सत्यमेव जयते

Department of Agriculture, Cooperation & Farmers Welfare
Ministry of Agriculture & Farmers Welfare
Government of India

PFDCs Research Findings on Fertigation

National Committee on Plasticulture Applications in Horticulture (NCPAH)
Ministry of Agriculture & Farmers Welfare, Government of India
10th Floor, International Trade Tower, Nehru Place, New Delhi-110019

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Precision Farming Development Centres Research Findings on Fertigation Techniques

Consolidated and Edited by

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Disclaimer: The data and information consolidated in this publication is based upon the research trials conducted at respective PFDCs and no result/outcome generated by its adoption is liability of NCPAH or the consolidator on the results derived by its adoption or otherwise.

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Dr.S.K.Pattanayak
Secretary (A,C&FW)

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भारत सरकार
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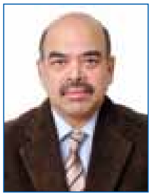

Message

India is bestowed with diversified agro-climatic conditions and varied soil type which make India an agrarian economy. Growing demand to feed the inhabitants of rural and urban India is a major challenge for the research community to develop soil-based/crop-based field technologies addressing the sustainability to the food basket and to have footprints on the global agricultural map by producing quality of Agri/Horti produce.

Advent of plasticulture Applications coupled with precision farming techniques have proved beneficial to the farmers of the country supported through structured applied research conducted by Precision Farming Development Centres (PFDCs) located at ICAR Institutes, IIT and SAUs. Earnest efforts by PFDCs in developing field protocols for micro irrigation has not only helped in addressing the soil health and environmental issues but also helped in growers to save and attain the best productivity in respect of different crops using the proven technology of fertigation.

I am sure that the research outcomes steered by PFDCs. Would help the researchers, farmers and other stakeholders in adopting precision farming technology to realize the vision of the Government in doubling of farmer's income by 2022.

I would like to compliment Dr. B.N.S. Murthy, Member Secretary (NCPAH), Dr. Neelam Patel, PI, PFDC and the entire team Of NCPAH for the painstaking efforts in consolidating these research findings and bring out this publication to popularize these technologies at the national level.

(S.K. Pattanayak)

Date: 7th September, 2017

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Foreward

Precision Farming Practices along with Plasticulture technologies have proved to be a driving force for enhancement of farmers' income through increased productivity & optimum utilisation of various inputs. Precision Farming Development Centres (PFDCs) located at varied agro-climatic regions in ICAR Institutes, IIT and State Agricultural Universities have been instrumental in carrying out operational research as well as testing / modification of oversees technologies in Indian context.

Fertigation is the best solution for optimum use of water as well as fertilizer & leads to intensive and economical crop production as both water and fertilizers are delivered to growing crops through microirrigation system. Fertigation provides direct placement of essential and required nutrition into the active root zone, thus not only minimizing losses of expensive nutrients, but also improving crop productivity and quality of farm produce. The technique also helps in saving of time & labour. Experiments have proved that the fertigation helps in saving of fertilizer and water ranging from 40-60 per cent. Fertigation is ideally suited for various hi-tech horticultural crops and agricultural crops grown under Micro Irrigation technologies.

Though micro irrigation has found widespread use in plantation and horticultural crop production in India, fertigation is confined to few high value crops such as grapes, pomegranate, banana, certain vegetables and flower crops, sugarcane, cotton etc. One of the main reasons for slow adoptionof fertigation is lack of awareness & technical information available on fertigation as well as lesser availability of water soluble / liquid fertilizers at affordable prices.

PFDCs have been carrying out trials on various crops in different agro climatic zones to evaluate the doses of various fertilizers with Micro Irrigation. An effort has been made to consolidate relevant information on Fertigation from various PFDCs for the farm practitioners who would use the reference manual to take maximum advantages through micro irrigation system.

Presently, twenty two PFDCs have been operating under the ambit of central sector programmes of Ministry of Agriculture & Farmers Welfare to bring out research recommendations for Agro climatic specific major crops with use of plasticulture applications for enhancing productivity & quality of produce in the region. I am happy to learn that a consolidation is being brought out in form of Research Findings by PFDCs on Fertigation. The effort made herein will encourage the plasticulture frontiers to enhance more area under these technologies especially fertigation, reduce farmers input costs & save land from hazardous effects to soil as well as environment of over fertigation.

I hereby acknowledge the efforts made by Dr. Neelam Patel, Shri Naresh Modi, Shri Rohit Lall and other PFDC colleagues who have contributed to bring out this much awaited publication which will help in many folds for field functionaries, researchers and Indian growers for popularising the fertigation technique in the country.

(B.N. Srinivasa Murthy)
Member Secretary (NCPAH)
& Horticulture Commissioner
Ministry of Agriculture & Farmers Welfare, GoI

CONTENTS

1

FERTILIZERS USE IN INDIA

Agriculture is and will remain the major user of water; it is facing stiff competition with other sectors like the industry, power and domestic users. It is estimated that the share of water to agriculture in India may reduce by 10 to 15 per cent in the next two decades. On the other hand, agricultural production has to be intensified to ensure food security to the ever increasing population under the constraints of less water and less land and with technologies that have to be necessarily eco-friendly. Increasing water productivity and water use efficiency is the only hard option left. Drip and sprinkler systems are gaining popularity in high value crops, such as horticulture, plantations and sugarcane. It is estimated that about 50 per cent of water conservation can be done through the use of drip and sprinkler systems. (Narayanamoorthy,1997)

The land in India suffers from varying degrees of degradation. Soil fertility depletion is a cause of concern for Indian agriculture. There exists a gap of about 10 million tonnes of nutrients (NPK) between the removal of nutrients by crops and their addition through fertilizers. The use of plant nutrients per hectare is relatively low and imbalanced, and this is one of the major reasons for low crop yields in India.

Land and water resources in the country are limited and other critical inputs in to agriculture include fertilizers, weedicides and pesticides etc which are expansive. To achieve the target of doubling farmer's income in 5 years time all the inputs need to be efficiently utilized.

There are about 116 million farm holdings in India, with an average size of 1.4 ha (FAO, 2005). The cultivated area is about 141 million ha and has remained constant for the past 30 years although the cropping intensity has increased from 118 to 135 percent during this period. Land use is a multifaceted subject concerning many disciplines and serves as a means of earning and meeting one's needs. The challenge of bringing additional land area under productive use necessitates the devising of a pragmatic and scientific approach (Table 1.1).

Table 1.1: Land use in Agriculture

Sl. No	Type of land	Area, mha	%
1.	Forest area	70	21.30
2.	Non-agricultural uses	26.5	8.05
3.	Barren & uncultivable	17.3	5.26
4.	Culturable waste	12.6	3.83
5.	Permanent pastures	10.2	3.12
6.	Miscellaneous tree crops	3.2	0.96
7.	Fallow land	26.3	8
8.	Agricultural land	181.95	55.3
9.	Net Sown Area	139.9	42.57

Source: *Land Use Statistics (2012-13), MoA&FW*

The country has been divided into 20 agro-ecological zones and the soils classified into 8 major groups. The organic carbon content of most Indian soils is very low and nitrogen deficiency is universal. Most of the soils are low to medium in phosphorus and potassium, and sulphur deficiencies have developed over time. Soil fertility depletion and the increasing deficiencies of certain micronutrients are causes of concern. (State of Indian Agriculture, 2015-16).

There are two main cropping seasons, namely Kharif (April–September) and Rabi (October–March). The major kharif crops include rice, sorghum, pearl millet, maize, cotton, sugar cane, soybean and groundnut, and the Rabi crops are wheat, barley, gram, linseed, rapeseed, mustard and vegetables. With its good range of climates and soils, India has a good potential for growing a wide range of horticultural crops such as fruits, vegetables, potato, tropical tuber crops, mushrooms, ornamental crops, medicinal and aromatic crops, spices and plantation crops.

1.1 Irrigated area in India

Water is the most critical resource for agriculture, gaining primacy even over soil. India has only about 4 per cent of the world's freshwater resources. With passage of time its availability is decreasing and India is fast approaching to a stage of water scarce country and decreasing per capita water availability in India (Fig. 1.1). Thus, large tracts of land are dependent on seasonal rainfall for crop cultivation, which hampers productivity

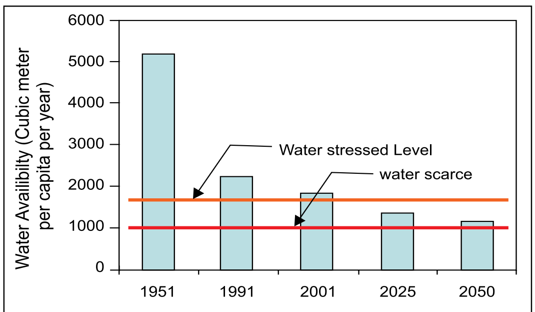
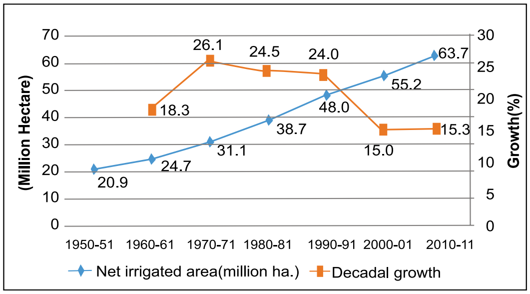


Fig. 1.1 Per capita water availability in India



Source: Directorate of Economics and Statistics, Ministry of Agriclture and Farmers Welfare

Fig. 1.2 Consumption of Fertilizers in India (Lakh tons)

and the adoption of high yielding varieties and other inputs. Yields in rain fed areas remain low, and this low yield underscores the importance of irrigation in the country. Decadal growth rates of net irrigated areas were very high till 1990-91 (Fig. 1.2). After 1990-91, the growth rate fell to around 15 per cent each in the next two decades. The area of land receiving irrigation from different sources is only about 55 million ha.

Management and maintenance of irrigation canal networks having less irrigation efficiency and field channels is also proving to be a major institutional challenge. In traditional type of surface irrigation, huge amount of water is lost through seepage and conveyance of water from the source to field. This loss can be avoided to a greater extent by adopting micro irrigation. Micro irrigation system allows frequent application of small quantities of water, which ultimately provides a nearly constant low-tension soil water condition in the major portion of the root zone. The quality of produce through drip irrigation is generally superior to conventionally irrigated crops.

Why Micro Irrigation?

