Year Plan, the AICRP on Water Management was continuing with 25 Centres. Now, the Coordinating Unit of AICRP on Water Management is now fully functional at Directorate of Water Management (DWM), Bhubaneswar and efforts are being made to bring all research work on water management under one umbrella to avoid duplicity and check wastage of research energy.

The AICRP (WM) since its inception has been catering to the research needs of water application in agriculture across the country. The project has been emphasizing on increasing water use efficiency across the crops and regions in the country through on station, on-farm and participatory mode of water management projects spread over twenty five centers in the country. The coordinating centers have been representing diversified agro economic and geo hydrological situations.

12.1.1 Progress and salient findings of the project

All India Coordinated Research Project on Water Management has made spectacular progress in developing a variety of strategies and technologies for improving sustainable use, planning and management of available water resources. During last four decades of its operation, the project has taken a lead role to evolve and evaluate location-specific improved water management practices and to promote their farm-level adoption. The major achievements of the project are summarized below:

- Assessed water demand and supply at distributary/minor/sub-minor levels in different reaches of 18 major command areas located in different agro-climatic situations. Crop plans/cropping systems have been suggested for existing supply situations and canal rescheduling suggested for proposed cropping systems. Proposed crop plans and rescheduling of canal system help bringing 22-28 percent additional cultivated area under irrigation. Proposed cropping systems have the potential to enhance farm productivity by 17-27 percent and net income by 20-30 percent in different agro-ecological situations.
- Developed canal delivery schedules for different reaches in arid, semi-arid, sub-humid and humid situations of the country. Proposed canal delivery schedules ensure crop water demand and help in equitable distribution of water in different reaches. Also moisture availability for subsequent timely sown crop is ensured with modified operation schedules.
- Developed water management technologies/strategies to suit water supply situations in different command areas. Alternate crop plans for existing water supply situations in different command areas. Alternate crop plans for existing water supply situation are suggested in Mula, Malprabha, Jayakwadi, Chambak, Lower Bhawani, Ramnagar and Tawa command areas. Proposed alternate crop plans help enhance crop productivity by 15-20 percent in *kharif* and 21-27 percent in *rabi* season.
- The water management technologies consisting of optimum irrigation schedules, proper land layouts, appropriate method of irrigation and judicious use of other production inputs such as quality seeds, adequate and balanced fertilizers and plant protection measures have been demonstrated through on-farm research programme of the project in 18 command areas, two tube well command areas, one tank command area. Results show that improved water management practices increases 15-37% crop yields and saves 28-40% irrigation water. This water saving can help enhance irrigated area by 15 -17%. It

is estimated that the improved water management technologies can be used on 10 million hectares.

- Techno-economic feasibility of drip irrigation in fruits and vegetables and high water requiring cash crops such as sugarcane and banana has been established in different agro climatic regions. Developed technologies for drip irrigation along with other inputs for orchards and plantation crops. Benefits of drip irrigation were obtained in terms of 20-40 percent water saving and 15-20 percent yield increase.
- Drip fertigation technology has been developed, refined and standardized for cash crops such as sugarcane, cotton, banana, groundnut, fruits and vegetables in different agor-climatic conditions of the country. Drip fetigation saved 15-40 percent irrigation water, 25-50 percent of N and K fertilizers and obtained 17-25 percent higher yield over surface irrigation.
- Developed modified crop geometry and production techniques to minimize the cost of drip irrigation system. Modified crop geometries reduced the cost of drip system by 30-50 percent without significant reduction of crop productivity and net income.
- Developed drip irrigation technology to suit its adoption in intensive cropping systems without winding up the drip irrigation system. This system is successfully demonstrated and deployed on farmers' fields in Tamil Nadu and Karnataka states.
- Developed and standardized irrigation schedule for 10 fruit crops, 15 vegetables, 5 spices, 4 plantation crops, 5 cash crops and 6 high value crops for drip, sub-surface drip, micro sprinkler, overhead sprinkler and raingun systems.
- Developed low-cost drip irrigation system which works efficiently with low energy requirement (LEPA) for adoption in plantation crops in place of micro-sprinklers. KAU micro-sprinkler developed by Chalakudy centre has tremendous demand in Kerela and Tamil Nadu state. New devise require 0.3 to 1.0 kg/cm^2 pressure, less than one HP pump, less clogging susceptibility, more uniform distribution, 50 percent less cost than conventional micro-sprinkler system.
- Developed the resource conservation technologies, which helped enhancing water, nutrient and other input use efficiency in maize-wheat, soybean-wheat and rice-wheat cropping system in sub mountaneous Himalaya conditions. Zero tillage in rice-wheat cropping system along with optimum irrigation schedule enhances crop yield by 10-17 percent , ensure timely sowing of wheat and increases water use efficiency of the system by 15 – 25 percent .
- Determined water requirement, stage-wise crop co-efficients and critical growth stages of 15 cereals, 7 pulses and 5 oilseed crops under different agro-ecological situations.
- In high water table areas, contribution of ground water-table towards crop evaporation has been quantified and irrigation water requirement is considerably reduced. Critical water-table depths have been quantified for different crops under different agro-climatic situations. In different crop studies, 30-40, 20-22 and 5-8 percent contribution of water-table towards crop ET was observed under shallow, medium and deep water table conditions respectively on varying textural soils.
- Studied drainage requirement of different soils to leach out the salts form root zones of the corps. At Hisar, Bhatinda and Sriganganagar, drainage requirements quantified along with gypsum requirement on silt loam, sandy loam, silt clay loam and sandy clay loam soils. At Chiplima, Gayeshpur and Jorhat centres, drainage

requirement quantified along with lime requirement on sandy loam and sandy loam soils.

- Developed techniques / agro-techniques / measures to ameliorate irrigation induced saline and waterlogged soils in different command areas of the country. Technologies consisting preventive and ameliorative measures have been deployed on farmers fields. Green manuring by *Susbenia* @20kg seed / ha has been found to be highly effective on all textured soils. Use of sulphonated press mud for amelioration irrigation induced saline and waterlogged soils resulted in fast reclamation of clay and clay loam soils.
- Studies the long term effects of faulty irrigation practices on the hydro-physical behavior (soil moisture characteristics, saturated hydraulic conductivity, infiltration rate, soil-water diffusivity and sorptivity) of different soil types. This has been studied in Mula, Jayakwadi, Malparbha, Sharda Sahayak, Ramnagar, IGNP, Chambal, Rawi-Tawi, Tawa, Lower Bhawni command areas.
- Optimum irrigation schedules have been developed for major cereals, pulses, oilseeds, vegetables, fruits, spices, cash crops, fodder crops, aromatic and medicinal crops and cut flowers in relation to optimum nutrient, tillage, mulches and other input requirements. Efficient water management technologies for 14 agro-ecological regions consisting of optimum irrigation schedules, optimum depth of irrigation, proper irrigation methods, soil-specific land layouts and judicious use of associated inputs for different cereals, pulses, oilseeds, vegetables and other important crops have been developed and standarized.
- Identified water-use efficient cropping systems and intercropping systems for different soil types in consideration with socio-economic needs and marketability of the produce. Water requirement of different intercropping systems have been evaluated under optimum, sub-optimal levels of water availability in about ten agro-ecological zones of the country.
- Developed irrigation schedules for crops and cropping systems for shallow, medium and deep water-table conditions in humid and sub-humid climatic situations. Water-use efficient rice-based, sugarcane based, soybean based, cotton based and maize based cropping systems suggested for optimum, sub-optimum and sub-sub-optimal water availability situations in view of their social relevance in different agro-ecological situations.
- Water-use efficient corps and crop sequences have been identified. Low water demanding sequences have been introduced in traditional crop sequence areas and evaluated for economic return and water use.
- Design specifications of various surface irrigation methods like border-strip, furrow and check-basin have been standardized under varying soil and agro-climatic situations in water scarcity areas. Irrigation in alternate furrows has produced encouraging results and need to be practiced for wide-row spaced crops. Alternate furrow irrigation in maize-chickpea cropping system saved 35 percent irrigation water on black clay soil at Belwatgi. This method has become highly popular in North Karnataka. Alternately alternate method of irrigation with high SAR waters developed by Bhatinda centre received attention of farmers of central Punjab.

12.2 On-Farm Water Management Research

During the last three decades, considerable efforts have been initiated for the development of suitable irrigation water management practices for agroclimatically diverse irrigated areas. Most of the research has however, been conducted on experimental research stations as on station trials under controlled and location specific condition. This has generated tremendous useful data which could eventually contribute to the establishment of a network of empirically derived relationship determining crop water requirements. These relationships however, should be tested under operational conditions for further modification and possible improvements in order that they can be used as tools to improve the operation of existing projects modernization and rehabilitation of the schemes currently being implemented. Controlled water management is important in projects with limited water supply as well as in scheme with abundant water supply. Over irrigation is the common feature which has resulted in high water tables, water logging, secondary salinization and subsequent degradation of the physical and chemical characteristics of irrigated soils.

For field testing of the validity and adoption of the water management technologies in irrigation commands, the On-Farm Water Management Research (OFWMR) was initiated in different commands. The feedback on effectiveness of the technologies and constraints in their adoption formed the basis of the research agenda to be addressed through future and collaborative research project. In this context, technologies developed by the centres of AICRP on Water Management in terms of efficient irrigation schedules, optimally designed surface irrigation methods, pressurized irrigation methods, fertigation, use of saline / good quality water, efficient crop planning and improved crop management towards substantial savings of irrigation water will form the best way of dissemination of technology.

The OFWMR on continuing basis is necessary to improve the operation and management of existing irrigation systems, the efficiency of which is generally low. It is also important to provide location specific information for planning of new irrigation projects. The OFWMR is warranted for to improve the design criteria for new projects. For example, lack of analysis of knowledge of internal drainage, properties of soils, the hydrology of shallow ground water tables, effectiveness of rainfall probability, rainfall distribution and critical crop water irrigation and drainage requirements has contributed to inadequate design and operation of the irrigation projects. This lack of understanding of the basic climatic and soil parameters has resulted in overuse of water and often caused an alarming rise in ground water tables and even water logging in many commands.

12.2.1 Major findings of OFWM

In order to study the effect of scientific irrigation schedule and excess water removeal on agricultural production, On Farm Water Management Research (OFWMR) in one tubewell and 10 major canal irrigation commands of the country has been conducted under aegis of AICRP on WM with the active support of Command Area Development Authority (CADA), Ministry of Water Resources, Government of India. The project aimed to quantitatively demonstrate to the farmers as to how the right decision about when to irrigate and how much water to apply to different crops affected the water saving and crop yields on their farms. Thus it was the first step in efficient operation and management of the tubewell and canal waters. The methodology of OFWMR consisted of selected the command of one or two outlets of a minor / distributary representing major farming situations of the irrigation system followed by diagnostic survey about water and other production constraints, and prescribing and adoption package intervention. The summary of the results in a few commands are presented in Table 12.1 to 12.4.

In the command of Bichpuri minor of Sahi distributary of Sharda Sahayak Canal (UP), the removal of water congestion by surface drainage and channelization of excess water to natural drainage system along with adoption of the water management technology considerably improved

Table 12.1 : Effect of water management technology on crop yield and water saving in the command of Bichpuri minor

Crop	No. of demonstrations	Yield (t/ha)		Increase in yield (%)	Saving in irrigation water
		Farmers' practice	Improved practice		
Rice	5	6.14	8.13	32.1	38
Wheat	7	3.20	4.17	30.3	42

the yield of rice and wheat (Table 12.1). Improved irrigation practices to rice comprised 5 irrigations, each after 3 DAD. Farmers generally prepared large size irrigation checks of 800 to 1000m^2 in their wheat fields. In order to improve application and distribution efficiencies, the large checks were converted into border strips of 5.5 x 50 m. Adoption of this practice reduced the depth of each irrigation from 10.6 cm to 6.2 cm. Drainage facilitated timely sowing of *rabi* crops, particularly wheat by advancing the date of sowing by 15 to 45 days.

The OFWM studies were conducted in the command of outlet No.2 of Rampuri and 6 of Pathera distributaries of Mohindergarh canal, Jawaharlal Nehru Lift Canal (Haryana) on seven crops for 3 years (1993-94 to 1995-96). In cotton, the impact of heavy pre-sowing irrigation of 8-10 cm depth or 2 irrigation of 5-6 cm depth each, followed by first irrigation at 40-45 DAS and termination of irrigation in the last week of September; irrigation in furrow made at 40-45 DAS, irrigation at square and boll formation stages in case of low rainfall was evaluated. In case of pearl millet, the impact of two irrigations one at tillering and another at antheses was studied. In pigeon pea and mung bean, the component technology trial consisted of sowing and irrigation in furrows; irrigation at critical stages i.e., flowering and pod formation. In wheat, the component technology trials consisted of light irrigation of 4 to 5 cm depth with sprinkler; irrigation at critical stages i.e. CRI, anthesis and grain development; and use of brackish ground water in conjunction with good quality water. In raya and chickpea, water management technology consisted of heavy pre-sowing irrigation at 8-10 cm depth with good quality water subsequently irrigation in raya with brackish water; and irrigation at critical stages i.e. pre-flowering and pod formation.

The results were compared with farmers' practices of application of invariably higher depth of irrigation in improperly leveled and large sized plots. It was observed that adoption of improved irrigation practices improved the crop yields from 20 to 63 percent and saved about 5-28 percent irrigation water over farmers' practices (Table 12.2). Maximum increase in grain yield and saving in irrigation was observed in the case of pigeon pea and minimum in case of chickpea.

On-Farm Water Management studies were conducted in the command of D-10, Mettupalayam distributary of Lower Bhawani Project (Tamil Nadu) on two major crops, rice and ground nut. The command has shallow well drained soils. In short duration rice (ADT 38), the effect of 5 cm irrigation one day after disappearance of poded water (DAD) normally coressponding to irrigation once in four days was demonstrated in study block. Rice (IR-20) and farmers applied heavier depth of irrigation (6-7 cm). The data (Table 12.3) indicated that grain yield of rice increased by 25 percent in study block as compared to control block and saved 22.6 percent irrigation water. In ground nut, application of irrigation of 5 cm depth at 10-12 days interval which corresponds to IW / CPE =0.6 increased the pod yield by about 18 percent and water saving of 21.6 percent over farmers' practice of heavier irrigation depth.

Table 12.2 : Impact of water management practices on crop yield (t/ha) and water saving (%) in the command of Jawaharlal Nehru Lift Irrigation Canal in Haryana

Crop (cm)	No. of trials	Yield (t/ha)		Increase in yield over farmers' practice (%)	Water use		Saving in water over farmers practice (%)
		Farmers' practice	Improved practice		Farmers' practice	Improved practice	
Cotton	67	0.74	1.09	47.2	22.5	17.1	24.0
Pigeon pea	35	0.76	1.25	63.1	15.4	11.0	28.5
Pearl millet	85	1.35	1.86	38.0	8.3	7.5	10.6
Mungbeam	25	0.53	0.73	38.4	8.2	7.2	12.1
Wheat	65	4.06	4.86	19.8	44.8	40.1	10.5
Raya	58	1.73	2.17	26.2	15.8	13.9	12.0
Chickpea	12	1.36	1.66	22.2	7.2	6.8	5.5

Table 12.3 : Impact of water management on rice and groundnut yield in Lower Bhawani Command

Crop	Crop yield (t/ha)		Irrigation (cm)		Rainfall (mm)	Increase in yield (%)	Water saving (%)
Rice	6.96	5.57	96	124	450	24.9	22.6
Groundnut	2.06	1.74	53.5	68.2	20	18.4	21.6

On-Farm Water Management studies were implemented in the commands of Kalady and Karukutty distributaries of Chalakudy Irrigation Project (Kerela). The command area receives high rainfall of over 3000 mm from south-west and north-east monsoons. Package interventions were introduced in a compact block of 45 ha of wetted and a nearby upland area of nearly 50 ha belonging to 200 farm families. A nearby area of 15 ha was slelected as control. In *kharif*, due to the abundance of rainfall, though canal water is not required for irrigation, yet the canals remain open since the system is rub-of-the river type. Consequently, in low lying area of Chalakudy command, flooding is a severe problem. Often the depth of flooding exceeds 20 cm during the crop season. The studies were conducted to channelize the excess water to drains and to regulate the depth of submergence to about 5cm. The provision of surface drain produced 92.6 percent higher grian yuiled of rice compared to no drainage treatments. In *rabi*, application of irrigation of 7 cm depth 1-2 days after disappearance of ponded water was demonstrated against field to field irrigation with deeper submergence in rice in control block. Earhten filed channels were provided to channelize irrigation. The improved irrigation regime produced a grain yield of 2.7 t / ha of rice (Cv. Chittni), 77 percent higher than that under traditional practice of field to field irrigation adopted in the control block besides a saving of 79 percent of water (Table 12.4). In summer rice, the schedule of one irrigation of 7 cm depth 3 DAD was adopted against the traditional practice of field to field irrigaton. The results indicated similar trends on grain yield of rice, as in *rabi* season. Application of one irrigation 3 DAD increased rice yield by 67 percent with a saving of of 87 percent of irrigation water over field to field irrigation.

Table 12.4 : Rice grain yield and water use in farmers' fields in Chalakudy irrigation command

Water management practice	No. of farmers	Grain yield (t/ha)	Irrigation depth (cm)	Relative grain yield	Saving in irrigation water
Kharif (Cv.Red Triveni)					
Surface drainage	10	2.92	-	162.60	-
No drainage	5	1.52	-	100.00	-
Rabi (Cv. Chittni)					
7 cm irrigation after 1-2 days of drainage	10	2.80	153	177.20	79
Control (field to field irrigation)	5	1.58	720	100.00	-
Summer (Cv. Red Triveni)					
7 cm irrigation after 3 days of drainage	10	3.35	54	167.00	87
Control (field to field irrigation)	5	2.01	420	100.00	-

12.3 Operational research in water management

Generally water management research confined to SAU, institutes and research stations. The agricultural scientists of these organizations did not have much opportunity to interact with irrigation engineers and farmers in tackling on farm management problems. This created a gap between the available research findings and their utilization for improving the design and operations of irrigation systems. There is a great need for establishing empirically derived design criteria for irrigation projects. On the farmer's fields, the degree of experimental control will be less and variations in physical and farm management factors will be considerably greater than in traditionally on-station experimentation. Therefore, important change in research methodology, observations and interpretation technique will be warranted. Without this expansion of research accomplishments and thereby alterations in the research methodology, most of the crop / soil water management research will remain location specific and its results will be limited relevance to farmers conditions.

Operational research is most needed at present so that the research findings should be relevant to farmers need. It should not only be a function of needs as perceived by farmers who are ultimate beneficiaries of the irrigation system, but should also respond to the project limitations and to the concerns of the irrigation department who manages it. For this purpose it is necessary to diagnose operational constraints for improving management and use of water; measure the impact of changes in water management on cropping pattern and consequently on the timing of farm operations; establish crop growth and yield responses to different levels of water supply over the full growing period for specific crops and crop sequences; and monitor and record factors influencing the supply of water which could disturb and change the underlying assumptions for designing water delivery schedule.

Taking into considerations of the above facts, different centers under AICRP on Water Management have been carrying out Operational Research Project (ORP) in collaboration with line departments, irrigation department and other agencies with active participation of farmers.

The technologies interventions like adoption of efficient cropping pattern as per availability of water, use of field channels and drainage under canal commands, appropriate tillage practices for better moisture conservation and weed control, irrigation application as per crop water demand, irrigation scheduling for optimization of production and productivity, application of pressurized irrigation system under different cropping sequence, introduction of high value crops under different water management regimes, mulching, adoption of a cropping pattern suiting to canal water supply under major, medium and minor irrigation projects have been demonstrated in participatory mode. The active participation of farmers in ORP has led to the adoption of new or improved technologies for higher and sustainable productivity. The success stories of ORP at different places have been helping other farmers to adopt the technologies and up-scaling it in larger areas under similar agro economic conditions. The centers have been monitoring the impacts of the ORP and the results have been reported and documented for policy planning. The feedbacks from the farmers have been examined by the scientists and suitable refinements have been done suiting agro ecological and socio-economic conditions in the ORP areas. The scientists have also analyzed benefit and cost of the new technology at farmers' condition and advocated for the upscaling of profitable technologies. Under the process of assessment, refinement and transfer of technologies, the scientists have been propagated a number of agricultural water management technologies that are under process of adoption at different locations across the country. The salient findings on enhanced crop productivity and water use efficiency in selected major commands of different regions are presented in coming chapters as selected case studies.

