CHAPTER - 3

METHODOLOGY

3.1 General

In traditional micro irrigation system either one or two laterals are used for one row of crop or one lateral is used for two rows of crop. On each lateral there are number of emitters, spaced at certain distance. Naturally number of emitters depends on the length of lateral and number of laterals. Therefore for a given field there are thousands of emitters and total length of laterals run into kilometers. The major share of cost of micro irrigation system consists of emitters and laterals.

To reduce the no. of emitters and no. of laterals a new model and new technology of combination of micro manifold, microtubes and polytube is developed. This new model concept is highly cost effective as it envisages one lateral serving four to six rows of crops. Instead of emitters, micro tubes will irrigate the field. The micro tubes will take off from the micro manifold, which will be connected, to the poly tube, which in turn will receive water from the lateral. This system will henceforth be referred as Indigenous Technical Know-how Micro Irrigation System (ITK MIS).

3.2 Study Area

Water Resources Engineering and Management Institute is situated at altitude 31.09 m and latitude 22° 15' N and 73° 06' E near village Samiala on Vadodara – Padra Road, 13 km from Vadodara.

Micro irrigation system is established in the indoor micro irrigation laboratory at WREMI, Samiala to carry out laboratory experiments. The field experiments are carried out at the Training Cum Demonstration (TCD) farm, WREMI, Samiala.

3.3 Cost Comparison

The rates of components of MIS and ITK MIS systems are taken from Gujarat Green Revolution Company Ltd (GGRC) which promotes micro irrigation in Gujarat. The cost of micro irrigation system (MIS) in practice for row crops for spacing 0.6 m is Rs.1, 89,345 / ha where as that using the ITK MIS comes to Rs.1, 00,080 / ha as given in Table 3.1 and for row spacing of 0.45 m the cost of MIS is Rs. 2, 38,102 / ha where as that using the ITK MIS comes to Rs. 1, 21,699 / ha as given in Table 3.2.

Table 3.1: Comparative Cost of ITK MIS and MIS for Summer Groundnut and Cauliflower for Row Spacing of 0.6 m

Cost of ITK MIS using Microtubes, Micro Manifolds, Polytubes for Plot of 100m x 100m					Cost of MIS for Plot of 100m x 100m				
	No.	Length	Cost	Total Cost		No.	Length	Cost	Total Cost
		m	Rs./m	Rs.			m	Rs./m	Rs.
Lateral 16 mm dia 2 kg/cm^2	240	16.6	5.26	20,956	Lateral 12 mm dia 2 kg/cm^2	1,008	16.6	3.85	64,421
Microtubes of 1.5 mm dia	34,272	0.45	1.15	17,736	Emitters (4 lph)	34,272	--	2.30 per no.	78,826
Micro Manifold of 16 mm dia +2 Rs. Making charge per No.	10,560	0.12	4.10	5,196	TEG set for 12 mm dia	1008	--	3.00	3,024
Polytubes of 6 mm dia	10,560	0.45	2.60	12,355	GM valve (2")	12	--	735.76	8,829
TEG set for 16 mm dia	240	--	3.18	763	63 mm (4 kg/cm^2) submain + main		246	45.55	11,205
GM valve (2")	12	--	735.76	8,829	63 mm (4 kg/cm^2) manifold	12	25	45.55	13,665
63 mm (4 kg/cm^2) submain+main		246	45.55	11,205					
63 mm (4 kg/cm^2) manifold	12	25	45.55	13,665					
Cost of gravel filter,screen filter, ventury set, pressure gauges etc.				9,375	Cost of gravel filter,screen filter, ventury set, pressure gauges etc.				9,375
Total cost of ITK MIS per ha for the field size of 100m x 100m				1,00,080	Total cost of MIS per ha for the field size of 100m x 100m				1,89,345

Table 3.2 Comparative Cost of ITK MIS and MIS for Summer Groundnut and Cauliflower for Row Spacing of 0.45 m

Cost of ITK MIS using Microtubes, Micro Manifolds, Polytubes for Plot of 100m X 100m					Cost of MIS for Plot of 100m X 100m				
	No.	Length	Cost	Total Cost		No.	Length	Cost	Total Cost
		m	Rs./m	Rs.			m	Rs./m	Rs.
Lateral 16 mm dia 2 kg/cm^2	336	16.6	5.26	29,338	Lateral 12 mm dia 2 kg/cm^2	1,344	16.6	3.85	85,895
Microtubes of 2 mm dia	45,696	0.45	1.15	23,648	Emitters (4 lph)	45,696	--	2.30 per no.	1,05,101
Micro Manifold of 16 mm dia +2 Rs. Making charge per No.	14,784	0.12	4.10	7,274	TEG set for 12 mm dia	1,344	--	3.00	4,032
Polytubes of 6 mm dia	14,784	0.45	2.60	17,297	GM valve (2")	12	--	735.76	8,829
TEG set for 16 mm dia	336	--	3.18	1,068	63 mm (4 kg/cm^2) submain+main		246	45.55	11,205
GM valve (2")	12	--	735.76	8,829	63 mm (4 kg/cm^2) manifold	12	25	45.55	13,665
63 mm (4 kg/cm^2) submain+main		246	45.55	11,205					
63 mm(4 kg/cm^2) manifold	12	25	45.55	13,665					
Cost of gravel filter,screen filter, ventury set, pressure gauges, jointers etc.				9,375	Cost of gravel filter,screen filter, ventury set, pressure gauges etc.				9,375
Total cost of ITK MIS per ha for the field size of 100m x 100m				1,21,699	Total cost of MIS per ha for the field size of 100m x 100m				2,38,102

3.4 Indoor ITK MIS Laboratory Work

Micro irrigation system is established in the indoor micro irrigation laboratory at WREMI, Samiala. The laboratory set up is shown in Fig.3.1.
Table 3.3 shows details of various components used for experimental work.

The objectives of indoor ITK MIS laboratory work are;

(1) To determine loss of head through various length (e.g. 15, 30, 45, 60, 75 and 90 cm) and diameter (4, 5, 6, 7 mm) of polytubes.

(2) To determine F factor for different diameters of laterals using ITK MIS.

(3) To develop regression equations for inlet pressure and discharge of microtubes.

(4) To determine length of microtube for various discharges.

(5) To determine minor loss of head at the outlets for different diameters of laterals.

ITK MIS consists of combination of polytube, micromanifold and microtubes which was used in place of emitters. Polytubes were inserted in lateral and micro manifold was attached at the end of poly tubes. Micro tubes were inserted in to micromanifolds. Micromanifold was prepared from 16 mm dia lateral (used/scrap) and is 15 cm long .Both the ends of micromanifold were sealed. Fig.3.2 shows enlarged view of ITK MIS. There were 8 outlets on lateral. First outlet at 1 m distance from inlet and two to eight outlets were at 2 m from inlet.

Limitation of the Study

Experiments were conducted in indoor ITK MIS laboratory. To obtain various discharge conditions in the lateral, three valves and pressure gauges, one at just downstream of screen filter, second at inlet of lateral and third at the end of lateral are installed. When the experiment was started flow meter for 12 mm, 16 mm and 20 mm laterals were either not available or not reliable. So various discharge conditions are achieved by operating these valves. Turns by turn experiments were conducted on various diameters of laterals and it was very difficult to achieve same discharge conditions by operating the valves for all diameters of laterals.

Thus, experiments for all laterals were not done for the same discharge conditions.

3.4.1 Calibration of lateral inlet discharge

To determine inlet discharge through 12 mm, 16 mm and 20 m laterals, the pressure gauges, P1 at just downstream of screen filter, P2 at inlet of lateral and P3 at the end of lateral were installed and corresponding discharges were measured with the help of a measuring tank.
Multiple Regression equations were developed to predict the discharge, Q of lateral. Q is dependent variable and P1, P2 and P3 are independent variables.

70 % of the data were used for model (regression equation) preparation and remaining 30 % data were used for model validation.

