CICR TECHNICAL BULLETIN NO: 31

MICRO IRRIGATION MANAGEMENT IN COTTON

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FOREWORD

Cotton is one of the most important, cash, commercial and fibre yielding *kharif* crop grown under both rainfed and irrigated conditions. India is having maximum (7.5-8.5 Mha) area with minimum (405 kg lint ha^{-1}) yield in the world. The cotton crop suffers due to moisture stress at one or the other stage. Moisture stress in cotton also varies from soil to soil. It is more severe in very shallow (<45 cm deep) and medium deep (45-90 cm deep) soils as compared to very deep (>90 cm deep) Vertisol. The total climatic water requirement of cotton is about 700-1000 mm, which depends on time of sowing and varies from genotype to genotype, region to region, soil to soil and scientific management to farmers management.

In Maharashtra, maximum cotton area (95%) is under rainfed situation. Irrigation water availability is also scanty in Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Karnataka and Gujarat. Majority of the soils in these states are black, black and red in mixture which create problem in irrigation due to development of deep and wide cracks. As a result, flood irrigation is not advisable and economical also. Undulating topography of these soils are creating hindrance in proper distribution of irrigation water through flood irrigation method. Besides the soil problems, irrigation water is also precious and limited due to poor recharge capacity of irrigation wells. Hence, micro (drip and sprinkler) irrigation is the only alternative for irrigation of cotton crop in this region. The efficiency of other irrigation systems is lesser than 30% and about 50% water of the total release is lost in transmission. Considerable amount of irrigation water is also lost due to length and duration of the system and hence irrigation efficiency in the country is rather low. Under micro-irrigation system, more than 90% irrigation efficiency is recorded with improved yield and quality of the produce. This is why more then 55.4% area under drip irrigation is in horticultural crops and only 7 % area is under other field crops. The micro-irrigation system leads to 10-100% increased yield in various crops. Further, looking to the decreasing trend in per capita water availability for irrigation and drinking purposes, micro-irrigation seems to be the only effective alternative to save 40-60 % water of the total water required for irrigation through flood. The present status of water for irrigation in agriculture is 85% of the developed water resources and in future, it is likely to be reduced by 10-15% to meet the ever increasing demand for drinking water, industrial and other uses. In India, on an average 34.8 % area is under irrigation in cotton from different sources. However, to make the best Use of available resources, efficient management of rain water in-situ and use of stored water through micro-irrigation is essential to cross the boundary of monocropping and enter into double cropping system on the same piece of land. Water harvesting and recycling as protective irrigation through micro-irrigation is essential for efficient natural resource management and sustainable cotton production-under rainfed situation. This bulletin provides comprehensive information about use of micro-irrigation vis-à-vis flood irrigation in cotton, cotton-based crops, vegetables, fruit crops· etc. The valuable information contained in this bulletin has been collected from various published and unpublished sources.

I feel pleasure in writing this foreword and congratulate Dr. K.S. Bhaskar, Principal Scientist (Agronomy) and his associates who have done commendable work in gathering information and compilation of the same to bring out in the form of a bulletin. I am confident that this bulletin will be useful to crop planners, natural resource managers, land use and irrigation planners, industrialists, extension workers, students and the farmers in the country.

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Director

ACKNOWLEDGEMENT

The research contributions of the scientists for the development of this bulletin entitled "Micro-irrigation management in cotton" of the various research and developmental organizations working in the country is thank fully acknowledged. The information provided in this bulletin is gathered from various research publications, personal contact and from the Reports/Publications of Research Institutions such as Mahatma Phule Agricultural University, Rahuri, Marathwada Agricultural University, Purbhani and other institutions such as Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Cotton Research Station, Navsari, WTC, IAIR, New Delhi and Jain Irrigation System, Jalgaon, Maharashtra besides published and unpublished research work of Dr. Jagvir Singh, Senior Scientist (Soil), Dr. A.R. Raju, Scientist (Agronomy) and Er. G. Majumdar, Scientist (SS). The authors are extremely grateful and thankfull to all the above scientists/Institutions.

Authors are grateful to Dr. M.S. Kairon and Dr. C.D. Mayee, former Directors, and Dr P. Singh, Acting Director, Central Institute for Cotton Research, Nagpur for their constant encouragement to bring out this bulletin. The authors are also highly thankful to Dr: S. K. Banerjee, Chief Coordinator, NATP Cell, CICR, Nagpur and NATP, Rainfed Agro-eco-system CRIDA, Hyderabad, Andhra Pradesh for providing financial assistance for bringing out this bulletin under NATP, RCPS-5 Project.

Authors are highly thankful to all the scientists whose contributions have been utilised / incorporated in this bulletin.

CONTENTS

TABLES

FIGURES

PLATES

	Description
Plate 1.	Tomato seedlings transplanted after the harvest of cotton crop under cotton-tomato double cropping system in farmer's field under irrigated condition
Plate 2.	4-6 lakh litres excess runoff water and its storage in farm pond for recycling to cotton crop as protective irrigation
Plate 3.	Square formation stage in cotton
Plate 4.	Early boll development stage in cotton
Plate 5.	Peak boll development stage in cotton
Plate 6.	Boll bursting stage in cotton
Plate 7.	Flood irrigation in rainfed cotton-treated as wastage of water
Plate 8.	Alternate furrow irrigation in cotton, a better alternative for saving of irrigation water to the extent of 40-49 %
Plate 9.	Two plants per hill of cotton under drip irrigation superior to one plant per hill
Plate 10.	Mulching of sunhemp in rainfed cotton

MICRO IRRIGATION MANAGEMENT IN COTTON

1. Introduction

India has the second largest net irrigated area in the world, after China. The irrigation efficiency under canal irrigation is not more than 40% and for ground water schemes, it is 69%. The net irrigated area in the country is 53.5 Mha, which is about 38% of the total sown area. Although considerable area has been brought under irrigation since independence; there is much scope for its expansion in the future. Irrigation water for agriculture finds competition from domestic use, industrial and hydroelectric projects. At present, the efficiency of the irrigation systems adopted is less than 30%. As such as 50% of the water release at the project head is lost in transmission of the canal outlet. Additional loss occurs in water courses which is directly proportional to their length and duration of water flow. Considerable scope exists for enhancing the water use efficiency to bring additional area under irrigation. Scientific management of irrigation water is necessary to improve crop productivity and alleviate irrigation related problems such as shortage of irrigation water, water logging, salinity etc.

The average grain yield in the country however is about 2 t ha^{-1} in irrigated and 1.5 t ha^{-1} in rainfed areas. With appropriate management practices, achieving a target of more than 450 Mt by the year 2050 AD is a distinct possibility. The estimated cotton requirement by 2020 is around 230 lakh bales with a share of 65-75% in textiles (Vision, 2020). Even all the water resources have been tapped for irrigation, almost 50% area will still remain rainfed. But, whether it is irrigated or rainfed agriculture water holds the key for enhancing and sustaining agricultural production. Since, sustainability and enhanced productivity are the need of the hour, the focus has to shift from crops to cropping systems that are more input use efficient going with resource conservation technologies. Out of the 250 cropping systems in India, 30 are the most common ones and out of them, several are well fitted under drip and sprinkler irrigation system.

There is immense scope for conservation, distribution and on farm utilization of water and attaining higher water use efficiency through micro irrigation system, yield can be maximized significantly with a limited amount of water. Modern irrigation techniques like sprinkler and drip should be promoted where water is scarce and the topographic and soil condition do not permit conventional methods of irrigation.

Irrigation in India has been practiced since Maurya's time who contributed the most in building ancient irrigation system in India. Irrigation through drip is a newly introduced system in the country and little work has been done on application and evaluation of drip for cotton and cotton-based cropping system in the country. Although there are various ways of irrigating crops, drip and sprinkler irrigation systems considered as the best in bringing about water and fertilizer use efficiency along with improved crop productivity. In this system, water is directly delivered to the root zone of the individual plants by network of tubing. The tubing can be moved around different locations, topography and slopes as per plan and convenience to deliver water at desired pressure through emitters / micro tubes to the plants.

2. History of Micro-Irrigation

Earlier attempts were made by the researchers in Germany during 1860 by simply pumping the irrigation water into the clay pipes through underground drainage system. The first work on MIS (Micro- irrigation systems) was initiated at Colorado in 1913 and it was concluded that drip system was too expensive. Later on an important breakthrough was made in Germany in 1920 when perforated pipes were used for irrigating the crops. However, in 1930, the peach growers in Australia, pumped water through 5 cm GI pipes laid along the tree rows with water emitting points made on the pipe as small triangular holes. In early 1940, Symcha Blass observed that a tree near a water leaking point exhibited vigorous growth as compared to other trees in the area. This led to the concept of MI (Micro-irrigation) where water is applied in very small amounts as drop by drop. Later on, a remarkable breakthrough was made in the material science, when poly ethylene, a crack resistant and cheaper alternative was accidentally produced in a British laboratory. Later LDPE (Low density poly ethylene) gave place to HDPE (High density poly ethtylene) and in 1977, LLDPE ((Low lenior density poly ethlene) was introduced. Thus, micro-irrigation systems really got off the ground with the developments in plastic industry. Later on the orifice emitters were developed to improve the consistency of "holes drilled into the pipes" and gradually sophisticated water emission small diameter plastic tubes and microtubes were developed. Turbulent flow emitters were also developed which are being used at present.