Micro-irrigation system is irrigation system with high frequency application of water in and around the root zone of plant system. The micro-irrigation system consists of a network of pipes along with a suitable emitting device. Micro irrigation is based on the fundamental concept of irrigating only the root zone of the crop rather than the entire land surface, as done during surface irrigation. Micro irrigation system is known to be able to achieve high water use efficiency, and also results in improved crop yield (Table 1.2). These pressurized irrigation systems are very useful particularly in undulating and uneven lands or very coarse textured soils. The use of these techniques must be promoted in irrigation commands where tube well irrigation is wide spread and for high value crops in peri-urban areas and for small holding farmers.

Table 1.2 Comparative irrigation efficiencies under different method of irrigation

Irrigation efficiencies	Irrigation efficiencies (%)		
	Flood irrigation	Sprinkler irrigation	Drip irrigation
Conveyance	40-50 (canal) 60-70 (well)	100	100
Application	60-70	70-80	90
Overall	30-35	50-60	80-90

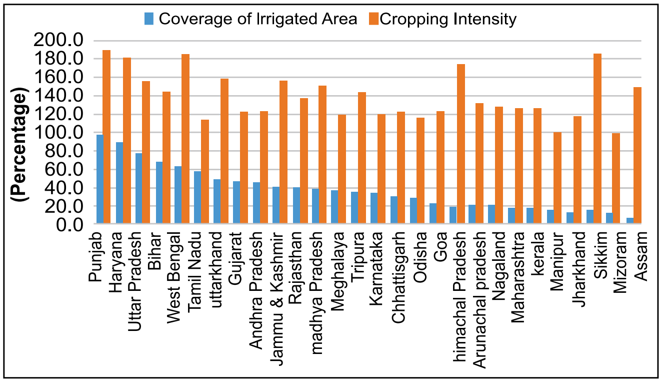
Source: *Sivanappan et al., 1987*

Keeping these factors in view, major emphasis has been laid, since the VIII Plan, on improving water use efficiency by promoting micro irrigation in the country. The total cropped area suitable for micro irrigation in the country is to the tune of 27 million ha. This technology has been prevalent in developed countries like USA, Israel etc. Micro irrigation has high water use efficiency and can save water up to 70% as compared to conventional methods. Moreover, effective use of micro irrigation system can make even `water scarce areas bloom. Horticultural crops in particular benefit the most from micro irrigation and with this facility can be cultivated profitably marginal productive lands. Micro irrigation not only makes such lands productive but also environmentally beneficial it can help in assisting soil erosion and other types of degradation.

1.2 Irrigated area and cropping intensity

The state-wise coverage of irrigated area under major crops in 2012-13 shows that several states have less than 50 per cent irrigated area (Fig. 1.3). However, the cropping intensity (cropping intensity is calculated as ratio of total cropped area to net area sown) in these states is very high, even when the proportion of irrigated area under crops is low. Hence, targeted efforts are required to expand irrigation in such states, where the investment is likely to lead to an increase in cropping intensity. The states that could meet these criteria include Maharashtra, Madhya Pradesh, Chhattisgarh, Gujarat, Rajasthan, Andhra Pradesh, Tamil Nadu and West Bengal. In the wake of these issues, policy has also turned to focus on increasing the efficiency of water use through micro irrigation, which includes drip and sprinkler systems. These methods, considered better in terms of water and fertilizer use efficiency, are being promoted in different states by providing financial assistance to adopt these modern and water saving techniques and also encourage farmers to conserve farming inputs. The annual average growth rate of the agriculture sector was 5 per cent between 2004-05 and 2007-08, but fell to 3 per cent between 2008-09 and 2013-14. During the same periods; the economy grew at an annual average of 9 per cent and 7 per cent, respectively.

According to a recent World Bank study,



Source: Directorate of Economics and Statistics, Ministry of Agriclture and Farmers Welfare

Fig. 1.3 Irrigated area and cropping intensity

India's water demand is going to double by 2050, and the triggering factors would be a GDP growth of 7.7 percent annually and an industrial output of 7 percent. However, the irrigation efficiencies at field level are very low particularly in canal command areas (Table 1).

In view of the rapidly declining water table in large part of the country, the Government of India through Ministry of Agriculture & Farmers Welfare after subsuming the National Mission on Sustainable Agriculture (NMSA)- On Farm Water Management (OFWM) component launched a new centre sector flagship program in 2014-15 called the Pradhan Mantri Krishi Sinchai Yojana (PMKSY) to ensure assured Irrigation to every field. The focus is to ensure end-to-end solutions in the area of irrigation, from source to- field application with the vision of *"har khet ko paani"* and *"per drop more crop"*. Moreover, in case of states like Punjab and Haryana, where the water table has already reached a critical level, in addition to improving water-use efficiency, a shift in cropping pattern towards low water-intensive crops is required for sustaining agricultural production (State of Indian Agriculture, 2015-16).

1.3 Soil fertility status

Soil fertility refers to the inherent capacity of the soil to supply nutrients in adequate amounts and in suitable proportions for crop growth and crop yield. The trend in increasing the yield by adopting high yielding varieties has resulted in deficiency of nutrients in soils and has reflected as deficiency symptoms in plants. Hence, it is required to know the fertility (N, P and K) status of the soils of the State for applying the required dosage of fertilizers and planning the regional distribution of fertilizers. For this purpose, the soil samples collected from grid points (1906 grids) all over the state were analysed for pH, EC., organic carbon, available phosphorus and potassium.

Site specific nutrient management involving soil test based application of fertilizers is critical to enhance fertilizer use efficiency. Fertigation involving the use of water soluble fertilizers through drip and sprinkler irrigation is expected to give better use efficiency for water and fertilizers.

Therefore, it is necessary to promote use of required sources of plant available forms of nutrients coupled with use of soil amendments in acidic/ alkaline soils so as to enhance soil nutrient availability. In India, in general, blanket fertilizer recommendations are followed for N, P & K which rarely matches soil fertility need, and often ignoring secondary and micro nutrients, in various cropping systems followed by small and marginal farmers. Keeping in view the above facts, Government of India is promoting integrated nutrient management (INM) i.e. balanced and judicious use of chemical fertilizers, along with bio fertilizers and locally available organic manures based on soil testing to maintain soil health and crop productivity.

1.3.1 Available nitrogen status

The available nitrogen status presented show that about 10.3 per cent of the soils in the state fall under the low category, 35.8 per cent under medium and 53.9 per cent under high category. The areas covering Western ghats, coastal plains and Malnad areas of the State, under forest and plantations, are high in nitrogen. Apart from this areas under irrigation and hilly regions of the plateau are high to medium in nitrogen. Rest of the area of the state is low in nitrogen.

1.3.2 Available phosphorus status

The available phosphorus status in the soils of Karnataka reveals that about 83 per cent of the soils in the state are low in phosphorus. About 17 per cent area is under medium category implying thereby that most of the soils need to be fertilised through phosphorus for sustained production.

1.3.3 Available potassium status

The potassium status in the soil of the State shows that potassium is medium to high in most of the soils of the state except in laterite soils of Coastal Plains and Western Ghats and in shallow red and black soils, where it is low.

1.3.4 Micronutrients status

In recent times, emphasis is given on soil micronutrient sufficiency /deficiency and are being intensively studied because of wide spread deficiencies in soils leading to reduced crop yields. The deficiencies are caused due to use of chemically pure and micronutrient free fertilizers, cultivation of improved crop varieties with high nutrient requirements and intensive cultivation of crops. Soil samples were analysed for zinc, iron, manganese and copper through standard methods.

1.4 Consumption of chemical fertilizers in India

All-India average consumption of fertilizers increased from 69.84 kg per ha in 1991-92 to 128.08 kg per ha in 2014-15 i.e. 83 percent in 23 years. It is clearly mention that we are increasing the nutrients and consumption of fertilizer (Kg/ha) in each and every year. The fertilizer consumption in 1991-92 was 69.84 Kg/ha and within a decade it increased by 13.82 percent i.e 89.63. In next decade i.e. 2012-13, it is increased by 37.40. Although it decreases in 2013-14 by 16.82 percent but in 2014-15 has been increased by 11.295 and the consumption became 128.08 Kg/ha (Table. 1.3). As the consumption increased so, the country needing more fertilizers to fulfil the requirement. The fertilizers namely Urea, DAP, MOP, NPK Complex, SSP are increased from 1991-92 by 118.58, 68.79, 67.72%, 157.0, 26.03 percent, respectively to 2014-15 i.e. in just 23 years (Table 1.4).

The consumption of fertilizers in India in terms of N, P and K has increased substantially from a mere 1.1 million tonnes

Table 1.3 : Consumption of fertilizers (NPK Nutrients, lakh tons)

S. No.	Nutrients	Years				
		1991-92	2000-01	2012-13	2013-14	2014-15
1	Nitrogenous (N)	80.46	109.2	168.21	167.5	169.46
	Phosphatic (P)	33.21	42.15	66.53	56.33	60.98
	Potassic (K)	13.61	15.67	20.62	20.99	25.32
	Total (N+P+K)	127.28	167.02	255.36	244.82	255.76
2	Consumption of Fertilizer, (Kg / ha)	69.84	89.63	131.36	118.55	128.08

Source: *State of Indian Agriculture 2015-16*

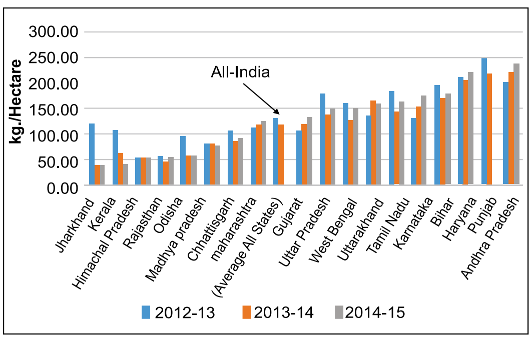
Table 1.4: Consumption of Fertilizers in India (Lakh tons)

S. No.	Fertilizers	1991-92	2000-01	2012-13	2013-14	2014-15
1	Urea	140.04	191.86	300.02	306	306.1
2	DAP	45.18	58.84	91.54	73.57	76.26
3	MOP	17.01	18.29	22.11	22.8	28.53
4	NPK Complex	32.21	47.8	75.27	72.64	82.78
5	SSP	31.65	28.6	40.3	38.79	39.89

***Source:** State of Indian Agriculture 2015-16*

Table 1.5 Fertilizer use efficiency under different methods of water application

Nutrients	Fertilizer use efficiency, %		
	Broadcasting	Drip	Drip + Fertigation
N	30-50	65	95
P	20	30	45
K	50	60	80



Source: State of Indian Agriculture 2015

Fig. 1.4 State-wise consumption of fertilizers (Kg/ha)

in 1966-67 in the pre-green revolution period to more than 25 million tonnes in 2014-15. As per the International Fertilizer Association, India ranked second in total world fertilizer consumption in 2012. The all-India average consumption of fertilizers has increased from 69.84 kg per hectare in 1991-92 to 128.08 kg per hectare in 2014-15 (Fig. 1.4).