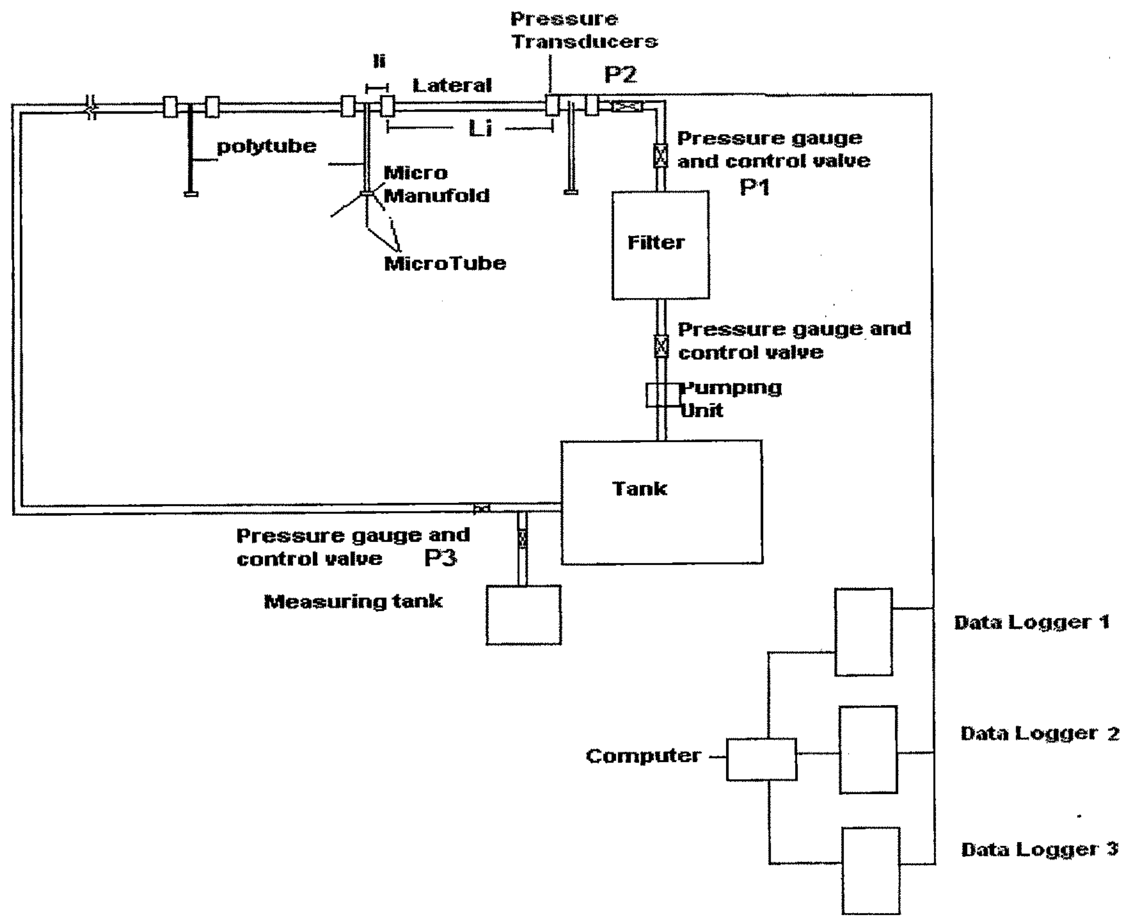


Fig. 3.1: Layout of indoor micro irrigation laboratory

Table 3.3: Details of Various Components of ITK MIS Used for Experimental Work

Lateral Dia	Polytube Dia				Polytube length						No.of Microtubes	Dia.of microtubes	Length of microtubes		
mm	mm				cm							mm	m		
20	4	5	6	7	15	30	45	60	75	90	1	1.0	0.3	0.6	0.9
												1.2	0.3	0.6	0.9
												1.5	0.3	0.6	0.9
											2	1.0	0.3	0.6	0.9
												1.2	0.3	0.6	0.9
												1.5	0.3	0.6	0.9
											3	1.0	0.3	0.6	0.9
												1.2	0.3	0.6	0.9
												1.5	0.3	0.6	0.9
											4	1.0	0.3	0.6	0.9
												1.2	0.3	0.6	0.9
												1.5	0.3	0.6	0.9
16	4	5	6		Polytube length same as for 20 mm dia. Lateral, No. of microtube, 1, 2 & 3										
12	4	5	6		Polytube length same as for 20 mm dia. Lateral, No. of microtube , 1, 2 & 3										

All above-mentioned experiments were carried out for 34 discharges.

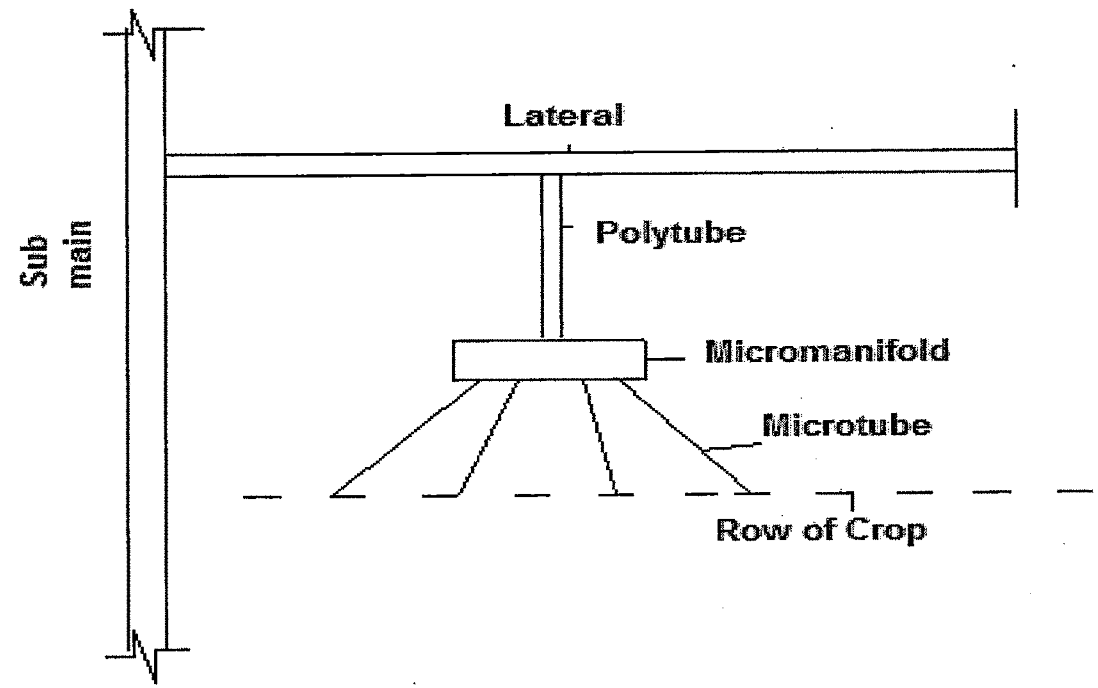


Fig. 3.2: Enlarged view of ITK MIS

3.4.2 Friction head loss in ITK MIS

ITK MIS is basically a pipe network and water distribution system operating at micro level and principles of hydraulics are governing the system. Design of ITK MIS involves friction head loss through various diameters of pipes, discharge through the pipes and length of the pipes.

Head loss through ITK MIS consists of all losses through main, submain, manifold, lateral, polytube, micro manifold, microtubes, minor losses due to expansion, contraction etc. Friction head losses through main, submain, manifold, lateral are known as various equations are available for multiple outlet pipes. Friction loss through combination of polytube, micromanifold and microtubes were determined. Experimental approach was adopted to determine friction head loss through these components of ITK MIS.

According to Darcy-Weisbach equation, frictional head loss (Hf_L) through lateral can be given as

$$Hf_L = \frac{f\,LQ^2}{12.1 \times D_i^{\,5}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3.1)$$

where,

Hf_L = friction head loss in the lateral, m

f = Friction factor of lateral

L = Length of lateral,m

Q = Lateral discharge, m^3/sec

D_i = Inner diameter of lateral, m

Fig. 3.1 shows experimental set up of indoor micro irrigation laboratory. Laterals of various diameters were laid with multiple outlets. There were eight outlets in lateral attached with eight polytubes. So, lateral length was divided into eight segments. i.e. L_i (i = 1 to 8). 8 sets were obtained along the length of lateral on each lateral diameter. Pressure transducers were installed on both the sides of each polytube on lateral, which was connected with data logger 1. i.e. nodes 1 to 16, which measured pressures along the length of the lateral.

Pressure transducers were attached at inlet and outlet of the polytube, which was connected with data logger 2. i.e. nodes po1 to po16, which measured pressure at inlet and outlet of each polytube (i.e. inlet of micromanifold).

At the end of each polytube micro manifold was attached and in each micro manifold microtubes were inserted. Pressure transducers were attached at the outlet of micromanifold i.e. inlet of microtubes. There were nodes 1 to 16, depending upon no. of microtubes attached with micromanifold. These pressure transducers were connected with data logger 3.

All the data loggers were connected with computer and it continuously downloads the pressure data simultaneously. So, there were 8 sets in which transducers were attached and at the same time pressures were measured. i.e. 48 nodes were measuring pressure at a time.

To achieve various discharge conditions in lateral, three valves were installed along with pressure gauges one at just downstream of filter (in manifold), second at inlet of lateral and third at outlet of lateral. i.e. P1, P2, P3, which give pressure at these three points.