3. Why Micro-Irrigation?

Cotton is one of the most important, cash, commercial and fibre crop of the country; occupying an area of about 8.5 M ha with an average yield of about 405 kg lint ha^{-1}. Cotton productivity (kg ha^{-1}) under rainfed situation in the Central and Southern zones, is the lowest in Maharashtra particularly in Vidarbha region. Low yield of cotton in the region is mainly associated with cultivation under rainfed (95%) situation. The shallow and sloppy topographic conditions of rainfed cotton growing areas also are not supporting good plant growth mainly due to shallow profile depth with poor organic matter status and low available water capacity of the soils (Bhaskar et al., 2002). Secondly, variability in rainfall pattern with uneven distribution, soil, crop variety and management levels are also affecting seed cotton yield adversely (Bhaskar, 2004). Under such circumstances, economization of available water and its proper management in rainfed cotton is having paramount importance and that could be made possible through advance cultivation of rainfed cotton with drip and sprinkler irrigation as the total water availability is also decreasing over the years all most in all the cotton growing states in the country.

According to a recent estimate, thirty four countries in the world will be facing water scarcity by 2025 AD indicating that per capita availability of fresh water supplies will be less than 100 m^3 person^{-1} year^{-1}. A country with renewable water availability on an annual per capita basis exceeding about 1700 m^3 will suffer only occasional or local water problems. Below this threshold, countries begin to experience periodic or regular water stress. India (1400 m^3) and China (1700 m^3) will come first into this category in the year 2025 AD, while USA will have more than 7000 m^3 person^{-1} year^{-1} and will not face any scarcity. Rising demand for urban and industrial water supplies in the world pose a serious threat to irrigated agriculture. The allocation of water for agriculture will come down to 50% from the present level of 70%. However, to achieve required food and fibre production with increasing population, India has to enhance the current irrigation potential of 91 Mha to 160 Mha. However, to fulfill the additional requirement of the irrigation with improved technologies for water harvesting, excess runoff collection, storage and recycling for precision water application by economizing the available amount of irrigation water needs to be adopted.

The major problem associated with decreasing amount of fresh water for irrigation is conveyance losses, reducing the net utilization of irrigation water to 46% only. The net utilization of irrigation water in drip system is 90% and through sprinkler system, it is 82%. In view of the same, micro-irrigation is having paramount importance with brighter future prospects.

4. Why Modern Irrigation Technologies Are Needed?

- The productivity of irrigated land is low compared to its potential
- The productivity per unit water is very low
- Water available for irrigation is becoming scarce
- Cost for generating water source is ever increasing
- The predominance of soils with low water retention capacities and very low hydraulic conductivities make the Arid and Semi-arid regions an ideal case for light and frequent irrigations through micro-irrigation
- Micro-irrigation will increase the irrigation cover using the existing available water
- Micro-irrigation with fertigation will enhance production per unit input in these nutrient poor, shallow and sloppy soils

Micro-irrigation is a co-ordinated and controlled water management system where water is made to flow under pressure through a net work of pipes of varying diameters, the main-line, the sub-main lines and the lateral lines with appropriately placed emitters along the length of the latter through which water is discharged to the root zone.

5. Need For Micro-Irrigation

To achieve required food production with increasing population, India has to enhance the current irrigation potential of 91 Mha to 160 Mha. But, the total water resources estimated are 230 Mhm will have to cater the need to the non-agricultural uses also. The country is likely to be water stressed in the coming years. Therefore hand in hand with technologies for water harvesting and storage, technologies for precision water application methods need to be adopted.

6. Advantages Of Micro-Irrigation System

- Saving of ample irrigation water
- Low water application rate
- Uniformity of water application around the plant
- Precision placement of water
- Efficient fertilizer and chemical application
- Better control of root zone environment

- Significant yield enhancement
- Improved quality of the farm produce
- Improved disease control
- Discourages weed growth
- Saving of power due to lesser use
- Reduces labour cost
- Being light in weight, the system can be shifted without any problem
- It can be moved on undulating topography
- It can be put to use during night also

7. Scope of Drip Technology

Maharashtra and Gujarat together contribute more than 50 % of the total cotton area in the country. But the lint productivity in these states is lesser than the national average. One of the major reasons for this lower productivity is the fact that in both the states cotton is predominantly grown as purely rainfed crop. This is about 65 to 67% in Gujarat and almost 97% in Maharashtra. In most of the cases, the rainfall is erratic with high coefficient of variation. In Gujarat, the government has announced as high as 85 % subsidy for the development of farm ponds. If the rainfed cotton growers of the state take advantage, of the scheme and adopt drip irrigation, the cotton productivity can be increased significantly. Secondly, Gujarat state has got the maximum (%) cultivated area as salt affected in India. Many of the cotton growing areas fall in the saline soil categories, as this crop is relatively more tolerant. In most of the area under these soil conditions and even in normal soil conditions, underground water is either very less or saline or both. Under such conditions, use of drip technology will greatly improve not only the existing lint productivity but also the fibre quality, overall production and more area can be cultivated with the same available water through drip. Farmers of North Gujarat have already put into use this technology especially for their seed production plots. As per farmers estimate, about 400 ha of seed plots of cotton in Sabarkantha district are under drip. Many growers in other parts of North Gujarat, Kutch and Saurashtra areas also adopt this system. Thus, the drip technology can boost the productivity and overall production of cotton in addition to betterment of soil and plant health especially in problematic conditions (Raman *et al.*, *1996).*

Apart from yield increase, water and fertilizer saving through drip has been especially useful in problematic soil and water conditions. In the sodic soil conditions of Thiruchirapalli of Tamil Nadu, Muthuchamy *et al.* (1993) used sodic water through drip in cotton and harvested 10% more yield than surface method and the important aspect under drip was that the water used was of 1/3 of the surface method.

Though drip irrigated area is about 3.60 M ha, it represents about 1 % of the world total irrigated area. In view of worsening water scarcity and raising water costs, there is tremendous scope for increasing the use of drip system in the world. Irrigation has a profound importance and influence in raising food production sofar. About 40 % world's food now comes from 17 % of the irrigated land of about 2553 Mha.

8. Micro-Irrigation Status in India

Drip irrigation techniques were developed economically in Israel, Australia, Mexico, Newzealand, South Africa and the USA and are being used for various crops. The adoption pattern of micro-irrigation techniques (Drip and Sprinkler) in various parts of the country is furnished in table 1.

Table 1. Area under drip and sprinkler irrigation in India

States	Area (lakh ha)	
	Drip	Sprinkler
Andhra Pradesh	39,500	17,090
Assam	200	90,000#
Bihar	-	160
Gujarat	10,000	27,740
Haryana	2,400	83,600
Himachal Pradesh	-	70
Jammu and Kashmir	-	30
Karnataka	50,000	41,900
Kerala	7,500	5,800
Madhya Pradesh*	3,800	149,980
Maharashtra	1,54,000	33,120
Orissa	3,000	400
Punjab	2,000	200
Rajasthan	35,000	47,850
Tamil Nadu	42,000	32,130
Uttar Pradesh*	2,500	7,360
West Bengal	200	120,040#
Others	2,000	500
Total	3,55,400	6,58,500

** Madhya Pradesh includes Chattisgarh, and Uttar Pradesh includes Uttaranchal.*

Source: *Ashwini and Singh (2002)*

 # Mainly for plantation

Source: *INCID (1994).*

Through the scientific approach for micro irrigation was initiated in mid-seventies, its commercial adoption took place in the country only during the eighth five year plan (Malviya and Devidayal, 2002).

Although the programme for promoting drip irrigation was taken up throughout the country, it is seen that maximum coverage has been in the states of Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu. The erratic rainfall pattern also played a significant role for the adoption of irrigation techniques in these states. In Haryana, the sprinkler system is very successfully employed in canal command areas where cotton is being grown as principal crop.

The extent and adoption of sprinkler in different states indicate that Madhya Pradesh with hectarage of 1 .5 lakh contributes to almost 25% of the total area under sprinkler in the country. This is followed by West Bengal, Assam, Haryana and Rajasthan (Table 2). Seeing the advantages and usefulness, this technology has been adopted by many countries in the world.

Table 2. State-wise area under sprinkler irrigation in India

State	Area (000 ha)	Number of sets installed in VIII plan (000 Nos.)
Assam	90.0	N.A.
Andhra Pradesh	17.1	19.4
Gujarat	27.7	12.9
Haryana	83.6	4.1
Karnataka	41.9	6.5
Kerala	5.8	N.A.
Madhya Pradesh	150.0	16.7
Maharashtra	33.1	18.5
Rajasthan	47.8	29.7
Tamil Nadu	32.1	12.0
Uttar Pradesh	7.4	11.6
West Bengal	120.0	N.A.
Others	1.4	3.2

Further, for the development of new irrigation system or project, financial resource is the crunch since the irrigation cost has increased and now the average is about Rs 4800 ha^{-1}. It may vary from region to region. It is very high in Africa and low in South Asia. In India, per hectare investment for irrigation projects has increased enormously. It is necessary to bring more area under micro irrigation because irrigated farms typically get higher yields and can easily grow 1 to 3 crops per year provided water is available. In view of the scarcity of water and the cost escalation of irrigation projects, it is essential and necessary to economize the use of water and at the same time increase the productivity per unit area in the 21st century. This could be achieved only by large-scale adoption of micro-irrigation system for achieving economy and precision as in drip irrigation and low energy precision application.