There is, however, wide inter-state variability in consumption of fertilizers, with states like Punjab, Haryana and Andhra Pradesh having per hectare consumption of over 200 kg and other states, like Odisha, Kerala, Madhya Pradesh, Jharkhand, Chhattisgarh and Rajasthan, having less than 100 kg per hectare consumption (State of Indian Agriculture, 2015-16).

1.5. Balanced use of fertilizers

Balanced use of fertilizers is normally defined as the timely application of all essential plant nutrients (which include primary, secondary and micronutrients) in readily available form, in optimum quantities and in the right proportion, through the correct method, suitable for specific soil / crop conditions. Balanced use aims at ensuring adequate availability of nutrients in soil to meet the requirement of plants at critical stages of growth. The DAC&FW has been promoting soil test based balanced and judicious use of chemical fertilizers, bio-fertilizers and locally available organic manures, like Farm Yard Manure (FYM), vermi-compost and green manure to maintain soil health and its productivity.

The Government is taking the following measures to promote the balanced use of fertilizers.

i). Soil Health Management (SHM)

ii). Soil Health Card (SHC) scheme

iii). Promotion of Customized Fertilizers

iv). Quality Control of Fertilizers

1.6 Issues and challenges & Recommendations

Urea is the only fertilizer under statutory price control, whereas P&K fertilizers are covered under Nutrient Based Subsidy (NBS) scheme since 01.04.2010, in which MRPs of fertilizers are fixed by fertilizer companies based on the prices prevailing in international market. Disparity in prices of Urea and P&K fertilizers are considered one of the reasons for distortion in the consumption pattern of NPK fertilizers.

In order to address the issue of price disparity, improvement in fertilizer policy is a must. The following policy measures are needed:

i). Balanced use of organic and inorganic fertilizers has a direct impact on soil fertility. Present policy may be revisited to promote both inorganic and organic fertilizers. Efforts may be made to move towards direct cash transfer on unit area basis so that farmers are free to choose between chemical fertilizers and organic fertilizers on their own as per soil health status/fertility.

ii). In short-medium term, gradual and reasonable increase in price of urea along with its inclusion under Nutrient Based Subsidy (NBS) scheme is a desirable policy option.

iii). Nutrient use efficiency varies from fertilizer to fertilizer; even nutrient use efficiency of a similar kind of fertilizer may vary depending upon its composition/coating and form (granulated/powdered). At present, subsidy is given on fertilizers depending upon the content of nutrients in the fertilizer. The present subsidy regime does not take in to account the nutrient use efficiency of the fertilizer due to which, there seems to be no initiative on part of industry on research and development of new efficient/better products. The ambit of NBS scheme may be made broader to consider nutrient use efficiency of fertilizers so that the focus is on efficient uptake of nutrients by the plants. Water-soluble fertilizers need to be promoted by bringing them under subsidy regime.

2

FERTIGATION

Applying plant nutrients by dissolving them in irrigation water (termed as fertigation) particularly with the drip system is a most efficient way of nutrient application. Fertigation has the potential to supply a right mixture of water and nutrients to the root zone, and thus meeting plants' water and nutrient requirements in most efficient possible manner (Patel and Rajput, 2001). Fertigation allows the crops to use up to 90 percent of the applied nutrients. Fertigation ensures saving in fertilizer (40-60 percent), due to "better fertilizer use efficiency"and "reduction in leaching" (Kumar and Singh, 2002).

2.1 Method of application of fertilizers

Fertilizers are compounds given to plants for promoting their growth; they are usually applied via soil. Majority of fertilizers can be dissolved in water which enables them to be mixed easily with water. Fertilizers can be buried around a tree's roots when it is planted, placed in bore holes near tree roots, spread onto soil, or sprayed by hand. Fertilization can also be achieved via aerial top dressing. There are two types of fertilizer: organic fertilizer and inorganic fertilizer. Organic fertilizers are more complex chemical substances that take time to be broken down into forms usable by plants. Cotton seed meal, blood meal, fish emulsion, manures and sewage sludge is examples of organic fertilizers. Inorganic fertilizers dissolve readily in water and are immediately available to plants for uptake. Inorganic fertilizers are derived from non-living sources and include most of our man-made, commercial fertilizers. Generally 4 methods of application of fertilizers are in practice.

i). **Broadcasting:** Uniform distribution over the whole cropped field (Fig. 2.1).

ii). **Placement:** Application in bands or in pockets near the plants or plant rows.

iii). **Foliar application:** Using low or high volume sprayers, the fertilizers are sprayed covering the plants.

iv). **Fertigation:** Fertigation is the injection of fertilizers through the irrigation system.

Fig. 2.1 Application of nutrients

Using the irrigation system, to apply fertilizer reduces the need to use mechanical operations and sometimes eliminates them altogether. Development was also driven by increasing labour costs, demands to prevent pollution and to minimize soil erosion, increasing compulsion to use saline water sources, and unfavourable soil quality. In fertigation, timing, amounts and concentration of fertilizers applied are easily controlled.

Drip irrigation is often preferred over other irrigation methods because of the high water-application efficiency on account of reduced surface evaporation and deep percolation losses. Because of high frequency water application, concentrations of salts remain manageable in the rooting zone. The regulated supplies of water through drippers not only affect the plant root and shoot growth but also the fertilizer use efficiency. Fertigation through drip irrigation reduces the wastage of water and chemical fertilizers, optimizes the nutrient use by applying them at critical stages and at proper place and time, which finally increase water and nutrient use efficiency.

2.2 Significance of fertigation

The right combination of water and nutrients is a prerequisite for higher yields and good quality production. The method of fertilizer application is also important in improving the use efficiency of nutrients. Fertigation enables adequate supplies of water and nutrients with precise timing and uniform distribution to meet the crop nutrient demand. Further, fertigation ensures substantial saving in fertilizer usage and reduces leaching losses (Mmolawa and Or, 2000).

Similar to frequent application of water, optimum split applications of fertilizer improves quality and quantity of crop yield than the conventional practice. Yield responses to the time of N and K application, either pre plant only or pre plant with fertigation, were dependent upon soil type. Less yield response resulted with fertigated N on heavier soils, compared to the lighter fine sands. Similar experiments on fine sands also indicated late season extra large and large fruit yields with 60 percent drip applied N and K compared to yield response with all pre-plant applied N and K.

Deficiency of N, P and K is a major production constraint in sandy soils, which have inherent constraints like P fixation, rapid hydraulic conductivity, faster infiltration rate, leaching of basic cations and low CEC. Hence, the cultivated crop in this soil requires large quantity of nutrients to support its growth and yield. Considering the soil and crop constraints, fertilizers should be applied in synchrony with crop demand in smaller quantities during the growing season.

2.3 Need of fertigation

i). Fertigation permits application of a nutrient directly at the site of a high concentration of active roots and as needed by the crop. Scheduling fertilizer applications on the basis of need offers the possibility of reducing nutrient element losses associated with conventional application. Methods that depend on the soil as a reservoir of nutrients thereby increasing nutrient use efficiency. Fertilizer savings through fertigation can be to the tune of 25-50 per cent (Haynes, 1985).

ii). The concept of fertigation is new but the rapid increase in area under micro irrigation, fertigation is getting popular. Fertigation is the technique to apply water soluble solids or liquid fertilizers through the drip irrigation on weekly or monthly basis so as to reach each and every plant regularly and uniformly.

It is the most effective and convenient means of maintaining optimum fertility level and water supply according to the specific requirement (Shirgure, et. al.; 2000).

iii). Fertilizers and pesticides applied through a drip irrigation system can improve efficiency, save labour and increase flexibility in scheduling of applications to fit crop needs. However, all chemicals must meet the following criteria for the successful maintenance of the drip irrigation system (Bucks and Nakayama, 1980).

However, increasing water scarcity and value crops and green houses to ensure higher escalating fertilizer prices may lead to greater efficiency of the two most critical inputs in crop adoption of the technology especially in high production.

2.4 Benefits of fertigation:

i). **Higher nutrient use efficiency**: Nutrient use efficiency by crops is greater under fertigation compared that under conventional application of fertilizers to the soil.

ii). **Less water pollution**: Intensification of agriculture led by the use of irrigation water and indiscriminate use of fertilizers has led to the pollution of surface and ground waters by chemical nutrients. Fertigation helps lessen pollution of water bodies through the leaching of nutrients such as N and potassium (K) out of agricultural fields.

iii). **Higher resource conservation**: Fertigation helps in saving of water, nutrients, energy, labor and time.

iv). **More flexibility in farm operations**: Fertigation provides flexibility in field operations e.g. nutrients can be applied to the soil when crop or soil conditions would otherwise prohibit entry into the field with conventional equipment.

v). **Efficient delivery of micronutrients**: Fertigation provides opportunity for efficient use of compound and ready-mix nutrient solutions containing small concentrations of micronutrients, which are otherwise very difficult to apply accurately to the soil when applied alone.

vi). **Healthy crop growth**: When fertigation is applied through the drip irrigation system, crop foliage can be kept dry thus avoiding leaf burn and delaying the development of plant pathogens.

vii). **Helps in effective weed management**: Fertigation helps to reduce weed menace particularly between the crop rows. Use of plastic mulch along with fertigation through drip system allows effective weed control in widely spaced crops.

However, to get maximum benefit of fertigation, care must be taken while selecting the fertilizer and injection equipment and the management and maintenance of the system.

2.5 Fertigated nutrients and its importance

Even though all soluble plant nutrients can be applied through fertigation with drip irrigation, but N and K remain the main nutrients, which can be applied more efficiently, because they move readily with the irrigation water. Fertigation with phosphorus (P) and most micronutrients is not very satisfactory as the carriers of these nutrients move rather poorly with water in the soil and thus do not reach the root zone. Besides, the use of fertigation to apply P and micronutrients together with Ca and Mg may cause precipitation and blockage of the emitters (Imas, 1999). However, application of through drip irrigation is more efficient than by the conventional application to soil, because fertigation supplies P directly to the active roots zone, which enables its immediate uptake, before it undergoes transformations especially fixation in the soil (Kafkafi, 2005). When the conditions require that P to be applied by fertigation, it should be applied alone and the irrigation water should be acidified to prevent clogging of the emitters (Rolston et. al., 1981). The soluble forms of the three lesser macronutrients (secondary) - calcium, magnesium and sulphur – do exist but these are much more expensive, not always compatible with mixes and can cause precipitation and clogging. The conventional forms of these nutrients- lime, gypsum and dolomite should be spread in the normal way. When micronutrients need to be applied through fertigation, fully soluble sources or chelates should be used.