Various diameter and length of polytube, microtube and micromanifolds were used for experimentation. Moreover, lateral diameters were also varied from 12 mm to 20 mm.

By controlling valves placed at above mentioned positions, 34 discharge conditions were regulated. These discharge conditions were regulated for all possible combination of polytube length, polytube diameter and No. of microtube- 1/2/3/4 per manifold, various diameters of microtube and various lengths of microtube. Pressures and discharges were measured for all possible combinations at 8 sets along the lateral length for various lateral diameters.

Lateral diameters are 12 mm, 16 mm, 20 mm. Let inner diameter of lateral is denoted by D_i. Polytubes were attached with lateral so diameter of polytube is denoted by dp and length of polytube is denoted by lp, discharge condition at inlet of lateral is denoted by Qin_i, (i = 1 to 34) and discharge measured at the end of microtube in each set is q_i, (i = 1to 8).

For one lateral diameter D_1 and one Qin_i, there are various combinations of, dp_i lp_j where i = 1 to 4, j = 1 to 6

3.4.3 Analytical approach to calculate head loss through length segments of lateral

As shown in Fig. 3.1 L_1 is the length segment between gauge P2 and polytube 1. Lateral length is further divided into length segments between successive polytubes, which is denoted by L_i (i=2 to 8) for segment L_1,

$$Hf_{Li} = \frac{f_i L_i Q_i^2}{12.1 \times D_i^5} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (3.2)$$

where,

Hf_{Li} = Friction head loss of length segment on lateral, m

f_i = Friction factor of length segment L_i of lateral

L_i = Length of first segment of lateral, m

Q_I = Lateral discharge through segment L_i,, m^3/sec

D_i = Inner diameter of lateral, m

As shown in Fig.3.1 pressure transducers were placed on both sides of polytubes at a distance of 2.5 cm from center of polytube on lateral i.e. 2.5 cm on both sides of each node. This is denoted by i.e. l_i = (1 to 16) and pressure measured are denoted by p_i = (1 to 16).discharge collected at the end of each set for 8 sets are denoted by q_i (i=1 to 8).

For length segment L_1, Qin_i is obtained from regression equation developed for various pressures at three locations, i.e. P1, P2 and P3 and discharge measured considering lateral as blind pipe. This discharge Qin_i (i=1 to 34) is obtained at the inlet of lateral for various discharge conditions.

For length segment L_1, Qin_i = Q_1

For length segment L_i (i =2 to 8), $Q_i = Q_{i-1} - q_{i-1}$

i.e. $Q_2 = Q_1 - q_1$, $Q_3 = Q_2 - q_2$ and so on for other length segments of lateral. For length segment L_1, Hf_{L1} was determined from P2 – p_1. i.e. pressure difference measured in water column between pressure gauge installed at the inlet of lateral and pressure measured at first node p_1. Let f_i is the friction factor for various length segments.

For segment L_1, friction factor f_1 is determined using Hf_{L1}, Q_1 and D_{in}

$$f_1 = \frac{Hf_{L1} \times 12.1 \times D_i^5}{L_1 Q_1^2} \quad \dots \quad \dots \quad (3.3)$$

Similarly for length segment L_2, Hf_{L2} is determined from p_2 - p_3. i.e. pressure difference measured in water column between pressure transducer installed at first node (left side of node) and second node (right side of node) and so on for other length segments of lateral. Data collected at data logger 1 was used for these calculations.

For segment L_2, friction factor f_2 is determined using Hf_{L2}, Q_2, L_2

$$f_2 = \frac{Hf_{L2} \times 12.1 \times D_i^5}{L_2 Q_2^2} \quad \dots \quad \dots \quad (3.4)$$

And so on for all 8 length segments.

For small length segment, l_1 head loss Hf_{l1} is determined using f1, Q_1, l_1

$$Hf_{l1} = \frac{f_1 \, l_1 Q_1^2}{12.1 \times D_i^5}$$

$$Hf_{l2} = \frac{f_2 \, l_2 Q_2^2}{12.1 \times D_i^5}$$

$$Hf_{l3} = \frac{f_2 \, l_3 Q_2^2}{12.1 \times D_i^5}$$

$$Hf_{l4} = \frac{f_3 \, l_4 Q_3^2}{12.1 \times D_i^5} \quad \dots \quad \dots \quad (3.5)$$

Similarly for other nodes, head losses were calculated.

Theoretically head loss between p_1- p_2 should be equal to Hf_{l1+} Hf_{l2} this is not achieved due to some loss. This loss is denoted by hf_i*(i=1 to 8), which is minor head loss at outlet.

$$hf_i^* = (p_1 - p_2) - (Hf_{l1} + Hf_{l2}) \qquad \ldots \quad \ldots \quad (3.6)$$

where,

hf_i*= Head loss at node or outlet on lateral, m

p_i = Pressure measured on both sides of polytube (node) on lateral, mwc

Hf_{li} = Friction head loss of small segment near node or outlet, m

All the head losses and friction factors through length segments and minor head losses at outlets were carried out for all Qin_i, (i=1 to 34).

3.4.4 Determination of minor head loss at outlets along the lateral by regression analysis

As discussed in 3.3.3, head loss at all 8 outlets were calculated. Head loss at outlet depends on lateral discharge Q_i, polytube discharge q_i and pressure p_i on lateral for particular outlet. Regression equations were developed outlet wise and no. of microtubes attached to micromanifold considering all combinations of poly tube and microtubes for every lateral.

For example, for 12 mm lateral to determine minor head loss at fist outlet and, one microtube attached, lateral discharge is Q_1, discharge observed on first outlet q_1 and pressure at first node p_1 were considered for regression analysis.

Similarly for second outlet, lateral discharge is Q_2, where $Q_2 = Q_1 - q_1$, discharge observed on second outlet q_2 and pressure at third node p_3 were considered for regression analysis.

For each lateral diameter of 12 mm, 16 mm and 20 mm, regression equations were developed as per no. of microtubes (i.e. 1/2/3/4) attached.

70 % of the data were used for model (regression equation) preparation and remaining 30 % data were used for model validation.

3.4.5 Determination of F factor for ITK MIS

The head loss due to friction in a pipe with multiple outlets along its length would be less than the head loss caused due to friction in a pipe without outlets, because of decreasing discharge along the length of the pipe.

Christainsen (1942) developed a factor F which is ratio of friction head loss along a pipe with multiple outlets to the friction head loss along a fully flowing pipe without outlets.

$$F = \frac{Hf_m}{Hf} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3.7)$$

where,

F = Factor for multiple outlet pipe

Hf_m = Friction head loss along multiple outlet pipe, m

Hf = Friction head loss along pipe without outlets, m

Christainsen's Factor F can be written as

$$F = \frac{1}{n+1} + \frac{1}{2N} + \frac{(n-1)^{0.5}}{6N^2} \quad \ldots \quad \ldots \quad \ldots \quad (3.8)$$

where,

n = Velocity exponent in the formula used for the computation of head loss caused by friction

N = Number of outlets along the pipe

Factor F is a function of the friction formula used and the number of outlets.

This factor was developed assuming the first outlet is one outlet spacing from the inlet of the pipe and the outlets along the pipe have equal discharge. In a pipe with multiple outlets, there will be energy losses caused by the coupler and structure of the outlet. There is gradual reduction in velocity head as flow passes the outlet and this will cause an increase in pressure, which will balance losses caused by turbulence at outlet. Hence exact procedures to calculate pressure losses in pipes with multiple outlets cannot be justified.

Christainsen (1942), Jensen and Fratini (1957), Scaloppi (1988) considered only the position of the first outlet from the pipe inlet and the values of exponent of the discharges, n.

The tables derived by above mentioned researchers indicate only number of outlets but not the type of outlets. The outlets may be emitters for micro irrigation system or polytube with micromanifold having no. of microtubes for ITK MIS for lateral.

Discharge through the pipe is not considered by these researchers and discharge through pipe depends on type of outlet. The Pipe diameter also play important role, as for the same discharge different diameter gives different Reynold number.

Reynold number determines the type of flow which decides which friction factor equation is to be used to calculate friction head loss. The value of exponent of discharge also depend on the friction factor equation used.

Looking to these facts, Shete (2000) developed new F factor tables which incorporate all above mentioned conditions. The exponent of discharge depends on friction factor equation and Churchill equation is used to determine friction factor. Churchill equation is proposed by no. of researchers and it also covers all the flow regimes with an average accuracy of $\pm$ 0.45 %.