9. Advantages of Sprinkler Irrigation

- Improve conveyance and application efficiency on coarse textured and shallow soils
- Low discharges may be used
- Applicable on undulating and steep terrain without need for land forming (Gravity head may be used to pressurize the system)
- Reduced labour requirement
- Enable uniform application of water
- Covers more land area uniformly and also the crop canopy
- Develops suitable micro climate for sowing of crop and better plant growth

10 Yield Increase and Water Saving Through Sprinkler Irrigation

Field experiments were conducted at Agricultural Engineering Research Institute, Agriculture Research Centre, Gizam, Egypt during 1998 to investigate the possibility of using sprinkler irrigation system in cotton crop production in the Old Valley by studying its ability to minimize water losses and increase cotton yield. Study revealed that sprinkler irrigation system saved 17.81 % of water applied and increased the yield by 22.6% compared to surface irrigation. The water utilization efficiency increased by 51.2% in sprinkler system compared to surface irrigation system (EI Yazal *et al.*, 1998).

11 Trend of Area Under Micro-Irrigation

The efforts of Government of India (Gal) for the promotion of micro-irrigation have resulted in bringing more than three lakh ha area under micro-irrigation. It is estimated that in all, about 4.5 lakh ha have been covered under micro-irrigation, which include 3.5lakh ha under GOI. It has been observed that due to reduction of subsidy for drip system and total stopage for sprinkler has affected the farmers and due to that the area under micro- irrigation system has shown a decline since 2000 (Fig.1).

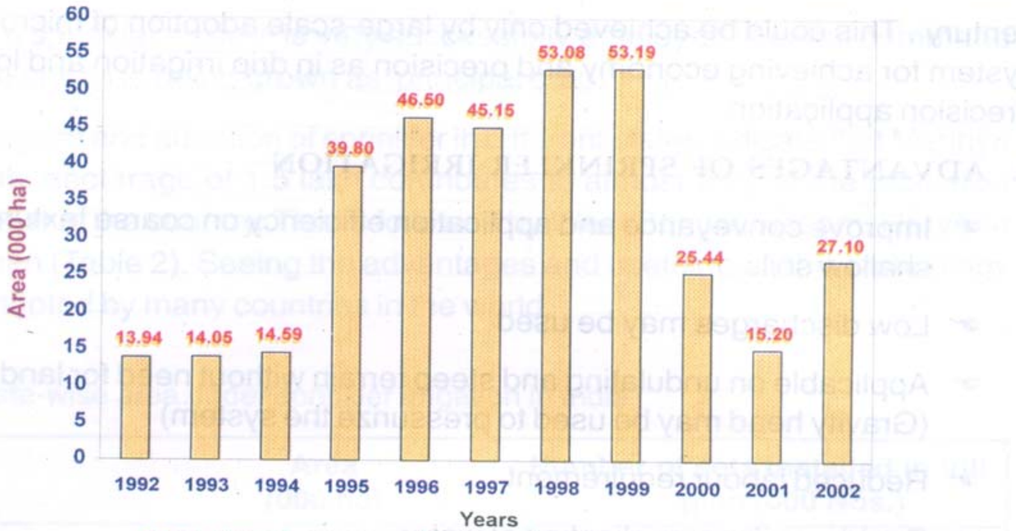

Fig.1. Annual coverage of area under micro-irrigation in India

12 World Scenario of Micro-Irrigation

Although there are various ways of irrigating crops, drip and sprinkler irrigation systems occupy the top place for enhancing water and fertilizer use efficiency and enhanced crop productivity. In this system, water is directly delivered to the root zone of the individual plants by network of different locations, topography and slopes as per plan and convenience to reduce delivery at low pressure through emitters and microtubes (Plate 1). Efficient drip irrigation techniques were developed in Israel, Australia, Mexico, New Zealand, South Africa and the USA and are being widely used for growing various crops successfully (Table 3). When we look at the world scenario of micro irrigation, USA stands first in terms of area under drip and sprinkler irrigation followed by China, France and Spain. India is in fifth place, covering 1.6% of total area (Table 3).

Plate 1. Tomato seedlings transplanted after the harvest of cotton crop under cotton-tomato double cropping system in farmer's field under irrigated conditions.

Table 3. Country wise micro- irrigation status in world

Country	Total irrigated area (Mha)	Sprinkler	Micro irrigation	Total sprinkler and micro-irrigation	% of total irrigated area
USA	21.4000	3,380,000	1,050,000	4,430,000	21.0
China	53.3000	1,200,00	267,000	1,467,000	2.8
France	1.6100	-	-	1,450,000	90.0
Spain	3.3400	800,945	562,854	1,363,799	40.8
India	57.000	658,500	260,000	918,500	1.6
Austria	0.0800	760,000	3,000	763,000	100.0
Mexico	6.2000	-	-	600,000	10.0
Egypt	3.3000	450,000	104,000	554,000	17.0
Germany	0.5320	530,000	2,000	532,000	100.0
South Africa	1.3000	255,000	220,000	475,000	36.5
Italy	2.7000	345,000	80,000	425,000	16.0
Slovak, Republic	0.3100	310,000	2,650	312,650	99.0
Iran	8.0500	199,075	53,717	252,792	3.1
Israel	0.2310	70,000	161,000	231,000	100.0
Great Britain	0.1600	156,000	2,000	157,000	99.0
Syria	1.2800	93,000	62,000	155,000	12.0

Czech, Republic	0.1530	151,011	1,224	152,235	99.5
Macedonia	0.1730	100,000	5000	100,500	58.0
Australia	2.0000	-	-	100,000	5.0
Zimbabwe	0.1500	87,000	8,000	95,000	63.0
Hungary	0.1300	85,000	4,200	89,200	68.6
Portugal	0.6300	40,000	25,000	65,000	10.0
Malawi	0.550	43,193	5,450	48,643	87.0
Jordan	0.0700	5,300	38,300	43,600	62.0
Cyprus	0.0550	2,000	25,000	27,000	49.0
Chinies Taipe	0.4560	8,500	18,100	26,600	5.8
Lithuaria	0.0081	8,122	-	8,122	100.0

Source: *icid@icid.org*

13 Use and Impact of Micro-Irrigation

Micro irrigation has given very high irrigation efficiency (> 90%) and significantly improved the yield and quality of the produce. However, majority of the area, (55.40%) covered under micro irrigation is in horticultural crops and only 7% area is under field crops (Alam and Kumar, 2001). However, yield improvement due to irrigation in sugarcane has been reported by 35-50%, in cotton by 5-10%, in castor by 15-42%, in groundnut by 20-66% and in potato 20-26.4%. The yield of ·other principal crops has also increased significantly over unirrigated conditions (Table 4).

Table 4. Yield of principal crops under irrigated and un-irrigated conditions

Crop	Yield (Kgha^{-1})		% increase expected over un-irrigated
	Irrigated	Un-irrigated	
Rice	1880.3	1220.4	54.1
Sorghum	1242.6	606.9	104.7
Pearlmillet	1170.2	596.2	96.2
Maize	2040.5	1339.2	52.4
Ragi	1966.8	995.9	97.5
Wheat	2068.1	1100.1	88.0
Barley	1836.6	1127.2	62.9
Gram	830.0	548.5	51.3
Groundnut	1244.2	844.4	47.3
Sugarcane	70687.5	43161.2	63.8
Rapeseed and Mustard	893.6	573.2	55.9
Cotton	440.3	195.1	125.7
Jute	1952.6	1502.8	29.9

Source: Central ground water commission (1995). Average of 1985-86 to 1991-92 over different states.

It is very clear from the above table that due to irrigation, the yield of different crops has increased considerably. Water consumption under flood or basin irrigation is too high but in case of drip and sprinkler irrigation, water consumption is just half with higher yield potential. However, under such circumstances drip and sprinkler are the best suited alternatives for irrigation as well as efficient crop stress management (Table 5).

Table 5. Water productivity gains by shifting from surface irrigation to drip irrigation in India.

Crop	Change in yield	Change in water use	Change in water productivity
Banana	+52	-45	+173
Cabbage	+02	-60	+150
Cotton	+25	-53	+169
Cotton	+25	-60	+255
Grapes	+23	-48	+134
Potato	+46	-00	+146
Sugarcane	+20	-30	+070
Sugarcane	+29	-47	+091
Sugarcane	+33	-60	+243
Sweet potato	+39	-60	+243
Tomato	+05	-27	+049
Tomato	+50	-39	+145

Source: Sandra Postel- Pillar of Sand (1999).

Various experiments were conducted at different Research Institutions/ Universities in India, Israel, Jordan, Spain, USA, Australia using drip irrigation. Results showed that in the drip method, the water saving was about 40-70% with an yield increase of about 10-100% in different crops.

14 Irrigation Resources of Indi

The net irrigated area in the country is about 5.5 Mha, through tanks 3.1 Mha, canal 17.1 Mha, tubewells 17.9 Mha, other wells 11.9 Mha and other sources including drip and sprinkler irrigation 6.5 Mha. The country as a whole receives good rainfall in both the monsoon seasons and there is ample scope for rainwater harvesting, storage and recycling (Plate 2). Through rain water harvesting more cropped area can be brought under irrigation where total rainfall exceed 700 mm per annum.

Plate 2. 4-6 lakh litre excess runoff water and its storage in farm pond for recycling to cotton crop as protective irrigation

The per capita per annum water availability for irrigation presently at the level of 2001 m^3 will be reduced to the stress level of 1700 m^3 in the next 2-3 decades. The ultimate irrigation potential of the country has been estimated at 139.9 M ha comprising of 58.5 M ha from major and medium schemes, 15 M ha from minor irrigation schemes and 66 M ha from ground water exploitation (Singh, 2002). The present irrigated area in the country is about 53 M ha. However, even after achieving full irrigation potential, nearly 50% of the total cultivated area will remain rainfed (Table 6).