2.6 Fertigation scheduling & its importance

Factors that affect fertigation schedules are soil type, available NPK status, organic carbon, soil pH, soil moisture at field capacity, available water capacity range, aggregate size distribution, crop type and its physiological growth stages, discharge variation and uniformity coefficient of installed drip irrigation system.

The efficient fertigation schedule needs the following considerations *viz.*

i). Crop and site specific nutrient management.

ii). Frequent nutrient delivery to meet crop needs.

iii). Controlling irrigation to minimize leaching of soluble nutrient below the effective root zone.

iv) Nutrient can be injected daily or bimonthly depending upon system design, soil type and farmer's preference.

In many situations, a small percentage of N and K (20-30 percent) and most or all P is applied in a pre-plant broadcast or banded application especially in the areas where either initial soil levels are low or early season irrigation is not required. Pre plant application of P is common since soluble P sources (Phosphoric acid) are costlier than granular forms, to avoid the chemical precipitation in drip line. Movement of drip applied P away from the injection point is governed by soil texture and soil pH. Movement of P is particularly restricted in fine textured and alkaline soil. When making a pre-plant application of any nutrient, it is important that the fertilizer be placed within the wet zone of the drip system.

A crop specific fertigation schedule can be developed using growing degree day's implementation. A soil with high N supply capacity may require substantially low N fertilizers. Application of N and K in excess of crop requirement can have adhesive effect such as ground water contamination with nitrate N, appearance of blossom end rot in tomato or pepper with heavy ammonical N application, reduction in specific gravity of potato and size of straw berry fruit with excessive K fertilization.

Frequent injection may be needed for sandy soil with poor water and nutrient capacity to reduce injection pump size and cost. Since leaching is possible with drip irrigation, nutrient applied through irrigation system must not be subjected to excessive irrigation during that application or in subsequent irrigations. It is possible to irrigate nutrient in non continuous (bulk) or continuous (concentration) fashion. Fertilizer should be injected in a period such that enough time remains to permit complete flushing of the system without over irrigation. Water that moves below the active crop root zone carry nitrate N or K in substantial quantities. One cm of leach rate at 100 mg nitrate N/litre would contain 10 kg N/ha.

2.7 Factors affecting fertilizer uptake by plants

Numerous factors affect how easily and well trees and shrubs absorb fertilizers. The most important uptake factors are:

i). Fertilizer form (inorganic, fast release, or liquid forms are absorbed faster than organic, slow-release, or dry forms)

ii). Soil type (clay particles and organic matter adsorb or bind more nutrients than sand, so fertilizer application needs to be more frequent in sandy soils, but with lower rates each time due to leaching potential)

iii). Soil moisture content and soil temperature (nutrient uptake is faster in warm soils)

iv). Plant vigor (plants under stress are less able to take up available nutrients due to damaged or reduced root systems)

2.8 Fertigation nutrient amount

The scheduling of nutrient application through drip irrigation system is vital to get the higher crop productivity and reduce losses of nutrients through leaching. To get desired results, it is pertinent to know how much amount of nutrients should be applied through fertigation.

2.9 Do's & Don'ts

A few rules should be followed, to achieve maximum benefit from fertigation.

i). The fertilizer type used and amount required must be soluble enough to dissolve completely in the fertilizer tank water.

ii). The drip irrigation system needs to be completely charged or pressurized before fertigation begins. The farthest point from the pump should be at full pressure before injection of any fertilizer begins. If the system is not fully charged, air surges could occur and cause uneven application rates.

iii). The fertilizer should be injected ahead of the filters to ensure that any undissolved particles are filtered out before fertilizer enters the drip irrigation system.

iv). The duration in which fertilizer is injected into the system must be at least as long as that required to bring the entire drip irrigation system up to full pressure. This will allow each dispensing orifice in the drip line to have the same contact time with the fertilizer solution as it passes through the system.

v). Any drip fertigation system should have an anti-siphon device, such as a vacuum breaker or backflow preventer (picture), to protect the water supply. This usually is required by law. If backflow prevention is not in place, fertilizer that remains in the system when it is shut down will siphon back through the pump and into the water source.

vi) All fertigation units should be wired to the pump switch or a flow control switch in the main line to prevent the unit from running when no water flows in the line.

3

FERTIGATION EQUIPMENTS AND STANDARDS

Fertigation technology distributes fertilizers to the crops/plant root zone along with water through drip or sprinkler irrigation at frequent intervals in controlled manner so as to allow for steady uptake of nutrients by plants and to effect savings in the costly inputs of both water and fertilizer (Fig. 3.1).

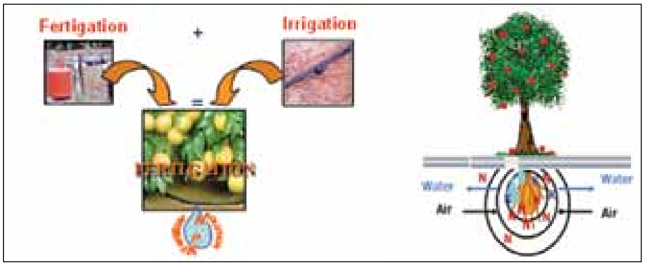


Fig. 3.1 Fertigation

3.1 Fertigation methods

Micro Irrigation Systems provides application of water soluble fertilizers and other chemicals along with irrigation water directly in the root zone and thereby significantly saving the costly inputs. For injecting liquid fertilizers or chemicals an additional component is needed which is called a fertilizer injecting system (Fig. 3.2).

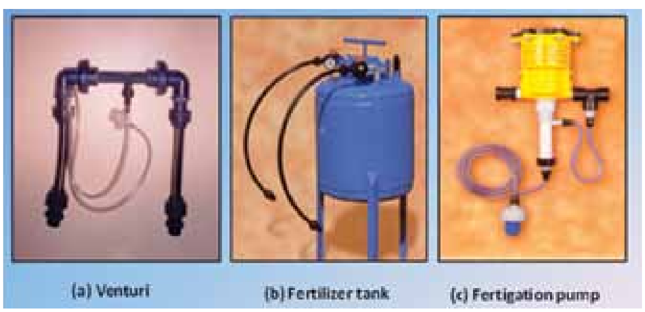


Fig. 3.2 Fertigation equipments

Different types of commonly used fertilizer injecting devices are discussed below.

3.1.1 Venturi injector

Venturi injector consists of converging section, throat and diverging section. When the flowing water passes through the constricted throat section, its velocity increases and the pressure reduces, creating a suction effect. Due to suction, liquid fertilizer enters into the drip system through a tube from the fertilizer tank. To start the venturi system (Fig. 3.4) the desired pressure difference between the entrance and exit gauges is created by using pressure regulating valves to enable the flow of fertilizer into the drip system. The rate of flow is regulated by means of the valves. The venturi system works because of differential pressure in the system (usually 20 %).

Fig. 3.3 Venturi injector

Venturi injectors come in various sizes and can be operated under different pressure conditions. Suction capacity (injection rate), head loss required, and working pressure range will depend on the model.

Fig. 3.4 Fertigation through Venturi

The advantages and disadvantages of using a venturi system for fertigation are given below:

Advantages

i). Simple in operation

ii). Relatively inexpensive in purchasing and maintenance.

iii). Good control over the fertilizer concentration with the irrigation water

Disadvantages

i). High pressure loss (i.e. about one third of the total operating pressure).

ii). Relatively low discharge rate system.

iii). Precise regulation of flow is difficult because the rate of injection is very sensitive to the pressure and rate of flow of water in the main system

iv). The irrigation system needs to be operated at full capacity prior to injecting the fertilizer solution.

3.1.2 Fertilizer Tank Method (By-Pass System)

This method employs a tank into which the fertilizer solution is filled. The fertilizer tank should have a sufficiently large capacity to contain the entire fertilizer solution required for the cropped area for any application. In this system part of irrigation water is diverted from the main line to flow through a tank containing the fertilizer in a fluid or soluble solid form, before returning to the main line, the pressure in the tank and the main line is the same but a slight drip in pressure is created between the off take and return pipes for the tank by means of a pressure reducing valve (Fig. 3.5). This causes water from main line to flow through the tank causing dilution and flow of the diluted fertilizer into the irrigation stream. With this system the concentration of the fertilizer entering the irrigation water charges continuously with the time, starting at high concentration. As a result uniformity of fertilizer distribution can be a problem.

Advantages

i). Simple in construction and operation.

ii). No external power supply needed.

iii). Relative insensitivity to changes in pressure or flow rate.

iv). Low costs for both purchasing of the system and for its maintenance.

v). Both dry (fully water-soluble) and liquid fertilizers can be used; this is the only method by which dry fertilizers can be directly employed.

vi). It enables a high fertilizer injection application rate.

vii). Hydraulic head loss is low.

Disadvantages

i). The tank must be refilled with fertilizer solution for each irrigation cycle, thus the system is not suitable for automatic or serial fertigation.

ii). Fertilization is not proportional, therefore, control over the fertilizer concentration in the water is limited.

Fig. 3.5 Fertilizer Tank

3.1.3 Fertilizer injection pump

In this method, a pump is used to draw the fertilizer stock solution from a storage tank and inject it under pressure into the irrigation system. These are piston or diaphragm pumps which are driven by the water pressure of the irrigation system and such as the injection rate is proportional to the flow of water in the system (Fig. 3.6). A high degree of control over the fertilizer injection rate is possible, no serious head losses are incurred and operating costs are low. Injection rates can be easily set to create a desirable mixing ratio. The solution is normally pumped from an un-pressurized reservoir, and the choice of pump type used is dependent on the power source.

Fig. 3.6 Fertilizer injection pump

The size of the injection pump should accommodate the maximum amount of fertilizer to be injected at any time during the season. Also, consider that on any given cycle, the fertigation process should be completed in less time than is necessary to meet the irrigation needs of the crop grown. The system should flush itself with clean water at least once after injecting the fertilizer solution.

Advantages

i). Flexible and high discharge rate.

ii). Dose not adds to head loss in drip irrigation system.

iii). Maintains constant concentration of nutrients throughout the fertigation period.

iv). Accurate and proportional injection rate.

v). Non electric, operates on hydraulic pressure.