To determine F factor for ITK MIS, friction head loss along pipe without outlets, Hf was determined. To calculate Hf, friction factor f was determined. Churchill's equation was used for friction factor, f

$$f = 8[(8/Re)^{12} + (1/(A+B)^{1.5}]^{1/12} \quad \ldots \quad \ldots \quad \ldots \quad (3.9)$$

$$A = [2.457 \ln(1/((7/Re)^{0.9} + 0.27e/D_i)]^{16} \ldots \quad \ldots \quad (3.10)$$

$$B = [37530/Re]^{16} \quad \ldots \quad \ldots \quad \ldots \quad (3.11)$$

where,

f = friction factor

Re = Reynold no.

e = equivalent surface roughness, m

D_i = diameter of pipe, m

Reynolds number was calculated for each diameter of lateral for various discharges of lateral, Qin_i.

The total head loss along a fully flowing pipe (without outlets) was determined by Darcy-Weisbach equation,

$$H_f = \frac{fLQ_i^2}{12.103\ D_i^5} \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.12)$$

where,

f = Friction factor computed by Churchill's equation

L = Length of lateral

Q_i = Lateral discharge

D_i = Inner diameter of lateral

In ITK MIS, instead of emitters poytubes were attached to the lateral and micromanifold were attached to polytubes. To micromanifold, microtubes were inserted and microtubes irrigate the field. The no. of microtubes connected to the in micromanifold may be one, two, three or four. These microtubes were of three different diameter and three lengths. Polytubes are also of different diameter and length.

To determine head loss for multiple outlet pipe (ITK MIS), Hf_m, experimental approach was adopted. The pressure transducers were placed at 16 nodes along the lateral on both the sides of outlet to measure the pressure head. To determine Hf_m for first outlet the Pressure difference between the inlet of the lateral, P2 and the pressure available at the first outlet, p_1 measured by transducers was considered. For example, Hf_m at 7^{th} outlet is the difference between P2 and the pressure head p_{13} available at outlet 7. In similar manner for all the possible combinations and on eight outlets, Hf_m was calculated for various discharge conditions, Qin_i.

F factor was determined for each combination considering lateral diameter, polytube diameter, polytube length, microtube diameter, microtube length and no.of microtubes attached. For example, one of the combinations is 20 mm lateral- 6 mm dia and 0.15 m long polytube – 1.5 mm dia and 0.30 m long microtube – two microtubes.

In actual practice, the number of outlets would be more than eight and to determine F factor for more number of outlets, regression analysis was carried out. From total discharge available and average discharge of outlets, no. of possible outlets which receives sufficient discharge was determined. The minimum discharge for one micro tube is 4 l.p.h. Using regression equation, F factor was determined for more number of outlets, provided sufficient discharge is available at the last outlet. For various discharge conditions, no of outlets which receive sufficient (average) discharge will vary.

3.4.6 Determination of the relationship between discharge - pressure and length for microtubes

In ITK MIS system, 1/2/3/4 microtubes were connected to polytube through micromanifold. The polytube length and diameter varies. Row spacing of crop governs the length of polytube. The average discharge of 8 outlets were determined for one length and diameter of polytube. For example one combination is 20 mm lateral - 4 mm dia and 0.15 m long polytube ,for 1-microtube. In that combination, there were 3 diameters (e.g. 1.0, 1.2 and 1.5 mm) and three lengths of microtubes.(e.g. 0.30, 0.60 and 0.90 m). These gives nine set of discharges for 4 mm dia - 15 cm long polytube for 1 microtube.

The microtube is a simple and cheap emitter that is widely used throughout the world. Its length can be adjusted according to the pressure distribution along the lateral line and the discharges from the microtube can be adjusted by its length, since operating head at the microtube's inlet are not constant.

According to Keller and Karmeli (1974) the discharge of emitter can be expressed as function of operating pressure through the power function.

$$q = kP2^x \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.13)$$

where,

q = discharge of emitter, lph

k = coefficient of entrance geometry of emitter

P2 = Pressure at inlet, mwc

x = coefficient of flow regime

The coefficient k is a function of the enterance geometry and the length and diameter of the flow path through the emitter and x is determined by the flow regime.

Rearranging Eq. 3.13 to make P2 the dependent variable, and using the nominal discharges, pressures were obtained for each length of microtube. The discharges for various diameter and length of microtubes are plotted with pressures and regression equations were obtained for each combination of diameter and length of microtube. Coefficients to the power model were found, which shows agreement with Keller and Karmeli (1974).

Nominal discharges are decided looking to the range of observed discharges through microtubes. The nominal discharges for the respective microtubes are applied to these equations to determine corresponding pressure for each length.

A single linear equation between pressure and length is found in the form,

$$L_m = aP2 - b \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.14)$$

where,

L_m = length of microtube, m.

P2 = Pressure at inlet, mwc

a = coefficient of inlet pressure P2

b = constant of the regression equation

This equation could be used to determine the length of microtube for given inlet Pressure.

3.4.7 Regression analysis

Regression analysis is a statistical device with the help of which it is possible to estimate the unknown values of one variable from known values of another variable. The variable which is used to predict the variable of interest is called the independent variable and the variable to be predicted is called the dependent variable.

It should be noted that the term 'dependent' and 'independent' refer to the mathematical or functional meaning of dependence; they do not imply that there is necessarily any cause and effect relationship between the variables.

(Source: Gupta, S. P. (2001) – "Statistical Methods", Sultan Chand & Sons, Educational Publisher, New Delhi, Ch.11, pp. 437)

Regression analysis gives us the ability to summarize a collection of sampled data by fitting it to a model that will accurately describe the data. Each regression model has adjustable parameters, or variables, which can be adjusted in order to achieve close agreement between values of the regression model and the sampled data. These model parameters typically come from derived scientific or statistical theory that the data is supposed to satisfy. Regression analysis can turn the sampled data points into a smooth continuous function that may be used analytically or utilized by a computer program to return expected values at certain values of the independent variable. The user may decide to fit all of the variables in the regression model, or constrain some of them in order to satisfy some known condition.

The basic idea behind regression analysis is to choose a method of measuring the agreement between your data and a regression model with a particular choice of variables. This measurement of agreement is called the merit function, and is arranged so that small values represent close agreement between the collected data and the regression model. The variables are then adjusted iteratively (in the case of nonlinear regression) in order to minimize the merit function. Once the merit function has been minimized, it is possible to determine how well the model describes the data.

There are two widely used and accepted methods for performing regression analysis. The first, and easiest to implement, is linear regression. The second more general method is called nonlinear regression.

Linear regression

Linear Regression estimates the coefficients of the linear equation, involving one or more independent variables, that best predict the value of the dependent variable. Datafit 8.2 software is used to carry out regression analysis in this study.

Goodness of fit test parameters

Coefficient of correlation, r

Measure of the "goodness of fit" is the coefficient of correlation, r. To explain the meaning of this measure, one has to define the standard deviation, which quantifies the spread of the data around the mean:

$$s_t = \sum_{i=1}^{n} \left(\bar{o} - o_i\right)^2 \qquad \ldots \quad \ldots \quad \ldots \quad (3.15)$$

Where st is the standard deviation, oi is the observed data points and ō is the average the observed data points given by

$$\bar{o} = \frac{1}{n}\sum_{i-1}^{n} o_i \qquad \ldots \quad \ldots \quad \ldots \quad (3.16)$$

The quantity s_t considers the spread around a constant line (the mean) as opposed to the spread around the regression model. This is the uncertainty of the dependent variable prior to regression. One also defines the deviation from the fitting curve as,

$$s_r = \sum_{i=1}^{n} \left(o_i - p_i\right)^2 \qquad \ldots \quad \ldots \quad \ldots \quad (3.17)$$

Where s_r is the deviation from the fitting curve, pi is the predicted data points.

$$r = \sqrt{\frac{s_t - s_r}{s_t}} \qquad \ldots \quad \ldots \quad \ldots \quad (3.18)$$

where r is defined as the coefficient of correlation. As the regression model starts improving describing the data, the correlation coefficient approaches unity. For a perfect fit, the standard error of the estimate will approach $s_r = 0$ and the correlation coefficient will approach r = 1.

Coefficient of determination, R^2

$$R^2 = \frac{SSR}{SST}$$

$$R^2 = 1.0 - \frac{SSE}{SST} \qquad \ldots \quad \ldots \quad \ldots \qquad (3.19)$$

where,

SSR = regression sum of squares

SSE = Residual or error sum of squares

SST = Total sum of squares

And, SST = SSE + SSR

SST measures the variation in the observed response.

SSR measures the "explained" variation.