Table 6. Water resources of India

Estimated utilizable water	Unit area
Surface	690 Kms^3
Ground	432 Kms^3
Total	1122 Kms^3
Irrigation potential	
* Major and medium (Surface water)	
Ultimate	58.5 M ha
Created (upto 1997-98)	33.6 M ha
Utilised (upto 1997-98)	29.0 M ha
* Minor irrigation	
A. Surface water	
Ultimate	17.4 M ha
Created (upto 1997-98)	12.6 M ha
Utilised (upto 1997-98)	11.0 M ha
B.Ground water	
Ultimate	64.0 M ha
Created (upto 1997-98)	46.5 M ha

Utilised (upto 1997-98)	42.7 M ha
C. Total (Surface and Ground)	
Ultimate	81.4 M ha
Created (upto 1993-94)	59.1 M ha
Utilised (upto 1993-94)	53.7 M ha
Total (Major and Medium + Minor)	
Ultimate	139.9 M ha
Created (upto 1997-98)	92.7 M ha
Utilised (upto 1997-98)	82.7 M ha

Source: *Singh (2002).*

The present allocation of water for agriculture is about 85% of the developed water resources and is likely to be reduced by 10-15% to meet the ever increasing demand for drinking water, industrial and other uses (Table 6).

On an average, 34.8 % irrigated area is under cotton in the country. In order to realise the full potential of cotton production on a sustainable basis, efficient management of rain water is very essential. It has also been reported that there is a big question of poor economic returns from major irrigation projects and the negative effects on environment resulting in soil degradation, water logging and salinisation in many canal command areas. In India, the percentage of area damaged by poor water management is highest in the world (36 %). Grave concerns are being expressed by many international and national organisations about the ill effects of poor management of irrigation on ecology of the command areas of many irrigation projects. The life of many irrigation reservoirs has been reduced by accelerated erosion in the catchment areas and increased rate of sedimentation than estimated by the planners (Singh, 2002).

14.1 Per Capita Water Availability

Water resources for irrigation are limited and needs proper management. Per capita water availability is decreasing. It was 5.3 thousand m^3 during 1955 and got reduced to 2.5 thousand m^3 during 1990 and it is estimated that during 2025 it will be 1.5 thousand m^3 only (Fig.2). Considering this decreasing trend of water availability, precious water resource should be used judiciously. A similar trend is also seen in other countries such as China, Pakistan, Bangladesh, Nepal and USA. However, the position of UK is comparatively better in this aspect as compared to other countries (Fig.2).

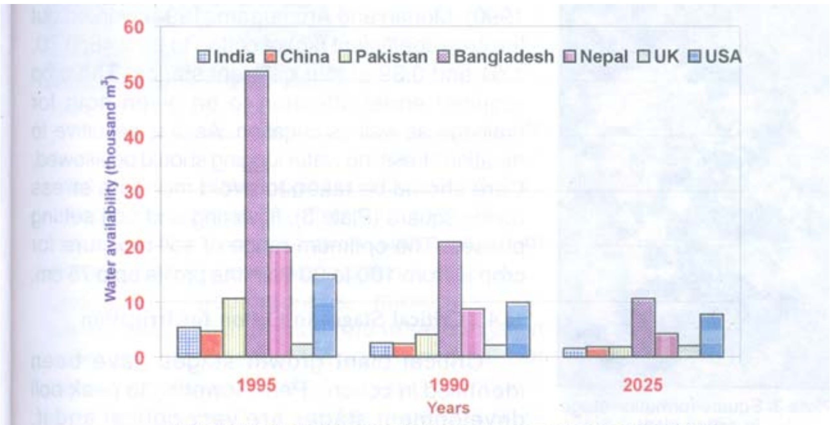

Fig.2. Trend of per capita water availability in different countries

14.2 Water Status in Cotton Plant

Favourable water status of plant is considered essential for maintaining turgidity of cells to sustain the over growth and ultimately yield (Kramer, 1984). Water status below optimum level (water deficit) will lead to adverse effect on physiological processes contributing towards yield (Levitt, 1980). However, exposure of the cotton crop to repeated cycles of moisture stress during the growth period has adverse effect on growth and development of cotton (Stewart and Musick, 1982).

Kuhad et al. (1991) found that cotton genotype H-777 and H-999 having significantly higher water retention value gave significantly better yield than other genotypes. Better water retention may help plants to maintain the physiological process at a level which facilitates better partitioning of dry matter towards sink and enables retention of more number of reproductive parts, (flower, flower buds and bolls) resulting in more yield.

14.3 Water Requirement of cotton

Cotton is mostly grown as *kharif* crop and needs 2 to 10 irrigations after cessation of monsoon under different soil and agroclimatic conditions of the country. Thus, the consumptive use varies from 650 to 1000 mm in different states (Bonde and Shanmugam, 1990). Mohan and Arumugam (1994) worked out the crop coefficient (kc) of cotton to be 0.46, 0.70, 1.01 and 0.39 at four different stages. The crop requires equal attention to be given both for drainage as well as irrigation. As, it is sensitive to aeration stress, no water logging should be allowed. Care should be taken to avoid moisture stress during square (Plate 3), flowering and boll setting phases. The optimum range of soil moisture for crop is from 100 to 20% in the profile upto 75 cm.

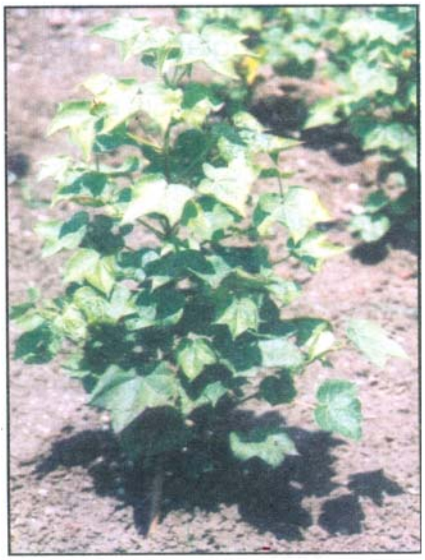
Plate 3. Square formation stage in cotton plant

14.4 Critical Stages in Cotton for Irrigation

Critical plant growth stages have been identified in cotton. Peak flowering to peak boll development stages are very critical and if, irrigation is not provided at this stage, the seed cotton yield declines drastically by about 5 to 8 q ha^{-1} depending upon soil, genotype and management levels (Bhaskar et al., 1998). If rainfall is less and distribution is not proper, light irrigation may be given from germination to four leaf stage. At this time, cotton plant is susceptible to drought.

Although, cotton plant is having tap root system after germination, the root penetration in the soil is faster as compared to other crops and hence if sufficient moisture is available in the soil then no need of irrigation to cotton crop. However, the irrigation requirement of cotton crop vary from climate, soil and management application and its adoption. When cotton plant shows signs of moisture stress during noon, one protective irrigation should be given to the crop to avoid moisture stress. This condition mainly appears in very shallow to medium deep soil where available water capacity is comparatively less than deep to very deep soil. Cotton is a hardy crop and requires good drainage. Water logging and excess moisture is not good for proper growth of root and shoot. It can survive many harsh situations upto a maximum extent, but to get higher yields irrigation is essential. Under such circumstances, micro irrigation system plays an important role to save irrigation water as well as to cover the maximum area. Our experience shows that when rainfall is sufficient and distribution of it is poor, two irrigations @ of 4-6 ha cm of water, first at early boll development stage (Plate 4) and second at peak boll development stage is essential. If rainfall is sufficient and distribution is proper one irrigation of same amount of water is essential at peak boll development stage (Plate 5) in shallow to medium deep (45-90 cm deep), but in case of very deep soil (>90 cm deep) there is no need of irrigation to cotton crop under normal climatic conditions. To maintain the fibre quality and enable good picking, irrigation should be avoided after boll bursting stage (Plate 6).


Plate 4. Early boll development stage in cotton plant


Plate 5. Peak boll development stage in cotton plant


Plate 6. Boll bursting stage in cotton plant

14.5 Scheduling of Irrigation to Cotton

Several methods have been experimentally evaluated and recommended to schedule irrigation to cotton crop. These methods include, scheduling of irrigation based on atmospheric parameters (ET, cumulative pan evaporation (CPE or IW/CPE), soil based scheduling (Soil moisture tension, available soil moisture depletion (ASMD) and leaf water potential (LWP) etc. For Irrigation scheduling, it is important to find out the total water demand by the crop plant in relation to supply from the soil. If water supply from the soil is limiting to the crop, then plant starts wilting (Bhaskar *et al.,* 2004). At this stage, there is a need to irrigate the crop. Many researchers have developed the criteria for scheduling the irrigation in cotton (Table 7). A few representative examples of scheduling irrigation to cotton based on different criteria in different regions are presented in table 7. The actual number of irrigations recommended and the amount of irrigation water applied using the above mentioned criteria are presented. Many of these, conventional methods of scheduling irrigation require several measurements in a given area.