Disadvantages

i). Expensive in purchasing and in maintenance.

ii). Need skilled personnel to operate and maintain the device.

iii). Changes in water flow rate, power failure or mechanical failure may cause serious deviations from planned concentrations.

iv). Need external power source to operate the device.

3.2 Requirements for chemical or fertilizer injection system

3.2.1 Injection method and rate

Fertilizers may be injected by a differential pressure system, venturi injector or by pumping under pressure (pressure injected) into the irrigation water. Other chemicals such as acids, bactericides chlorine which require a constant concentration rate entering the irrigation water shall be injected by constant rate injection devices only.

Chemicals shall be injected into the system after the primary filter and before the fine filter. The required rate of chemical injection depends on the initial concentration of chemical and the desired concentration of chemical to be app1ied during the irrigation. An injector that will operate within a range of injection rates for a number of chemicals may be desired.

3.2.2 Concentration

The concentration of chemicals to be injected in the irrigation water is normally very low, with ranges of 200 to 500 ppm for fertilizers and chemicals and 0.5-10 mg/l (0.5-10 ppm) for bactericides. Chemical concentrations should be routinely measured after filters and before main pipelines, and occasionally at the end of the last lateral line, to check if the entire micro irrigation system is being treated.

3.2.3 Storage Tank Capacity

Large, low cost tanks constructed from epoxy-coated metal, plastic or fibre glass are usually practical when injection pumps are used, for a pressure differential injection system, the high pressure rated chemical tank should have enough capacity for a complete application.

3.2.4 Contamination of water supply

When the water supply or pump fails, it may be possible to have reverse flow from the injection or irrigation system. A pressure switch or other means should be used to turn off the injector pump or close solenoid operated valve on a differential pressure system so that chemicals cannot be injected when the irrigation pump is not operating. A vacuum-breaker and check valve should be placed between the water supply pump and the injection point to prevent backflow from the pipeline to the water supply. In addition, municipalities may require other backflow prevention valves at connections to municipal water lines to prevent reverse flow, particularly when water is being treated with chemicals or amendments.

3.3 Bureau of Indian Standards (BIS) for chemical or fertilizer injection system

This Indian Standard was adopted by the Bureau of Indian Standards after the draft finalized by the Farm Irrigation and Drainage Systems Sectional Committee had been approved by the Food and Agriculture Division Council.(BIS, 1997-2017).

As the fertigation technique that is application of fertilizers through irrigation water in drip irrigation systems is fast becoming popular in the country with the increased use of drip/sprinkler irrigation systems, need was felt to formulate this new standard to Standardize and improve the quality of fertilizer tanks in use and to rationalize the specifications.

As per BIS standards, these are some of the more important standards issued for considerations that shall be considered in the design of a chemical or fertilizer injection system.

I. IS 14483 (Part 1) : 1997 Indian Standard Fertilizer and chemical injection system Part 1 Venturi injector

II. IS 14483 (Part 2) : 2002 Indian Standard Fertilizer and chemical injection system Part 2 Water-driven chemical injector pump

III. IS 14483 (Part 3) : 2017 Indian Standard Fertilizer and chemical injection system Part 3 Fertilizer Tank

4

FERTILIZERS FOR FERTIGATION

4.1 Forms of fertilizers

Fertilizers are available as solid, liquid or soluble formulations. They may either be quick acting or have a slow or controlled release mode of action. The differences of each type and when to use them are explained below.

4.1.1. Solid fertilizers

Solid fertilizers are available in powder or granular form. They release nutrients readily - but are not quick acting. Organic fertilizers such as blood and bone meal and fish and bone meal are slower acting since they need to be broken down by soil bacteria before the nutrients are available to the plant. Solid fertilizers are generally used as pre-sowing or planting fertilizers or routine top dressings. They are less useful where plants are suffering from a nutrient deficiency because of the time it takes for plants to be able to absorb and then use the nutrients. Solid fertilizers require good soil moisture to transport the nutrients to plant roots. Thus, in dry periods, watering will be necessary. The main benefits of solid fertilizers are their familiarity, ease of application and the fact that they are usually cheaper per unit of nutrient.

4.1.2. Liquid or soluble fertilizers

Liquid or soluble fertilizers are quicker acting, especially if they can be applied as a foliar feed. This is an important consideration when treating nutrient deficiencies. They are a better option in dry weather although in wet weather, the nutrients can be more easily leached through the soil.

4.1.3. 'Straight' fertilizers

'Straight' Fertilizers, which contain one key nutrient, are suitable if a gardener needs a particular plant nutrient in preference to others, either because of a deficiency problem or if a crop has a particularly high demand for an individual nutrient. These fertilizers are relatively inexpensive and are often used by 'traditional' gardeners.

4.1.4. Houseplant fertilizers

Houseplant fertilizers are available in different formulations to suit different types of users. Some are available as concentrated liquids or soluble powders for dilution by the user. These tend to be more cost effective. Some are available ready diluted, for speed and ease of use. Others (eg. spikes or tablets) will supply nutrient for several months and are ideal if a user tends to be forgetful about feeding their plants.

4.1.5. Controlled release fertilizers

Controlled release fertilizers are becoming extremely popular with gardeners - they are easy to use and effective, provide plants with nutrients for a whole season and release nutrients at times when plants have the greatest demand for them. They are particularly good for containers and hanging baskets. They are put into the containers at planting time and perform well throughout the season, without the need for supplementary feeding.

4.2 Types of fertilizers

4.2.1 Nitrogen fertilizers

Plants absorb and use most of the nitrogen as nitrate or ammonium ions. The main types of nitrogen are:

i). nitrate - ammonium nitrate

ii). ammonium - sulphate of ammonia

iii). amide - urea

iv). combination of nitrate and amide

v). Brand name products as straights or compounds.

Urea is commonly used and preferred because:

i). it is most concentrated and usually the best price per kilogram of nutrient

ii). it does not leach readily

iii). it dissolves readily, converting to ammonium carbonate (alkaline) then nitrate.

Compared with ammonium nitrogen, which can be held on clay and organic particles, and with nitrate, which moves freely and can be leached quickly, moving to the perimeter of the wetted zone in the soil, urea offers the best value. In colder soil conditions during winter, nitrate forms of nitrogen are preferred (IPI, 2003).

4.2.2 Phosphorous fertilizers

Phosphorus supply is usually provided by:

i). Phosphoric acid

ii). MAP (mono-ammonium phosphate)

iii). DAP (di-ammonium phosphate)

iv). Brand name liquids.

The possibility of precipitation of insoluble phosphates is high when using MAP or DAP with irrigation water that is high in calcium or magnesium. This will cause clogging of drippers and pipelines. Phosphoric acid provides the advantage of cleansing lines and sprays and is a concentrated liquid offering ease of use. Providing the pH of the water is kept low, clogging or precipitation should not be a problem. This can be done by using more acid. Phosphoric acid must be injected at a point beyond any metal connections or filters in order to avoid corrosion. MAP or DAP, although not as soluble as phosphoric acid, have the added bonus of also supplying nitrogen. One litre of phosphoric acid (this contains 60% H_3PO_4) weighs 1.55 kg and is equal to 20 % P (actual) and therefore equals 0.31 kg of P/litre. Single super equals 9 % P, so 1 kg = 0.09 kg of P. Therefore, one litre of phosphoric acid is equivalent to: 3.44 kg of single super, or 1.94 kg of double super, or 1.68 kg of trifos.

4.2.3 Potassium fertilizers

Irrigators can choose from:

i). potassium nitrate

ii). potassium sulphate

iii). potassium chloride

iv). brand name mixed fertilizers and liquids.

Potassium nitrate is the recommended source of potassium for use in fertigation programs because of its solubility and added bonus of providing nitrogen. It is, however, the most expensive of the potassium fertilizers. Potassium sulphate is inferior to the other two sources as its solubility is not as high. Potassium chloride is the most economic of the potassium fertilizers, but can be a problem with crops that are sensitive to high chlorine concentrations such as stone fruit, pecans, citrus, strawberries and avocados. For these crops a mixture of potassium sulphate and potassium chloride can be used to reduce costs (IFA, 2016).

4.2.4 Other macronutrients

Soluble forms of the three lesser macronutrients - calcium, magnesium and sulphur - do exist but these are much more expensive, not always compatible with mixes and can cause precipitation and clogging. The conventional forms of these nutrients - lime, gypsum and dolomite - should be spread in the normal way.

4.2.5 Micronutrients

Chelates and sulphate compounds of various micronutrients are generally used for correcting micronutrient deficiencies. These compounds should be pre-dissolved and metered as a liquid. The micronutrients that can be supplied via irrigation system include: copper, iron, zinc, manganese, boron and molybdenum.

4.3 Characteristics of fertilizers used in fertigation

i). Full solubility.

ii). Quick dissolution in water.

iii). Fine grained product.

iv). High nutrient content in the saturated solution.

v). Compatibility with other fertilizers,

vi). Absence of chemical interaction with irrigation water.

vii). Minimum content of conditioning agents.

viii). No clogging of filters and emitters.

ix). Low content of insoluble (< 0.02 per cent).

x). No drastic change of water pH (3.5< pH> 9.0).

xi). Low corrosives for control and head system.

4.4 Solubility

Not all fertilizers are suitable for fertigation as some are insoluble due to their chemical properties or manufacturing process. As a rule of thumb the following chemical properties should be adhered to in determining the solubility of certain fertilizers.

i). All ammonium, nitrate, potassium, sodium and chloride salts are soluble.

ii). All oxides, hydroxides and carbonates are insoluble.

iii). All sulfates are soluble except for calcium sulphate.

Using these rules, calcium nitrate is soluble (rule I). Calcium carbonate and magnesium carbonate (lime & dolomite) are insoluble (rule II). Magnesium sulphate (Epsom salts) is soluble but calcium sulphate (gypsum) isn't (rule III).Urea, muriate of potash, potassium nitrate & chelated trace elements are generally considered safe to mix. However phosphates, sulphates, calcium, magnesium and trace elements can create problems. When this happens the following can occur:-

i). Precipitates may settle to the bottom of the tank or block filters and emitters.

ii). Precipitates may also form if the water is hard (i.e. high in Ca and Mg or contains carbonate).

Therefore, the trace elements to avoid are copper, zinc, manganese and iron sulphates. These cannot be mixed with calcium nitrate, MAP, MKP and always use chelated forms of trace elements if mixing products.