SSE measures the "unexplained" variation

A value of R^2 = 1.0 means that the curve passes through every data point. A value of R^2 = 0.0 means that the regression model does not describe the data any better than a horizontal line passing through the average of the data points. (Source: Walpole, R. E., Myers, R. H., Myers S. L., and Ye, K. (2002) – "Probability and Statistics for Engineers & Scientists", Pearson Education, Indian Branch, Patparganj, Delhi, pp. 367)

Discrepancy ratio, D

$$D = oi / pi \qquad \ldots \quad \ldots \quad \ldots \qquad (3.20)$$

Where oi and pi are the observed and predicted data points and $\bar{o}$ and $\bar{p}$ are the mean of the observed and predicted data points. This ratio is selected because it is widely accepted and easily interpreted. If this ratio is one, the equation exactly predicts the measured rate. If the ratio is less than one or greater than one the equation under or over predicts measured data respectively. (Source: Patel, N. R.,and Shete, D. T. (2008) – "Annual – Monsoon Rainfall Relationship in North Gujarat Region, India", National conference on Hydraulics and Water Resources, Jaipur, December 15-16.)

Root Mean Squared Error (RMSE)

The RMSE is the square root of the variance of the residuals. It indicates the absolute fit of the model to the data–how close the observed data points are to the model's predicted values. Whereas R-squared is a relative measure of fit, RMSE is an absolute measure of fit. As the square root of a variance, RMSE can be interpreted as the standard deviation of the unexplained variance, and has the useful property of being in the same units as the response variable. Lower values of RMSE indicate better fit. RMSE is a good measure of how accurately the model predicts the response, and is the most important criterion for fit if the main purpose of the model is prediction

$$RMSE = \left[\sum_{i=1}^{n} \frac{(oi - pi)^2}{n} \right]^{0.5} \quad \dots \quad \dots \quad \dots \quad (3.21)$$

3.5 Field Work

The MIS and ITK MIS were installed for summer groundnut and cauliflower at Training cum Demonstration (T.C.D.) farm, Water Resources Engineering and Management Institute (WREMI), Samiala, Taluka and District, Vadodara. Summer groundnut and cauliflower were grown on field 1 by Micro irrigation system and on field 2 by ITK Micro irrigation system. Dimensions of field 1 and field 2 were 57.6 m x 28.8 m.

The experimental field plots of summer groundnut and cauliflower were random block designed as shown in Fig.3.3 and Fig.3.4. Both standard micro irrigation system and ITK Micro irrigation system using low cost appropriate technology irrigated the crops. Both the systems were operated in two blocks. For summer groundnut and cauliflower, in the first block (B_1) the row spacing was 60 cm and in the second block (B_2) row spacing was 45 cm. Layout of Block for both crop is shown in Fig.3.5.

Moreover crops were irrigated at three different irrigation depths.

T_1 = 75% of crop water requirement,

T_2 = 100% of crop water requirement and

T_3 = 125% of crop water requirement.

Each experiment/trial e.g. B_1T_1, B_1T_2, B_1T_3, B_2T_1, B_2T_2, B_2T_3 was replicated four times. Average yields of these four replications are used in the study. Summer groundnut and cauliflower were grown for three years in 2005, 2006 and 2007.

$B_2\ T_3\ R_1$	$B_2\ T_1\ R_4$	$B_1\ T_3\ R_1$	$B_1\ T_2\ R_3$
$B_1\ T_1\ R_4$	$B_2\ T_1\ R_2$	$B_1\ T_2\ R_2$	$B_2\ T_3\ R_3$
$B_2\ T_1\ R_3$	$B_1\ T_3\ R_3$	$B_2\ T_2\ R_2$	$B_2\ T_1\ R_1$
$B_1\ T_2\ R_1$	$B_2\ T_2\ R_1$	$B_1\ T_3\ R_4$	$B_2\ T_3\ R_4$
$B_2\ T_2\ R_3$	$B_1\ T_1\ R_2$	$B_1\ T_2R_4$	$B_1\ T_1\ R_1$
$B_1\ T_3\ R_2$	$B_1\ T_1R_3$	$B_2\ T_3\ R_2$	$B_2\ T_2\ R_4$

Fig. 3.3: Random block design of field 1 (MIS)
Field Size: 57.6 m X 28.8 m

$B_2\ T_3\ R_1$	$B_2\ T_1\ R_4$	$B_1\ T_3\ R_1$	$B_1\ T_2\ R_3$
$B_1\ T_1\ R_4$	$B_2\ T_1\ R_2$	$B_1\ T_2\ R_2$	$B_2\ T_3\ R_3$
$B_2\ T_1\ R_3$	$B_1\ T_3\ R_3$	$B_2\ T_2\ R_2$	$B_2\ T_1\ R_1$
$B_1\ T_2\ R_1$	$B_2\ T_2\ R_1$	$B_1\ T_3\ R_4$	$B_2\ T_3\ R_4$
$B_2\ T_2\ R_3$	$B_1\ T_1\ R_2$	$B_1\ T_2R_4$	$B_1\ T_1\ R_1$
$B_1\ T_3\ R_2$	$B_1\ T_1R_3$	$B_2\ T_3\ R_2$	$B_2\ T_2\ R_4$

Fig.3. 4: Random block design of field 2 (ITK MIS)
Field Size: 57.6 m X 28.8 m

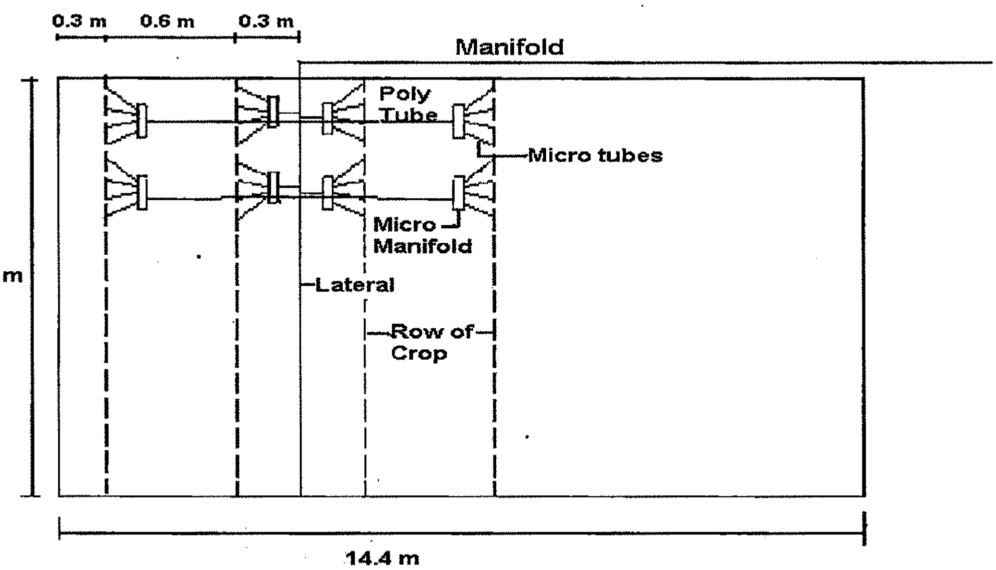


Fig. 3.5: Layout of block for summer groundnut and cauliflower

3.5.1 Micro and ITK MIS system layout

The position of source of water and crop spacing affects the micro and ITK MIS system layout. For this study two row crops, summer groundnut and cauliflower were raised with same system, on same field for two different the spacing, o.45 m and 0.6 m. The layout would remain same upto manifold for both the systems. No. of laterals would be reduced in ITK MIS system considering one lateral would serve four rows of crop. The layout was prepared in such a way that all subunits/sets were square ones. Dimension of the block was decided in such a way that no of rows in each block was integer for both row spacings.

The field road dimensions and locations were selected in such a way that each subunit/set is surrounded by 5 m wide road.

Fig. 3.6 and Fig. 3.7 shows the field size, position of source of water, position of main, submain, manifold and lateral for micro and ITK MIS system respectively. Real photographs of the experimental field and close up photos of microtubes, micromanifold, polytube and lateral etc. are enclosed in DVD.