The scheduling based on these criteria are location specific and very often, farmers lack an access to such information during the current season to make rational decisions regarding water application. Moreover, the availability of water at these critical stages is also not augmented at farmers level. There are many references in the literature, which give emphasis for rapid and early season growth before flowering to provide a sufficient framework for heavy fruiting and many cite evidence that plants should never be allowed to develop moisture stress. It has been observed that soil moisture stress during pre-flowering period as a practice is followed by growers in northern India, which effect the plant growth. However, the best yield of cotton was obtained with the time lag of 30-35 days after first irrigation

Table 7. Irrigation scheduling criteria for cotton-based on soil and atmospheric parameters

Place	Schedule	Reference
Sriganganagar (Rajasthan)	100 mm CPE	Saig and Verma, 1994
Sriganganagar (Rajasthan)	0.80 IW/CPE	Verma and Deg, 1992
Hisar (Haryana)	25% ASMD	Yadav, 1972
Parbhani (Maharashtra)	125 mm CPE	Chimanshette, 1990
Rahuri (Maharashtra)	0.75 IW/CPE	Suryavanshi *et al.,* 1992
Akola (Maharashtra)	75 mm CPE	Sethi *et al.,* 1995
Coimbatore (Tamil Nadu)	75% ASMD	Iruthyaraj, 1980
Bhavanisagar (Tamil Nadu)	50% ASMD	Ali *et al.,* 1974
Siriguppa (Karnataka)	75% ASMD	Yadav, 1972

Source: *Bonde (1992)*

14.5.1 Mid-season irrigation

The timing of irrigation is crucial during the main fruiting period in mid-season. This is also the period of maximum water consumption. The stress during this period, shortens the period of boll formation and reduces the yield. If there is drought during boll development stage, one or two protective irrigations will help to retain maximum number of bolls and higher yield (Bhaskar et al., 2002).

14.5.2 Late-season irrigation

It has been observed that consumptive use declines in late season as a result of limited new growth, cooler climate and maturation of crop. The moisture stress during this stage hastens maturity. Many investigators revealed that irrigation should be stopped after first boll opening. If irrigation is continued, opening of bolls will be affected and subsequently seed cotton yield will be reduced considerably.

14.5.3 Methods of irrigation

While comparing the yield performance of cotton under different irrigation systems, Mukherjee et al. (1990) reported that seed cotton yield was increased significantly in alternate furrow irrigation over flood or every furrow irrigation. Total quantity of water applied was also lowest under alternate furrow irrigation as compared to flood and every furrow irrigation (Table 8).

Table 8. Method of irrigation

Irrigation treatment	Total water applied (000 gallon)	Water Use kg^{-1} kapas (gallon)	Saving in Water (%)	Seed cotton yield (qha^{-1})	Total uptake (kg ha^{-1})			Quantity of nutrients required to produce 1 q of kapas		
					N	P	K	N	P	K
I_0 Flooding	1312	570	-	21.51	151.60	18.83	73.50	6.60	0.82	3.10
I_1 Irrigation in each furrow	991	420	25	22.30	138.10	15.00	73.81	5.80	0.63	3.10
I_2 Irrigation in alternate furrow	788	350	40	22.91	122.40	14.05	65.74	5.40	0.62	2.90

Source: Mukharjee *et al*., *(1990)*

- In many rainfed areas, irrigation is being given to the cotton crop by flood method (Plate 7), which is not desirable because, 40-60% irrigation water goes waste and the same amount could be saved through drip/sprinkler irrigation and double area can be irrigated from same amount of water.
- In Maharashtra, Tamil Nadu and Karnataka furrow irrigation is followed which is more rational. In this method, more quantity of water as compared to drip / sprinkler irrigation is applied and water is made available to the plants.
- Field study conducted at Hissar indicated that application of water in alternate furrows could save irrigation water to the extent of 24 to 49% without any loss of yield (Plate 8). Besides economizing water use, there is also a saving on fertilizer nutrient requirement

Plate 7. Food irrigation in rainfed cotton treated as wastage of water

Plate 8. Alternate furrow irrigation in cotton, a better alternative for saving of irrigation water to the extent of 40-49%

- Four years experiments conducted at Dr. PDKV, Akola (1973-77) showed that the drip method of irrigation to cotton crop gave significantly higher yield than bulk water application through other method of irrigation and beyond that seed cotton yield declines (Verma *et al.*, 1991).

5 Irrigation Management

The response of different levels of irrigation on seed cotton yield under drip was evaluated at Central Institute for Cotton Research, Nagpur for (1998-2000) 3 years. Results showed that higher dose (150+75+75) of N, P and K (kg ha^{-1}) through fertigation was not effective in increasing seed cotton yield over recommended (120 +60 +60 NPK kg ha^{-1}) dose of fertilizer through soil application to (Table 9).

Table 9. Effect of different levels of management on seed cotton yield under drip in Vertisol at CICR, Nagpur

Management levels	Seed cotton yield (q ha^{-1})			Mean
	1998	1999	2000	
A. Fertilizers level				
F_1 120 + 60 + 60 NPK kg ha^{-1} (Soil application)	13.24	12.15	11.06	12.15
F_2 150+75+75 NPK kg ha^{-1} (Soil application)	13.47	1221	12.22	12.63
F_3 150+75+75 NPK kg ha^{-1} (Fertigation)	9.87	10.19	10.56	10.21
C.D. (P=0.05)	N.S	N.S	N.S	-
B. Irrigation level				
I_1 Gravimetric method	11.25	11.58	10.79	11.21
1_2 IW/CPE	13.13	11.47	11.77	12.12

C.D. (P=0.05)	1.82	N.S	N.S	-
C. Weed management level				
W_1 Diuron pre-emergence + Stomp + PPI + 4 I/C	11.59	11.29	11.03	11.30
W_2 Diuron pre-emergence+ Trefflan + PPI + 4 I/C	12.79	11.75	11.35	11.96
C.D. (P=0.05)	N.S.	N.S.	N.S.	-

Source*: Unpublished work of Bhaskar et al.,*

Irrigation of cotton by IW / CPE ratio was found better over gravimetric method which improved seed cotton yield by about 80 kg ha^{-1}.

15.1 Weed Management

The influence of weedicide on seed cotton yield was also evaluated. Diuron, pre-emergence + Trefflon PPI+ 4 I/C was found slightly better in increasing seed cotton yield by about 60 kg ha^{-1} over Diuron pre-emergence+Stamp PPI 4 I/c. Pre- emergence application of 1.0 kg Diuron + 1.5 kg Trifluralin ha^{-1} resulted in the lowest weed population and dry weight of weeds per m^2 at 35 days after sowing. This treatment, 1.5 kg Trifluralin alone, 1.0 kg Diuron alone and the weed-free control gave the highest seed cotton yields. Oxyfluorfen @ 0.2 kg ha^{-1} gave the lowest seed cotton yield (Satao *et al*., 1999).

15.2 Nutrient Use Efficiency

Nutrient use efficiency in cotton showed that recommended level (120:60:60 NPK kg ha^{-1}) had higher N and P % in seeds and leaves as compared to 150:75:75 NPK kg ha^{-1} with higher dose of fertilizer mainly due to higher biomass.

Based on the crop yield performance and rainfall distribution pattern at Nagpur, very deep black soils are not amenable for yield improvement in cotton crop through drip, probably due to ill drained conditions with high available water capacity (300 mm per meter soil depth).

15.3 Irrigation Efficiency

Irrigation efficiency is the percentage of irrigation water that is available for consumptive use by the crops. When the water is delivered and measured at the farm headgate, it is called farm irrigation efficiency. When it is measured at the field or plot it may be designated as field irrigation efficiency. However, irrigation efficiency of 70 to 80% is considered good for higher yield potential of rainfed cotton.

16 Role of Micro –Irrigation in Yield Maximization of Rainfed Cotton

Drip system proved advantageous over surface furrow irrigation and sprinkler system in cotton. Drip required 31 % less water with a water application efficiency 69% and water storage efficiency 83% as compared to sprinkler and open furrow irrigations. The encouraging results from available literature on rainfed cotton due to drip irrigation led to the research work at various leading institutions in different cotton growing states in the country. The results of the field experiment (1995-97) entitled, "Comparative evaluation of drip, sprinkler and furrow irrigation system in hybrid cotton" conducted at Central Institute for Cotton Research, Nagpur are given below:

16.1 Central Institute for Cotton Research, Nagpur, Maharashtra

The field experiments on 15-20 days advance sown hybrid cotton conducted at the Institute indicated the response of micro-irrigation on seed cotton yield, water application efficiency and fertilizer use efficiency as very encouraging. The comparative response of drip with sprinkler and open furrow has. indicated a significant difference in gross water application efficiency (69%), water distribution efficiency (17%) and water storage efficiency (83%) over sprinkler and open furrow (Table 10).

Table 10. Water use efficiency in cotton

Particulars	Irrigation system		
	Drip	Sprinkler	Open furrow
Gross water requirement (ha cm)	38	37.7	37.7
Water applied as part of gross water requirement (%)	Less by 31 %	Less by 26 %	Less by 53 %
Water application efficiency (%)	69	64	56
Water distribution efficiency (%)	17	89	88
Water storage efficiency (%)	83	62	52
Coefficient of uniformity	61	16	-

Source: *CICR, Annual Report (1996).*

Results further showed that the response of fertilizer levels with irrigation scheduling by IW/CPE 0.75 ratio produced significantly higher seed cotton yield over gravimetric method (50 % field capacity) of scheduling at recommended level of 120:60:60 and 150:75:75 NPK (kg ha^{-1}). Irrigation at 0.75 IW/CPE requires 38% more irrigation water but increased seed cotton yield by 187 kg ha^{-1} only.

16.1.1 Water use efficiency in cotton

In the central zone, utilization of micro irrigation systems particularly drip system to establish a pre-monsoon hybrid cotton will substantially help in improving the yield of cotton, wherever limited water is available during summer. However, a complete package of practices to reap the benefits of drip irrigation, particularly plant geometry, fertigation, herbigation, water delivery rates, pest management etc. need to be standardized to offset the high initial investment in stabilizing drip irrigation. Field experiments conducted at CICR, Nagpur, and elsewhere have established the superiority of drip over sprinkler system in economizing water and improving water use efficiency (Table 11).