Solubility indicates the amount of fertilizer that can be dissolved in unit quantity of water. Solubility of fertilizer is a critical factor when preparing the fertilizer solutions for fertigation, especially from dry granular fertilizers (Patel and Rajput, 2001a). Solubility limit is very important to know how much of a fertilizers can be dissolved in a certain amount of water. If this amount is exceeded, the fertilizer will precipitate, which is commonly called 'salting out' (Snyder & Thomas, 1994). All nitrogen and potassic fertilizers such as DAP and SSP, which have a low solubility and do not readily, dissolve in water. Un-dissolved fertilizers can clog the system and drippers therefore it should be removed from the fertilizer solution by appropriate filtration before injecting into the drip irrigation system.

4.5 Selection and compatibility of fertilizers:

Liquid fertilizers are best suited for fertigation as they readily dissolve in irrigation water. In developing countries like India however, inadequate availability and the high cost of liquid fertilizers restrict their use. Fertigation using granular fertilizers poses several problems including differences in solubility in water, compatibility among different fertilizers and problems in filtration of undissolved fertilizers and impurities.

Different granular fertilizers have different solubility in water, which is further affected by irrigation water temperature. When the solutions of two or more fertilizers are mixed together, one or more of them may tend to precipitate if the fertilizers are not compatible with each other. Therefore, such fertilizers may be unsuitable for simultaneous application through fertigation and would have to be applied separately (Patel and Rajput, 2004). For example, when $(NH_4)_2SO4$ and KCl are mixed together in the tank, the solubility of the mixture is considerably reduced due to the formation of K_2SO_4. Other unusable mixtures include calcium nitrate with any phosphates or sulfates, magnesium sulphate with di-or mono-ammonium phosphate, phosphoric acid with iron, zinc, copper and manganese sulfates, etc.

Water temperature is also an important factor when determining solubility. The solubility of most fertilizers decreases with decreasing temperatures. Most granular nitrogenous fertilizers will absorb heat from the water when they are mixed, since cold water will not hold the same amount of soluble material as warm water. Consequently, it can be difficult to dissolve as much fertilizer as needed. Dry fertilizer product that significantly lower the temperatures of the water in which they are dissolved include, urea, ammonium nitrate, calcium nitrate, and potassium nitrate (Table. 4.1). Figure shows the solubility limit of some fertilizers in grams per litre. Putting more than these amounts of fertilizer in this volume of water will result in some fertilizers not being completely dissolved.

Table 4.1 Solubility of different fertilizers

Fertilizers	Solubility (gram per liter water)		
	10ºC	20ºC	30ºC
Nitrogen fertilizers			
Ammonium Nitrate	610	660	710
Urea	450	510	570
Calcium Nitrate	950	1200	1500
Phosphate fertilizers			
Mono-Ammonium Phosphate	290	370	460
Urea Phosphate	410	495	565
Single Super Phosphate	100	150	170
Potassic fertilizers			
Potassium Nitrate	210	310	450
Multi-K Mg (2Mgo)	230	320	460
NPK mixture	210	330	480
Potassium sulphate	80	100	110
Mono-potassium phosphate	180	230	290
Potassium Chloride	240	310	350

The problem of precipitation and incompatibility among solid fertilizers can be minimised by using two fertilization tanks to separate the fertilizers that interact and cause precipitation, e.g. placing in one tank the calcium, magnesium and microelements, and in the other tank the phosphorus and the sulphate sources. Nitric or phosphoric acids are used to lower the pH level in fertigation. Their advantage, besides the dissolution of basic precipitates in the line is that they also supply the plants with the essential nutrients, and thereby replace N and P fertilizers. With the use of saline water and in calcareous clay soils, nitric acid increases Ca dissolution and thereby minimizes salinity injury due to Ca/Na competition and also reduces chloride salinity in the root zone, as the nitrate counterbalances excess chloride (Xu et. al., 2000). Papadopoulos and Ristimäki (2000) found that urea phosphate as a source of P gave higher yield of both tomato and eggplant as compared to mono-ammonium phosphate and di-ammonium phosphate even when P_2O_5 supplied was 25% less. Most probable explanation is the "double acidification effect" of the urea phosphate fertilizer. Potassium nitrate is the recommended source of potassium for use in fertigation

	Urea	Ammonium nitrate	Ammonium sulphate	Mono-ammonium Phosphate Map	Mono-potassium Phosphate Mkp	Potassium nitrate	Potassium sulphate	Potassium chloride	Ca;coum nitrate	Magnesium sulphate	Soluble boron
urea		YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Ammonium nitrate	YES		YES	YES	YES	YES	YES	YES	YES	YES	YES
Ammonium sulphate	YES	YES		YES	YES	YES	YES	YES	No	YES	YES
Mono-ammonium phosphate MAP	YES	YES	YES		YES	YES	YES	YES	No	No	YES
Mono-potassium phosphate MKP	YES	YES	YES	YES		YES	YES	YES	No	No	YES
Potassium nitrate	YES	YES	YES	YES	YES		YES	YES	YES	YES	YES
Potassium sulphate	YES	YES	YES	YES	YES	YES		YES		YES	YES
Potassium chloride	YES	YES	YES	YES	YES	YES	YES		YES	YES	YES
Calcium nitrate	YES	YES	YES	YES	YES	YES	YES	YES		No	No
Magnesium sulphate	YES	YES	YES	YES	YES	YES	YES	YES	YES		No
Soluble boron	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	

Source: *Fertigation, Scott & Rochester, 2012, Section 5, Irrigation systems*

Fig. 4.1 Fertilizer compatibility chart programs because of its solubility and added bonus of providing N. It is, however, the most expensive of the K fertilizers.

The options for applying incompatible products include:

i). Apply the fertilizers at different times (e.g. apply MAP or MKP and sulphate fertilizers at different times to calcium fertilizers);

ii). Alternate between the products each time the crop is irrigated; and,

iii). Use two mixing tanks and injectors - as the concentration of nutrients in the irrigation lines is very dilute and therefore there is less chance of precipitate formation.

4.6 Mobility of fertilizers in soil

The ability of a fertilizer to dissolve in water does not always give a good indication of the potential for the fertilizer or its components to move through the soil. Table 4.2 gives a general guide to the mobility of fertilizer (Khasawneh, *et. al.*,1974) components in soil.

Table 4.2 Mobility of different fertilizers in soil

Fertilizers	Mobility
Urea	Good
Nitrate	Good
Ammonium	Low
Potassium	Low
Phosphate	Low

For example, urea is very mobile in soil and is easily leached down the soil profile, past the majority of fine roots if fertigation duration is excessive. Ammonium 'sticks' to clay particles and is much less mobile. As a result ammonium (in mono ammonium phosphate, ammonium sulphate etc) is much less likely to be leached down past the tree roots. An interesting example is ammonium nitrate where the nitrate component is mobile and easily lost by leaching, while the ammonium component binds strongly or 'sticks' to clay particles and is much less likely to be leached. This does not mean that mobile fertilizers should be avoided (McNab *et al.*, 1995), in fact some offer distinct advantages in their effect on soil pH, eg. Calcium nitrate or potassium nitrate may slowly increase soil pH. However, mobile fertilizers do need to be applied carefully to minimize leaching losses (Fig. 4.2).

Another point to remember is that

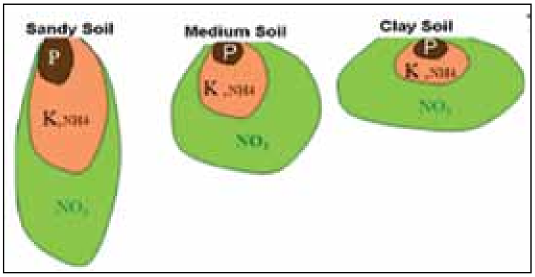


Fig. 4.2 Mobility of fertilizers in the soil

although one may apply a fertilizer of lower mobility (i.e. ammonium), it will be naturally broken down in the soil to form nitrate, which is very mobile. All types of fully-water soluble granular and liquid fertilizers are suitable for fertigation. However, for higher yield and quality, chloride-free fertilizers such as Multi-K (potassium nitrate), Mono Ammonium Phosphate and Mono Potassium Phosphate are preferable. Soluble dry fertilizers containing N, P and K in different combinations are also available in the market. Liquid fertilizers with varying N, P and K contents are also available but these are more expensive (Table 4.3). Mostly, Nitrogen (N), Potassium (K), or both are injected. But

Table 4.3 Water soluble fertilizers

N	K
Urea (46:0:0) Ammonium nitrate (34:0:0) Ammonium sulphate (21:0:0) Calcium nitrate (16:0:0) Magnesium nitrate (11:0:0) Urea Ammonium Nitrate (32:0:0) Potassium Nitrate (13:0:46) MAP (12:61:0)	Potassium Chloride (0:0:60) Potassium Nitrate (13:0:46) Potassium Sulphate (0:0:50) Potassium Thiosulphate (0:0:25) MKP (0:52:34)
P	**Micro nutrients**
MAP (12:61:0) MKP (0:52:34) Phosphoric acid (0:52:0) NPK (18:18:18 :: 19:19:19 :: 20:20:20)	FeEDTA (13%) FeDTPA (12%) FeEDDHA (6%) ZnEDTA (16%) CaEDTA (9.7 %)

Phosphorous does not move very freely in the soil therefore half of its recommended dose be normally applied before planting (Owens & Johnson, 1996).

4.7 Concentration of different nutrients in fertilizer solution

Nutrient concentrations in fertilizer stock solutions can range from very weak to near maximum strength. The maximum strength (maximum possible concentration) of a stock solution is limited by the solubility of the fertilizers dissolved in the solution. But the stock solution should be diluted to bring the concentration of different nutrients up to their acceptable limits by the plant shown in the Table 4.4. Lower or higher concentrations could result in poor plant health.

The actual concentration of nutrients needed in irrigation water depends on the fertilizing material and the crop requirement. The estimation of nutrient concentration in irrigation water is given in Table 4.4.