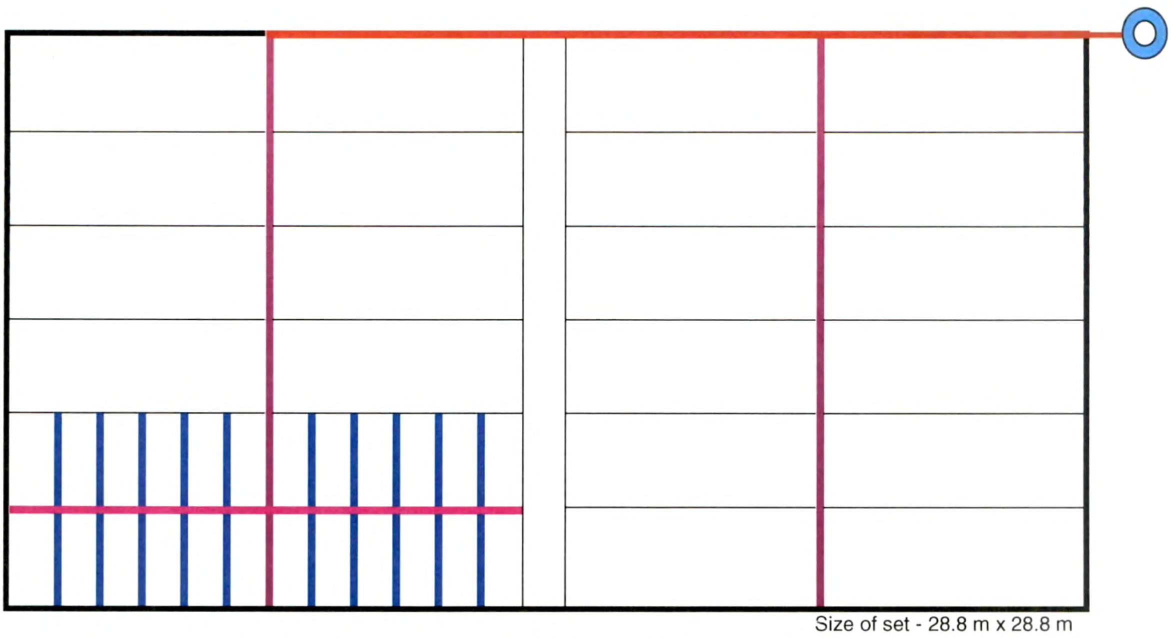


Fig. 3.6: MIS layout of field 1 at T.C.D. farm, Samiala

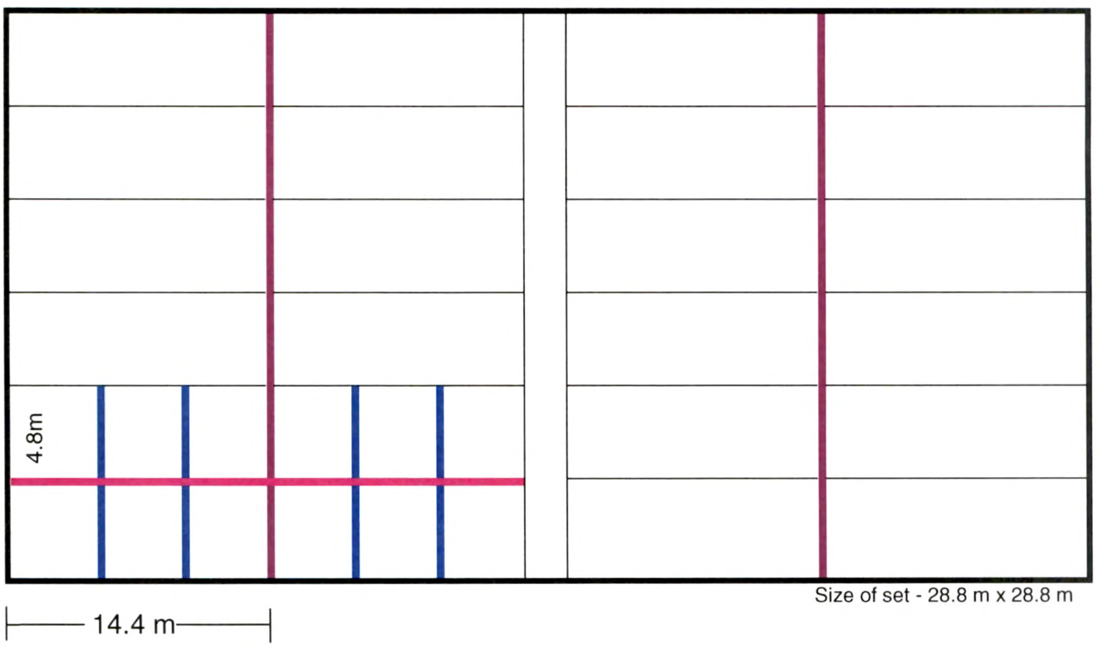
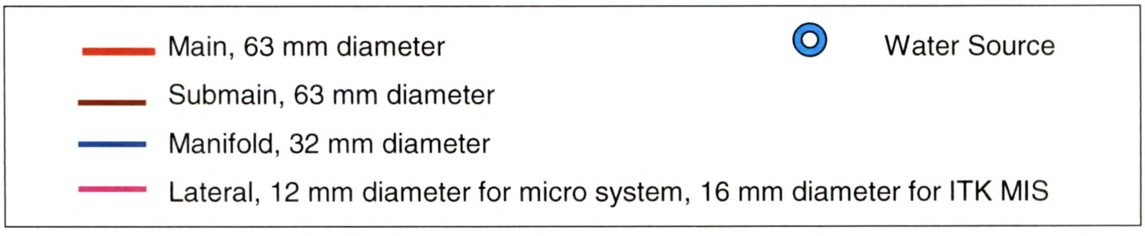


Fig. 3.7: ITK MIS layout of field 2 at T.C.D. Farm, Samiala



3.5.2 Crop water requirement

Crop water requirement is calculated as per the "Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56".
To calculate crop water requirement, first step is to calculate reference crop evapotranspiration and secondly crop coefficient.

The calculation procedure for crop evapotranspiration, ETc, consists of:

(1) Identifying the lengths of crop growth stages, and selecting the corresponding Kcb coefficients
(2) Adjusting the selected Kcb coefficients for climatic conditions during the stage
(3) Constructing the basal crop coefficient curve (to determine Kcb values for crop growth stages during the growing period)
(4) Determining daily Ke values for surface evaporation; and
(5) Calculating ETc as the product of ETo and (Kcb + Ke).

Reference crop evapotranspiration

The Committee on Irrigation Water Requirements of the American Society of Civil Engineers (ASCE) recommended the FAO Penman-Monteith method as the sole standard method for the computation of ETo. It is a method with strong likelihood of correctly predicting ETo in a wide range of locations and climates and has provision for application in data-short situations. (Source: Allen, R.G., Pereira L.S., Raes, D., and Smith, M. (1998) – "Crop evapotranspiration – Guidelines for computing crop water requirements – FAO irrigation and drainage paper 56", Rome, Ch.2, pp.30)

The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in the ASCE and European studies compared to other methods.
The FAO Penman-Monteith method was used for calculation of reference crop evapotranspiration. Decision Support System for Estimating Reference Evapotranspiration (DSS_ET Model version 3.0) software designed by Department of Agricultural and Food Engineering, Indian Institute of

Technology, Kharagpur was used to calculate reference crop evapotranspiration.

Crop coefficient

The crop evapotranspiration differs distinctly from the reference evapotranspiration (ETo) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (Kc). In the crop coefficient approach, crop evapotranspiration is calculated by multiplying ETo by Kc.

FAO 56 recommended dual crop coefficient approach for research work. The dual coefficient approach requires more numerical calculations than the procedure using the single time-averaged Kc coefficient. The dual procedure is best for real time irrigation scheduling, for soil water balance computations, and for research studies where effects of day-to-day variations in soil surface wetness and the resulting impacts on daily ETc, the soil water profile, and deep percolation fluxes are important. This is the case for high frequency irrigation with micro irrigation systems or lateral move systems such as centre pivots and linear move systems.

Dual crop coefficient (Kcb+Ke)

In the dual crop coefficient approach, the effects of crop transpiration and soil evaporation are determined separately. Two coefficients are used: the basal crop coefficient (Kcb) to describe plant transpiration, and the soil water evaporation coefficient (Ke) to describe evaporation from the soil surface. The single Kc coefficient is replaced by:

$$Kc = Kcb + Ke \qquad \ldots \quad \ldots \quad \ldots \quad (3.22)$$

where,

Kc = Crop coefficient

Kcb = Basal crop coefficient

Ke = Soil evaporation coefficient

Forces acting on the soil water decrease its potential energy and make it less available for plant root extraction. When the soil is wet, the water has a high potential energy, is relatively free to move and is easily taken up by the plant roots. In dry soils, the water has a low potential energy and is strongly bound by capillary and absorptive forces to the soil matrix, and is less easily extracted by the crop.

When the potential energy of the soil water drops below a threshold value, the crop is said to be water stressed. The effects of soil water stress are described by multiplying the basal crop coefficient by the water stress coefficient, K_s

$$ETc\_adj = (K_s\,Kcb + Ke)\,ETo \qquad \ldots \quad \ldots \quad (3.23)$$

where,

ETc_adj = Crop evapotranspiration under no soil water stress condition, mm / day

ETo = Reference crop evapotranspiration, mm / day

K_s = Water stress coefficient

The calculation procedure consists in determining:

(a) Reference evaporation, ETo

Estimated ETo by FAO Penman-Monteith method

(b) Growth stages

Determined the locally adjusted lengths of the four growth stages

Initial growth stage: L_{ini},

Crop development stage: L_{dev},

Mid-season stage: L_{mid},

Late season stage: L_{late}.