Table 11. Water use efficiency under different irrigation systems

Irrigation system	Seed cotton yield (q ha^{-1})	Water applied (ha cm^{-1})	Water use efficiency (kg ha^{-1} cm)
Drip	12.07	13.63	88.50
Sprinkler*	11.45	11.81	96.90
Furrow	11.99	19.72	77.90

* at 0.6 IW/CPE (6 cm of water at 100 CPE)

Source: *CICR, Annual Report (1996).*

16.1.1.1 Water use efficiency in cotton

Higher water saving and higher water use efficiency was recorded in alternate furrow irrigation both in maize and cotton, while yield of these two crops was comparatively superior under irrigation in every furrow (Table 12).

Table 12. Increase of production and water saving through furrow irrigation

Name of crop	Irrigation in every furrow	Alternate furrow irrigation
Maize		
Water saving (%)	-	30.0
Yield (q ha^{-1})	41.3	36.7
Water use efficiency	25.8	36.7
Cotton		
Water saving (%)	-	27.1
Yield (q ha^{-1})	20.5	19.8
Water use efficiency	6.0	8.0

Source: *Singh (2002).*

16.1.1.2 Water use efficiency in Sprinkler Irrigation

Micro irrigation plays an important role in increasing crops yield and improving water use efficiency. Sprinkler irrigation maintained superiority in case of groundnut and chilly and increased yield significantly over irrigation in furrow, border or check (Table 13).

Table 13. Effect of different methods of irrigation on production and water use efficiency

Methods of irrigation	Yield (q ha^{-1})	Water use efficiency (kg ha^{-1} cm^{-1})
Groundnut		
Border irrigation	23.10	25.85
Check (basin)	23.80	26.45
Sprinkler	28.90	46.80
Chilly		
Furrow irrigation	18.87	45.03
Sprinkler	25.23	81.57

Source: *Singh (2002).*

16.1.1.3 Water use Efficiency in Drip Irrigation

Irrigation through drip in different vegetable crops such as tomato, bhindi, radish, brinjal, ipomea batata and sugarcane crops maintain its superiority over surface irrigation. Similarly, drip recorded higher water use efficiency in all these crops over surface irrigation (Table 14).

Table 14. Effect of drip and conventional irrigation on the yield of crops

Crops	Yield (q ha^{-1})		Water use efficiency (kg ha^{-1} cm^{-1})	
	Drip	Surface	Drip	Surface
Tomato	88.7	61.9	253.4	84.3
Bhindi	113.1	100.0	344.8	128.7
Radish	41.9	40.4	387.9	87.1
Brinjal	133.0	124.0	294.9	143.5
Cotton	32.5	26.0	116.1	31.6
Ipomea batata	58.9	42.4	157.9	56.4
Sugarcane	750.0	860.0	704.9	519.9

Source: *Singh (2002).*

Irrigation scheduling in hybrid cotton through drip based on 0.6 ETc. enhanced seed cotton yield by 44 % and water use efficiency by 20% as compared to surface irrigation. Application of 75% recommended dose of fertilizer (RDF) through drip enhanced seed cotton yield by 30% as compared 100% RDF through soil (Jadhav *et al.*, 2002).

16.1.2 Effect of Irrigation through Drip on Yield Maximization of Rainfed Cotton

16.1.2.1 Plant Population

The effect of plant population under drip in increasing seed cotton yield of advanced sown cotton was evaluated. Results showed that two plants per hill (Plate 9) was found effective to increase the seed cotton yield by about 3 q ha^{-1} and the yield of three plants per hill was almost equal to two plants per hill (Table 15).

Plate 9. Two plants per hill of cotton under drip arrigation found superior to one plant per hill

Table 15. Effect of plant population on seed cotton yield under drip in Vertisol at CICR, Nagpur

Treatment		Plant population (ha^{-1})	Seed cotton yield (q ha^{-1})		Mean
			2001	2002	
T1	One plant $hill^{-1}$	13889	17.50	13.66	15.58
T2	Two plants $hill^{-1}$	27778	18.50	18.75	18.63
T3	Three plants $hill^{-1}$	49667	19.70	17.58	18.64

Source: *Unpublished work of Bhaskar et al.,*

16.1.2.2 Crop geometry

Among the various methods of cotton planting, paired row planting at 30+30+120 cm apart with continuous furrow irrigation was found suitable and has given maximum seed cotton yield over other methods of planting and methods of irrigation (Table 16).

Table 16. Effect of crop geometry and irrigation methods on seed cotton yield

Crop geometry	Irrigation method	Irrigation depth (cm)	Seed cotton yield (q ha^{-1})
Normal planting (75 cm) in flat beds	Border	5.0	19.9
Normal planting (70 cm) at the top of ridge	Continuous furrow	4.3	23.7
Normal planting (70 cm) at the top of ridge	Alternate furrow	2.2	19.8
Paired row planting (30 + 120 cm) at bottom of furrow	Continuous furrow	2.1	29.3

Source: *Singh and Sharma (1993)*

16.1.2.3 Nutrient use efficiency

Results showed that recommended level of fertilizer (120:60:60 NPK kg ha^{-1}) had higher (%) N and P in seeds and leaves as compared to higher dose of 150:75:75 (NPK kg ha^{-1}) mainly due to higher biomass.

16.1.2.4 Biomass generation

The study on biomass generation in rainfed cotton under drip irrigation was carried out at maturity stage (110 days). Higher biomass accumulation in cotton (NHH-44) through drip irrigation was recorded at higher level of NPK (150:75:75 kg ha^{-1}) through soil application followed by recommended dose of fertilizer (120: 60: 60 NPK kg ha^{-1}) as soil application.

16.1.2.5 Nutrient uptake

Results over 3 years on total nutrient uptake (N and P) by the cotton at 110 DAS indicated that soil application of higher doses of NPK (150:75:75 kg ha^{-1}) lead to higher total N and P uptake as compared to fertigation or recommended dose of fertilizers as soil application. Similar trend in nutrient use efficiency was also observed by application of higher doses (150:75:75 kg NPK ha^{-1}) of fertilizer. Further, improvement in nitrogen use efficiency by 25-30% and P use efficiency by 12-15% was observed at higher doses of NPK either through soil application or fertigation.

16.1.2.6 Yield target

Yield attainment in the range of 20-25 q ha^{-1} is possible under life saving and surface irrigated condition in black cotton soils. However, to realise higher seed cotton yield with drip irrigation and fertigation, the following approaches need to be adopted:

Approach 1: Advanced sowing of the crop in (25-30 days in advance) prior to the onset of regular monsoon and extension of crop duration with the winter irrigations through drip system.

Approach 2: To achieve higher yields under higher fertilizer doses through drip by soil application.

Approach 3: Improving resource use efficiency by scheduling of irrigations and efficiently managing weeds through weedicide.

16.1.2.7 Economics of drip irrigation system

The economics of the drip system:

i. Total cost and installation charges-Rs.50,000 ha^{-1} in cotton
ii. Duration of irrigation set-1 0-15 years
iii. Yield maximization upto-25-30 q ha^{-1}

A. Fixed cost	
i. Annual depreciation	Rs 5000.00 ha^{-1} annum^{-1}
ii. Annual interest	Rs 2750.00 ha^{-1} annum^{-1}
B. Variable cost	
i. Repair and maintenance	Rs 500.00 ha^{-1} annum^{-1}
ii. Operational cost	Rs 1500.00 ha^{-1} annum^{-1}
iii. Labour charges	Rs 1000.00
Total cost per year (A + B)	Rs 10750.00
Additional yield raised over rainfed system	Rs 16800.00
B:C ratio	Rs. 1.56

16.2 Mahatma Phule Agricultural University, Rahuri, Maharashtra

16.2.1 Scheduling of irrigation

The research work carried out at MPKV, Rahuri indicated that with drip irrigation, seed cotton yield could be increased by about 34 % over normal practice (Sonwane, 1984).

During 1980-81 a beginning was made at Rahuri centre representing hot semi-arid eco-region with deep black cotton soils to evaluate drip irrigation system in comparison with traditional furrow irrigation method. In furrow method, 7 cm irrigation was applied to replenish moisture at 0.60 PE followed by 0.70 PE and 0.80 PE during the next 30-50 days and 50 days onwards respectively.

16.2.2 Water use efficiency

The efficiency of the drip irrigation system was improved significantly with a coefficient of uniformity of 86%. Application of fertilizer through irrigation water (fertigation) was also attempted. Results (Table 17) showed an improvement in cotton yield by 40 and 11 % (with and without mulch respectively) while saving more than 89% water. Similar trend was observed during 1982-83 and 1983-84. Mean (1981 to 1984) seed cotton yield in drip irrigated plots with mulching was 33% higher than that of cotton furrow irrigated (with mulch) plots (Plate 10). In the plots without mulching, similar trend continued with 21 % more yield in drip irrigated plots. Throughout the experimentation, mulching with sugarcane trash @ 5 t ha^{-1} had a desirable effect in moisture conservation and yield irrespective of irrigation method.

In another study conducted by Benke (1996) at the same station, the increase in seed cotton yield was observed to be 27% with water saving of 53 %. Similarly, results from on going trial from Akola, indicated that 50% of fertilizer can be saved when applied through drip as liquid fertilizer without any reduction in the yield. But, when the recommended dose was applied through drip, the yield increase was to the extent of 28%.