CASE STUDY

13.0 IMPACT OF CONJUNCTIVE USE ON WATER PRODUCTIVITY ACROSS A CANAL COMMAND OF BHAKRA IRRIGATION SYSTEM

RAVISH CHANDRA

By nature, Haryana state is in a disadvantageous position with regard to rainfall, surface water quantum and ground water quality. About 50% of the area of the state constituting the eastern zone has a semi-arid climate while the remaining 50% constituting the western zone has an arid climate. The utilizable potential both from surface and ground water resources has been estimated at 2.75 m ha-m (surface 1.51 m ha-m and ground water, including marginal quality 1.24 m ha-m), which is just about 60 % of the irrigation requirement (Anonymous, 2008). The state receives an effective rainfall of about one m ha-m to meet the consumptive use demand of crops. The net irrigated area in the state is 2.89 m ha; almost 50-50% each from surface and ground waters. The entire area is covered under three basins: Yamuna basin (16,330 Km^2), Ghaggar basin (1,067 Km^2) and internal basin (17,207 Km^2). In the north of the state, the land area slopes from north-east to south-west, whereas in the south, it slopes from south-west to north-west along the Delhi-Rohtak-Hisar-Sirsa axis. This physiographic situation makes a depressional saucer shape zone around this axis and is mainly responsible for the problem of flooding, waterlogging, high water table conditions and salinity of roughly 15,318 Km^2 area in the inland drainage basin (Anonymous, 2008).

The West Yamuna and Bhakra canals are the two major canal irrigation systems in Haryana. The ground water is exploited through a battery of mainly shallow tubewells. The Western Yamuna Canal system supplies surface water to eastern and southern parts and Bhakra Canal System to the western parts of the state. These canal systems comprises of canals, distributaries, minors, sub minors and watercourses. In about 88% of culturable command area (CCA) of these canal systems, topography allows gravity flow. In this region fresh water from canals is supplied through a rotational *Warabandi* system (Malhotra, 1982) which has been designed to provide equitable water supplies. Irrigation intensity is around 50% (4960 m^3/ha) in Western Yamuna command, 62% (6070 m^3/ha) in Bhakra command. Canal water allowance, however, is generally not sufficient to irrigate the total landholding of the farmer. Substantial seepage from earthen distribution channels and illegal use of canal water by head-end farmers create large variations in supply, spatially as well as temporally. Because of this variation in supply and the low reliability of canal water supplies, groundwater has become important, including in the irrigated canal command of Bhakra system. Shallow and deep tube wells irrigate an area equal to or greater than the area irrigated by canal water (Economic and Statistical Organization 1995). Twenty-four percent of the command area is underlain by marginally saline to saline water, and in the last two decades, the water table has risen substantially (5 to 10 m) in a large portion (64%) of the command. The continuing rise in water tables in these areas is one of the major problems in the command. But in Kaithal, Kurukshetra, and Ambala districts, due to extensive development of good quality groundwater, the water table has dropped substantially. Such an overdependence on groundwater and weak regulatory mechanisms for water use have resulted in growing water scarcity and an increasing threat to the sustainability of water-intensive cropping systems. The challenge for irrigated agriculture will be to grow more food with less water (Guerra *et al.*, 1998). The old notion of increased input applications will have to be changed, and new paradigms of optimized resource use in sustainable ways need to be evolved. The focus of improving land productivity has to be shifted toward improving water productivity. Therefore it is extremely important to address some of the issues at the field level. Studies were conducted to determine the impact of conjunctive use on water productivity in a rice-wheat cropping system at the real field level in 'Pabnawa Minor' of Bhakra canal command of Haryana. This study also tried to assess profitability of farmers across the canal command and the contribution of groundwater in total irrigation across the canal command.

13.1 Detail of Study area

The study area is the command area of Pabnawa minor (tertiary canal) of Bhakra irrigation system, located in the semiarid tropics in Haryana, India at 29°31' - 30°12' N and 76°10' – 76°43' E. Average annual rainfall is 625 mm, about 80% of which is received during the monsoon period (July to September). Average evapotranspiration is about 1550 mm. For this study, villages (Jyotisar and Raogarh) at the head of the Pabnawa minor, Barna in the middle, Pabnawa at the far middle, and Faral in the tail stretch of the Pabnawa minor were selected. Details of four watercourses supplying canal water to them are summarized in Table 13.1. Fields of 122 farmers (at least 30 farmers in each of the four stretches–with at least 10 located in the head, middle, and tail reaches of each watercourse) were selected for detailed data collection. Information on agricultural practices, irrigation water supply from tubewells and canal water, cropping pattern, cost of cultivation, and yields were collected through specifically designed questionnaires. The primary data for this study were collected for *rabi* 2006-07 and *kharif* 2007. Gauge readings of the canal were collected for the last 3 years from Kurukshetra Irrigation division. Discharges of tubewells were estimated using the coordinate method (Michael, 1978). Historical data regarding the canal irrigated area, water table fluctuations and various other data related to groundwater were collected from Kurukshetra Irrigation Division, Agriculture Department and Groundwater Cell.

Table 13.1 : Details of selected watercourses

Watercourse (stretch of canal)	Design discharge (m^3/sec)	Gross command area (ha)
Pabnawa 2820R (Head)	0.028	231.6
Pabnawa 23400R (Middle)	0.040	213.6
Pabnawa 53705L (Far Middle)	0.041	320.2
Pabnawa 80000L (Tail)	0.052	283.0

13.2 Salient achievements

i) Groundwater use

Crop production is directly related to canal water supply. The rigid schedule of water distribution and the inadequacy of the canal water supply do not provide much scope to the farmers for decision making in respect of canal water utilization. Their decisions are mostly limited to managing the readily available groundwater. The canal irrigated area in Pabnawa minor is shrinking due to management inadequacies. From 1995 to 2005, the canal irrigated area decreased in the middle reach by 11 to 65% during the *kharif* season and by 11 to 44% during the *rabi* season. Tubewell water use is very high in the tail and far middle reaches in both seasons (Table 13.2).

ii) Water productivity at field level

Water productivity (WP) refers to the benefits derived from use of water. It is expressed in terms of kg/m^3 of water or Rs/m^3 of water. Productivity of total irrigation water (canal + groundwater) increases from head to tail stretches for paddy (2007), Basmati (2007), and decreased from head to tail for wheat (2006-07)

Table 13.2. Use of canal water and groundwater for irrigation (cm) during *rabi* and *kharif* season in 2006-07.

Season	Sources of irrigation	Head	Middle	Far Middle	Tail
Rabi(wheat)	Canal	6.8	10.0	3.1	0.84
	Groundwater	18.3	12.8	19.5	19.8
Kharif (Paddy)	Canal	61.7	97.3	40.3	3.2
	Groundwater	94.3	55.9	101	116

(Table 13.3). The irrigation water productivity for coarse paddy and basmati paddy is higher by 35 and 21% for the tail stretch as compared to the head stretch. This is probably because of wastage of low-cost canal water in the upper reaches, and careful use of groundwater in the tail stretch. Electricity is supplied every alternate day for 6-7 hours, and hence the tail end farmers have to use these electricity supply hours judiciously. The same phenomenon is found for irrigation water productivity within the stretch. For wheat, irrigation water productivity is lower by 12% in the tail stretch and by 2.5% in the far middle stretch than in the head stretch. This was unexpected as the wheat crop in the tail stretch was badly affected due to heavy rain in February 2007 (216 mm). The soil in the tail stretch is clay loam, which encourages water stagnation and yield loss. Water productivity of paddy and wheat for different sources of irrigation is given in Table 13.4. The highest irrigation water productivity for paddy is for tubewell irrigated farmers, followed by conjunctive users and then by canal-irrigated farms. Irrigation water productivity is Rs 3.63 / m^3 for coarse rice, Rs5.62 / m^3 for basmati rice, and Rs14.87 / m^3 for wheat. The information gives an impression that farmers are cheaply using water for paddy as compared to wheat. But it is worth noting that farmers tend to maximize their crop income and basmati rice gives the highest gross margin per hectare, followed by coarse rice and wheat. This emphasizes the challenge of enhancing water productivity while increasing or sustaining the economic benefits to the farmer.

Table 13.3. Water productivity for wheat (2006-07), coarse paddy, and basmati paddy (2007).

Crop	Location of watercorse	Irrigation water productivity(Rs/m^3)	Total water productivity (Rs/m^3)
Paddy	Head	3.30	2.56
	Middle	3.31	2.57
	Far Middle	3.44	2.60
	Tail	4.48	3.18
Basmati paddy	Head	5.54	4.32
	Middle	4.49	3.95
	Far Middle	5.57	4.34
	Tail	6.88	5.03
Wheat	Head	15.08	7.17
	Middle	16.42	7.39
	Far Middle	14.73	6.84
	Tail	13.25	5.79

Price of crops is of year of study

Table 13.4. Water productivity of paddy and wheat for different sources of irrigation.

Crop	Sources of irrigation	Irrigation water productivity (Rs/m^3)	Total water productivity(Rs/m^3)
Paddy	Canal irrigation	2.19	1.77
	Conjunctive Irrigation	3.07	2.43
	Tubewell Irrigation	4.21	3.06
Basmati paddy	Canal irrigation	4.13	3.39
	Conjunctive Irrigation	4.44	3.80
	Tubewell Irrigation	6.63	4.93
Wheat	Canal Irrigation	18.40	7.96
	Conjunctive Irrigation	15.10	7.15
	Tubewell Irrigation	14.30	6.46

iii) Profitability

The profitability of crop production depends on the crop yield, output price, and cost of production. The cost of production is highest for basmati rice and lowest for wheat (Table 13.5). The average cost of production is Rs15065 / ha for basmati paddy, Rs13301 / ha for coarse paddy, and Rs12495 / ha for wheat. The gross value of product is calculated using the minimum support prices for coarse paddy and wheat. For basmati paddy the average prices received by the farmers were used. The gross margin is highest for basmati rice, followed by coarse rice and wheat. The gross margins for basmati paddy and coarse paddy are 3.2 and 1.7 times higher than the gross margin of wheat. The average G.M / C.O.P. ratio is 4.55 for Basmati paddy, 2.76 for coarse paddy compared to 1.76 for wheat. The gross margin of basmati rice cultivation in tail watercourse was 14% less than the gross margin at the head . Gross margin for coarse rice was 11% less at Pabnawa tail compared to the head end watercourses. But in the case of wheat the gap in gross margin between the tail and head was 59%. The flat tariff for electricity (based upon the HP of the pump and not the actual pumping hours) helps maintain the higher profitability of rice for the farmers. If the cost of water were different for rice and wheat, this would change.

Table 13.5. Profitability of crop production (*rabi*, 2006-07, *kharif*, 2007).

Crop	Location	Cost of production (COP) (Rs/ha)	Gross value of product (Rs/ha)	Gross margin (GM) (Rs/ha)	GM/COP
Basmati paddy	Head	15705	87771	72066	4.59
	Middle	14562	84522	69960	4.80
	Far Middle	15718	84233	68515	4.36
	Tail	14275	77047	63452	4.45
Coarse paddy	Head	13309	51719	38409	2.89
	Middle	12523	51149	38626	3.08
	Far Middle	13571	48536	34965	2.58
	Tail	13800	48398	34558	2.50
Wheat	Head	13098	36550	23452	1.79
	Middle	11925	36852	24778	2.08
	Far Middle	12452	35022	22834	1.83
	Tail	12506	27248	14742	1.18

Price of output taken as of 2007: Coarse paddy-Rs 7.5/kg, Basmati paddy-Rs 25/kg, Wheat-Rs 8.5/kg

The profitability of crop production was also determined for different sources of irrigation (Table 13.6). The cost of cultivation was highest for conjunctive irrigation compared to tubewell and canal irrigation alone. But the gross value of product was also highest for conjunctive irrigation compared to other sources of irrigation, resulting in higher gross margin for conjunctive irrigation of basmati paddy and coarse paddy. This analysis suggests that with the flat rate of electricity and higher return of paddy, high water use will continue. There is an urgent need to look into this serious issue.

Table 13.6. Profitability of crop production under different sources of irrigation

Crop	Sources of irrigation	Cost of production (COP) (Rs/ha)	Gross value of product (Rs/ha)	Gross margin (GM) (Rs/ha)	GM/COP
Basmati paddy	Canal	11399	40218	28819	2.53
	Conjunctive	13673	51201	37528	2.74
	Tubewell	13334	50062	36728	2.75
Coarse paddy	Canal	14568	82550	67982	4.67
	Conjunctive	15942	84373	68431	4.29
	Tubewell	14297	82544	68247	4.77
Wheat	Canal	12330	36703	24373	1.98
	Conjunctive	12512	36828	24207	1.93
	Tubewell	12521	31424	18903	1.51

Price of output taken as of 2007: Coarse paddy-Rs 7.5/kg, Basmati paddy-Rs 25/kg, Wheat-Rs 8.5/kg

13.3 Options for improvement

i) Artificial recharge of groundwater

Harnessing surplus monsoon flows and canal flows to recharge the aquifer system could, in principle, augment groundwater resources. Artificial groundwater recharge should be done on a priority basis, through rooftop rainwater harvesting and a combination of recharge shafts and injection wells (CGWB, 2004). The impact assessment of artificial groundwater recharge by combination of recharge shafts and injection wells in Haryana has 3.45 M m^3 runoff water recharged in one year and the rate of water table decline reduced from 1.175 m/year to 0.25 m/year. Recharging of confined aquifers by injection tubewells in Kurukshetra district indicates water recharges at the rate of 7.2 m^3/day/tubewell (Kaledhonkar *et al.*, 2003). In 2002-03 many farmers of this area changed from centrifugal to submersible pumps. The abandoned wells and pipes are still there and can be modified and used for groundwater recharge.

ii) Conjunctive use of water

Conjunctive use of water from different sources is considered to be a valuable tool to overcome the constraints of the surface and groundwater systems, if operated independently. A typical canal irrigator in this area gets surface water 12-18 times a year. Most of these head-end farmers also have tubewells for supplemental irrigation. The ratio of canal water and tubewell water for head-end farmers is about 70:30. But if this ratio can be reversed to 30:70 and the surplus canal water can be transferred to tail-end farmers it will minimize tubewell water use. The lining of watercourses is also essential for conjunctive use of water. The lining of watercourse no. 23400R of Pabnawa minor has increased the irrigated area from 18 ha to 40 ha. This lined watercourse can also be used while irrigating from tubewell. Conjunctive use planning requires establishment of firm water supplies and their distribution and use of groundwater and allocation of water to different users.

iii) Promotion of resource conservation technologies

The use of resource conservation technologies needs to be encouraged by providing subsidies to farmers to adopt technologies such as zero tillage, bed planting, laser leveling, and SRI technique for growing paddy. It will improve groundwater use efficiency. Chandra *et al.* (2007) suggest superiority of zero tillage over conventional tillage in wheat in terms of irrigation water productivity, land productivity, and profitability of crops. Similarly, bed planting and laser leveling have great potential. At the same time there should be some incentives for farmers to save water.

13.4 Conclusions and recommendations

In the canal water distribution system, a gap between head and tail farm gate supply always exists, and the system investigated is no exception. The inadequate, inequitable, and irregular canal water supply has led to shrinkage of the canal irrigated area over time and groundwater is playing an important role in crop production. Groundwater accounts for more than 50% of the total irrigation water use in the Pabnawa canal command.

Water productivity increases from head to tail watercourses for coarse and basmati rice. This trend is due to wastage of low-cost canal water upstream and judicious use of costly groundwater at the tail end. The gross margin is highest for basmati rice, followed by coarse rice and wheat. The higher profitability of rice and flat rate electricity charges result in high water use for canal and groundwater, causing water table decline. This system of intensive irrigated agriculture is unsustainable in the long run, because of declining water tables and high use of energy. In the short term, food security, poorly designed electricity tariffs, and high minimum support price for rice need to be rationalized. Conjunctive use farmers have the highest profitability and moderate water productivity compared to tubewell irrigators and canal irrigators. Conjunctive use of water from different sources is considered to be a valuable tool to overcome the constraints of the surface and groundwater systems, if operated independently.

This study produced some important policy recommendations:

- There is an urgent need to enact groundwater legislation to stop indiscriminate exploitation. A state groundwater body should be set up to regulate and control groundwater development and management on a sustainable basis.
- There should be strong incentives to the farmers for establishing artificial groundwater recharge structures in the form of waiving electricity costs.
- Conjunctive use planning requires the establishment of firm water supplies and their distribution, effects of water development and use of groundwater, and allocation of water to different users.
- Resource conservation technologies need to be encouraged by providing subsidies to farmers to adopt technologies such as zero tillage, bed planting, laser leveling, and SRI technique for growing paddy which will improve water use efficiency.
- Artificial groundwater recharge should be done on a priority basis, through rooftop rainwater harvesting, and combination of recharge shafts and injection wells.

References

Anonymous. 2008. Enhancing water productivity in Haryana. (Eds.) Dhindwal, A S., Phogat, V K and Hooda, I S. Department of Soil Science, CCS H A U, Hisar

Central Ground Water Board, CGWB. 2004. Water security through groundwater management in Haryana. North Western Region, Chandigarh.

Chandra, R, Sikka, A. , Singh, S., Gupta, R., Upadhyaya, A.K and Sakthivadivel. R. 2007. Impact of resource conserving technologies on water use and water productivity in Pabnawa minor of Bhakra canal system. Rice-Wheat Consortium Technical Bulletin 10.

Guerra, L.C., Bhuiyan, S.I., Tuong, T.P and Barker, R. 1998. Producing more rice with less water from irrigated systems. SWIM Paper 5. Sri Lanka, Colombo: International Water Management Institute.

Kaledhonkar, M.J., Singh, O.P., Ambast, S.K., Tyagi, N.K and Tyagi, K.C. 2003. Artificial groundwater recharge through recharge tubewells: a case study, IE (I) Journal-AG, 84: 28-32.

Malhotra, S.P. 1982. Warabandi system and its infrastructure. Central Board of Irrigation and Power. Publication No.146. New Delhi, India.

Michael, A.M. 1978. Irrigation: Theory and Practice. Vikash Publication, New Delhi, India.

CASE STUDY

14.0 ENHANCING WATER PRODUCTIVITY THROUGH CANAL WATER HARVESTING AND BY INTRODUCING MICROIRRIGATION IN TAIL-END

Rajbir Singh, Satyendra Kumar and Ashwani Kumar

About 31% of total geographical area of India falls under arid and semi-arid region where agriculture is dependent either upon rain or surface and underground water resources. The limited availability of water is the most limiting factor for crop diversification in these areas and problem further aggravates if underground water is also not fit for irrigation. Though, canal network has been developed in many such areas, but the problem of water logging, salinity and loss of nutrients have appeared due to unscientific manner of water application particularly at heads of the canal command (Agarwal *et al.* 2009). However, at the middle and tail end, many times water supply is not adequate. Besides this, canal water supply is not regular throughout the year and authorities distribute water among the farmers and the turn for canal water supply hardly comes once in a week. The overall efficiency of canal irrigation system worldwide is very low. This leads to poor utilization of irrigation potential, created at a huge cost. The average overall project efficiency of several canal irrigation projects has been estimated as 23 – 40 %. Navalwala (1991) reported that 71 % of the irrigation water is lost in the conveyance from source head to the actual field. The wastage occurring during conveyance and application ultimately results in delivery of only 30-35% of stored water for plant uptake (Anbumozhi *et al.*, 2001). Moreover, conventional method is more of supply driven than crop-demand driven causing a mismatch between need of the crop and the quantity of water supplied. Hence, inadequate water supply and requirements for higher agricultural productivity necessitates improving water use efficiency. Therefore, shifting from traditional to drip system would result in higher water productivity and minimize problems associated with traditional irrigation methods (Kumar *et al.*, 2007).

Microirrigation in conjunction with secondary reservoir may be an alternate for crop diversification with fruits and vegetables in canal command by providing ensured irrigation with limited available water. Research studies carried out in India and abroad categorically exhibited beneficial effect of microirrigation, which can save precious water with enhancement of yield of different crops under varied agro-climatic conditions (Hanson *et al.*, 1997; Kumar *et al.*, 2007, 2008.; Singh *et al.*,2009). Secondary reservoirs are storage structures (ponds) located in irrigated areas that allow farmers to store whole or a part of canal water and use judiciously through microirrigation (Kumar *et al.*, 2008). During lean period or in rainy season when canal water is not needed for irrigation, can also be stored and being used during critical periods. Despite of numerous benefits and government financial support (subsidy), farmers are hesitant to adopt microirrigation in canal command. Perhaps, the greatest barrier is the lack of information about the techno-economic feasibility of microirrigation with secondary reservoir. Information about the use of microirrigation in fruit and vegetables in canal command is limited while in conjunction with water storage facility is perhaps not available. In order to breeze the information gap and to answer whether crop diversification with fruits and vegetables using microirrigation in canal-irrigated areas is profitable, the study was planned.