Table 4.4 Acceptable concentration of different nutrients

S. No.	Nutrients	Acceptable limits of concentration, ppm	Average acceptable concentration, ppm
1.	Nitrogen	150 - 1000	250
2.	Phosphorus	50 - 100	80
3.	Potassium	100 - 400	300
4.	Calcium	100 - 500	200
5.	Magnesium	50 - 100	75
6.	Sulphur	200 - 1000	400
7.	Copper	0.1 - 0.5	0.25
8.	Boron	0.5 - 5.0	1.0
9.	Iron	2.0 - 10	5.0

S. No.	Nutrients	Acceptable limits of concentration, ppm	Average acceptable concentration, ppm
10.	Manganese	0.5 - 5.0	2.0
11.	Molybdenum	0.01 - 0.05	0.02
12.	Zinc	0.5 - 1.0	0.5
13.	Sodium	20 - 100	50
14.	Carbonates	20 - 100	60
15.	Sulphate	200 - 300	250
16.	Chloride	50 - 100	70

4.8 Quick diagnosis of nutrient deficiencies in plants

If the plants suffering from a nutrient deficiency, but are not certain which nutrient it is, symptoms have been given below as a quick reference. To confirm the diagnosis, look up the more detailed descriptions of the symptoms and problem soils etc. under the separate heading for the individual nutrients.

i). Leaves pale green, plants stunted - Nitrogen

ii). Leaves with purple or bronze tints - Phosphorus

iii). Marginal discolouration/scorch - Potassium

iv). Leaves yellow, veins green - Iron, magnesium (also see manganese)

v). Dark water-soaked areas on fruit, brown pitting, internal browning, brittle tissue - Calcium or boron

vi). Narrowing of leaves (brassicas) - Molybdenum

5

FERTIGATION SYSTEMS DESIGN

5.1 Fertigation System Design

Fertigation offers precise control on fertilizer application and can be adjusted to the rate of plant nutrient uptake. Factors crucial for effective fertigation design include:

i. Estimation of available nutrients in soil
ii. Estimation of amount of fertilizer required
iii. Fertilizer tank capacity
iv. Irrigation water requirement
v. Capacity of drip system
vi. Injection duration
vii. Estimation of concentration of nutrients in irrigation water
viii. Injection rate

5.1.1 Availability of nutrients (Nitrate-Nitrogen and P_2O_5) on the basis of soil analysis is given in Figure. 5.1.

Estimation of available nutrients in soil

$$C_n = Ex \times CEC \times C_{nmeq} \times 10^{-2}$$

where,

C_n = Concentration of available nutrients in soil, ppm
CEC = Cation-exchange capacity, meq/100g of soil
Ex = Exchangeable nutrients (% of CEC)
C_{nmeq} = Concentration of 1 meq of nutrient per 100 g of soil, ppm

Fig. 5.1 Estimation of available nutrients in soil

5.1.2 Estimation of amount of fertilizer required

The amount of nutrients to be applied during any given fertigation and the total amount to be applied during the crop season depend on the frequency of fertigation, soil type, nutrient requirements of the crop and its availability in the soil. The nutrients applied to soil by the fertilizers are not fully available to the plant due to leaching, run-off, volatilization and adsorption losses. Requirement of fertilizer changes according to the stage of plant growth. The amount of nutrients to be applied during any given fertigation and the total amount to be applied during the production season depend on the frequency of fertigation, soil type, nutrient requirements of the crop and its availability in the soil. Estimation of required amount of fertilizer is given in Fig. 5.2.

Estimation of amount of fertilizer required

$$F_n = (R - A_n) \times Fcf$$

where,

F_n = Nutrient requirement, kg/ha
R = Recommended dose of fertilizer for the crop, kg/ha
Fcf = Fertilization correction factor
(offset leaching, run-off, volatilization and adsorption losses)

Nutrients	Correction factors
Nitrogen	1.1 - 1.2
Phosphorus	1.6 - 1.9
Potassium	1.2 - 1.4

Fig. 5.2 Estimation of amount of fertilizer required

5.1.3 Frequency of fertigation

Fertilizer can be injected into the irrigation system at various frequencies once a day or once every two days or even once a week. The frequency depends on system design, irrigation scheduling, soil type, nutrients requirement of crop and the farmer's preference. It is also important to monitor the application of water as fertilizer application is linked to water application. In any case, it is extremely important that the nutrients applied in any irrigation are not subject to leaching either during that same irrigation or during subsequent irrigations.

5.1.4 Capacity of fertilizer tank

The stock solution is prepared by dissolving the granular fertilizer in water. The amount of water needed to dissolve the required amount of granular fertilizer depends on its solubility. Depending upon the compatibility of the granular fertilizers, either one stock solution of N-P-K fertilizers or different stock solutions of N, P and K fertilizers were prepared separately. Stock solutions could be prepared for each fertigation or for injection during fertigation over a period of time. The capacity of fertilizer tank was calculated on the basis of frequency of fertigation, area irrigated in one application, application rate and concentration of stock solutions prepared for fertigation.

Low cost tanks are practical where an injection pump or a venturi is used. A large tank provides a good place to store fertilizer for long period as it reduces the labour requirement associated with frequent filling. The tank is generally made of stainless steel. Commercially available fertilizer tank ranges form 30 to 600 litres. This is not enough, because some fertilizers need larger quantities because of high application rates or low solubility. The stock solution can be prepared based on the solubility of the fertilizers used. Normally highest concentration is not desirable and it is recommended that stock solution is prepared with slightly lesser concentration. The size of the fertilizer tank is calculated on the basis of the total volume of stock solution required and the frequency of irrigation as follows:

Capacity of fertilizer tank, V_t depends on the area irrigated in one application through the control head in question, and the application rate (amount per hectares).

Capacity of fertilizer tank:

$$(V_1=(RF\times A)/(C\times nf)$$

where,

V_1 = Capacity of tank, L

RF = Recommended dose of fertilizer,

A = Irrigated area, ha

C = the concentration of the fertilizers in the stock solution, kg/L

nf = Number of fertigation during the crop season

5.1.5 Injection duration

The maximum injection duration depends on soil type and nutrient and water requirements of the crop. A maximum duration of 45 to 60 minutes is generally recommended with enough time for flushing of fertilizer residues from the lines before shutting the pump off. This injection duration is sufficient for uniform distribution of nutrients throughout the fertigation zone. Injection duration is kept within permissible limits to prevent the application of too much water, because excessive water leaches plant nutrients below the root zone. In addition, too much water saturates the soil, causing damage to roots and plants. If any large field is having more than one block then drip irrigation system is installed in such a way that one block can be fertigated at time.

5.2 Preparation of stock solution

Stock solution having different NPK ratio can be prepared by using water soluble fertilizer. An example to prepare 100 litre stock solution having N: P: K in the ratio of 6.4-2.1-6.4 is given below-

- *fill 70 liters of water in the tank,*
- *add 4 kg MKP,*
- *add 14 kg Urea,*
- *add 8.2 kg KCl,*
- *bring volume to 100 liters.*

4 kg MKP = 4 kg MKP x 52% P_2O_5= 2.1 kg P_2O_5/100L = 21,000 ppm P_2O_5 = 4 kg MKP x 34% K_2O = 1.36 kg K_2O/100L = 13,600 ppm K_2O

14 kg Urea = 14 kg urea x 46% N = 6.44 kg N/100L = 64,400 ppm N

8.2 kg KCl = 8.2 kg KCl x 61% K_2O = 5 kg K_2O/100L = 50,000 ppm K_2O

1 ppm = 1 mg/l = 1 gram / m^3

Apply 2 liter stock solution per 1m^3 water to reach 130, 40 and 130 ppm of N, P_2O_5 and K_2O, respectively

When 2 liters of the stock solution is applied to 1m^3 of water; the plants will receive in the dripper:

N = 64,400 ppm x 2L/1000L = 128.8 ≈ 130 ppm N

P = 21,000 ppm x 2L/1000L = 42 ≈ 40 ppm P_2O_5

K = (13,600+50,000) ppm x 2L/1000L = 127.2 ≈ 130 ppm K_2O

5.3 Chemical treatments in drip irrigation system

Quality of water is the most important factor for the successful functioning of a drip system. Drip system consists of large number of emitters which have very small flow paths. The emitters are prone to blockage or clogging due to the contamination through the source water. The factors responsible for clogging phenomenon include the–1) presence of microorganisms, 2) the size and quantity of suspended solids in the water, and 3) the presence of certain dissolved solids such as iron, manganese and calcium which may precipitate and form deposits within the lateral lines and emitters. The clogging of a drip system could be due to the following reasons.

5.3.1 Acid Treatment

The injection of acid into drip irrigation system is primarily carried out to :

1. Presence of large particles as well as suspended silt and clay load in water
2. Growth of bacterial slime in the system
3. Growth of algae in the water source and in the drip system
4. Bacterial precipitation of iron or sulphur
5. Chemical precipitation of iron
6. Chemical precipitation of dissolved salts in laterals, drip tapes and drippers

For Acid treatment any one of the following acids can be used.

1. Hydrochloric Acid.
2. Sulphuric Acid.
3. Nitric Acid and
4. Phosphoric Acid

Physical treatment like filtration will not remove the dissolved solids/salts, bacteria or microscopic algae from water. The bacteria and algae can grow in the drip system or can interact with particles of silt and clay and form clusters or can catalyze precipitation of salts. Such precipitation can cause clogging or blockage of laterals and drippers. Therefore, chemical treatment of water either at source or within the system is the most useful method of preventing or rectifying the clogging problem. In chemical treatment acid or chlorine is injected in the drip irrigation system along with irrigation water. The equipments such as ventury, fertilizer tank and injector pump are used for applying chemicals and fertilizers through Drip Irrigation System.

5.3.2 Chlorine Treatment

Bacterial and organic growth can be controlled by injecting chlorine into the drip irrigation system. Chlorine when dissolved in water acts as a powerful oxidizing agent and vigorously attacks microorganisms such as algae, fungi and bacteria. The quantity of chlorine required and the frequency of treatment depends on the amount of organic matter (i.e., level of contaminants) present in water. Generally a chlorine concentration of 10-20 ppm is required to control the growth of biological matter in the system. The efficiency of chlorination will be more, if the pH of source water is less than 7. The maximum chlorine concentration injected should not exceed 20 ppm, otherwise it may precipitate solids that could clog the drippers. It is very important to treat the system regularly to prevent blockage. Treatment on a 15 day cycle with chlorine injection at the end of irrigation is a good practice. If no organic matter is built up, this period can be extended. System should be chlorinated at the end of a crop season and prior to use in the next season to keep laterals / In-lines sterilized.

5.3.3 Safety Precautions during Acid and Chlorine Treatment

i). Acids are dangerous. All acids should be handled with care. Protective glass and hand gloves should be used to protect eyes and to prevent skin contacts.

ii). Never add water to acid. Always add acid to water for dilution.

iii). Acid treatment and chlorine treatment should not be carried out simultaneously as chlorine gas may be liberated, which is poisonous.

iv). Irrigation water mixed with acid or high chlorine concentration is hazardous. Ensure that human beings and animals do not drink the system water during chemical treatments.

v). If acid comes in contact with any part of the body during the treatment, was the burns using copious water and consult a Doctor.

vi). Do not inhale acid fumes or chlorine gas. Do not bend on the tank or bucket containing chlorine or acid solution.

vii). Ensure that equipments used to handle the acid are resistant to acid attack.

viii). Backwash the sand filter before performing acid or chlorine treatment. This will prevent entry of decomposed / decayed impurities into the drip system.

ix). After completing chemical treatment [acid or chlorine] rinse / wash the filtering element of screen filter and fertilizer tank with clean water.