Plate 10. Mulching of sunhemp in rainfed cotton

Table 17. Effect of drip and furrow irrigation methods on water requirement and yield of cotton at Rahuri

Description	Year									
	1980-81		1981-82		1982-83		1983-84		Mean	
	Yield (t ha^{-1})	Water applied (cm)	Yield (t ha^{-1})	Water applied (cm)	Yield (t ha^{-1})	Water applied (cm)	Yield (t ha^{-1})	Water applied (cm)	Yield (t ha^{-1})	Water applied (cm)
Furrow	3.63	71.90	2.16	83.70	2.26	89.53	2.41	91.00	2.27	84.03
Furrow with mulch	3.66	55.00	2.25	89.50	2.25	89.53	2.48	91.00	2.32	81.25
Drip	3.11	41.92	2.40	44.20	3.13	51.14	2.76	33.09	2.76	42.58
Drip with mulch	3.15	35.83	3.14	44.20	3.20	51.14	2.97	33.09	3.10	41.06
Drip + fertigation	-	-	-	-	2.55	51.14	2.73	33.09	2.64	42.11
Drip + fertigation+ mulch	-	-	-	-	2.61	51.14	2.94	33.09	2.77	42.11

Source: *Annual Report of AICCIP on water management, Rahuri centre 1981-82, 1982-83, 1983-84 and 1984-85.*

16.3 Marathwada Agricultural University, Parbhani, Maharashtra

16.3.1 Planting pattern and fertilizer levels

Research was focused on economic design and adoption of the system. During 1993-94 yield response to varied irrigation and nitrogen levels was studied in hot, semi-arid eco-region with medium to deep black soils. Planting pattern was changed to reduce the cost of the drip system. Normal (90x90 cm) and paired (60-60x120 cm) planting were evaluated. Four irrigation regimes namely 0.4, 0.6, 0.8 and 1.0 PE with alternate day application in drip and 6 cm irrigation at IW/CPE=0.9 in alternate furrows were imposed. Three nitrogen levels viz. 50, 75 and 100 % of the recommended dose were applied through drip system. Results (Table 18a and 18b) indicated that the change in planting pattern did not affect cotton yield adversely. In paired row planting, one lateral served two cotton rows and one dripper was placed for two plants reducing the cost of laterals and drippers by 50%.

16.3.2 Water use efficiency

The system showed a high coefficient of uniformity of 98.2%. The moisture distribution at the land surface from individual dripper was 76 cm in diameter, hence exceeding the required plant spacing of 60 cm (Table 18 a). Scheduling irrigation at 0.8 PE by drip method recorded the highest yield, which was statistically at par with 0.6 and 1.0 PE. About 10% saving in irrigation water and 10 to 21 % higher yield was recorded in drip method as compared to furrow method (Table 18 a).

Table 18 a. Effect of planting pattern and levels of fertilizer on cotton yield and water requirement

Treatment	Year					
	1993-94		1994-95		Mean	
	Yield (t ha^{-1})	Water applied (cm)	Yield (t ha^{-1})	Water applied (cm)	Yield (t ha^{-1})	Water applied (cm)
Water (PE)	Drip method, normal (90x90 cm) planting % PE					
0.4	2.44	9.00	1.69	7.20	2.06	8.10
0.6	2.57	13.50	1.67	10.80	2.12	12.15
0.8	2.80	18.10	1.99	14.40	2.39	16.25
1.0	2.63	18.00	1.84	18.00	2.23	18.00
Water (PE)	Paired (60-60x120 cm) planting % PE					
0.4	2.35	9.00	1.74	7.20	2.04	8.10
0.6	2.65	13.50	1.77	10.80	2.21	12.15
0.8	2.59	18.10	1.94	14.40	2.26	16.25
1.0	2.57	18.00	1.90	18.00	2.23	18.00
	Alternate furrow irrigation, normal (90x90 cm) planting					
IW/CPE 0.9	2.32	18.00	1.60	18.00	1.96	18.00

Source: *Official communication from Parbhani*

16.3.3 Fertilizer use efficiency

Result showed that significantly higher yield (about 16%) of cotton was recorded when 100% of recommended dose of nitrogen was applied through drip as compared to conventional method. The yield at 75% dose through drip was statistically at par with 100% dose through furrow irrigation indicating potential saving of 25% fertilizer (Table 18b).

Table 18 b. Effect of planting pattern and levels of fertilizer on cotton yield and water requirement

Treatment	Seed cotton yield (t ha^{-1})	Water applied (cm)
Planting patterns		
Normal: 90x90cm	2.20	14.2
Paired row: 60-60x120 cm	2.19	14.2
Irrigation management		
100 kg N ha^{-1} and irrigation in alternate furrow	1.82	18.0
Fertilizer level		
50 % recommended dose	1.65	12.2
75 % of recommended dose	1.89	12.2
100 % of recommended dose	2.10	12.2

Source: *Annual Report of AICCIP on water management, Parbhani centre 1994-95*

16.4 Gujarat Agricultural University, Gujarat

16.4.1 Response of drip to cotton

In Gujarat, systematic research for finding out the economic feasibility of drip in cotton in different agroclimatic conditions is in progress since the last 3 to 4 years. An ongoing experiment at the Cotton Research Station, Surat indicates that with drip, water saving to the tune of about 47% (Table 19) can be achieved without affecting the seed cotton yield (Anonymous, 1995).

Table 19. Response of cotton to drip in South Gujarat

Treatments	Seed cotton yield (kg ha^{-1})		Average
	1993-94	1995-96	
0.4 IW/CPE through drip	2591	2270	2430
0.6 IW/CPE through drip	2770	2460	2615
0.8 IW/CPE through drip	2989	2609	2799
Traditional system of irrigation	2988	2487	2737
SEM±	118	153	-
CD (P=05)	NS	NS	NS

Source: *Official communication of data*

However, in the black soil area of Narmada command, irrigating cotton G. Cot. hybrid 8 through drip was found to increase the seed cotton yield by about 25 % with water saving of about 50%. There was a curvilinear response observed upto 70%, replenishment of evaporated water from the open pan. Further increase in irrigation level (i.e. 90% replenishment) results in yield reduction.

16.4.2 Economics of drip irrigation system

The economics of the drip irrigation system was worked out, With the use of drip system, the farmer can get about two thousand rupees more per hectare and about 50,000 rupees more for the same quantity of water used as in the surface method (Table 20). In Navsari conditions of South Gujarat, (heavy rainfall zone) where *Kharif* cotton is on the decline due to waterlogging problems, *Rabi cotton* was found to have good prospects. Field experimentation conducted over a couple of years showed that due to drip irrigation, the seed cotton yield increased significantly. Apart from, 50% saving in water there can be saving of 30 % in nitrogen fertilizer (Table 20).

Table 20. Relative economics of drip in Narmada command

Sr.No.	Particulars	Surface method	Drip ratios (PE)			
			0.3	0.5	0.7	0.9
1	Fixed cost (Rs)	-	11.60	11.60	11.60	11.60
2	Variable cost (Rs)	9.20	9.40	9.65	9.80	9.50
3	Total cost (Rs)	9.20	21.00	21.25	21.40	21.10
4	Seed cotton yield (t ha^{-1})	2.36	2.70	3.00	3.15	2.86
5	Gross income (Rs)	42.48	48.60	54.00	56.70	51.48
6	Net income (Rs)	33.28	27.60	32.75	35.30	30.38
7	Additional income over control (Rs)	-	-05.68	-0.53	2.02	- 2.90
8	Amount of water applied (mm)	500	155	227	299	371
9	Water saving (%)	-	68	53	28	23
10	Additional/Projected area (ha)	-	2.00	1.10	0.60	0.30
11	Additional expenditure (Rs)	-	42.00	23.38	12.80	6.30
12.	Additional gross income (Rs)	-	97.20	59.40	34.02	15.44
13.	Additional net income (Rs)	-	55.20	36.02	21.22	9.14
14.	Total net income (Rs) over control	-	49.52	35.49	23.24	+6.24

Source: *Official communication of data from Parbhani*

16.5 Dr.Punjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra

Trials on irrigation through drip were conducted at Akola for a number of years. Results revealed that:

Fertilizer saving : 50% saving applied through drip as liquid fertilizer.

Seed cotton yield : 28% more seed cotton yield over conventional method (Benke, 1996).

16.6 Cotton Research Station, Navasari, Gujarat

Field experiments conducted at this station indicated that the performance of *Kharif* cotton is declining due to heavy rainfall and the *Rabi* cotton found to have good response. Further, results showed that drip irrigation has resulted in:

Water saving	:	50%
Fertilizer (N) saving	:	30% (Anonymous, 1995)
Yield target	:	Seed cotton yield of 30-35 q ha^{-1} under drip through fertigation

17. Multi-Crop Use Of Micro Irrigation in India

The use of drip irrigation is not only limited to cotton and cotton-based cropping systems, it is used widely in fruit and vegetable crops and their production and productivity has increased significantly with increased fertilizer and water use efficiency. The work done at different places in the country on different crops is highly encouraging with the main objective to economise the irrigation water with higher yield and economic return per unit of land and water. Crop wise salient features are as given below:

17.1 Sugarcane (*Saccharum officinarum*)

Drip system resulted in cane yield of 171.4 t ha^{-1} as compared to conventional surface irrigation (86.9 t ha^{-1}). Application of 80% recommended dose of fertilizer by drip gave the highest cane yield (182.84 t ha^{-1}) and superiority was recorded in increasing WUE over conventional method (Shelke *et a/.*, 2002)

17.2 Summer cotton (*Gossypium* species)

Drip irrigation improved seed sprouting by 66% within 6 days, while only 46% germinated under flood irrigation during the same period resulting in 74.9% germination in the conventional system as compared to 93.5% in drip system (Nalayini and Shanmugham, 2002). Water use efficiency ranges from 16.3 to 35 kg ha^{-1} for drip as against 4.9-8.3 kg ha^{-1} for flood irrigation system.