14.1 Detail of case study

a) Experimental site: Investigations were carried out at the research farm of Central Institute of Post Harvest Engineering and Technology, Abohar (30° 09' N ; 74° 13' E; 185.6 m MSL). Abohar is situated in southwest parts of Punjab, India. The topography of experimental field was flat. Soil was sandy loam with the bulk density of 1.55 Mg m^{-3} and available soil moisture of 0.125 cm^3 cm^{-3}. The site is located in a semi-arid (dry) monsoonal region with mean annual rainfall of < 400 mm, of which 70-80 % is received in July, August and September months. Groundwater is inadequately available and not suitable for irrigation due to salinity (14.7 dS m^{-1}). Hence, agriculture in this area depends only upon canal water supply. The minimum and maximum temperature, humidity, pan evaporation and wind speed during the study period ranged between 5 and 48°C, 29 and 96%, 0.5 and 10.0 mm day^{-1}, and 1.0 and 3.6 m s^{-1}, respectively. May and June are the hottest and December and January are the coolest months of the region.

b) Water resource development for drip system: Regular water supply is pre requisite to have maximum benefits from adoption of micro irrigation system. A dugout pond (secondary reservoir) of 1500 m^3 capacity was constructed at the research farm for harvesting canal water and lined with LDPE sheet (250-micron) to eliminate seepage losses. Reservoir was fed with good quality canal water (pH 8.2 and electrical conductivity 0.51 dS m^{-1}) from Punjawa minor of Abohar distributory under Sirhind Canal System. Stored water subsequently used by drip system. A line-sketch of canal-fed secondary reservoir, pumping unit and drip system is illustrated in Fig 14.1. The same secondary reservoir was used to irrigate other crops at the research farm. The required capacity of secondary reservoir was estimated as 400 m^3 per hectare on the basis of peak irrigation water demand. Though farmers get the canal water supply once in a week, capacity of reservoir was estimated on the basis of irrigation water requirements of the crops for the period of two weeks to cover risk. The same capacity was utilized for the purpose of estimation of cost of service reservoir for the economic analysis.

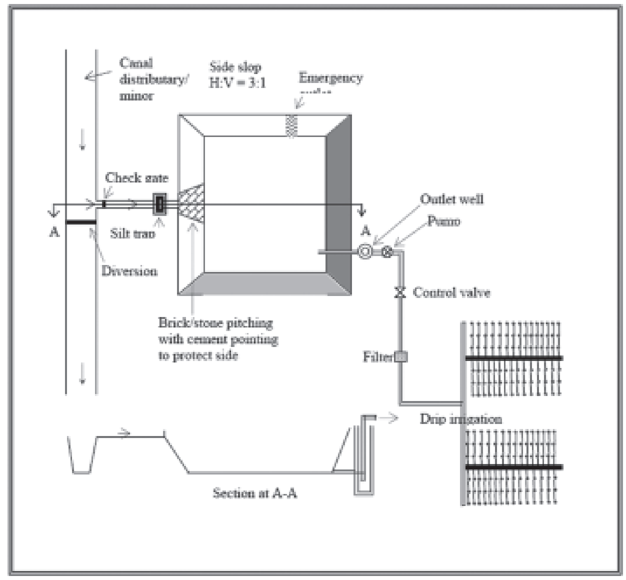


Fig. 14.1 Line sketch of service reservoir connected with source of water supply of Micro-irrigation system

c) Installation of micro irrigation systems for selected crops: Vegetables and fruit crops were planned in place of traditional cotton crop under crop diversification plan. Selected vegetable crops were onion, potato, tomato and capsicum; and horticultural crops were pomegranate, guava, strawberry and *kinnow*. Micro sprinkler was planned for onion and potato. Drip was planned for tomato, capsicum and other fruit crops. The layouts of micro irrigation (micro sprinklers) systems for onion and potato crops were prepared considering source of irrigation, slope and shape of field. The field was divided into two parts with sub main of 90 mm diameter at the centre of the field and laterals of 16 mm diameter on the both sides of sub main. The spacing between two micro sprinklers in case of onion and potato was kept as 3 m. The drip irrigation system was preferred for tomato and capsicum. Spacing for inline drip laterals was 0.90 m and 0.5 m for tomato and capsicum, respectively. Emitters were placed at distance of 0.50 m for both the crops. Crop geometry of potato, onion, tomato and capsicum was 60 x 10, 15 x 10, 90 x 50 and 50 x 50 cm, respectively. In case of fruit crops such as pomegranate, guava and *kinnow*, sub-main passed through the centre of the field and laterals of 16 mm were laid out on both sides of the sub-main along the row of fruit trees. Four emitters, each of 4-lph discharge, were fixed around the tree stem in circular loop, made of 12 mm lateral pipe to maintain the equidistance between two adjacent emitters. Plant to plant spacing of pomegranate, guava, and *kinnow* orchard was 3.5 x 3.5, 6 x 6 and 6.6 x 6.5 m, respectively. Drip system was installed in one year old plantation of pomegranate and guava while it was installed in 3 years old orchard in case of *kinnow*.

d) Growing of selected crops by surface irrigation method: As the basic aim of the research was to assess the feasibility of drip system in conjunction with service reservoir under irregular/ limited canal water supply conditions, crops were also grown with the surface irrigation methods for the purpose of comparison as per farmers' practice. As far as irrigation scheduling is concerned, farmers irrigate the fruit crops twice in a month during May and June and rest of the year once in a month, if canal is running and there is no rainfall. Some times during the hot summer months, trees do not get irrigation for the period of fortnight due to lack of canal supply. Flowering and fruit bearing are affected particularly in *Kinnow* and pomegranate orchards due to moisture stress. Sometimes, farmers give preference to cotton crop over fruit crops in case of limited canal supply assuming that fruit crop can withstand moisture stress for longer time.

e) Irrigation scheduling of different crops under MIS : Irrigation of different crops was scheduled on the basis of previous day pan evaporation data. Reference crop evapotranspiration was calculated by using FAO-24 pan evaporation method (Doorenbos and Pruitt, 1977). The actual evapotranspiration was estimated by multiplying reference evapotranspiration and crop coefficients for different months based on growth stages. The daily net irrigation water requirement of different vegetable crops for drip irrigation system was estimated by using the following relationship:

$$V = (E_0.K_c.A) - (A.R_e) \qquad (1)$$

Where V is net irrigation water requirement on volumetric basis (litre / day / plant); E_0 is reference crop evapotranspiration (mm / day), which was estimated as E_0 equal to Pan evaporation (E_p) multiplied by pan factor (K_p); K_c is crop factor; A is area to be irrigated, m^2 (i.e. spacing between rows multiplied by spacing between plants); and R_e is effective rainfall (mm / day). Pan factor (K_p) for calculating reference crop evapotranspiration was adopted on the basis of Doorenbos and Pruitt (1977) considering pan siting, prevailing wind speed and relative humidity. In case of drip system, estimated amount of irrigation water was applied on alternate days during hot summer (April, May and June) while it was scheduled twice in a week during remaining period of the year. The same schedule was followed for micro-sprinkler system.

In case of fruit crops, net water requirement on volumetric basis under drip irrigation system was estimated by using the following equation, where canopy coverage of plant was considered.

$$V = (E_0.K_c.C_c.A) - (C_c.A.R_e) \qquad (2)$$

Where C_c is canopy factor and other parameters are the same as mentioned above. The Cc, for estimation of crop water requirement of tree, was determined as per Allen *et al.*. (1998). The K_c for estimating actual crop water demand for different fruit crops were considered on the basis of Allen *et al.*. (1998). In case of fruit crops, irrigation was applied twice in a week during peak summer i.e. April, May, and June and once in a week during the remaining year to meet water requirement as estimated by using equation 2.

Irrigation production efficiency (IPE) was estimated to assess the production per unit volume of water applied by using the following relationship.

$$\text{Irrigation production efficiency (kg / m}^3) = \frac{\text{Crop yield (kg / ha)}}{\text{Irrigation water applied (m}^3\text{ / ha)}} \quad (3)$$

f) Economic Evaluation: In case of economic evaluation, production cost, gross return and net return of produce for different irrigation systems were estimated with assumption that salvage value of the different components of irrigation systems will be zero after their useful life. Useful life of motor and sand filter was assumed as 12 years. It was taken as 20 years for storage water tank and 8 years for other components of irrigation system. Fixed and operating costs were considered during the analysis. The annual fixed costs of different components used for water storage, pumping and irrigation systems were calculated using the approach of James and Lee (1971) as given below.

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (4)$$

Where CRF = capital recovery factor, i = interest rate (fraction) at 9%, n = useful life of the component (years). Annual fixed cost/ha was estimated as CRF multiplied by fixed cost/ha.

The operating cost included labour charges (system installation and agronomic practices such as land preparation, irrigation, planting, hoeing, application of fertilizers and chemicals, harvesting, etc) land rent, fertilizers and chemicals cost, electricity charges, repair and maintenance cost. The gross return was calculated considering the produce yield and current wholesale price. Subsequently, the net return and benefit-cost ratio, payback period were calculated considering total cost of production (fixed and operating) and gross return. Pay back period of this technology was estimated as the number of years by which the net return equaled to the establishment cost of drip system in conjunction with service. Additional income was estimated as income with drip system over conventional system which included income from additional area cultivated with saved water by drip as well as increase in yield by adoption of the technology.

14.2 Results of the study

Studies were conducted in important fruits (guava, pomegranate, *kinnow* and strawberry) and vegetables (tomato, capsicum, potato and onion) of Northern India under different spacing to determine the effect of micro irrigation on water saving and economics by storing canal water in secondary reservoir. Effect of irrigation system on irrigation production efficiency and economics of fruits and vegetables in Northern India is presented in Table 14.1. The detail of result is presented crop wise:

14.2.1 Effect of microirrigation on guava: The detail of water applied and fruit yield of guava is presented in Table 14.1 which clearly indicated significant water saving with the use of drip irrigation in guava. About 29.05 and 29.10 cm irrigation water was applied in drip irrigated guava under 6 x 6 m 5 x 5 m crop geometry, respectively, as compared to 40.90 cm of conventionally irrigated guava. The plants maintained under drip irrigation system started bearing in 3rd year of planting whereas in flood irrigation fruit production started one year later i.e., 4th year. For analysis, 4th year data are considered. The drip irrigation produced about 69 and 67 percent higher fruit yield under 6 x 6 m 5 x 5 m crop spacing respectively over conventional irrigation system which resulted into better irrigation production efficiency (Table 14.1). Extra income due to drip irrigation was found to be Rs.44,835 and 81,566 per ha under 6 x 6 m 5 x 5 m crop spacing respectively. Hence guava cultivation with drip irrigation is profitable, and can be popularized in large scale in canal irrigated area of the arid to semi-arid eco-system of the country.

14.2.2 Effect of microirrigation on pomegranate: The amount of water applied to pomegranate was 29.37 and 29.98 cm under drip irrigation as compared to 43.8 and 44.2 cm respectively in basin system under 3.5 x 3.5 and 4 x 3 m plant spacing (Table 14.1). Saving of irrigation water allowed bringing about 0.49 and 0.47 ha more area under pomegranate with drip irrigation. The yield of crop was about 21.64 and 22.04 t/ha compared to 17.39 and 17.70 t/ha in basin method of irrigation for 3.5 x 3.5 and 4 x 3 m plant spacing, respectively. Further, it was worth mentioning that the quality in the form of fruit size was uniform than conventionally irrigated fruits. The net per ha extra income due to drip irrigation over conventional irrigation was about to Rs.134158 and 150915 in 3.5 x 3.5 and 4 x 3 m plant spacing, respectively. The investment required for adopting drip irrigation in canal irrigated area was about Rs. 136393 and 136060 per ha with plant geometry of 3.5 x 3.5 and 4 x 3 m, respectively. The interesting observation in pomegranate was that drip irrigation helped in regulating the flowering in such a way that crop could be harvested before the start of greater fluctuation in day and night temperature i.e. before 15 October which resulted into less cracking of fruits which is a serious problem in this region.

14.2.3 Effect of microirrigation on *kinnow*: The irrigation production efficiency of *kinnow* was found to be 5.39 and 5.68 kg/m^3 with drip irrigation as compared to 3.07 and 2.73 kg/m^3 under 6 x 6 m 6.5 x 6.5 m plant geometry, respectively. Investment of about 1,12,732 Rs/ha in 6 x 6 m plant spacing and Rs. 1,05,732 Rs/ha in 6.5 x 6.5 m spaced orchard is required to introduce drip irrigation system (including water storage facility etc.) in *Kinnow* orchard (Table 14.1). The net extra income Rs 1,35,791 and 1,74,581per ha was recorded due to adoption of drip irrigation system over conventional irrigation system under the plant spacing of 6 x 6 m and 6.5 x 6.5 m, respectively.

Table 14.1 : Effect of irrigation system on irrigation production efficiency and economics of fruit crops in Northern India

Particulars	Drip		Surface	
Guava				
Plant spacing (m x m)	6 x 6	5 x 5	6 x 6	5 x 5
Water applied (cm)	29.05	29.10	40.90	40.90
Yield (t/ha)	14.90	21.60	8.80	12.90
Benefit cost ratio	1.58	1.86	1.17	1.23
Irrigation production efficiency , Kg/m^3	5.13	7.42	2.15	3.15
Net extra income due to drip irrigation system over conventional irrigation system (Rupees)	44835	81566	-	-
Pomegranate				
Plant spacing (m x m)	3.5 x 3.5	4 x 3	3.5 x 3.5	4 x 3
Water applied (cm)	29.37	29.98	43.80	44.20
Yield (t/ha)	21.64	22.07	17.39	17.70
Benefit cost ratio	2.96	2.94	3.04	2.88
Irrigation production efficiency , Kg/m^3	7.28	7.36	3.97	4.00
Net extra income due to drip irrigation system over conventional irrigation system (Rupees)	134158	150915	-	-
Kinnow				
Plant spacing (m x m)	6 x 6	6.5 x 6.5	6 x 6	6.5 x 6.5
Water applied (cm)	82	71.05	126	126
Yield (t/ha)	44.20	40.40	37.9	34.5
Benefit cost ratio	1.92	1.95	1.55	1.69
Irrigation production efficiency , kg/m^3	5.39	5.68	3.07	2.73
Net extra income due to drip irrigation system over conventional irrigation system (Rupees)	135791	174581	-	-

Strawberry	Drip + Microsprinkler	Surface
Water applied (cm)	31.60	54.0
Yield (t/ha)	14.10	8.30
Benefit cost ratio	2.03	1.66
Irrigation production efficiency , Kg/m^3	4.46	1.54
Net extra income due to drip irrigation system over conventional irrigation system (Rupees)	439344	-

The important point is that pest and disease attack was very less in the orchard irrigated with drip system compared to conventional method due to better micro-climate. The number of fungicide sprays significantly reduced from 7 to 2 in case of drip irrigated orchard compared to conventional irrigated. It was found that during peak summer, when irrigation water is limited, sufficient amount of water can be provided by drip system which otherwise result into water stress in conventional system. This helps in mitigating water stress in drip irrigation system at any point of time and result into normal bearing (less flower drop in May-June and less fruit drop in November-December). Hence, application of water through drip can be managed according to climatic conditions for better and uniform fruit retention. Drip system reduces fruit drop due to constant supply of water by mitigating water stress during adverse climatic conditions. Normal bearing resulted in to higher yield for drip irrigated *Kinnow* orchard as compared to conventional irrigation method.

14.2.4 Effect of microirrigation on strawberry: Strawberry being a low surface creeping herb having shallow root system, hence water management is one of the most crucial factors for its cultivation in canal conman area, particularly in arid and semi-arid regions. Use of MIS (drip system + microsprinkler system) is well suited for proper growth and development of the plant water application through MIS helps in supplying precise water to the crop according to the stage of growth of the crop. Microsprinkler during early stage ensure early and easy establishment of runners besides vigorous growth of the plant. During reproductive phase (flowering and fruiting), micro-sprinkler system is replaced by drip irrigation which provide uniform & timely irrigation and facilitate fertigation. In traditional method, irrigation is given through furrow irrigation which results into fluctuation in soil moisture result into poor growth and fruit yields. Significant water saving has been recorded by introducing MIS in strawberry cultivation. In general, 31.6 cm irrigation water was applied in MIS compared to 54 cm in traditional method or irrigation thus shaving about 70 percent of water and 49 percent increase in fruit yield of strawberry (Table 14.1). Economic analysis of strawberry cultivation clearly show better B:C ratio of 2.03 compared to 1.66 under traditional method of furrow irrigation. Besides saving in water, with the use of microirrigation system, plastic mulch can also be used efficiently which help in moisture conservation, check weed growth and better fruit yield and quality of fruits. In brief, strawberry cultivation can be revolutionized with the use of microirrigation for higher productivity and profitability under arid and semi-arid regions.

14.2.5 Effect of microirrigation on tomato and capsicum: Tomato is the most important vegetable crop in term of area and production. Irrigation with drip system result into saving of 39 percent of water besides 47 percent increase in yield (Table 14.2). Adoption of drip irrigation in tomato can result in to increase in about 40 percent area, which can be put under cultivation with the use of drip system. Economic analysis of tomato production under drip irrigation system clearly indicate higher B:C ratio of 1.57. Besides higher fruit yield, the quality of the produce was also excellent into term of TSS, acidity and ascorbic acid content. Similarly, drip irrigation in capsicum result in to quality production of fruits, which can fetch higher prices in the market. Irrigation with drip system result into saving of 46 percent of water besides 30 % increases in yield. Adoption of drip irrigation in capsicum can result in to increase in about 45% area, which can be put under cultivation with the use of drip system. It has also been observed that adoption of drip system in tomato and capsicum resulted into saving of crop from frost during winter. Further, precise application of water through drip system also helps in controlling weeds, less disease incidence and less damage due to fruit rotting result into higher productivity and consequently higher profitability. The study clearly indicated that tomato and capsicum production with micro irrigation can facilitate better utilization of resources and higher productivity.

Table 14. 2 : Effect of irrigation methods on water productivity and economics of capsicum and tomato

Items	Capsicum		Tomato	
	Drip	Surface	Drip	Surface
Water productivity (kg / m^3)	7.32	3.85	13.1	6.43
Total cost of cultivation (Rs / ha)	96852	71900	97525	76500
Net returns (Rs / ha)	228148	178100	67475	36000
B:C ratio	3.36	3.47	1.69	1.47
Payback period (years)	2	-	4	-
Additional income due to adoption of technology	155096	-	57790	-

14.2.6 Effect of microirrigation on potato and onion: The seasonal water requirement of potato was found to be 25.75, 22.45 and 28.15 cm, respectively with microsprinkler, drip and surface irrigation methods. The yield of potato was about 32.1, 29.8 and 22.6 t / ha respectively, for microsprinkler, drip and surface irrigation methods. Further, it is possible to get the crop 7 to 10 days earlier in the market with microirrigation system than conventional irrigation method. The net return was highest in microsprinkler, while it was minimum in surface irrigated potato. The additional income due to microsprinkler and drip irrigation over conventional method is about Rs. 31,024 and 18,770 per ha, respectively (Table 14.3).

Table 14.3 : Effect of irrigation methods on water productivity and economics of potato and onion

Items	Potato			Onion		
	MS*	D**	S***	MS*	D**	S***
Water productivity (kg / m^3)	12.5	13.3	8.03	8.1	7.1	4.7
Total cost of cultivation (Rs / ha)	59190	65833	47892	54543	61669	38352
Net returns (Rs / ha)	56473	42152	33920	53011	43113	33042
B:C ratio	1.94	1.64	1.71	1.97	1.70	1.86
Payback period (years)	4	7	-	5	8	-
Additional income due to adoption of technology	31024	18770	-	27391	11365	-

***MS: Microsprinkler; **D: Drip system; ***S: Surface irrigation**

The seasonal irrigation water applied to onion was recorded as 43.26, 47.75 and 49.36 cm, respectively under microsprinkler, drip and surface irrigation methods. It has been observed that crop got matured about 10- 15 days earlier than conventional irrigation methods due to faster growth during early stages. Additional area cultivated due to saving of water by virtue of adoption of microsprinkler and drip was 0.14 and 0.03 ha. The extra income due to microsprinkler and drip irrigation over conventional method is about Rs. 27,391 and 11,365 per ha, respectively. It is clear that onion production with microsprinkler and drip irrigation systems were profitable than traditional irrigation method, however, microsprinkler was found to be the most appropriate irrigation technique to maximize the profit from per unit cropped area by storing canal water in secondary reservoir. Further, since, in the present experiment, conventional irrigation method also had ensured water supply from stored water for microirrigation, but in actual condition, there is uncertainty in canal water availability, which may lead to further water stress and yield reduction. Hence, comparative economics may be even better than this in favour of introducing microirrigation systems in canal irrigated areas.