(c) Basal crop coefficient, Kcb

Calculated basal crop coefficients for each day of the growing period

- selected Kcb_{ini}, Kcb_{mid} and Kcb_{end}
  (From Table 17, FAO 56)
- adjusted Kcb_{mid} and Kcb_{end} to the local climatic conditions using equation,

$$Kcb = Kcb_{(Tab)} + [\,0.04\,(u_2-2) - 0.004\,(RH_{min}-45)\,]\,(h/3)^{0.3} \quad \ldots \quad (3.24)$$

where,

RH_{min} = Daily minimum relative humidity , %

u_2 = Wind speed at 2 m above ground surface , m/s

h = Crop height , m

- determined the daily Kcb values

  initial growth stage: Kcb = Kcb_{ini},

  crop development stage: from Kcb_{ini} to Kcb_{mid}

  $Kc_i = Kc_{prev} + [\ i - \sum (L_{prev}) / L_{stage}\ ] (Kc_{next} - Kc_{prev})$ ... (3.25)

  mid-season stage: Kcb = Kcb_{mid},

  late season stage: from Kcb_{mid} to Kcb_{end}

Same equation used for crop development stage

(d) Evaporation coefficient, Ke

- Calculated the maximum value of Kc, i.e., the upper limit Kc max and determined for each day of the growing period:

  Kc_{max}= max [{1.1+ [0.04 (u_2-2) - 0.004 (RHmin-45)] $(h/3)^{0.3}$}, {Kcb + 0.05}] ... ... (3.26)

- The fraction of soil covered by vegetation, fc

  $f_c = [\ (Kcb - Kc_{min})/(Kc_{max} - Kc_{min})\ ]^{(1+0.5h)}$ ... ... (3.27)

- The fraction of soil surface wetted by irrigation, fw = 0.3 for trickle irrigation

  (from Table 20, FAO 56)

- The fraction of soil surface from which most evaporation occurs, few

  $f_{ew} = \min[\ 1 - f_c , (\{1-0.67 f_c\} f_w)\ ]$ ... ... (3.28)

- The cumulative depletion from the evaporating soil layer, De, determined by means of a daily soil water balance of the topsoil.

  $D_{e,i} = D_{e,i-1} - (P_i - RO_i) - (I_i/f_w) + (E_i/f_{ew}) + T_{ew,i} + DP_{e,I}$ ... (3.29)

  where,

  E = Evaporation (mm / day)

  DP_e = Deep percolation from the evaporation layer (mm)

For row crops, most of the water extracted by the roots may be extracted from beneath the vegetation canopy. Therefore, T_{ew} from the few fraction of soil surface can be assumed to be zero.

Following heavy rain or irrigation, the soil water content in the top soil layer might exceed field capacity. It is assumed that the soil water content is at θ_{FC} nearly immediately following a complete wetting event, so that the depletion $D_{e,i}$ in Equation 3.29 is zero. Following heavy rain or irrigation, downward drainage (percolation) of water from the topsoil layer is calculated as:

$$DP_{e,i} = (P_i - RO_i) + (I_i / f_w) - De_{,i-1} \geq 0 \quad \ldots \quad \ldots \quad \ldots \quad (3.30)$$

As long as the soil water content in the evaporation layer is below field capacity (i.e., $D_{e,i} > 0$), the soil will not drain and $DP_{e,i} = 0$.

$$TEW = 1000\,(\theta_{FC} - 0.5\,\theta_{WP})\,Z_e \quad \ldots \quad \ldots \quad \ldots \quad (3.31)$$

where,

TEW = Total evaporable water (mm)

θ_{FC} = Soil water content at field capacity (m^3/m^3 soil))

θ_{WP} = Soil water content at wilting point (m^3/m^3 soil)

Z_e = Depth of surface soil layer subjected to drying by evaporation (m)

REW = Readily evaporable water from Table 19 of FAO 56 as per soil type.

- The evaporation reduction coefficient, K_r

$$K_r = (TEW - D_{e,i-1})/(TEW - REW) \quad \text{for } D_{e,i-1} > REW \quad \ldots \quad (3.32)$$

$K_r = 1$ when $D_{e,i-1} \leq REW$

$K_r = 0$ when maximum cumulative depth of evaporation = TEW

- The soil evaporation coefficient, Ke

$$Ke = K_r\,(Kc_{max} - Kcb) \leq f_{ew}\,Kc_{max} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3.33)$$

(e) Crop evapotranspiration, ETc:

$$ETc = (Kcb + Ke)\,ETo \quad \ldots \quad \ldots \quad \ldots \quad (3.34)$$

3.6 Irrigation Scheduling

Daily water balance computation for crop water requirement also includes irrigation time and irrigation depth. So, irrigation scheduling was carried out along with the calculation of crop water requirement.

Forces acting on the soil water decrease its potential energy and make it less available for plant root extraction. When the soil is wet, the water has a high potential energy, is relatively free to move and is easily taken up by the plant roots. In dry soils, the water has a low potential energy and is strongly bound by capillary and absorptive forces to the soil matrix, and is less easily extracted by the crop.

When the potential energy of the soil water drops below a threshold value, the crop is said to be water stressed. The effects of soil water stress are described by multiplying the basal crop coefficient by the water stress coefficient, K_s

$$ETc\_adj = (K_s\, Kcb + Ke)\, ETo \qquad \ldots \quad \ldots \quad (3.35)$$

For this study, irrigation scheduling is carried out considering there is no water stress.

(a) Soil water availability

- Total available water, TAW

$$TAW = 1000(\theta_{FC} - \theta_{WP})\, Z_r \qquad \ldots \quad \ldots \quad (3.36)$$

where,

TAW = Total available soil water of the root zone (mm)

Z_r = Rooting depth (m)

- Readily available water, RAW

$$RAW = p\, TAW \qquad \ldots \quad \ldots \quad (3.37)$$

where,

p = Evapotranspiration depletion factor

- Average fraction of TAW that can be depleted from the root zone before moisture stress (reduction in ET) occurs, p

$$p = p_{Table\ 22} + 0.04\,(5 - ETc) \qquad \ldots \quad \ldots \quad (3.38)$$

$p_{Table\ 22}$ = Values for p from Table 22 of FAO 56 ... (3.39)

(b) Water stress coefficient

$$K_s = (TAW - D_{r,i}) \,/\, ((1-p)\, TAW), \text{ for } D_{r,i} > RAW \qquad \ldots \quad \ldots \quad (3.40)$$

$$K_s = 1, \text{ for } D_{r,i} < RAW \qquad \ldots \quad \ldots \quad (3.41)$$

where,

$D_{r,I}$ = Cumulative depth of evapotranspiration from the root zone (mm)

(c) Soil water balance

$$D_{r,i} = D_{r,i-1} - (P - RO)_i - I_i - CR_i + ETc_{,i} + DP_i \qquad \ldots \quad \ldots \quad (3.42)$$

where,

P = Rainfall (mm)

RO = Surface runoff (mm)

CR_i = Capillary rise (mm/day)

I_i = Irrigation depth (mm)

$D_{r,i-1} = 1000(\theta_{FC} - \theta_{i-1}) Z_r$ ... ... (3.43)

$DP_i = (P_i - RO_i) + I_i - ETc_{,i} - D_{r,i-1} \geq 0$ ... ... (3.44)

where,

D_r = Cumulative depth of evapotranspiration from the root zone (mm)

Following heavy rain or irrigation, the soil water content in the root zone might exceed field capacity. In this simple procedure it is assumed that the soil water content is at θ_{FC} within the same day of the wetting event, so that the depletion $D_{r,i}$ becomes zero. Therefore, following heavy rain or irrigation

As long as the soil water content in the root zone is below field capacity (i.e., $D_{r,i} > 0$), the soil will not drain and $DP_i = 0$.

CR is assumed to be zero when the water table is more than about 1 m below the bottom of the root zone.