Drip irrigation favoured the growth of summer cotton at Coimbatore and resulted in saving of 50% water besides increasing seed cotton yield by 34.5% as compared to conventional (flood irrigation) method.

17.3 Summer groundnut (*Arachis hypogaea*)

Application of 20 kg N+ 40 kg P_20_5 ha^{-1} as drip fertigation significantly improved the nutrient availability in the soil and uptake by crop and resulted an increase in pod yield by 20.7% as compared with fertilizer applied in soil under surface irrigation (Devidayal and Malviya, 2002).

17.4 Potato (*Solanum tuberosum*)

Study revealed that 75% of recommended N, P, K kg ha^{-1} through drip fertigation produced significantly higher yield of tubers alongwith 25% saving of NPK nutrients and 40% saving of irrigation water as compared to conventional furrow method of irrigation (Singh and Sharma, 2002).

17.5 Tomato (*Lycopersicon esculentum*)

The scheduling of irrigation at 0.8 Pan evaporation coefficient and applying water on canopy area basis combined with 180 kg N ha^{-1} resulted in maximizing production per unit of water (Saxena, *et al.*, 2002)

17.6 Bush black pepper (*Piper nigrum*)

The bush pepper planted as an inter crop in coconut garden, may be irrigated @ 8 litres day^{-1} by using drip. If water is limiting, drip irrigation @ 4 litres day^{-1} may be preferred to pot watering instead of watering @ 10 litres day^{-1} (Thankamani and Ashokan, 2002).

18. Future Line of Work

- Need for improving WUE under surface irrigation method.
- Evaluation of appropriate micro-irrigation systems.
- Modification in crop geometry for making micro-irrigation systems economically more viable.
- Development of appropriate agronomic practices under micro-irrigation including fertigation for enhancing the productivity further.
- Use of drip under problematic soil and water conditions.
- Evaluation of drip along with mulch.
- Development of mulching technologies with special reference to rainfed and salt affected soil conditions.
- Feasibility of sprinkler irrigation

19. Futuristic Strategies

- **Bringing additional area under irrigated cotton:** It has been estimated that about 6.281akh ha land can be additionally brought under irrigated cotton in the command areas of different irrigation projects. However, there is an urgent need to identify or develop suitable short duration, high yielding varieties/ hybrids of cotton along with a package of agro-techniques to enable cotton to profitably fit into the double cropping system in these areas, made possible by extending irrigation facilities.
- **Economizing water use in northern cotton zone:** Flooding is most commonly adopted method for irrigating cotton in canal irrigated areas. This system is neither economic nor ecologically sustainable. Furrow and alternate furrow irrigations are the viable alternatives by saving upto 30 and 50% of irrigation water respectively.
- **Use of infra-red thermometry for scheduling irrigation:** Cotton plant temperature

measured with infra-red thermometer can be combined with ambient air temperature and vapour pressure deficit to develop Crop Water Stress Index (CWSI). Monitoring CWSI on a large area, on a repetitive basis, can then be used to schedule irrigation. This system is becoming increasingly popular in Arizona (USA) for both upland and Pima cotton. However, research on these aspects needs to be initiated in India.

- **Utilization of remote sensing for irrigation management:** Recent experiments based on satellite imageries and ground based observations on canopy temperature have provided encouraging evidence to show that remote sensing techniques can be employed as an aid in scheduling irrigation and also in estimating ET and water use by crops. In wheat, scheduling of irrigation based on canopy air temperature difference has been successfully accomplished in India. This is another frontier area, where research needs to be initiated in cotton.
- **Use of remote sensing and geographical information system (GIS) for water potential assessment and watershed development:** Water resource development should logically be done on micro-watershed basis. Many of the surface and crop parameters needed for watershed development can be precisely surveyed through remote sensing. A spatial data base can be generated using remote sensing data and it can be integrated using the available socio-economic, climatic, soil and demographic profiles in a GIS mode to generate valuable information. Cotton research and development agencies should collaborate with the different Regional remote sensing centers of ISRO which have operationalised this technique on pilot project basis, for effectively managing the water resources in cotton growing areas.
- **Micro-irrigation system:** In the central zone, utilization of micro-irrigation systems particularly drip system, to establish a pre-monsoon hybrid cotton will substantially help in improving the yield of cotton, where ever limited water is available during summer. However, a complete package of practices to reap the benefits of drip irrigation, particularly plant geometry, fertigation, herbigation, water delivery rates, pest management etc. need to be standardized to offset the high initial investment in stabilizing drip irrigation. Field experiments conducted at CICR, Nagpur as well as elsewhere have established, the superiority of drip and sprinkler system in economizing water and improving its use efficiency. Rainwater can be suitably harvested, stored and recycled to cover a larger area through drip system as a life saving irrigation during the post and pre monsoon season at the time of long spell of drought.

Agricultural research workers, extension functionaries and developmental agencies (including meteorology department) should work in close coordination so that their expertise can be synergistically explored and a strong advisory service could be set up which could help the farmers in taking rational decisions on water used (being precious production resource in the rainfed cotton production system).

20 Summary and Conclusion

India with 59 M ha of net irrigated area (38 % of the total sown area) is next to China in the world. Over all, the irrigation efficiency of the system in the country is less than 30 %. Even after development of all the irrigation resources, almost 50 % area will still remain un-irrigated, and rain dependent. Flood irrigation in cotton consumes 40-50 % more water as compared to micro-irrigation. Under rainfed situation, cotton is mainly grown on black, black + red or red soils which developed naturally on basalt having undulating shallow and sloppy topography where normal irrigation is not feasible and economical also. In view of the same, micro (drip and sprinkler) irrigation system will play an important role in water saving, fertilizer saving, weed management and easy handling, efficient shifting and transportation from one place to another. The area under micro-irrigation system is increasing not only under cotton but in many other crops such as grains, vegetables and fruit crops within and out side the country also.

The research and development work carried out at different Agricultural Universities, ICAR Institutes, Agricultural Research farms and farmers fields during the past few years is summarized below:

- Micro irrigation has given very high (> 90 %) irrigation efficiency with significant improvement in yield and quality of cotton, vegetables and horticultural crops.
- Majority of the area (55.40 %) covered under micro irrigation is in horticultural crops, while 7 % it is under field crops.
- Yield improvement due to micro irrigation has been reported upto 35-50%, in cotton 5-10%, in castor 15-42%, in groundnut 20-66% and in potato 20-26%. The yield improvement in principal crops is to the tune of 30-105%.
- Square formation, flowering, early boll development and peak boll development are the important critical stages in cotton for irrigation. However, peak boll development stage is the most crucial in cotton,
- Climatic water requirement of cotton varies from 650 - 1000 mm in different cotton growing states.
- Irrigation through drip system was found superior to flood, alternate furrow irrigation, irrigation in each furrow and sprinkler irrigation with higher water saving and quality produce.
- Field experiments conducted at different research centres indicated that through drip irrigation, higher fertilizer use efficiency in cotton is possible.
- Irrigation through drip is a better alternative for cotton on uneven, undulating topography with or without saline sodic water.
- Drip irrigation system requires less water with high water application efficiency (69%), high water storage efficiency (83 %) over sprinkler and furrow irrigation method.
- Drip requires less gross water (31 %), with high water application efficiency (69 %) , water distribution efficiency (17 %) and water storage efficiency ratio (83 %) over sprinkler and open furrow irrigation.
- Through fertigation, 30-50 % fertilizer can be saved in drip with higher yield (27%) and higher water saving (53 %).
- Highest coefficient of uniformity in moisture distribution (98.2%) due to drip irrigation at the land surface was recorded.
- With the use of drip, farmer can get Rs 2000 ha^{-1} more and about Rs 50,000 more for the same quantity of water used as in the surface method.
- The yield target of 20-25 q ha^{-1} under irrigation through drip can be achieved by sowing of cotton 20-25 days over the monsoon sowing.
- The life span of drip is estimated to be 1 0-15 years by taking all due care in handling the system costing Rs 30,000-50,000 ha-1
- The area under micro-irrigation is increasing over the years in the country, mainly due to its utility in water saving and better water use efficiency. At 39 present, about 6.7 lakh ha area is

under sprinkler and 3.5 lakh ha under drip in the country.

On the basis of the review collected from available literature and as discussed above, some broad conclusions could be arrived at regarding use of drip and sprinkler system in cotton:

- **Response of cotton to drip varies under different soil and agroclimatic conditions.**
- **Under conditions of ample availability of irrigation water and in non-problematic conditions, the yield response may be poor though considerable saving in irrigation water can be achieved.**
- **Under conditions of good quality irrigation water, but with enough land availability, drip may be a boon to bring more area under irrigation and improve the overall economy of the farmers with the same quantity of water used as in the surface method.**
- **In salt affected soils, availability of either good or moderately saline water, drip can be most profitably used both for increasing cotton productivity and maintaining soil health.**
- **Fertigation through drip can save 40-50 % of fertilizer requirement.**
- **Under high water table conditions with poor quality under ground water, irrigating through drip to maintain shallow and restricted root zone is a better proposition than the surface irrigation.**

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Digitized & Designed by M.Sabesh, CICR
Report Published in 2005