Conclusions

Study indicated that microirrigation technologies recorded significant improvement in productivity over the conventional methods of irrigation for all the test crops. Drip system was found most suitable for irrigating fruit crops and tomato and capsicum in a canal command by storing water in secondary reservoir. However, the yield response to the microsprinkler system was superior to that of drip system for onion and potato. Out come of the study suggests that microirrigation with secondary reservoir is technically feasible and economically viable alternate for crop diversification at the tail end of a canal command for higher water use efficiency and profitability. The same model can be adopted with some element of creativity for enhancing water productivity in other tail-end of the canal commands for sustainable development.

References

Aggarwal, R., Kaushal, M. P., Kaur , S and Marwaha, B. 2009. Water resource management for sustainable agriculture in Punjab. *Water Science and Technology*. 60 (11): 2905-2911.

Allen, R.G, Pereira, L.S, Raes, D and Smith, M. 1998. *Crop evapotranspiration-guidelines for computing crop water requirements.* Food and Agricultural Organization of United Nation (FAO), irrigation and drainage paper No. 56.

Anbumozhi, V, Matsumoto, K and Yamaji, E. 2001. Towards improved performance of irrigation tanks in semi-arid regions of India: modernization opportunities and challenges. *Irrigation and Drainage System* 15(4), 293-309

Doorenbos, J and Pruit, W.O. 1977. Guidelines for predicting crop water requirement. *Food and agricultural Organization of United Nation. FAO irrigation and drainage paper.* No.24, 144.

Hanson, B.R., Schwanki, L.J., Schulbach, K.F. and Pettygove, G. S. 1997. A Comparison of furrow, surface drip and subsurface drip irrigation on lettuce yield and applied water. *Agricultural Water Management.* 33: 139-157.

James, L.D and Lee, R.R.1971. *Economics of water resources planning.* McGraw Hill, New Delhi. P: 20.

Kumar S., Singh Rajbir., Bhatnagar P.R., Gupta R.K.and Nangare D.D. 2008. Microirrigation in conjunction with service reservoir in canal command. *Technical Bulletin APA/Pub/03/2008.* Central Institute of Post Harvest Engineering and Technology, Ludhiana.

Kumar, S., Imtiyaz, M., Kumar, A. and Singh, Rajbir. 2007. Response of onion (Allium cepa L.) to different levels of irrigation water. *Agricultural Water Management.* 89 (1-2): 161-166.

Navalwala, B.N .1991. Waterlogging and its related issues in India. *J Irrigation and Power* 55–64.

Singh, R., Kumar, S., Nangare, D.D. and Meena, M.S. 2009. Drip irrigation and black polyethylene mulch influence on growth, yield and WUE of tomato. *African Journal of Agricultural Research* 4 (12): 1427-1431.

CASE STUDY

15.0 ENHANCING CROP PRODUCTIVITY AND WATER USE EFFICIENCY IN JLN LIFT IRRIGATION PROJECT

A.S Dhindwal and V.K. Phogat

The growth in population combined with the expected increase in prosperity will put enormous pressure on water resources in more than 60% of the world. The availability and utilization pattern of water varies with respect to time and space. Water being a finite natural resource, enhancing water productivity by producing more food per drop of water is the only available option to feed ever-increasing population. Scarcity and gradual decrease in the share of water for agriculture in semi-arid regions necessitate adoption of efficient technologies, and integrated management of available water resources at farm and regional scale. Therefore, water management in India is going to play a crucial role in shaping the national economy.

Haryana is basically a water resources deficit state. About 75% areas have an aridity index of less than -40. In spite of the fact that two third of the ground waters are of poor quality its exploitation has reached an alarming level of more than 90%. At present, the total utilizable water resources fall short by over 40% and there is limited possibility to further increase the irrigation potential. This gap will further widen as the share of water for irrigation is likely to reduce from 82% at present to 75% by 2025 due to competition from other sectors. Productivity of water is extremely low at farm and regional scale. During the last four decades, location specific technologies for water resource scarce regions have been developed to improve the water productivity. However, their real time adoption is not very encouraging owing to many factors. Identification, dissemination and adoption of efficient water management and other production technologies suiting to varying socio-economic and agro-ecological conditions and their refinement at various levels will lead to considerable improvement in the water productivity, maintain hydrological balance and soil health. The study aimed at reconciliation of water supply and crop demand, testing the efficient water management practices on the selected ditstriburaries of the JLN command in southern Haryana and assessing their impact on water productivity.

15.1 The detail of study

The study area, a compact block of about 1800 ha, covering mainly the arid and semi-arid parts of southern Haryana was located between 27º 48' N and 28º 28' N latitude and 75º 55' and 76º 53.5' longitude (Fig.15.1). It represented the entire command with regard to cropping pattern, irrigation water resources, weather conditions and soil characteristics. Studies were taken up from 1992 to 2000 on eight outlets located at head, middle and tail reaches of the two representative distributaries namely Rampuri and Pathera under the command of JLN Lift Irrigation Project, details of which are given in Table 15.1.

The area was faced with following major water management problems:

- Untimely and inadequate canal irrigation water supplies.
- Unauthorized pumping of canal water from canal and upper reaches of distributaries.
- Non-implementation of warabandi (supply based on area by rotation) system.
- Very poor maintenance of water courses.
- High seepage losses in watercourses and distributaries
- Brackish ground waters and overexploitation of ground waters

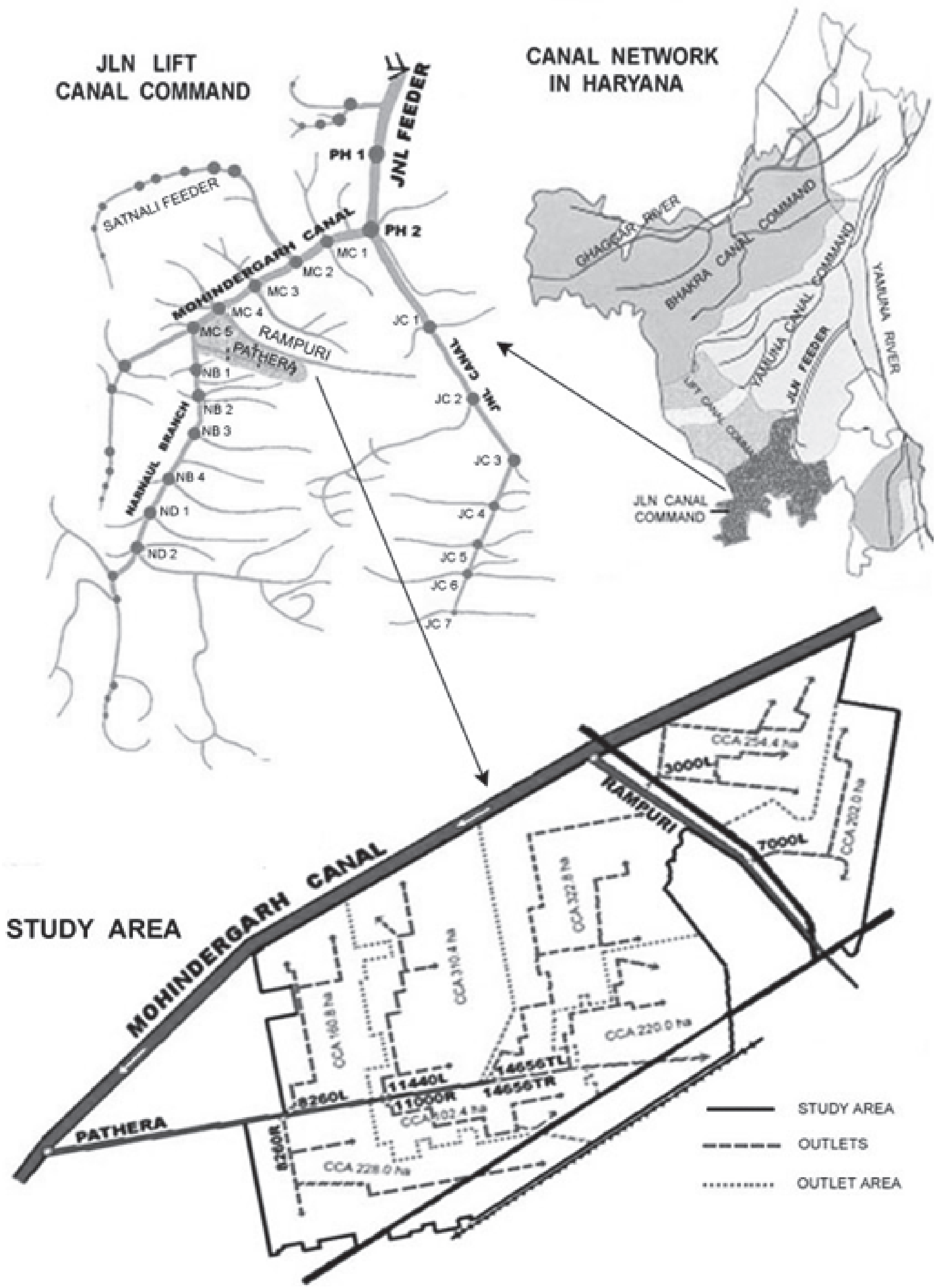


Fig. 15.1 Irrigation map of Haryana, JLN lift irrigation project and the study area

- Mis-match between cropping pattern and water supplies
- Ineffective water users' associations and
- Non-judicious use of irrigation water by the farmers

15.2 Water balance of the study area

The various water balance parameters were estimated at field, farm and regional scale during the study period. Effective rainfall was estimated using USDA Soil Conservation Service method. Reference ET was computed according to Penman-Monteith approach. Crop and irrigation requirements, and scheme water supply were estimated by using CROPWAT model. This model provided the irrigation calendar for the entire season, the efficiency of irrigation schedule, efficiency of rainfall, total and gross irrigation and actual water use by crops, and the reduction in yield. Ground water exploitation was worked out on the basis of tube-well discharge and the running hours. Discharge at the head of distributary and outlets and running hours were used to calculate the actual canal water availability. RWS_{CWR} is the total water supply (i.e., rainfall + canal + ground water) as a percentage of the net crop water requirement. RWS_{IWR} is the total irrigation water supply (i.e., canal + ground water) as a percentage of the net irrigation requirement. Water productivity of each crop was worked out by taking into account the economic yield and water used. The water availability is presented in Fig. 15.2.

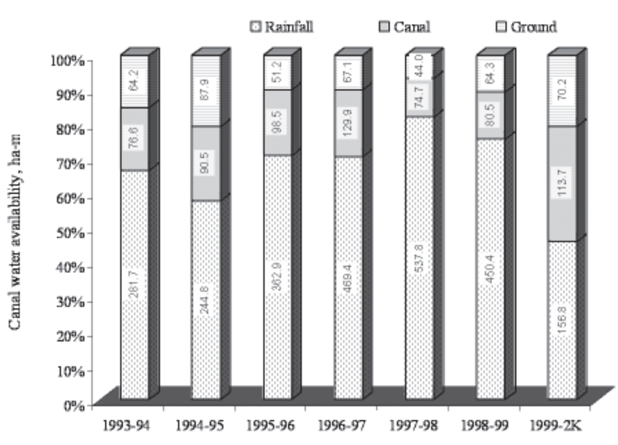


Fig. 15.2 Water availability in the study area different sources

The combined RWS_{CWR} of kharif and rabi seasons was more than 80% in 1997-98, around 74% in 1996-97 and 1998-99, around 70% in 1995-96, around 63% in 1993-94 and 1994-95 and 54% in 1999-2000. RWS_{IWR} fluctuated between 45.3% and 37.3% (Fig. 15.3).

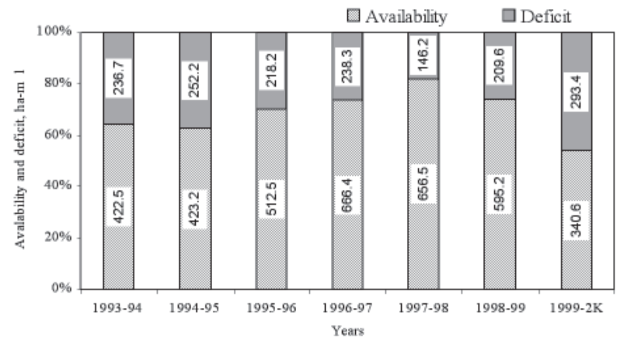


Fig. 15.3 Availability and deficit of water and relative water supply in the study area

15.3 Yield and Water Productivity

With the adoption of recommended crop production and water management practices, the average yield of wheat increased by about 9%, raya, pearlmillet and clusterbean by 16%, and chickpea by 24% as compared to the farmers' practices (Table 15.1). Cotton, pigeonpea, mungbean and fenufgreek registered about 30% increase in yield. Hussein et al. 2003 observed yield variations with the amount of irrigation and the timing of water stress. The amount of irrigation water used was substantially reduced as result of these interventions. Thus, a saving of 10% irrigation water in wheat, around 15% in raya and clusterbean, around 17% in chickpea and cotton, around, 20% in mungbean and pearlmillet, and 28% in pigeonpea was recorded (Table 15.1). Higher yield and water saving in different crops were observed with improved water management practices at farmers' fields in semi-arid region. At farmers' fields substantial increase in water productivity of all the crops was achieved with the improved practices in comparison with farmers' practices. It increased by 21.6, 35.7, 48.8, 56.9, 47.3, 37.8, 60.6, 93.4 and

Table 15.1 : Yield, water used and WP of different crops under farmers' and efficient practices

Crops	Number of trials	Yields (kg/ha)		Irrigation water used (ha cm)		Water productivity (kg/m^3)	
		Farmers	Efficient	Farmers	Efficient	Farmers	Efficient
Wheat	252	3953	4324	40.0	36.0	0.99	1.20
Raya	217	1504	1745	14.5	12.4	1.04	1.41
Chickpea	65	531	657	7.7	6.4	0.69	1.03
Fenugreek	52	363	471	8.1	6.7	0.45	0.70
Pearl millet	100	979	1140	5.7	4.5	1.78	2.53
Cl. bean	121	706	827	6.0	5.1	1.18	1.62
Cotton	69	535	715	18.0	15.0	0.30	0.48
Pigeon pea	32	503	703	7.2	5.2	0.70	1.35
Mungbean	45	348	457	5.3	4.3	0.66	1.06

Table 15.2 : Adoption level of WM technologies by the farmers of the study area

Crops	Adoption level of technology (%)				Irrigation (no. and amount)	Mean grain yield, kg/ha
	Land levelling	Irrigation method	Irrigation scheduling	Conjunctive use		
Clusterbean	64	78	56	27	2.4 (17.2)	1376
Pearlmillet	62	78	61	56	2.1 (14.3)	1739
Cotton	87	81	73	64	4.5 (27.4)	812
Mungbean	92	62	76	35	2.4 (14.2)	735
Wheat	96	96	86	88	5.8 (32.8)	4302
Raya	94	93	75	92	2.2 (14.5)	2102
Chickpea	65	45	64	71	1.8 (12.8)	645

61.8% in wheat, raya, chickpea, fenugreek, pearlmillet, clusterbean, cotton, pigeonpea, and mungbean, respectively. Hamdy et al., 2003 also reported increased water productivity under deficit irrigation.

The total amount of water which could be saved by the adoption of improved water management practices in the study area varied from 19.4 in 1995-96 to 51.4 ha m in 1998-99 (Fig. 15.4). In certain years, no irrigation was applied in kharif crops due to good rains and hence no saving of irrigation water. Depending upon the area under a particular crop, the water saving varied from 0.45 ha m in pigeonpea to 14.71 ha m. Due to

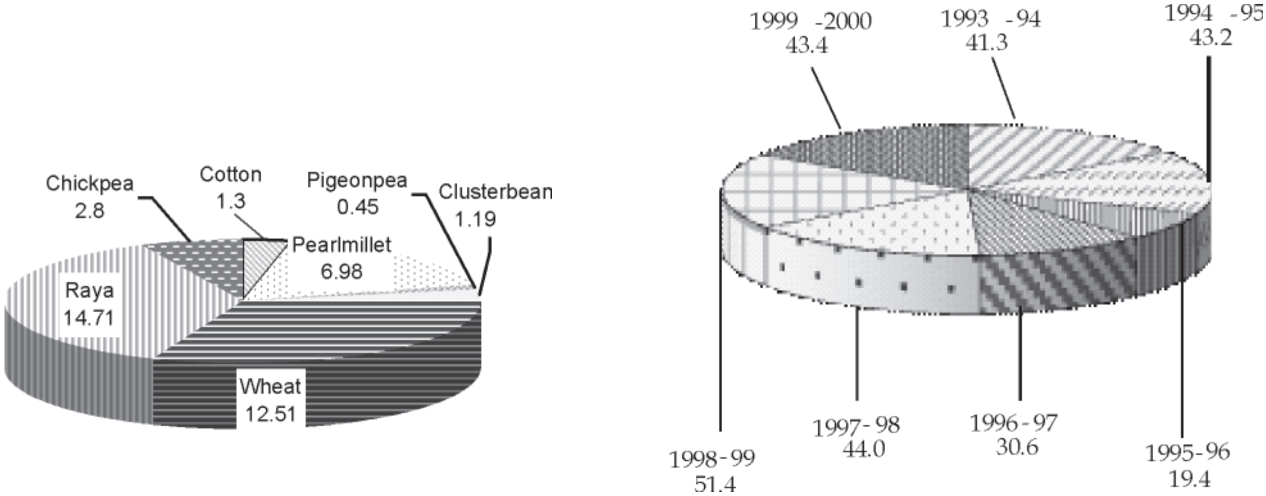


Fig. 15.4 Averaged crop wise and year wise water saved (ha-m) in the study area

package interventions, about 40 ha m water could be saved in the study area, annually. The water thus saved can be used to either enhance the irrigation potential of the area or to provide optimum irrigation, without stress, to the existing crops. This will ultimately improve the total crop and water productivity.

15.4 Adoption Level of Improved Water Management Technologies

The efficient WM technologies, demonstrated in the selected outlet command of Rampuri and Pathera distributaries during the study period, were evaluated for their adoption by the farmers. Adoption of land leveling was more than 90% in mungbean, wheat and raya crops (Table 15.2). It was 87% in cotton and more than 65% in other crops. The adoption of appropriate irrigation method was more than 90% in wheat and raya, around 80% in *kharif* crops, except mungbean (62%), chickpea (45%). Irrigation scheduling as per crop water requirement was highest in wheat (86%) and lowest in clusterbean (56%) and was around 75% in other crops. Conjunctive use of ground water with canal water was greater in *rabi* crops (71-92%) as compared to *kharif* crops (27 to 64%).

CASE STUDY

16.0 ENHANCING CROP PRODUCTIVITY AND WATER USE EFFICIENCY IN DEEP TUBE WELL COMMAND (DTW)

S.K. Patra and A. Zaman

West Bengal with 2.7 per cent of geographical area and 7.5 per cent of water resource can mitigate the demands of 8 per cent of the country's population. In the state, water is going to be the limited commodity in near future due to the competing demands from the other sectors as a result of rapid industrialization and urbanization and economic development. Out of the available water resource of 14.75 mham, the surface water resources is 13.29 mham of which less than 40 percent i.e. about 5.31 mham is utilized. The available ground water resource accounts for 1.46 mham, which is fully utilizable. The present water crisis is largely due to misuse or abuse of water and lack of adequate reservoirs to harvest the excess rainfall. The greatest culprit is the agricultural sector which consumes the largest quantity of water especially after introduction of high yielding *boro* paddy. The gangetic basin once described as the areas of excess water now suffers from acute dearth of water especially during the lean summer months. The spatial and temporal variability of rainfall is uneven and erratic and so wide that it causes the twin menaces of flood and drought in one region or others. Out of six agro-climatic zones in the state, the Deep Tube Well command (DTW) encompassing the New Alluvial Zone is of much relevance.