(d) Water stress coefficient

$K_s = (TAW - D_{r,i}) / ((1-p) TAW)$, for $D_{r,i} > RAW$ ... ... (3.45)

$K_s = 1$, for $D_{r,i} < RAW$

$Kc = (K_s Kcb + Ke)$

$ETc\_adj = (K_s Kcb + Ke) ETo$

3.6.1 Forecasting or allocating irrigations

Irrigation is required when rainfall is insufficient to compensate for the water lost by evapotranspiration. The primary objective of irrigation is to apply water at the right period and in the right amount. By calculating the soil water balance of the root zone on a daily basis, the timing and the depth of future irrigations could be planned. To avoid crop water stress, irrigations should be applied before or at the moment when the readily available soil water is depleted. To avoid deep percolation losses that may leach relevant nutrients out of the root zone, the net irrigation depth should be smaller than or equal to the root zone depletion. Practical approach is considered for deciding timing and depth of irrigation. Emergence of crop summer groundnut is on 10th day after sowing. At the time of sowing the moisture content in the soil layer is at field capacity. After ten days first irrigation is applied which is equal to $D_{r,i-1}$ i.e. soil moisture depletion at the end of ninth day. Second irrigation is applied after 2 weeks of 15 minutes. Water is applied on first day of every week for 15 minutes for one month considering crop water requirement and no water stress condition. After that water is applied everyday as per daily crop water requirement i.e. ETc_adj. Operation time is calculated and round up for last digit and decimal. i.e. 22.4 min is considered as 25 min. New depth of water applied is calculated considering roundup operation time. Similarly for Cauliflower, irrigation is given before transplantation of saplings.

3.6.2 Operation Time

Operation time of a MIS for Summer Groundnut and cauliflower,

$$T = \frac{\text{Volume of water required to meet crop evapotranspiration requirement}}{\text{Emitter discharge}}$$

$$= \frac{\dfrac{ETc}{Ea} \; \dfrac{(0.9\{q / i\}^{0.5})}{Sl} \; Se \; Sl}{q} \quad \ldots \quad \ldots \quad (3.46)$$

where,

ETc = Crop evapotranspiration, mm

Ea = Application efficiency

= 98% (assumed)

(Source: Nakayama, F.S., and Bucks D.A.(1986) – "Trickle Irrigation for Crop Prouction Design, Operation and Management", Elesevier, Amsterdam, Oxford, New York, Tokyo, Ch.2, pp.86-89)

q = Emitter discharge for MIS, lph

q_i = Microtube discharge for ITK MIS system. lph

i = Infiltration rate, mm/hr

Se = Emitter spacing, m

Sl = Lateral spacing, m

3.7 Statistical Analysis

The experimental fields were random block designed. The objective was to determine the effect of operation methods, row spacing and irrigation depths on the yield and internal rate of return of the crops.

Here the experimental conditions, the treatments, consist of appropriate combinations of the levels (or values) of the various factors.

Factor	Level 1	Level 2	Level 3
A : Row spacings	0.60 m	0.45 m	
B : Irrigation Depth	0.75 ETc	1.00 ETc	1.25 ETc
C : Operation method	MIS	ITK MIS	

In case groundnut and cauliflower, three factor experiments are conducted. If y_{ijkl} is the yield obtained at the ith level of irrigation method, the jth level of row spacing, the kth level of irrigation depth, in the lth replicate, it can be written

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \nu_k + (\alpha\beta)_{ij} + (\alpha\nu)_{ik} + (\beta\nu)_{jk} + (\alpha\beta\nu)_{ijk} + \rho_l + \varepsilon_{ijkl}$$

for $i = 1, 2, \ldots, a$, $j = 1, 2, \ldots, b$, $k = 1, 2, \ldots, c$, and $l = 1, 2, \ldots, r$. ... ... (3.47)

It is assumed that the sums of the main effects (α's, β's and ν's) as well as the sum of the replication effects are equal to zero, that the sums of the two way interaction effects summed on either subscript equal zero for any value of the other subscript and that the sum of the three way interaction effects summed on any one of the subscripts is zero for any values of the other two subscripts. As before, the $\varepsilon ijkl$ are assumed to be values of independent random variables having zero means and the common variance σ^2.

The treatment sum of squares can be subdivided into the three main effect sums of squares SSA, SSB, SSC, the three two way interaction sums of squares SS(AB), SS(AC) and SS(BC) and the three way interaction sum of squares SS(ABC).

In practice, the necessary sums of squares are calculated by means of short cut equations rather than by using the expressions which define these sums of squares. These shortcut equations are as follows:

$$SST = \sum_{i=1}^{a} \sum_{j=1}^{b} y^2_{ij} - C \qquad \ldots \quad \ldots \qquad (3.48)$$

$$SS(Tr) = \frac{\sum_{i=1}^{a} T^2_{i.}}{b} - C \qquad \ldots \quad \ldots \qquad (3.49)$$

$$SSR = \frac{\sum_{j=1}^{b} T^2_{.j}}{a} - C \qquad \ldots \quad \ldots \qquad (3.50)$$

in which, C = Correction term

$$= \frac{T^2_{..}}{ab} \qquad \ldots \quad \ldots \qquad (3.51)$$

$T_{i.}$ = Sum of the b observations for the i^{th} treatment

T_j = Sum of the a observations in the j^{th} block

$T_{..}$ = Grand total of all the observations

The divisors for SS (Tr) and SSR are the numbers of observations in the respective totals Ti. and Tj. The error sum of squares SSE is then obtained by subtractions, as

$$SSE = SST - SS(Tr) - SSR \qquad \ldots \quad \ldots \qquad (3.52)$$

The treatment sum of squares are subdivided into the three main effect sums of squares, SSA, SSB and SSC, the three two way interaction sum of squares, SS(AB), SS(AC), and SS(BC) and the three way interaction sum of squares SS(ABC).

The degrees of freedom for each main effect are one less than the number of levels of the corresponding factor. The degrees of freedom for each interaction are the product of the degrees of freedom for those factors appearing in the interaction. (Miller and Freund, 1985).

3.8 Internal Rate of Return (IRR)

Internal Rate of return is the discount rate that equates the present value of the expected net cash flows with the initial cash outflow.

$$ICO = \frac{CF_1}{(1+IRR)^1} + \frac{CF_2}{(1+IRR)^2} + \frac{CF_n}{(1+IRR)^n} \quad \ldots \quad \ldots (3.53)$$

In the present study, net cash flows were calculated as follows:

Where,

ICO = Initial Cash Outflow

CF = Cash inflow- Net cash outflow

Cash inflow = total income – total cultivation cost

Cash outflow = depreciation/repayment of capital cost +interest @9% + insurance @0.75 % + maintenance and repairs + permanent farm laborers' wages + pump operator's salary

Net cash outflow = cash outflow-repayment of capital cost

In the present study, depreciation was calculated using the modified accelerated cost recovery system for 7 years class property class.

It is assumed that the repayment of the capital cost of the system is along the depreciation calculations. Summer groundnut is seasonal crop, so seasonal capital cost is considered for the calculations of IRR. Interest rate at 9% is considered while insurance rate at 0.75 % is considered. Maintenance and repairs rates are spread over 10 years such as 0.5 % for the first two years, 1 % for the third year, 1.5 % for the fourth year, 2 % for fifth year and then 2.5 % from the six to tenth year.

3.9 Energy Cost

Energy cost is divided into two parts for metered tariff given by Madhya Gujarat Vij Company Limited (MGVCL) for agriculture for the year 2006-07.

(A) Variable charges:

Power of the pump set required to irrigate field,

Power of pump set, P

$$P = \frac{\rho \; Q \; H}{75} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3.54)$$

where,

P = Power of pump set , H.P.

ρ = density of water , 1000 kg/m3

H = head required, m

Considering pump & motor overall efficiency as 50 %,

$$\text{The power of pump set} = \frac{\text{Power in HP}}{\text{overall efficiency}}$$

Now, using relation 1 H.P = 735.5 watts

Power of pump set in Kw = power in HP x 0.7355

Energy consumed in Kwh per day,

= power of pump set in Kw x operating time in hr per day.

Total energy consumed per season of crop,

= Energy consumed per day x no. of days

Considering unit energy charges as per MGVCL - Rs 0.50 per unit

Total variable charges = Total energy consumed per season x 0.50

(B) Fixed charges

Fixed charges for the pump set are on H.P basis. The applicable rate for the pump set is Rs. 10 per BHP per month

Therefore , total energy cost

= Total variable charges + fixed charges

3.10 Design of ITK MIS and MIS

ITK MIS and MIS are designed for row crops - summer groundnut and cauliflower. Design of ITK MIS & MIS involves design of laterals, manifold and main. In ITK MIS design of laterals & manifold differs from design of laterals & manifold in MIS. In ITK MIS lateral serves more than two row of crop. Therefore, no. of laterals are less in case of ITK MIS.

ITK MIS design also includes determination of microtube length, no. of polytubes per lateral and no. of microtubes per micromanifold. Rest of the design steps, i.e. design of blind pipe, main will remain same for ITK MIS & MIS and are enclosed in Appendix – I.