The DTW command is the largest and agriculturally most potential fertile tract of the state. The cultivable area is 17.274 lakh ha. The land topography in general is flat alluvial flood plain characterized with many concave basins or depressions. The areas are criss-crossed with many rivers such as Bhagirathi (Hooghly), Mahananda, Ichamati, Churni, Jalangi and Saraswati etc. All types of agricultural crops are grown with assured supply irrigation water. The main water resources are canal, river lift irrigation, and shallow and deep tube wells. However, chronic or temporary inundation of the flat land by ravaging floods almost in every year seriously impairs the agricultural activity in general and the socio-economic fabric as a whole. Waterlogging occurred at varying degree in the districts like Nadia and parts of Malda, Murshidabad, Hooghly, Howrah, Burdwan and North-West Dinajpur. This adverse situation is associated with prolonged siltation, impeded drainage and reduction of the hydraulic capacity of the rivers and the drainage canals. In the rainy months, the water level of almost all rivers rises up to dangerous level due to rainfall-runoff water accumulation. The water release from these rivers and upper catchments causes inundation of the crop lands, which situational locations lies either at a same level or below the nearest river bed flow line. Besides, the structural design of most of the embankments is not strong enough to withstand the high pressure of stagnated water level. This results in the release of vast quantity of excess water either by overtopping or by breaking embankments or through sluice gates. As a consequence, a huge land mass is flooded every year. However, the depth and duration of land submergence varies considerably according to the land topography and natural drainage behaviour.

16.1 AICRP on WM

The AICRP on Water Management, BCKV, Gayespur center developed various technology packages for higher water use efficiency in different crops. The some of the important are mentioned below:

a) Conversion of earthen irrigation channels into low-cost bamboo reinforcement *pucca* channel and use of PVC pipes for delivering water in the crop field were well accepted by local farmers to avoid conveyance and deep percolation losses and increasing the irrigated areas.

b) Conventionally summer rice is raised under continuous submergence with excessive amount of irrigation water and lower water use efficiency. However, under constraints situation, the water use efficiency can be increased with lower irrigation requirement when irrigation is given intermittently at 5 cm depth, 1 day after disappearance of ponded water. This could save about 15% of costly irrigation water. This finding is highly accepted by the boro rice growers, the highest consumer of irrigation water, for significant savings of irrigation water without compromisation of yield and profitability of rice.

c) The AICRP on Water Management, BCKV center developed different irrigation scheduling criteria for different crops (Table 16.1) based on the different physiological stages of the crop or soil moisture depletion or pan evaporation reading with a view to considerably saving of irrigation water.

Table 16.1 : Different irrigation scheduling criteria for different crops

Crop	Phenological stages	Moisture tension (Bar)	IW:CPE
Wheat	CRI, Till, Fl, Gr-fill	0.6	1.0
Potato	-	0.33 (20 cm)	1.2
Mustard	Br, Fl	0.8	0.6
Groundnut	Fl, Pod dev	0.6	0.6-1.0
Maize	Ini, Tass, Milk	0.55 (veg), 0.35 (repro)	1.2
Cabbage	Ini, Head dev	0.6	1.5
Cauliflower	Ini, Curd dev	0.6	1.5
Onion	Ini, Veg, Ma	0.5	1.2

d) On long-term field trials, Irrigation Calendar was also developed based on IW / CPE ratio under different dates of planting of crops (Table 16.2). This 'Irrigation Calender' was recommended for the DTW command in alluvial zone.

The AICRP on Water Management developed numerous water management technologies on different field crops including fruits, vegetables and flowers under assured supply of irrigation water in deep tube well command with a view to increasing crop and water productivity and nutrient efficiency for onward transmission and adoption in the farmers' fields. Some promising, adoptable and remunerative technologies are hereunder:

Table 16.2 : Irrigation calendar in the deep tube well command for efficient water use

Crop	Date of planting	Day of irrigation after sowing							
		1	2	3	4	5	6	7	8
Wheat	1st Nov	21	47	77	100				
	15th Nov	24	53	80	106				
	1st Dec	27	50	75	94				

Potato	1st Nov	7	20	33	51	69	84	98	108
	15th Nov	5	15	29	47	64	79	91	103
	1st Dec	5	16	34	52	67	79	90	107
Mustard	15th Oct	23	53	89					
	1st Nov	27	58	93					
Groundnut	1st Feb	31	53	67	84	100			
(Summer)	15th Feb	26	47	66	79	96			
	1st Mar	23	42	59	72	89			
Cabbage &	1st Sep	43	63						
Cauliflower	15th Sep	28	48	77					
	1st Oct	13	20	29	49	50	64		
Rice (*kharif*)	3 days after disappearance of ponded water								
Rice (*boro*)	1 day after disappearance of ponded water								

Water Management Technologies generation for enhanced WUE in DTW Command

Summer Rice (Transplanted)	Continuous submergence of 5±2 cm water gave the highest grain yield of rice with 100 kg N / ha (6.08 t / ha). WUE increased with lesser number of irrigation and found maximum when irrigation was given at 5 cm depth, 1day after disappearance of ponded water which could save about 42% of irrigation water.
Wheat	Irrigation with IW / CPE 1.2 at 5 cm depth (cv.UP 262) with 100 kg N / ha gave the highest grain yield of 28.75 q / ha.
Rice-wheat	Practice of shallow intense puddling of rice followed by normal tillage of 15 cm depth by tractor drawn cultivator gave maximum productivity of wheat up to 31.66 q / ha with a water use efficiency of 0.755 kg / ha / cm
Crop Sequences	Rice-potato-m*oong* showed the maximum benefit:cost ratio while it was minimum with rice-mustard-sesame sequence, although showing maximum water use efficiency.
Potato	Three irrigations, one each at weekly interval before furrow making followed by three irrigations one each at 20 days intervals (IW / PE 0.9 at 5 cm irrigation) was the best irrigation schedule for potato.
	In lowland rice ecosystem, single irrigation at IW / CPE 0.6 with 4 cm depth produced 11.26 t / ha tuber yield showing water use efficiency of 9.69 kg / ha / mm. Mulching with paddy straw enhanced potato yield.
Mustard	The grain yield of mustard was recorded highest when two-irrigation at IW / CPE of 0.6 with 5 cm depth of irrigation applied at branching (33 DAS) and flowering (55 DAS) stage with 80 kg N / ha.

Winter Maize	The grain yield of maize performed better when irrigation was applied at IW / CPE of 1.2 with 5 cm irrigation depth compared to irrigation at 0.6 IW / CPE. The crop significantly responded to increasing levels of nitrogen up to 160 kg N / ha. Water use and water use efficiency values were also found to respond accordingly.
Cauliflower	Curd yield of cauliflower was increased by 23% when it was irrigated at IW / PE of 1.2 at the irrigation depth of 5 cm each which required 5 irrigations at about 15 days interval.
Cabbage	Irrigation at 20 mm cumulative pan evaporation (CPE) with 120 kg N / ha gave the highest head yield of cabbage to the tune of 41.92 t / ha with water use efficiency value of 1.8 t / ha / cm
Onion	Three irrigations at IW / PE of 1.2 ratio (5 cm depth each) found optimum for maximum crop yield. The crop was transplanted in December after harvesting lowland rice.
Soil Water Balance	The capillary contribution towards the evapotranspiration of various arable crops was estimated to be 15 to 20% of the total actual ET contributed from groundwater source when the depth of water table lying within 2 m which reduced to 5% if it remained below 2 m depth.
Coriander	Four irrigations at an interval of 12-16 days (ø = 0.03 Mpa soil-water suction) with 60 kg N / ha gave the highest yield of 7.94 q / ha with WUE of 2.52 q / ha / mm.
Garlic	In alluvial sandy loam soils, irrigation at 25 mm CPE with 5 cm water produced 4.3 t / ha of bulb yield with water use efficiency of 15.8 kg / ha / mm. Mulching with paddy straw or water hyacinth saved considerable water and enhanced yield.
Sunflower	The contingent crop cultivated on residual soil moisture after *kharif* rice and irrigated at IW / CPE 1.2 produced 5.25 t / ha seed yield and water use efficiency of 19.94 kg / ha / cm. Sowing within second fortnight of December was favourable for higher seed yield.
Tomato	Five Irrigations at 15 days interval at 25 mm CPE with black polythene mulch registered maximum yield of tomato (cv. *Rocky*, F_1 hybrid) to the tune of 47.0 t / ha with water use efficiency of 2.64 q / ha / mm.
Field pea	The crop cv. *B-22* irrigated at ø = -0.03 Mpa soil-water suction at 20 cm depth (three irrigation at 20-23 days interval) and fertilized with 60 kg P_2O_5 / ha produced 1.47 t / ha seed yield and water use efficiency of 6.31 kg / ha / mm.
Chilli	Three irrigations one each at 1.2 IW / CPE (5 cm irrigation depth) was found optimum to get highest yield of green chilli to the tune of 5.87 t / ha with water use efficiency of 44.54 kg / ha / cm.
Rajmash	The crop cv. *Contender* irrigated at ø = -0.04 Mpa soil-water suction at 20 cm depth (two irrigations at 25 days interval) and fertilized with 60 kg P_2O_5 / ha produced 8.74 q / ha seed yield and WUE of 5.26 kg / ha / mm.

16.2 Impact of water technologies adopted by the farmers

The pattern of adoption and non-adoption of the water management technologies in the farmers' field and its corresponding benefit in terms of socio-economic goal in different command areas (Mayurakshi, DVC or DTW irrigated command) have shown positive impact and now farmers in small groups have taken interest to adopt the proven technologies in their fields and are benefited substantially. The adoption of proven water saving technologies in the farmers' plots reflected higher crop production compared to their traditional methods. The technologies generated increased the water use efficiency and prevented application and conveyance losses. Selection of appropriate crop(s) and crop sequence(s) played an important role for enhancement of water use efficiency. The success gave encouragement and impetus to the fellow farmers to keep the process towards adoption through formation of various Water Users' Committees. Following are the most important changes:

- Rice was the dominant crop during rainy season in the study area. There was no difference in yield of rice under farmers' practice and experimental blocks due to sufficient amount of well-distributed rainfall. But there was difference in yield of *Aus* paddy in farmers' practices and experimental block. The fertilizer response was variable because of differential depth of submergence followed by the end-users. The farmers' practice to use more fertilizers with more depth of submergence was resisted.
- The farmers traditionally followed potato cultivation with high doses of fertilizers and more water. The intervention to apply optimal fertilizers as well as irrigation for yield maximization of the crop was succeeded.
- With recommended water management practices, grain yield of mustard was increased by 9% with water use efficiency of more than 36%.
- Summer groundnut was introduced with recommended water management practices wherein the farmers achieved higher seed yield, more WUE and remunerative value.
- About 36% of potato growers, 25% of rapeseed-mustard growers and 50% of summer rice growers followed the proven water management technologies to achieve higher water use efficiency. Low water-requiring crops like onion and groundnut gained popularity over summer rice resulting in considerable saving of irrigation water during the lean summer season.

16.3 Case study of enhanced WUE in ORP

The center has made stupendous effort in the adoption of proven water management technologies in the farmers' field with a participatory mode. A large number of site-specific and need based technologies like raised bed-furrow irrigation on tomato, cabbage and cauliflower; use of polythene channel lining and polythene pipes (PVC) to reduce the conveyance and application losses of irrigation water; intermittent ponding of summer rice (boro) for saving of irrigation water to the extent of 30%; scheduling of irrigation for wheat and mustard; spout-wise rotational water supply to rice and wheat grown simultaneously and minimal tillage in wheat and mustard were adopted in the farmers' fields successfully. The cost-effective water management technologies that are affordable and acceptable to the farming community are given below:

i) Zero-tillage wheat in lowland rice ecosystem

The transplantation and harvesting of *kharif* rice in lowland ecosystem is delayed due to late monsoon rain. The excessive wetness of soil poses difficulty in achieving proper soil workable condition and maintaining timeliness of field operation, thereby sowing of *rabi* crops in time.

Under these circumstances, sowing crops like wheat and mustard using minimal or zero tillage technique is a good proposition and better option to exploit the available residual soil moisture for seed germination.

Sowing of wheat was done immediately after *kharif* rice harvest with zero-tilled seed drill machine in lowland under prevailing sufficient residual soil moisture preferably within the first week of December.

The results in Table 16.3 showed that zero-tilled (ZT) wheat with three irrigations recorded the grain yields ranging from 1160 to 2460 kg / ha obtained by the eighteen farmers with an average of 1536 kg / ha. On the contrary, the conventional tillage (CT) with three irrigations recorded the grain yields ranging from 1720 to 2800 kg / ha with an average of 2020 kg / ha. Wheat cultivation under conventional tillage in lowland clay soil was not feasible due to drainage congestion and water excess especially at CRI stage on applied irrigation causing yellowing of plant leaf. Water use efficiency of ZT wheat was 6.16 to 11.60 kg / ha / mm, while CT showed the highest WUE of 12.20 kg / ha / mm. Farmers' acceptance for growing wheat under zero tilled conditions was mainly attributed to higher benefit-cost ratio compared with conventional tillage.

Table 16.3 : Yield and water use efficiency of wheat under zero tillage situation

Parameter	Zero tillage		Conventional *	
	Case 1	Case 2	Case 3	Average
Area covered (ha)	0.13	0.06	0.09	0.13
Grain yield (q / ha)	24.6	18.2	11.6	20.2
No. of irrigation	3	3	2**	3
Water used (mm)	226	214	189	243
WUE (kg / ha / mm)	8.71	8.50	6.16	7.20

*** Two passes of harrowing done by tractor and seeds were broadcasted, ** No irrigation at CRI**

ii) Water management of wet seeded rice during kharif season (drum seeder)

Drum seeding of wet rice in well-drained medium upland was done during *kharif* season. Shallow puddling using one pass of power tiller followed by a bullock drawn country plough was adequate for drum seeding in clay soil. Sprouted seeds and Philippines 12-row plastic drum seeder involving two farmers were used in the adaptive trial. The crop performances under wet direct seeding (DR) and transplanted rice (TR) methods is given in Table 16.4 as follows:

Table 16.4 : Crop performances of drum seeding technique during *kharif* season

Item	Case study 1		Case study 2	
	DR	TR	DR	TR
Date of sowing	27.7.06	27.7.06	27.706	27.7.06
Variety used	Ratna	Ratna	IET 4094	IET 4094
NPK (kg / ha)	60:30:30	60:30:30	60:30:30	60:30:30
Date of harvesting	2.11.06	8.11.06	2.11.06	8.11.06
Grain yield (t / ha)	4.30	3.53	3.90	3.40
Straw yield (t / ha)	6.05	4.70	5.40	4.85

DR: wet direct seeding, TR: transplanted rice

The above results showed that the grain and straw yields of wet seeded rice in the command was superior to transplanted one. The increase in grain yield was 22.8 and 14.7% for Ratna and IET 4094, respectively. Harvesting of wet seeded rice was completed one week earlier than transplanted one. Hence, the resource poor farmers accepted the drum seeding technique well especially during the period of low rainfall. However, there is a limitation of this technology in water stagnated condition under high rainfall condition because of the difficulty in the operational mechanism as well as plant emergence problem.

iii) Residual moisture utilization through paira cropping (Utera) in rice with mustard and toria

Aman rice is generally harvested in the middle of November leaving behind a significant amount of residual soil moisture in lowland ecosystem. Brown mustard (rai) and toria (rapeseed) were broadcasted over the standing rice 10-15 days before harvest of winter rice. Complex fertilizer like Suphala @ 150 kg / ha and seeds @ 7.5 kg / ha each were applied. One irrigation at maturity for toria and two irrigations at branching and flowering for mustard were given. Crops were harvested within February to first week of March. About 20-27 farmers participated in the programme over the years 2006-2010 and the area coverage was 2.30 to 2.84 ha. The yields of mustard and toria amongst 27 farmers varied between 580-1150 kg / ha with an average of 760 kg / ha. In *Paira* cropping with lowland rice, the residual moisture utilization pattern was 39.1 to 50.1 mm in clayey soil. The performances of both crops are given in Table 16.5 as below:

Table 16.5 : Performances of mustard and toria as *paira* crops in standing rice

Item	Mustard	Toria
Date of seeding	3 / / 11 / 05	5 / 11 / 05
Irrigation number	23 / 12, 15 / 1	23 / 12
Plant height (cm)	96.3	56.0
Seed yield (q / ha)	11.5	7.5
Water used (cm)	17.8	12.5
WUE (kg / ha / mm)	6.46	6.0

Paira cropping of mustard and toria was very promising for residual moisture utilization after rice harvest especially where irrigation water supply was scarce or limited. One and two irrigations were sufficient for successful raising of toria and mustard. Water use efficiency of mustard and *toria* varied between 4.63 to 6.46 kg / ha / mm.

CASE STUDY

17.0 ENHANCING CROP PRODUCTIVITY AND WATER USE EFFICIENCY IN PERIYAR VAIGAI COMMAND

S. KRISHNASAMY

The Periyar Vaigai Irrigation System is one of the oldest irrigation systems in India existing since 1898. It is the second largest irrigation project in Tamilnadu next only to the Cauvery System. The command area of the project is located in the plains of the Southern districts of Tamil Nadu between 9°45' and 10° 15' N latitudes and 77°.0' and 78° 10' E longitudes. It extends over parts of Madurai, Theni, Dindigul and Sivagangai districts. It is bounded on the north by Coimbatore and Tiruchi districts, on the east by Bay of Bengal, on the west by the State of Kerala and Coimbatore district and on the south by Sivagangai and Virudunagar districts. Periyar-Vaigai System is the first exercise in the interstate transbasin transfer of west flowing rivers to the east wherein the waters from the Periyar Basin in Kerala are diverted to the Vaigai Basin in Tamil Nadu. The system consists of two reservoirs viz., Periyar and Vaigai Reservoirs, the command area in Cumbum valley and the downstream area of Vaigai Reservoir.

17.1.1 Periyar Reservoir

The Periyar River originates in Kerala State on the western slopes of the Western Ghats and flows in a northerly direction for a length of 57.6 km (36 miles) in the hilly tract and ends up in Arabian Sea. Across an inaccessible gorge at this place, a solid masonry gravity dam was built in 1895. Given the technical constraints of the period of construction and the nature of terrain, it is indeed a great engineering marvel. The dam is 158' (47.4 m) in height and 1440' (432 m) in length. The storage capacity is 443.5 million cubic meters (15660.43 million cubic feet – 15.66 TMC).

17.1.2 Vaigai Reservoir

The River Vaigai originates on the eastern slopes of the Western Ghats, flows through Madurai, Theni, Sivagangai and Ramanathapuram districts and ends up in the Bay of Bengal. It has many tributaries, the major ones being Suruliyar, Theniar, Varattar, Nagalar, Pambar, Varaganathi, Marudhanathi, Manjalar, Sirumalaiyar, Sathiar and Uppar. The river basin extends over 7031 sq.km and is one of the 17 major river basins of Tamil Nadu. The basin receives an annual rainfall of 882 mm of which 291 mm is received during South West monsoon and 402 mm during North East monsoon. The Vaigai Dam stores the water diverted from Periyar Reservoir as well as the water from the catchment of Vaigai river. Out of the total storage capacity of Vaigai dam, Periyar credit is 4000 M.cu.ft (4 TMC) and Vaigai credit is 2800 M cu ft (2.8 TMC).

Salient features of reservoirs

Periyar Reservoir			
1.	Full Reservoir Level (FRL)	46.33 m	(152.00 ft *)
2.	Minimum Draw Down Level (MDDL)	31.70 m	(104.00 ft)
3.	Reservoir capacity at FRL	443.50 MCM	(15660.43 Mcft)
4.	Reservoir capacity at MDDL	144.20 MCM	(5091.85 Mcft)
5.	Tunnel Discharge Capacity	3.92 MCM / day	(1600.00 Cusec)
* Elevation with reference to MSL 2861.1 ft			

Vaigai Reservoir			
1.	Full Reservoir Level (FRL)	21.64 m	(71.00 ft)
2.	Minimum Draw Down Level (MDDL)	0 m	(0 ft)
3.	Reservoir capacity at FRL	194.79 MCM	(6878.00 Mcft)
4.	Reservoir capacity at MDDL	1.46 MCM	(51.39 Mcft)
5.	Water spread Area at FRL	24.20 Sq. M	
6.	Periyar Credit	113.28 MCM	(4000.00 Mcft)
7.	Vaigai Credit	79.30 MCM	(2800.00 Mcft)

17.1.3 Command area of Periyar – Vaigai Irrigation System (PVIS)

Prior to the construction of Periyar Reservoir and Vaigai Reservoir, the command area in the two basins was only 5263 ha in Cumbum valley and 55104 ha in the erstwhile Madurai and Ramanathapuram Districts. But after their construction, the net irrigated area has risen to 81809 ha. The Periyar Vaigai Command as on date consists of the area irrigated in Cumbum valley, a pre-project area and the extension area created after structural improvements effected in the distribution network through the World Bank assisted Periyar Vaigai modernization Programme. The total area irrigated by PVIS including the pre-project area, extension area and Cumbum valley is put at 81069 ha. Various estimates of the command area have however been reported in different sources. The Periyar Vaigai command area consists of five segments.

- The Cumbum Valley
- Periyar Main Canal Pre-project Area
- Periyar Main Canal Extension Area
- Thirumangalam Main Canal Pre-project Area
- Thirumangalam Main Canal Extension Area

Geographical location of PVIS Command Area

Zone	District	Taluks	Command area (ha)
I – Cumbum valley	Theni	Uthamapalayam	5594
		Periakulam	397
II- Periyar Main Canal	Madurai	Melur	26325
		Madurai North	20893
		Vadipatti	9468
	Dindigul	Nilakottai	2014
	Sivagangai	Tirupathur	3614
		Sivagangai	8320
III Thirumangalam Main canal	Theni	Usilampatti	5556
	Madurai	Thirumangalam	1769

17.1.4 Details of command

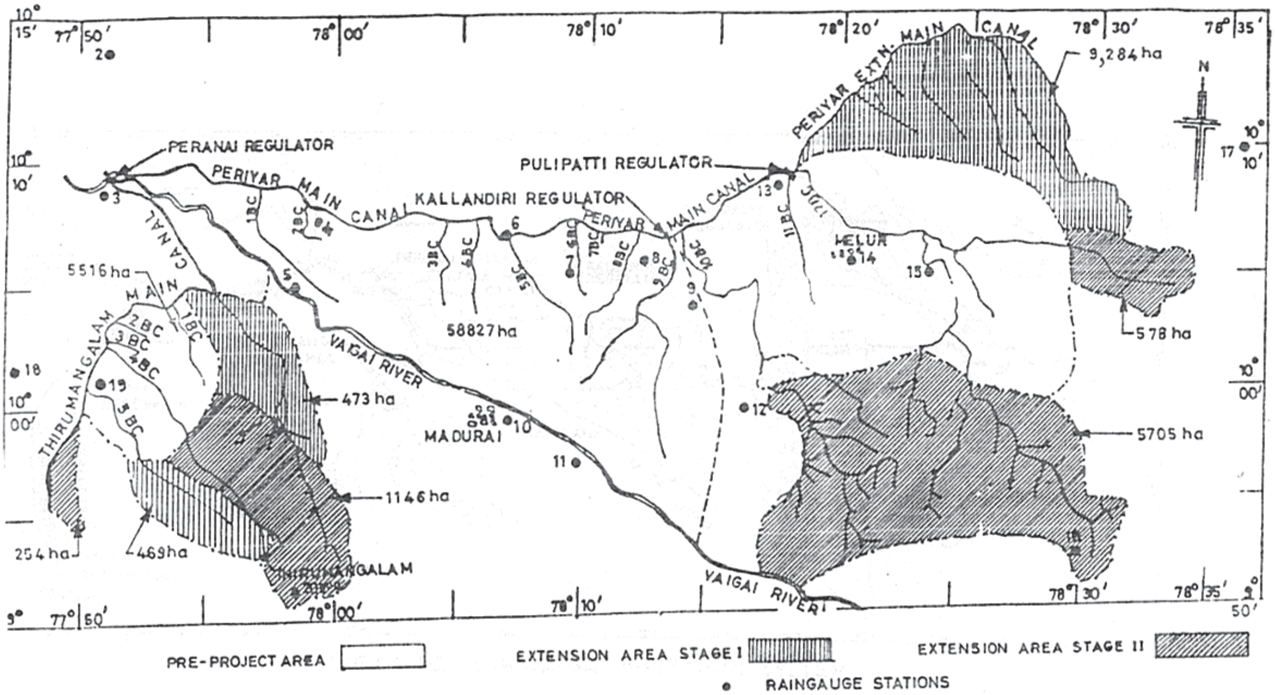
Soils of the command area are of sandy loam to clay loam. They are of shallow to medium soil – depth with slow to medium infiltration rate and hydraulic conductivity. The soils have low availability of N, medium availability of P and K and low organic matter content.

The cropping system followed in the command is as follows:

Double crop lands : rice – rice – pulse or gingerly

Single crop lands : rice – pulse or gingerly

The third crop of pulse or gingerly is grown depending on the water availability after two rice crops with carry over soil moisture and summer rains.



Periyar Vaigai Command area

In places where wells are used in conjunction with canal water the following cropping system is also practiced.

i) Sugarcane – ratoon sugarcane – rice (2 years rotation)

ii) Wetland banana – rice (1 ½ year duration)

17.2 AICRP on Water Management

AICRP on Water Management at the Agricultural College and Research Institute, Madurai developed improved water management technologies for different crops for enhanced water use efficiency. The generated technologies have yielded many useful and practical results for effective water management in agricultural production. In this process not only the improved water management technologies are tested at on-farm levels but also the field level situation is studied thoroughly for necessary feed back and improvement of the technology.

17.2.1 Major technologies developed by the centre to improve WUE in command

1. Irrigation to rice one day after disappearance of ponded water
2. Integrated water management technology for rice
3. Rotational water supply and stress management for rice
4. SRI for rice
5. Drum seeding of rice
6. Drip fertigation technology under paired row, pit and sub surface method of planting to sugarcane
7. Micro irrigation and fertigation for field and horticultural crops

17.3 Operational Research Project

Crop management technologies developed at the research stations have to be tested in farmers' fields to validate their suitability, to improve the awareness about the technologies among farmers, to identify any constraints for their adoption and to refine the technology suitably so as to ensure early adoption by farmers.. With these objectives an Operational Research Project (ORP) was initiated from 1980-81 for on-farm testing and demonstration of the improved water management technologies, especially for rice, developed by the centre. The ORP was conducted in direct canal command as well as in indirect tank command.

- Manthikulam–Direct cannal command and indirect tank command (1980 – 1989)
- Kodimangalam–Direct cannal command (1990 – 1995)
- Andaman–1996–2003–Indirect tank command
- Mathur – 2004 – 2009 tank command

17.3.1 ORP in Direct command

The enormous losses of irrigation water through deep percolation and seepage under the traditional practice of continuous submergence irrigation to the rice crop can be minimized by following improved irrigation practice of irrigating rice fields to 5 cm depth one day after disappearance of previously ponded water (1 DADPW). This improved irrigation practice saves water, improves the grain yields and increases the water use efficiency in rice. The test verification of this improved irrigation practice was conducted in the farmers' holdings over a larger area at a sluice level in direct canal command area.

Mandikulam village: During 1980-81 Mandikulam village along the Madurai – Natham road was chosen for this study. Continuous submergence of 5 cm was compared with the improved irrigation regime of irrigation to 5 cm on disappearance of ponded water during kharif and rabi seasons. During kharif the improved irrigation regime saved 9% of water with only a marginal reduction in yield (1.9 %). During rabi water saving by adoption of the improved irrigation schedule was 21% but yield was unaffected.

Kodimangalam village: During 1983 – 1988 and 1990-1994 the direct commands of sluices 14 R and 15 L of 6th branch canal of Periyar Main Canal (PMC) in Kodimangalam and Maruni villages of Madurai North taluk were taken up for on-farm water management studies. Fields irrigated from sluice 14R covering an area of 14.7 ha were treated as control under traditional irrigation management of continuous submergence. An area of 15.8 ha commanded by sluice 15L was taken for demonstrating the improved technology of irrigation of 5 cm one day after disappearance of ponded water (I DAD). Results obtained during 1983-1988 indicated that total water used under improved technology of irrigating rice one day after disappearance of ponded water varied from 64.5 cm to 106.6 amount the highest average yield obtained was 5575 Kg / ha (Table 17.1). The improved water management technology conserved water by 15 to 20% and improved the water use efficiency by more than 20%.

Table-17.1 : Year wise experimental results of one day after disappearance of ponded water and farmers method of irrigation

Year	Total water applied (cm)		Grain yield (kg/ha)		WUE (Kg/ha/cm)	
	1 DAD	Conventional	1 DAD	Conventional	1 DAD	Conventional
1983-84	64.5	79.5	4850	4950	75.0	62.4
1984-85	75.7	90.4	2422	2358	32.0	26.1
1985-86	106.6	119.5	6060	5575	56.8	46.6
1986-87	69.9	82.1	5495	5193	79.6	63.2
1987-88	84.2	126.5	5394	5071	64.0	40.0

1 DAD - One day after disappearance of ponded wate; Conventional - Farmers practice

Results from five seasons of on-farm testing established the superiority of the improved technology of irrigation of 5 cm one day after disappearance of ponded water (1DAD) over the traditional irrigation management of continuous submergence. Total water use under the improved water management ranged from 81.6 to 107.0 cm which amounted to a saving of 13.4 to 19.7 per cent over continuous submergence which required 97.9 to 127.7 cm (Table 17.2). Grain yield of rice was higher (5810 kg/ha) by 7.1 per cent under irrigation 1 DADPW over continuous submergence (5424 kg/ha). Lesser water use and higher yield led to higher water use efficiency of 52.53 kg/ha-cm with improved irrigation method as compared to 42.47 kg/ha-cm under continuous submergence.

Table- 17.2 : Water use and rice yield under improved irrigation scheduling in direct canal command of PVC – Kodimangalam village (1990-94)

Particulars	Mean of 5 seasons	
	Control	Improved technology
Irrigation depth (cm)	115.2	98.1
Effective rainfall (cm)	12.5	12.5
Total water use (cm)	127.7	110.6
Saving in water (%)	-	13.4
Grain yield kg/ha	5424	5810
Increase in yield (%)	-	7.1
WUE (kg/ha-cm)	42.47	52.53

Control: Farmers practice; Improved technology: I DAD

The existing water use efficiency for rice under farmers conditions of continuous sub mergence varied from 40 to 50%. The improved water management technology of irrigating rice one day disappearance of ponded water increased the water use efficiency upto 60 to 80%. Similarly under drum seeding and SRI system of planting the water use efficiency increased to 5.71 and 4.54 Kg/ha/mm when compared to traditional planting which resulted in 3.8%.

17.3.2 ORP in Indirect Command (Tank Command)

The success of the demonstration of improved water management technologies through ORP in direct (canal) command over 5 years in educating the farmers prompted the initiation of such demonstrations in tank command areas also. Tanks command a considerable share of irrigated rice area in Periyar Vaigai irrigation system. An operational research project in a tank command area is useful to demonstrate the improved irrigation management technology as well as associated component technologies in rice production to the farmers to enable adoption of the technologies. For the purpose, a system tank in the village of Andaman was selected for the ORP during 1996 to 2000. The Andaman tank is fed by 27 (R) sluice of Periyar Main Canal (PMC) by gravitational flow. Irrigation is regulated through three outlets (sluices) with a total command area of 66.06 ha. Tank water supply is supplemented by twelve wells in the command area. Well water is used for advance rice nursery preparation, irrigation requirements during scarcity situations and for summer cropping.

The percolation and run off losses estimated by using drum culture technique in rice field were high under continuous submergence (traditional method), accounting for 264 and 520 mm respectively (Table 17.3). The lowest percolation and run off were noticed in the treatment receiving Rotational Water Supply (RWS). Under

Table -17.3 : Percolation (mm) and run off (mm) in drum culture studies

Treatments	Percolation (mm)	Reduction (mm)	Run off (mm)	Reduction (mm)
Continuous submergence (CS)	264	—	520	—
Irrigation to 5 cm one DADPW	202	62	466	54
Rotational Water Supply	184	80	438	82

DADPW : Days after Disappearance of ponded water

irrigation to 5 cm one day after disappearance of ponded water, the percolation and run off losses were considerably reduced by 62 and 54 mm in comparison with continuous submergence.

Data collected over five years (1996 -2000) of on-farm testing in the Andaman tank command established the superiority of irrigation to 5 cm 1DADPW over continuous submergence in terms of water saving (6.8%), higher yield (6.6%) and increased water use efficiency. Averaged over five seasons, water use under irrigation 1 DADPW was 89.4 cm as against 95.9 cm for continuous submergence. Grain yield under irrigation 1 DADPW was 5506 kg / ha compared with 5163 kg / ha with continuous submergence (Table 17.4). Rotational water supply also recorded comparable yield (5172 kg / ha) with continuous submergence but with reduced water use (90.6 cm).

Table-17.4 : Effect of improved irrigation management for rice in Andaman tank command (1995-2000)

Particulars	Mean of 5 seasons (1995-2000)		
	Conventional	1DAD	RWS
Area (ha)	15.4	25.3	15.9
Irrigation given (cm)	75.1	68.6	69.8
Effective Rainfall (cm)	20.8	20.8	20.8
Total water use (cm)	95.9	89.4	90.6
Water saving (%)	-	6.8	5.5
Yield (kg / ha)	5163	5506	5172
Increase in yield(%)	—	6.6	0.2
WUE (Kg / ha-cm)	53.8	61.6	57.1

Conventional - Farmers method; 1 DAD - One day after disappearance of ponded water; RWS: Rotational water supply

17.3.3 Interventions for matching water supply in tank commands

The most appropriate water management technology is the one which enables a match between water supply from the irrigation source and water demand of the production system. Water management technologies developed at research institutes need to be tested extensively under farmers' field conditions to verify whether they help to achieve this objective of matching demand and supply through irrigation management. This formed the theme of the Operational Research Project of AICRP-WM during 2001 to 2005. The ORP was conducted in indirect (tank) command area. The objectives of the study were the following:

- collection of basic data about the tank irrigation system
- water availability through surface and ground water flows
- assessment of water demand and supply
- devising interventions like changes in cropping pattern, irrigation methods,

- irrigation scheduling, agronomical manipulation and conjunctive use of water
- optimizing production after reconciliation of gaps in supply and demand
- development of alternate operational schedule to improve the system performance in the tank command

17.3.4 Description of the ORP area

The Operational Research Project area is located in the command area of a chain of four irrigation tanks viz., Mathur East tank, Mathur West tank, Vadakundam tank and Mudaliyendal tank. All the four tanks are system tanks fed by Periyar-Vaigai Irrigation System. The Mathur east and west tanks are fed by 5 (L) sluice of 8th branch channel (8th B.C.) of Periyar Main Canal (PMC). There is a balancing culvert between these two tanks. The Vadakundam tank receives the drain flow of the command area of Mathur west tank apart from some drain flow from the direct command of 7(L) sluice of 8th B.C. The Mudaliyendal tank receives the drain flow from the direct command of 7(L) sluice. Tank capacity and command area of all the four tanks is given below :

Tank Capacity and Command Area

Name of tank	Command area		Designed Capacity		Full tank level	
	sluices	Hectare	M cft	L m^3	ft	m
Mathur West	5	68.47	2.16	2.01	5.00	1.524
Mathur East	2	59.33	4.61	4.28	6.00	1.829
Vadakundam	3	26.19	7.52	6.99	6.00	1.829
Mudaliyendal	1	15.14	4.71	4.38	4.00	1.219

The existing cropping system in the tank commands is the sequence of rice (Sep. -Feb.) – Fallow in single crop wetlands and rice (June – Sep.) – rice (Oct. - Feb.) in the double crop wetlands. The ORP was conducted from 2000 to 2004. Basic data on weather conditions, soils, tank and groundwater availability and demand and socio-economic aspects were collected and analyzed. Interactions with farmers on irrigation related constraints and other crop management problems revealed the existence of the following constraints.

- Uncertainty regarding time of release of water from branch channel for filling the tanks
- Inadequate water supply at the end of cropping season
- Insufficient water supply to tail end area
- Ineffective control over water distribution among users
- Ipomea weed encroachment in the water spread area of tank
- Silting of tanks and reduction in storage capacity
- Defective sluice shutters
- Leaks and seepage loss in distribution channels
- Poor drainage and water logging
- Increasing cost of inputs and non-remunerative price of paddy
- Insufficient institutional support on technical and administrative issues
- Unethical practices in water distribution by a few users.

a) Interventions designed in ORP : Based on the constraint analysis, interventions were designed under three categories as shown below. These interventions were tested / refined / demonstrated in the farmers' holdings during the five years of experimentation.

a) Augmentation of water storage

- Assessment of actual storage capacity of the tanks
- Removal of encroachment by Ipomea weed
- Repairs to feeder channel from branch canal
- Deepening of tank bed

b) Improving distribution of water among users

- Repairs to sluice shutters
- Closing breaches in distribution channels from various sluices
- Revival of water user association for managing distribution
- Formation of separate distribution channel for tail end areas

c) Conservation of water and increasing water use efficiency

- Demonstration of improved irrigation scheduling in large area
- Integrated Water Management Technology (IWM)
- Varietal evaluation in rice to suit water supply
- Training and technical guidance to farmers
- Farmers' meetings / seminars
- Survey and Impact assessment

b) Demand - supply gap

Water supply measurements were done in each tank throughout irrigation season to assess the demand-supply gap. Water requirement for the rice crop was assessed based on mean fortnightly weather data by estimation of reference crop evapotranspiration based on Thornthwaite method and crop coefficient for rice based on growth stage. The deficit in tank water supply during 2002-03 season was estimated to vary from 60 to 86 % in the four tanks under observation. During 2003-04 season the deficit in tank water supply for potential command area varied from 83 to 100 per cent in the four tanks. During 2004-05 season the tank water demand estimated for normal command area showed a supply deficit of 44 to 76 % in the four tanks under observation

17.3.5 Results of on-farm testing of technology interventions

a) Improved irrigation scheduling to rice

Improved irrigation scheduling of irrigation of 5 cm water one day after disappearance of ponded water (1DA) was demonstrated in a large contiguous block of farmers' fields in Mathur East and West tank commands during 2000 – 01 and 2001-02. Parshall flumes were installed in the supply channel to measure irrigation water input for the demonstration plots. Graduated marker bamboo sticks were placed in each field to enable irrigation to designed depth. Daily water measurements were made to schedule irrigation. Other fields adjacent to this block were treated as control plots with farmers' practice of continuous submergence. The improved practice conserved water and increased the rice grain yield by 11 % over continuous submergence during the two seasons (Table 17.5).

Table- 17.5 : Grain yield of rice (kg/ha) with improved irrigation scheduling

Rice variety	Continuous submergence	Irrigation of 5 cm 1 DADPW	Yield increase (%)
ADT 39	4568	4792	4.9
Co 43	4107	4265	3.8
Ponni	3942	4950	25.6
Mean	4206	4669	11.0

b) Integrated Water Management Technology

Irrigation method or irrigation schedule may not yield the desired results if other components associated with these technologies are not followed. As in nutrient management, pest management or weed management, integrated adoption of many component technologies as a package is warranted in water management also. Accordingly an Integrated Water Management Technology package termed as 'IWaM' was designed and tested through on farm trials in Mathur east and Mathur west tanks every season during 2000-01 to 2004-05. The components of IWaM (water management and associated technologies) included in the technology package are described below.

Water management	Associated technology
• Land leveling	• Closer planting
• Choice of variety according to water availability.	• Split application of N and K
• Irrigation to 5cm 1DADPW	• Herbicide application
• Midseason drainage at maximum tillering	• $ZnSO_4$ application
• Draining water before fertilizer topdressing	
• No moisture stress at flowering to milky stage	
• Draining water one week before harvest	

Integrated Water Management (IWaM) technology improved the yield of rice grown under various establishment systems such as transplanting, wet-seeding (drum seeding) and semi-dry rice by 3.5 to 22.1 per cent during different years. IWaM Technology resulted in 4.6 to 8.3 % saving in irrigation water requirement and increase in yield by 3.5 to 12.5 % over traditional method (Table 17.6). Water productivity and water use efficiency with IWaM technology were increased over traditional method of irrigation management through continuous submergence of 4 – 5 cm.

Table-17.6 : Grain yield of rice (kg/ha) with Integrated Water Management Technology (IWaM)

Establishment system	Mathur East tank command			Mathur West tank command		
	Traditional	IWaM	% increase	Traditional	IWaM	%increase
Transplanted rice						
2000-01	5305	5942	12.0	5252	5848	11.3
2001-02	5244	5748	9.6	5119	6194	21.0
2002-03	4944	6036	22.1	4481	4685	4.6
2003-04	—	—	—	3960	4120	4.0
2004-05	—	—	—	4290	4538	5.8
Wet seeded rice 2003-04	—	—	—	2276	2357	3.5
Semi dry rice 2003-04	—	—	—	2778	3126	12.5

c) Selection of varieties for higher WUE

In order to identify and recommend rice varieties capable of high yield potential under the prevailing soil conditions and water availability situations in the tank commands, yield assessment of various rice varieties grown by the farmers was done every year. Short duration varieties were recommended under conditions of delayed release of water, inadequate storage in tanks, reduced duration of water supply in the tanks and terminal stress due to early closure of water supply from the irrigation project to the tanks. Sustained efforts to promote short duration varieties were made through individual contacts, group meetings, information bulletins, notice boards in the villages and demonstrations in farmers' fields. Consequent on the continuous promotional efforts under AICRP–WM, there is a pronounced shift in preference towards short duration rice varieties (105 -115 days) instead of medium and long duration varieties (130 – 140 days) from 0-5% in 2000 to 44 – 76% in 2004 during single crop season and second crop season in all the tank commands of the ORP area (Table 17.7).

Table 17.7 : Trend in choice of rice varieties in the Mathur East tank command (% coverage)

Season	2000-01		2001-02		2002-03		2003-04		2004-05	
	SD	MD	SD	MD	SD	MD	SD	MD	SD	MD
First crop	100	—	100	—	—	—	—	—	100	—
Second crop	—	100	—	100	—	—	—	—	44	56
Single crop		100	3	97	36	64	—	100	72	28
Single crop season	3	97	—	100	36	64	38	62	40	60

SD - Short duration varieties MD- Medium duration varieties

Rice establishment system for efficient water use

Change in rice establishment system from conventional transplanting to wet-seeding in puddle and System of Rice Intensification (SRI) is being recommended for reducing water requirement in rice culture. In order to test and validate this technology, on-station trials and on-farm trials were laid out during 2004-05 season. In both the locations higher grain yield with less water use was recorded under drum seeding method of rice culture. It was followed by System of Rice Intensification. The lowest water use efficiency and productivity were recorded under conventional planting (Table 17.8).

Water use and water productivity of rice under different establishment systems

Details	OFT at Mathur East tank			Experimental Farm		
	C	DS	SRI	C	DS	SRI
Grain yield (kg / ha)	3931	6187	5500	3428	4571	3857
Irrigation water use (mm)	600	500	550	600	500	550
Water saving over traditional planting (%)	-	11.0	5.5	—	16.7	8.4
Water productivity (Rs / m^3)	2.16	3.82	3.20	0.46	1.82	1.17
Water use efficiency(kg / ha-mm)	4.32	7.65	6.40	3.80	5.71	4.54

C: Conventional; DS: Drum seeded method; SRI: System of Rice INtensification

e) Drip irrigation for sugarcane

Sugarcane, one of the most important commercial crops is being grown in an area of around 3.0 lakh hectare in Tamil Nadu with an average productivity of 106 Mt ha^{-1}. Under the present water scarce conditions, efficient use of irrigation water becomes an important means to increase the cane productivity per unit quantity of applied irrigation water. Unlike flood irrigation, the water and nutrient use efficiency are higher in drip fertigation, since the technology helps to supply the required quantity of irrigation water and nutrients directly to root zone of the crop on need base. Generally drip fertigation offers the scope to cultivate cane crop with 25 to 40 less water besides increasing the cane yield substantially.

Drip irrigation regimes and intervals were compared with surface irrigation through furrows in sugarcane from 1998 to 2000 in plant and ratoon canes. The results proved the superiority of drip irrigation over surface irrigation in terms of higher cane yield and saving in water. Drip irrigation at 40% ETc (crop evapotranspiration) resulted in cane yield on par with surface irrigation in both plant and ratoon canes but water use with drip was less by 36%. Drip irrigation at 100, 80 and 60 % ETc resulted in yield increase by 14 to 18 % in plant cane and 11 to 18 % in ratoon cane over surface irrigation. There was no difference in yield due to drip irrigation interval at one or three days. Water saving with drip irrigation was in the range of 7% at 80% ETc , 22% at 60% ETc and 36% at 40% ETc. Because of the comparable cane yield and greater savings in water, drip irrigation at 60% Etc at 3 day interval is recommended.

i) Pit method of sugarcane planting: In general increase in irrigation water levels resulted reduced water use efficiency and percent water saving. The highest water use efficiency of 169.5 Kg / ha / mm was recorded in 1.5 x 1.5 M spacing with 60 cm dia pits (4444 pits / ha) irrigated with 50% irrigation regime. In conventional method of planting the water use efficiency was 48.4 Kg / ha / mm as given below :

Method of planting	Yieldt/ha	Total water used (mm)	Water use efficiency (Kg/ha/mm)
Conventional planting	114.3	2362	48.4
1.5 x 1.5 M spacing with 60 cm dia pits irrigated with 50% irrigation regime	195.4	1150	169.5

ii) Paired row method of Sugarcane planting: The highest water use efficiency (143.5 Kg / ha / mm) was recorded in 50% Etc irrigation level with paired row planting at a spacing of 75 cm (25x25x25cm) / 120cm. The results also indicated that a saving of 45.6% of irrigation water can be obtained under 50% Etc level. The lowest water use efficiency of 43.7 Kg / ha / mm was recorded under surface irrigation as given below :

Method of planting	Yieldt/ha	Total water used (mm)	Water use efficiency (Kg/ha/mm)
Conventional planting	98.5	2250	43.7
Paired row with a spacing of 75 cm (25x25x25cm) / 120cm	215.3	1500	143.5

iii) Sub surface method of sugarcane planting: The results on water use studies revealed that the treatment 75% Etc with 100% RDF as water soluble fertilizers under sub surface method of sugarcane planting (6 feet lateral to lateral spacing with double row sett planting in 40 cm width trenches) recorded the highest water use efficiency (178.3 Kg / ha / mm). The conventional method of sugarcane planting recorded the lowest water use efficiency (63.8Kg / ha / mm) as given below :

Method of planting	Yieldt/ha	Total water used (mm)	Water use efficiency (Kg/ha/mm)
Conventional planting	105.1.	2350	63.8
75% Etc with 100% RDF as water soluble fertilizers	240.7	1350	178.3

f) Drip irrigation and fertigation in chillies (*Capsicum annuum*)

Drip irrigation (DI) at 100%, 75% or 50 % of PE in combination with 75%, 100% or 125% N and K through fertigation was evaluated with gravity irrigation (S_1) of 6 cm at 0.9 IW / CPE ratio in furrows as check. Drip irrigation and fertigation improved the pod yield of chillies substantially to the extent of 50 to 67% over surface irrigation with soil application of fertilizers. Drip irrigation regimes of 50, 75 and 100% PE were at par in improving the growth and yield of chillies and fertigation of 100% NK was more advantageous. Total water use was 443 mm and 590 mm with drip irrigation at 50% and 75% PE as compared to 702 mm with surface irrigation resulting in water saving of 19 to 37%. Water use efficiency was higher with drip irrigation and fertigation as given below :

Comparison of drip irrigation – Fertigation with furrow irrigation in chillies

Irrigation	Pod yield (kg/ha)	% over SI	Water use- mm	WUE Kg/ha/mm
Gravity irrigation in furrows (SI)	1327	—	702	1.89
Drip irrigation + fertigation	2106	58.7	593	3.55

g) Micro irrigation in groundnut

To encourage farmers to use groundwater during summer, water saving technology of microirrigation was demonstrated through an on-farm trial on microsprinkler fertigation to groundnut TMV 7 during July to November, 2004 at Alagapuri village. Microsprinkler irrigation at 100% PE along with application of 50% NK as basal and remaining 50% as fertigation in four equal splits on 15, 30, 45 and 60 DAS produced 7% higher pod yield over surface irrigation and soil application of entire NK. Water saving with microsprinkler irrigation was 20.5 % (Table 17.9).

Table 17.9 : Groundnut growth and yield under surface irrigation and microsprinkler irrigation

Particulars	Microsprinkler	Surface irrigationin check basins
Pod yield (kg / ha)	1933	1813
Yield increase (%)	6.7	—
Irrigation water applied (mm)	318	400
Saving in irrigation water use (%)	20.5	—
Water use efficiency (kg / ha-mm)	4.54	3.57
Water productivity (Rs / m^3)	6.80	5.35

17.5 Major challenges and problems to improve WUE in the Periyar Vaigai irrigation command

- Monsoon failures
- Uncertainty in water release
- Late release of water
- Terminal stress
- Small holdings
- Field to field irrigation
- Seepage and percolation losses in conveyance
- High cost for micro irrigation

17.6 Future thrust area for enhanced WUE in command

- Improving irrigation efficiency by modernizing the irrigation structures
- If there is sufficient storage and supply of water to the entire cropping period due to normal rainfall, water saving technologies in rice like alternate wetting and drying and SRI method can be unanimously followed in the command.
- In the water scarced situation, the micro irrigation can be strictly followed for the cultivation of irrigated dry crops under well commands
- Crop diversification

CASE STUDY

18.0 ENHANCING CROP PRODUCTIVITY AND WATER USE EFFICIENCY IN MULA AND KUKADI COMMANDS

M.B. Dhonde and B.D. Bhakare

Mula and Kukadi projects are the major irrigation projects situated entirely in Ahmednagar and Pune districts of Maharastra. The command area falls in scarcity tract of Maharashtra having average annual rainfall of 520 mm. The major crops of the region are sorghum, groundnut, pearl millet, pigeon pea and soybean during *kharif* and wheat, gram and sunflower during *rabi* whereas sugarcane and cotton are major cash crops of the command area. The Mula dam was constructed on the Mula River in the early 1970s near the village Bargaon Nandur in Rahuri tehsil of Ahmednagar district of Maharastra. The catchment area of the dam is about 2274 km^2. This is an earthen type of dam which is 2857 m long and has gross storage capacity of 736 Mm^3. The command area is divided into Mula Right Bank canal (58 km) and Mula Left Bank canal (24 km). Mula command area caters the irrigation needs of Rahuri, Newasa, Shevgaon and Pathardi tehsils of Ahmednagar district of Maharashtra state. Soil types near the canals are medium soil, black cotton soil and hard murum. Kukadi dam is constructed on Kukadi river and is a group of five dams with a catchment of 1139 km^2. Kukadi command area caters the irrigation needs of Ambegon, Junnar, Sirur, Parner, Shrigonda, Karjat, Karmala tahsils of Pune, Ahmednagar and Solapur of Maharashtra state covering about 251 villages. Soil types near the canals are medium soil, black cotton soil and hard murum. The cropping patterns in the study area are diverse, and the major crops are sugarcane, sorghum, fodder grass, chickpea, onion, groundnut and wheat. The details regarding the Mula and Kukadi projects are indicated below:

Brief description of irrigation commands

		Mula	Kukadi
1.	**Location**	On Mula river in the area of village Baragaon nandur, Tal.Rahuri., Dist- Ahmednagar.	On Kukadi river of villages Yedgaon, Manikdoh, Dimbhe, (Ambegaon) Wadaj and Ahmednagar Pimpalgaon joga, Tal-Junner, Dist-Pune.
2.	**Year of Construction**	1968-1969	1972-1973
a.	Catchment area	2274km^2	1139 km^2
b.	Annual rainfall	5080 mm in Ghat area and 508 mm in catchment	4850 mm in Ghat and 850 mm in catchment
c.	Year of release of water	1971-72	1989-90
d.	Year of full development	1975-76	1990-91
3.	**Dam**		
a.	Type	Earthen	Earthen
b.	Length	2857 m	Group of 5 dams
c.	Main river basin	Godavari	Krishna

d.	Sub-basin	Mula	Bhima	
4.	**Command**	MRBC	MLBC	KLBC
a.	G.C.A.(ha)	110183	17004	232480
b.	C.C.A.(ha)	103749	14453	224699
c.	ICA (ha)	70690	10120	146053
d.	Canal length (km)	58	18	KLBC-253;DLBC-60Sina LBC-19;Sina RBC-29
5	**Districts benefitted**	Ahmendangar		Part of Pune, Ahmednagar and Solapur.
6. a.	Area coverd	1,27,187 ha		1,46,053
b.	Tehsils benefited	Rahuri Newasa Shevgaon Pathardi		Ambegon, Junnar, Sirur, Parner, Shrigonda, Karjat, Karmala
c.	Village benefitted	149		251

18.1 AICRP on Water Management

AICRP on Water Management, Rahuri centre is the pioneer in developing and demonstrating the appropriate water management technologies for this region along with the selection of crops and cropping system for enhanced water use efficiency in the command. On-Farm Water Management (OFWM) demonstrations were carried out in Mula and Kukadi commands on farmers' fields to demonstrate the scientific water management techniques for higher productivity and sustainability. The various crop component interventions, package of practices, use of pressurized irrigation, adoption of soil reclamation techniques for improvement of problematic soils, monitoring seepage losses through earthen field channels and minors were tried in the study areas. In order to assess the impact of these interventions, the survey approach was adopted by preparing exhaustive questionnaire and distributed among the farmer beneficiaries both at study area of Mula and Kukadi command were selected. They were also personally interviewed for assessing the impact of adoption of water management technology.

18.2 Technologies intervention in Mula command

The highlights of the research findings emerged from the studies as indicated above are summarized below.

18.2.1 Component Crop Technology

a) Cereals

In this programme, six interventions were studied on pearlmillet in *Kharif* and wheat in *Rabi* seasons. The inerventionwise results are as follow:

- Adoption of improved layout for irrigation (border method) in wheat crop (27 locations) resulted into 19 per cent higher grain yield and about 22 percent saving in water compared with farmers conventional practice. In case of pearl millet (3 locations), exhibited the yield increment to the tune of 22 per cent with 4 percent saving in water.
- Adoption of improved agronomic package of practices including layout for irrigation water in wheat (29 locations) increased the grain production by 46 per cent with saving in irrigation water by 13 percent over the control (20 locations), while the

corresponding values for pearl millet were 34 and 9 per cent.

- Scheduling of irrigation at critical growth stages of wheat (7 locations) improved the grain yield by 14 per cent with saving in irrigation water to the extent of 15 per cent compared to traditional scheduling adopted by the farmers.
- Adoption of improved variety of wheat (HD 2189 and HD 2380) on 32 locations indicated the increment in yield by 10 per cent, while the use of improved variety of pearlmillet (MLBH 104 and RHRBH 8609) exhibited the increase in grain yield by 25 per cent compared to traditional varieties used by farmers.
- Land leveling with iron leveler (Keni) prior to sowing of wheat (2 locations) brought out the increment in yield by 70 per cent with saving in irrigation water by 27 per cent compared to unleveled fields.
- Use of recommended dose of fertilizers (120:60:60 kg NPK/ha for wheat and 100:50:50kg. NPK/ha for pearl millet) coupled with application of irrigation water at critical growth stages (18 locations), yield was increased by 24 and 31 per cent in wheat and pearl millet respectively compared with farmers level of fertilizer application.
- Adoption of package of improved technology comprised of efficient lay out, appropriate scheduling of irrigation and recommended dose of fertilizers (66 locations) revealed that wheat yields increased by 132 per cent with saving in irrigation water by 29 per cent and resulted into 187 per cent increase in net returns. Similar studies on pearl millet (11 locations) increased the grain yield by 107 per cent with increased in net profit to the tune of 177 per cent. The same set of interventions tested in combination on *Adsali* sugarcane, increased the cane production by 25 per cent with increased net monetary returns by 32 per cent. The corresponding values for ratoon sugarcane and *suru* sugarcane were 26 and 30 per cent for productivity and 32 and 36 per cent for increment in net returns.

b) Pulse and Oilseed Crops

- Improved layout (border method) when adopted and compared with traditional layout for irrigation in crops viz, chick pea, groundnut (summer) and pigeon pea on 20,13 and 7 farmers fields revealed that, the grain production of these crops was increased by 30, 21 and 28 per cent with saving in irrigation water by 15, 23 and 3 per cent, respectively.
- Adoption of improved package of practices on chick pea tested at 14 locations revealed that the grain yield was increased by 32 per cent with saving in irrigation water by 14 per cent compared to traditional method adopted by farmers.
- Use of recommended dose of fertilizer for chick pea (25+50kg NP ha^{-1}), summer groundnut (25+50 kg NP ha^{-1}) and pigeon pea (37.5 +75kg NP ha^{-1}) revealed that the yield increase in these crops was 21, 22 and 28 per cent, respectively compared to farmers practices.
- Use of improved variety of chickpea (PG 12 and PG 5) and summer groundnut (SB XI and ICGS 11) on 8 and 5 location indicated that yield was 34 and 45 percent higher respectively in chickpea and groundnut respectively compared to traditional varieties adopted by farmers.
- In summer groundnut, the broad bed and furrow (BBF) layout was compared with border layout of irrigation at 3 locations and it was observed that the pod yield was increased by 34 per cent in BBF layout coupled with saving in irrigation water by 15 per cent over border method.
- Comparative performance of mustard, a newly introduced high value oilseed crop

and traditional crop of wheat revealed that the mustard crop fetched 267 per cent higher net frugal returns, over wheat, with saving in irrigation water by 11 per cent.

- Introduction of sunflower in lieu of groundnut in summer, soybean in lieu of pearl milliet and groundnut in place of pearl millet in *Kharif* fetched 12, 377 and 535 per cent increased net returns over their respective counter parts, while pigeon pea + its ratoon when compared with sugarcane *(suru)* reduced the net returns by 36 per cent but saved 78 per cent irrigation water.
- A set of improved layout + scheduling of irrigation water at the critical growth stages of different crops + fertilizer use at recommended level when tested in combination and compared with the application of these inputs at farmers level on various crops like chick pea, mustard in *Rabi*, groundnut and sunflower in summer and groundnut, sunflower, pigeon pea and soybean in *Kharif*, revealed that, the adoption of these interventions increased the productivity of these crops coupled with saving in irrigation water and resultantly increased the net monetary gains from crops. The yield increment in different crops ranged from 22 to 272 per cent. Saving in irrigation water ranged from 20 to 25 per cent, barring *Kharif* crops, while the increase in net monetary gains was in the range of 18 to 230 per cent.
- Adoption of improved layout for irrigation as a single intervention resulted in increasing the yield of *Rabi* corps viz. chick pea and mustard and *Kharif* pigeon pea to the extent of 16, 112 and 27 per cent, respectively over their controls. The saving of irrigation water for *Rabi* crops was from 14 to 24 per cent. This intervention alone could increase the net monetary gains to these crops over their traditional practice of irrigation. The gains from chick pea were increased by 18 per cent while the same were 118 and 38 per cent in the case of mustard and pigeon pea, respectively.

Thus, it could be inferred that the adoption of interventions like improved irrigation layouts, scheduling of irrigation at critical growth stages of crops and adjusting same with conjunctive use of well water during closer of canal, application of fertilizer at recommended dose, use of improved variety of crops, etc. when tried either in isolation or in combination, increased the productivity, net monetary returns of the crops irrespective of season, while the saving in irrigation water was significant especially during *Rabi* and summer season.

18.2.2 Package demonstrations

The aspect of package demonstrations in various crops was introduced especially to convince the farmers for the benefits accrued from improved crop technology. D.O.No.19, outlet No. 2 R was identified for the purpose. The cropping pattern of the cultivators was not altered but the crops raised on the selected outlet were grown on fields of identified farmers in different seasons by adopting the improved package of practices of these crops. This package of practice included the interventions like timely seeding of improved high yielding varieties, maintaining the optimum plant population and geometry from seeding to harvest, irrigation layouts with schedule of the same at the critical growth stages of the respective crops, fertilizer use at recommended levels inclusive of use of organic manures, inter-cultivation with appropriate plant protection cover and was compared with these crop plots as a control grown in adjoining outlet.

- Amongst the *Rabi* crops tested, wheat in study area produced 83 percent higher grain yield with saving in irrigation water by 26 per cent. The economic advantage was 111 per cent over control. The chick-pea and mustard registered 145 and 123 per cent higher yield with 23 and 17 per cent saving in irrigation water as compared to control, respectively. The net gains were in the order of 232 and 149 per cent higher than control in these crops.

- In the case of *Adsali* sugarcane (18 months), the improved package of practices increased the cane yield by 49 per cent with 15per cent irrigation water saving when compared with traditional method of irrigation. This eventually increased the net monetary gains by 61 per cent. The production of *Adsali* ratoon cane was also found increased by 29 per cent with 13 per cent water saving and 37 per cent additional monetary gains when compared with the control.
- Adoption of the package of improved practices increased the pod yield of late summer groundnut by 49 per cent with additional net returns of 66 per cent when compared to traditional method. The irrigation water saving in this demonstration was marginal as the effective rains received compensated the effects. In the case of *Kharif* groundnut, the yield increment due to adoption of improved practices was 40 per cent with 50 per cent additional increased net monetary gains.
- Adoption of the package of improved practices on *Kharif* crops viz., pearlmillet and pigeon pea increased the grain yield of these crops by 147 and 58 per cent. The net monetary returns of these corps were increased due to improved technology package in the order of 162 and 78 per cent.

18.2.3 Development of water logged and salt affected soils in command

Due to over irrigation and unscientific use of irrigation water, the problem of water logging and secondary salanization has become a serious problem in Mula and Kukadi commands. During 1970-72, the problematic area under water logging and salinity was 259 ha which increased to 6604 hectares during 1979-80. However, thereafter, the area under problematic situation is decreasing year after year. This is because of tendency of farmers to grow short duration, low water requiring crops in place of sugarcane which was over irrigated during earlier years and had caused the rise in water table and thereby hasten the water logging and soil salinity problems. Farmers are now getting educated about the water management technology and have realized the ill effects of over irrigation both on production and productivity of their lands. The depth of water table is now decreasing year by year due to judicious use of irrigation water and also more use of groundwater from wells especially during scarcity conditions. Moreover, water logged soils were inspected during the months of November to February, where salt affected soils were demarked during March to April every year. Water logging condition was visualized by observing well water levels of selected sites. The water table hazards to the crop was within the limit of 1.2 m. To overcome the problematic situation, DIRD opened the drains and maintained it wherever possible.

Contrary to the observations recorded in Mula command, the land affected due to water logging and secondary salinizations was very meager in Kukadi command. This may be due to shallow to medium type of soils and new introduction of canal water in the command.

18.2.4 Reclamation of problematic soils

The reclamation of salt affected soils was carried out on an area of 15.2 ha. of 16 farmers on D.O. 18 by adopting the techniques like, opening of suitable lateral and link drains, green manuring with *Dhaincha* , growing of suitable salt tolerant crops and leaching of soluble salts with canal water after ponding. The results revealed following observations :

- There was reduction in water table upto a depth of 3m by opening of lateral drains. The growing of green manuring crop like *Dhaincha* in *Kharif* resulted into improvement of phisico-chemical properties of soil like basic infiltration rate, hydraulic conductivity, organic carbon, available N, P and K but there was reduction in bulk density, pH, ECe, SAR and ESP. Growing of salt tolerant crops like wheat and mustard in *Rabi* after green manuring revealed that there was increment in yield by 46 and 61 per cent with saving in irrigation water by 27 and 13 per cent, respectively.

- The leaching of soluble salts with 223 cm of good quality canal water (LR) after ponding in summer indicated that, there was reduction in pH from 8.41 to 8.33, ECe from 7.27 to 5.95 dSm^{-1}, ESP from 14.25 to 12.42 and SAR from 12.09 to 10.28, indicating reduction in salinity of soils. Growing of salt tolerant crops like pearlmillet in *Kharif* followed by wheat in *Rabi* compared with control (without leaching) indicated that there was not only increment in grain yields by 14 and 101 per cent but also saving in irrigation water by 12 and 27 per cent, respectively.
- Growing of salt tolerant crops like mustard, sugarcane and lucerne by adopting improved agronomic package viz., right time of seeding / planting, improved irrigation layout, fertilizer use and plant protection measures when compared with control with traditional practice revealed that, there was increment in yield of crops by 46, 48 and 63 per cent with saving in irrigation water by 28, 3 and 16 per cent, respectively.

Thus, it is implicit that, it is not only possible to ameliorate the saline soils but also dilate the productivity of soils / crops by adopting the soil reclamation techniques like opening of drains, leaching of salts by good quality water, growing of green manuring and salt tolerant crops.

18.2.5 Estimation of seepage losses

Seepage losses of water through minor and field channels as estimated by inflow and outflow methods during k*harif*, r*abi* and summer seasons indicated that

- There were comparatively more seepage losses of water (21.44 lph / m^2) in k*harif* and minimum in r*abi* (18.79 lph / m^2).
- Between the uncleaned field channel the higher seepage losses (33.67 lph / m^2) were recorded by uncleaned field channel in *Kharif* season and minimum in *Rabi* seasons (27.69 lph / m^2).
- Comparison of seepage losses amongst lined, cleaned and uncleaned field channels in various seasons indicated that lining of channel resulted into minimum (11.64 lph / m^2) loss of water through seepage followed by cleaned field channel and maximum was due to uncleaned field channel (30.24 lph / m^2).

Thus, it can be inferred that by simple cleaning of field channel, the seepage losses could be reduced by 40 per cent over uncleaned channel. Due to lining of field channel, the seepage losses could be reduced by 35.8 and 61.5 per cent over cleaned and uncleaned field channels, respectively.

18.3. Technologies intervention in Kukadi command

In this command, the crops like pearlmillet, wheat, onion, groundnut and vegetables with local varieties were grown as ruling crops with traditional local practices, the new crops introduced were soybean (MACS-124), Pigeon pea (ICPL-87), mustard (Sita and Pusa bold). In addition, improved cultivars of pearlmillet (RHRBH-8609), wheat (HD-2189), onion (N-2-4-1), gram (Vishal, Vijay), ground nut (SB-XI) were also tried. These crops were grown by adopting improved water management packages comprised of seed treatment, timely seeding, appropriate seed rate, proper plant architecture, irrigation layout, scheduling of irrigation as per CGS, recommended dose of fertilizers and plant protection covers. These were compared with traditional method adopted by farmers. The results are summarized below:

- Introduction of pigeon pea along with improved package augmented the grain yield in the range of 33 to 74 per cent, water saving by 15 per cent, increasing net profit by 8.5 folds and B:C ratio 2.51 over local variety with traditional practices.
- Introduction of improved high yielding crop cultivar like pearlmillet (RHRBH-8609) along with improved water management package increased the grain yield in the range of 50 to 173 per cent, net profit by 168 per cent, WUE in the range of 37 to 93.9 kg / ha cm and B:C ratio 1.23 over the local variety coupled with traditional practices.
- By introduction of improved cultivar of wheat (HD-2189) along with improved package resulted in to increased in grain yield in the range of 93 to 104 per cent, net profit by 168 per cent, B:C ratio in the range of 2.4 to 2.6 and WUE 34.7 to 92.6 kg. / ha cm over the local cultivar cultivated by adopting local practices.
- By introduction of new crops like chickpea (Vijay & Vishal), mustard (Pusa bold) and pigeon pea (ratoon) (ICPL-87) yielded 18.91, 26.32 , 11.43 and 12.86 q / ha and WUE by 85.2, 87.7, 54.4 and 71.4 kg. / ha cm. net profit accured was in the order of 16783, 27716, 10995 and 13718 Rs. / ha respectively. This has fetched more monetary returns over that of ruling crops.
- Growing of improved ground nut cultivar (SB XI) sown in right time (first week of Feb.) with improved water management technologies resulted into increase in productivity by 63 per cent, saving in irrigation water by 13 per cent and WUE by 86.43 per cent over control. Even by mere adoption of improved package under conditions of delayed sowing resulted into increasing in productivity by 39 per cent, WUE by 86 per cent, water saving by 25 per cent over that of control. This has indicated that, by mere adoption of non cash input like timely sowing, the productivity increased was 23 per cent over that of delayed sowing.

18.4 Impact assessment of on farm water management

After completion of on farm water management studies in Mula and Kukadi, 60 to 99 per cent with an average of 94.8 per cent farmers in Mula command and 17 to 89 per cent with an average of 56.2 per cent in Kukadi command have adopted different improved water management technologies including improved crop production package. This has reflected in improving the socio economic conditions of the peasants.

18.4.1 Irrigation layouts : Irrigation layout of appropriate sizes are very essential for proper distribution of irrigation water, encourages uniform crop growth, reduces water losses, helps in soil and water arrestation along with nutrient conservation. It has been noticed that farmers do not adopt the suitable layouts as per the crop requirements. Usually, restricted flooding is followed. In the case of *rabi* sorghum, usually no layout is prepared since the crop receives only 2-3 irrigation at late stage (usually boot stage). This leads to uneven distribution of water which reflects on growth. The studies on these aspects revealed that at least 20-25% yield could be increase by layout. Usually borders (Sara) of 3 m width and 25 m length are recommended. But modification can be done looking to the slope and infiltration rate of soil. To make the formation of border easy, a device called “Sarayantra” is provided which can be drawn by a pair of animals immediately after seeding. No wastage of land is noticed. Farmers are also seen to fabricate the implement locally.

Demonstration conducted in Mula command with intervention like adoption of improved layout for irrigation (border) when compared with farmers practice on wheat (cv.HD-2189) at 27 locations increased grain yield by 19 per cent and saved irrigation water by 22 percent over control (Table 18.1). In case of pearlmillet (13 locations) yield increase was to the tune of 22 per cent with saving in irrigation water by 4 percent compared to tradition method adopted by farmers. While, the crops like chickpea, mustard, pigeonpea and summer groundnut tried in this intervention, the productions were increased by 16, 112, 28 and 27 per cent with saving in irrigation water by 14, 24, 3 and 21 per cent, respectively.

Table 18.1 : Effect of layout on yield and water saving by different crops in Mula command during 1989-94.

Crop	Yield (q/ha)		Yield increase (%)	Water saving (%)
	Improved layout	Traditional layout		
Wheat (Avg.27 trials)	26.06	21.84	18.92	21.81
Pearl millet (Avg. 3 trails)	13.88	11.36	22.18	04.55
Chickpea (Avg. 2 trails)	05.83	05.03	15.90	14.00
S. Groundnut (Avg. 18 trails)	20.62	16.53	24.77	21.38
Mustard (Avg. 9 trails)	05.69	02.67	112.35	24.20
Pigeonpea (Avg. 7 trails)	11.57	09.06	27.84	0.3.30

The problem however, is the availability of irrigation water at right time. As per the system prevailing, farmers have to submit application in advance for irrigation water. Unless it is done, irrigation water is not released. Farmers do not realize how much they are loosing due to dryspell. It is, therefore, appropriate to educate the farmers to application in advance for irrigation. At the same time, irrigation policy needs to be changed to release water when farmers demand. This could possibly happen in case decision is taken to release water on volumetric basis to collect the appropriate revenue.

18.4.2 Fertilizer management : Fertilization application is an important aspect of irrigation water management. The time and method of application are equally important. Rarely, it is realized that farmers in irrigated areas have used the appropriate fertilizer combination.

Rabi sorghum is a major crop in Mula command areas. It would be very difficult to understand as to why the farmers do not apply fertilizer. It has been demonstrated that application of recommended dose of fertilizers along with scientific water management resulted into doubling the grain yield of *rabi* sorghum. The full utilization of irrigation could only be possible due to improving the crop management practices, particularly fertilizers. Where farmers use fertilizers, they need to be educated in balanced use. This is particularly so for legume crops. Unlike the cereals, legumes require more phosphate and less of nitrogen. Survey indicated that even for legumes, farmers have practice to top dress the crop with N, which is highly undesirable.

The balance fertilizer use and thereby enhancing fertilizer use efficiency can be achieved by its application based on soil test. The anticipated maximum targeted yield can be achieved by using fertilizer prescription equations based on soil test (Table 18.2). In the Kukadi command, the yields of pearl millet, pigeon pea, onion, wheat and groundnut (summer) obtained were 48.8, 28.3, 401, 43.1 and 41.6q/ha as against anticipated yield target of 50,30,450,50 and 45 q/ ha indicating validation of yield targeting

Table 18.2 : Yield maximization of different crops as influenced by use of yield targeting equations and water management practices

Sr. No.	Name of crop	Yield (q/ha)		Yield increase (%)	Water saving (%)	Benefit over (F.P.) (Rs./ha)
		Yield target achieved	Farmers practice			
1.	Pearl millet	48.48	22.65	115.63	25.00	12525
2.	Pigeonpea	28.28	09.75	190.01	—	25975
3.	Onion (*Rabi*)	400.10	175.00	129.10	7.00	54932
4.	Wheat	43.07	19.28	123.40	15.00	11632
5.	Groundnut (Summer)	41.60	14.53	186.30	33.33	32044

equations. This has increased the yields of these crops in the order of 116,190,129,123 and 186 per cent and water saving by 25,0, 7,15 and 33 per cent, respectively, over that of conventional farmer's practice.

18.4.3 Appropriate and remunerative crop sequences/crop: Adoption of appropriate and remunerative crop sequences is yet another aspect of adaptive research. By introducing seed production in Mula command area, the entire economy of farmers changed. The Kaike village and near by villages have become a pocket of certified seed production giving attractive returns to the farmers. Besides this, certain remunerative crop sequences have also been identified. The research experiments on identified crop sequences (Table 18.3) were conducted in Kukadi command during and the data revealed that among the identified crop sequences, the sequences like pearl millet-onion and soybean-onion achieved maximum monetary returns with the benefit cost ratio of 5.12 and 5.07, respectively, closely followed by pigeon pea-wheat sequence as compared to green gram- sorghum. The soybean and pigeon pea were the newly introduced crops in the sequence.

18.5 Impact of improved package of practices

A. Mula command

Adoption of improved package of practices (improved irrigation layout, timely sowing, appropriate seed rate, improved variety, irrigation scheduling at critical growth stages of crop, balance fertilizer use and plant protection measures etc) when compared to the traditional

Table 18.3 : Remunerative crop sequences in Kukadi command

Season and Crop sequence		Benefit: cost ratio
Kharif	***Rabi***	
Soybean	Wheat	2.97
Pearl millet	Onion	5.12
Pigeonpea	Wheat	3.71
Soybean	Onion	5.07
Green gram	Sorghum	1.81
Onion	Wheat	1.97

practice of growing wheat (29 locations), increased grain production by 46 per cent with saving of irrigation water by 13 per cent over control, whereas the corresponding increase in values for chickpea, pearl millet, mustard, summer groundnut and sunflower were 32,34,272,38 and 174 per cent with saving of irrigation water by 14,9,20,31 and 25 per cent, respectively (Table 18.4). Similarly, in sugarcane (Adsali, Suru and ratoon), the increase in yield was to the tune of 25, 30 and 26 per cent and irrigation water saving was 16, 17 and 11 per cent, respectively. The *Kharif* groundnut, sunflower and soybean were tried and achieved the production potential by 9.37,18.75 and 11.25 q/

ha in study plots which was increased by 166,44 and 50 per cent over control. The pigeon pea grown on 23 farmers' fields, increased the grain yield by 90 per cent over control and *kharif* hybrid pearl millet cultivar RHRBH-8609 grown on 11 fields, the grain yield was increased by 107.30 per cent over the local control.

B. Kukadi command

Employment of improved package intervention as that of Mula command, the yield increase due to the crops like gram, pearl millet, mustard and pigeon pea were 142, 98, 95, 101 and 53 per cent respectively, over the conventional practices of farmers. Further, it is added that the water saving for wheat, mustard and pigeon pea crops were 27, 13 and 15 per cent respectively, over the conventional practices. Further, monitoring was done through the studies on one of the adjoining control outlets regarding efficient utilization of water in Mula command. The data are reported in Table 18.5. It was observed that water application is reduced due to proper layouts. At the same time the yield is improved resulting into better water use efficiency. This was increased by 37.4%. Thus, the adaptive research has been found to be useful to improve the production potential and water use efficiency.

Table 18.4 : Effect on yield, water saving and yield increase in different crops due to adoption of package of practices in various irrigation commands

Crop	Yield (q/ha)		Yield increase (%)	Water saving (%)
	Improved package	Traditional Method		
Mula Command				
Wheat (Avg. 29 trials)	29.20	20.57	45.99	13.00
Chickpea (Avg. 14 trails)	26.70	17.90	31.77	14.15
Pearl millet (Avg. 3 trails)	15.03	11.20	33.92	9.17
Mustard (Avg. 30 trails)	9.98	2.67	272.25	20.21
S.Groundnut (Avg. 5 trails)	19.38	14.00	38.43	31.41
S.Sunflower (Avg.2 trails)	22.50	8.20	174.40	25.00
Sugarcane (Ad)-(Avg. 2 trails)	1375	1100	25.00	16.00
Sugarcane (R))-(Avg. 2 trails)	820	650	26.20	10.90
Sugarcane (Suru))-(Avg. 2 trails)	1080	830	30.10	17.20
Sunflower (K) (Avg.4 trials)	9.37	3.75	116.50	25.19
K.Groundnut (Avg. 3 trails)	18.75	13.65	44.40	—
Soybean (Avg. 2 trails)	11.25	7.50	50.00	—
Pigeonpea (Avg. 23 trails)	14.30	9.25	90.30	—
Pearl millet (Avg.11 trails)	31.10	15.00	107.30	—
Pearl millet (Avg. 2 trails)	58.10	35.00	66.00	—
Kukadi Command				
Pigeonpea (Avg. 4 trails)	15.33	10.00	53.50	15.00
Pearl millet (Avg. 7 trails)	24.41	12.50	95.28	—
Wheat (Avg. 6 trails)	31.38	15.80	98.60	27.00
Chickpea (Avg. 4 trails)	26.32	10.84	142.80	—
Mustard (Avg. 2 trails)	11.43	5.67	101.58	13.20
Pigeonpea (Ratoon)	12.86	7.27	76.89	10.00

Table 18.5 : Relative data on water use efficiencies of pearl millet in Vanjarvadi village (Mula command)

Parameter	Control area	Study area
Number of farmers involved	16	17
Study area (ha)	16.44	9.5
No.of irrigations applied	1	1
Total water applied (cm)	41.2	39.2
Yield of main produce (q/ha)	19.3	25.2
WUE (kg-ha-cm)	46.9	64.3
% increase in WUE	—	37.4

18.6 Pressurized irrigation for different crops:

The fertilizer application (fertigation) was done through drip irrigation for different crops in Kukadi command. The results indicated that the four row planting technique with water soluble fertilizer (NPK) registered higher cane yields than paired row and conventional method (Table 18.6). Further, it is added that the water soluble fertilizers (NPK) were better than nitrogen applied through urea and P and K as a basal in increase in yield of cane. There was 41 to 63 per cent water saving due to drip irrigation over conventional one.

18.7 Beyond the adaptive research outlets

It would be interesting to see how far the knowledge of water management has percolated beyond the study outlets. Since the studies outlets have been provided with persons equipped with technical know how, the others beyond the outlets were not getting the first hand knowledge of the technique. One of the objectives of the study was to assess the impact beyond the outlets. This helps to know the strength and weakness of the technology. Some of the aspects of water management like layouts, fertilizer use etc. were examined in this direction.

Table 18.6: Cane yield, water use efficiency, water saving and increase in yield as influenced by planting technique and fertigation (drip) in Kukadi Command

Treatment	Cane yield (t/ha)	Water saving (%)	Yield increase (%)
A. Paired row planting (0.75 m)			
i. 'N' (Urea)	175.30	51.00	19.90
ii. WSF (NPK)	191.70	51.00	31.10
B. Four row planting (0.75 m)			
i. 'N' (Urea)	183.20	51.00	25.30
ii. WSF (NPK)	198.90	51.00	36.00
C. Conventional method	146.2	—	—

*** WSF : Water Soluble Fertilizer**

Even though, some selected aspects have been taken by the farmers, there is need to make efforts to see the off-take of technology beyond the selected outlets. Irrigation layout which helps to improve the productivity by 20-25% should receive the attention. It may be a fact that cost of implement is still high for farmers to purchase, through some of them got fabricated. Balanced fertilizer use should result in reducing the cost of fertilizer and thereby increasing profits.

18.8 Some suggestion for improving improve water use efficiency in future

- The canal water should be supplied to the crops considering actual water requirement and critical growth stages of the crop in different seasons.
- The canal water distribution structures like outlets, gates, feed cannels and water measuring structures should be repaired.
- Promoting the formation of water users association in study area is the necessity of the day rather than depending on irrigation staff for efficient use of irrigation water.

- There should be bottom up approach rather than top down approach so as to increase the direct association of the farmers in the management of irrigation water distribution system.
- There should be reliability and timely delivery of water to the farmers. The irrigation water at least should be released by the irrigation engineers in consulation with the technical staff from agriculture.
- The seepage and conveyance losses of water should be minimized by lining, cleaning of water courses so as to increase the efficiency of irrigation project.
- The field channel/ distributaries/ minors should be cleaned/ maintained by the established water users association for which the compensatory funds should be provided by the irrigation department.
- The structures of outlets / minors at the head, middle and tail reaches of distributory are not in a proper working condition. As such, this has reflected in uneven distribution of irrigation water. The structures should also be maintained by the water users' association.
- The sugarcane is the dominate crop in the most of the irrigation commands. As such, the farmers are habituated to irrigate the crop by adopting overland flow of water especially during night hours. This has resulted into development of secondary salinity. In order to hault such degradation of soils to certain extent, it is necessary to increase area of sugarcane under drip especially under well irrigation. Similarly the suitable remunerative crop sequences should be followed by keeping the sugarcane as a base crop.
- The problematic soils viz., saline, saline-alkali and alkali should be reclaimed by adopting suitable amelioration technique on prority basis. The irrigation department should give subsidy to the farmers for digging out drains and outlets developments.
- In utilization of saline water, cyclic use of ground water with canal water should be encouraged. This will help not only in improvement in the problematic soils but also increased the crop production and project irrigation efficiency.

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