6

TECHNOLOGIES DEVELOPMENT AND DISSEMINATION THROUGH PFDCS

The Department of Chemicals & Petrochemicals, Government of India has been considering the promotion and development of uses of plastics in agriculture and irrigation as a major step in improving agricultural yields & efficiencies for a committee was constituted during 1981 which has been functioning in the Department of Agriculture & Cooperation, Ministry of Agriculture since 1983. The committee was reconstituted in 1996. In order to make this committee more effective and to focus its endeavour in a coordinated manner for promoting the applications in Horticulture, NCPAH was reconstituted in 2001 as National Committee on Plasticulture Applications in Horticulture (NCPAH).

National Committee on Plasticulture Applications in Horticulture (NCPAH), Ministry of Agriculture & Farmers Welfare, GoI has the mandate to promote and develop the use of plastics in agriculture, horticulture, water management and other allied areas. The Committee during its tenure has submitted several reports and policy documents to the Government of India which have paved the way for plasticulture development in the country. On the recommendation of NCPAH, the Government of India has also established 22 Precision Farming Development Centres (PFDCs) all over the country according to agro-climatic zone of India to promote research and extension activities in promotion of these applications under GoI flagship programmes.

Precision Farming Development Centres (PFDCs) have been established in State Agricultural Universities (SAUs); ICAR Institutes such as IARI, New Delhi; CIAE, Bhopal & CISH, Lucknow and IIT, Kharagpur etc. Presently 22 PFDCs have been operating to promote various plasticulture applications in horticulture by undertaking trials, demonstrations in state focused crops, workshops / seminar, transfer of technology through training & awareness programmes, use of Radio / TV programmes, Publications etc in different agriculture climate zones of the country. These 22 PFDCs operate under the supervision of NCPAH and are funded by MIDH scheme, MoA&FW.

6.1 Thrust area of PFDC's in last three decades

The research works conducted were conceptualized as per the need of the time, keeping the central theme of enhancing water and fertilizer use efficiency through micro irrigation technology, during the period 1985 to 2016. Micro irrigation system came to India in seventies but its adoption started only in late eighties. Government started making efforts to promote micro irrigation through part financial support to offset its high initial cost syndrome. During initial stages it was important to evaluate the different micro irrigation system (drip and sprinkler) in field, to investigate its benefits to convince the farmers for its adoption. Initial researches included the comparisons of micro irrigation system with conventional systems in terms of water savings and yield enhancements.

After establishing the superiority of micro irrigation systems, the focus of research shifted to estimate water requirements, hydraulics of water movement in different soils, modifications of crop geometry and use of mulches in drip irrigated fields for realizing the potential benefits of the system. With passing time that is in nineties the emphasis gradually shifted to different fertigation including fertilizer selection, evaluation of fertigation equipment, stock solution preparation, fertigation frequency, nutrients dynamics. During last decade, efforts were made to develop hardware, software for cost reduction, design modifications and fertigation program and chemigation. In the recent years the emphasis has emerged on precision farming, including the use and application of software and more efficient instruments in agriculture besides the use of simulation and modeling of moisture and nutrients movement under different soil and dripper characteristics, improved micro irrigation systems including automated systems and subsurface drip systems including protected cultivation (Table 6.1).

Table 6.1 Change in thrust area with time

Time period	Researchable issues for technology development
1985-1995	Evaluation of micro irrigation system Selection of nozzles and pipes Drip hydraulics and drip design Micro irrigation comparison with conventional methods Installation of micro irrigation in fruit crops
1995-2005	Estimation of crop water requirement Crop geometry to minimize the cost Fertilizer application with micro irrigation Evaluation of fertilizer applicators Fertigation study in vegetables in orchards
2005-2015	Fertigation scheduling in open field and protected cultivation Use of alternate energy in micro irrigation Softwares development for design of MI system Computer programs for estimation of crop water demand MI in field crops and use of MI in cropping system Automation in micro irrigation and fertigation Subsurface drip system for cost reduction
2015- onwards	Vertical farming Hydroponics and soil less cultivation MI in field and non-conventional crops Sensor development and IT application in MI Development of fertigation program Fertigation scheduling in open field and protected cultivation Solar energy, rainwater harvesting and linkage with MI MI in canal command and rainfed areas

6.2 Development of fertigation technology for horticultural crops

India, with its diverse soil and climate comprising several agro-ecological regions, provides the opportunity to grow a variety of horticulture crops. These crops form a significant part of total agricultural produce in the country comprised of fruits, vegetables, root and tuber crops, flowers, ornamental plants, medicinal and aromatic plants, spices, condiments, plantation crops, and mushrooms. Horticultural crops play a unique role in India's economy by improving the income of the rural people. In three decades of research, PFDCs as located in different ago climatic zone of India (XI five year plan, 2012) make a significant role in technology development suitable for that region and also disseminated to farmers through training and demonstration. Research conducted by different PFDC's pertaining to fertigation is summarized and given below in the Table 6.2.

Table 6.2 Details of fertigation experiments conducted by different PFDCs

S. No.	Agro-Climatic Regions	PFDC	Crops
1	Southern Plateau and Hills region	Bangalore	Bird of paradise, Cardamom Carnation, Cashew, cauliflower, Coconut, Coffee, Cucumber, Fig,Geranium, Gerbera, Onion.Potato, Rosemary, Sapota, Tomato
2	Central Plateau and Hills Region	Bhopal	Capsicum, Guava, Mango, Tomato
3	Eastern Plateau and Hills Region	Bhubaneswar	Mango
4	Western Himalayas Region	Bikaner	Brinjal, Cabbage, Cucumber, Garlic, Mosambi, Tomato
5	Southern Plateau and Hills Region	Coimbatore	Banana, Brinjal, Chilli, Coconut Okra, Tomato
6	Eastern Himalayan Region	Guwahati	Broccoli, Cabbage, Cauliflower
7	Trans-Gangetic Plains region	Hisar	Kinnow, Potato
8	Southern Plateau & Hills Region	Hyderabad	
9	Eastern Himalayan Region	Kharagpur	Banana, Dutch Roses ,Guava
10	Western Himalayan Region	Leh	
11	Upper Gangetic Plains Region	Lucknow	Guava, Mango
12	Trans-Gangetic Plains region	Ludhiana	Brinjal, Chilli, Maize, Onion, Pea, Potato
13	Gujarat Plains & Hills Region	Navsari	Banana (Intercropping), Banana, Brinjal, Capsicum, Leafy Vegetable (Amaranthus, Coriander, Fenugreek, Spinach) Gladiolus, Onion, Papaya Sweet corn, Tomato,
14	Trans-Gangetic Plains region	New Delhi	Baby corn, Bottle gourd, Broccoli, Cabbage, Cauliflower, Cotton, Garlic, Kharif Onion,Okra, Potato, Rabi Onion, Tomato
15	Western Himalayan Region	Pantnagar	Capsicum, Chilli, Cucumber, Gladiolus, Lillium, Tomato
16	Western Plateau and Hills region	Rahuri	Banana, Capsicum, Carnation, Gerbera, Tomato
17	Eastern Plateau and Hills Region	Raipur	Capsicum, Cauliflower, Cowpea, Cucumber, Onion, Paddy, Tomato
18	Middle Gangetic plains region	Ranchi	Cauliflower, Okra, Potato
19	Middle Gangetic Plains Region	Samastipur	Banana, Brinjal, Carnation, Litchi, Sapota, Tomato
21	Western Himalayan region	Solan	Apple, Apricot, Capsicum, Pea, Tomato
22	West Coast Plains & Ghats Region	Tavanur	Coconut, Cucumber, Okra

Crops wise technologies developed by different PFDC's to enhance water and fertilizer use efficiency is given below-

6.2.1. Apple

Crop and variety	Apple (Red Spur)
Technology	Drip irrigation with fertigation
PFDC	Dr. YSPUH&F , Solan, Himachal Pradesh
Fertilizer dose and scheduling	Recommended dose of fertilizer - 1960g:1540g:820g (Urea: Single super phosphate (SSP) : Muriate of Potash (KCl) per tree per year. Fertigation done weekly once
Crop period	Perennial

Table 6.3 Fertigation scheduling

Growth stage	Week	No. of fertigation (weekly intervals)	Fertilizer applied (gm/tree/fertigation)		
			19:19:19	Urea	KCl
Green tip- Pink Bud	1-3	3	95	36	30
Flowering- Fruit set	4-6	3	95	36	30
Walnut	7-9	3	95	36	30
Fruit Development	10-15	6	95	36	30

PFDC finding

Fertigation should commence from green tip stage in split applications of fertilizers, applied at weekly intervals for getting maximum yield (14 t/ha) of high density apple plantations. For full grown apple plants, 95, 36 and 30 gm 19:19:19, Urea and Muriate of Potash per tree per fertigation is recommended. Total 2415 gm/tree fertilizers are required for fertigation for whole season whereas under conventional fertilization, a total of 4320 gm/ tree fertilizer is required.

Fig. 6.1 Apple crop under drip Fertigation at PFDC, Dr. YSPUH&F, Solan

6.2.2. Apricot

Crop and variety	**Apricot (New Castle)**
Technology	Drip irrigation with fertigation
PFDC	Dr. YSPUH&F Solan, Himachal Pradesh
Fertilizer dose and scheduling	Recommended dose of fertilizer (N:P: K: : 1960g:1540g:820g (Urea: SSP:MOP)/tree per year
Crop period	Perennial

Table 6.4 Fertigation scheduling

Plant age in years	Fertilizer applied, gm/tree		
	N:P:K :: (19:19:19)	Urea	MOP
4	50	21	29
5	62	26	36
6	75	31	43
Above 7	88	36	50

PFDC finding

Fertigation should start from 15th February and continued upto 15-20 days before crop ripens i.e. up to May end. For full grown apricot plants, 88, 36 and 50 gm 19:19:19, N:P:K, Urea and Muriate of Potash per tree per fertigation should be applied. Total of 2784 gm/tree fertilizers are required for whole season under fertigation whereas under conventional fertilization, a total of 4320gm/tree fertilizer is required. Maximum achievable yield (10 t/ha).

Fig.6.2 Apricot crop under drip Fertigation at PFDC, Dr. YSPUH&F, Solan

6.2.3. Baby corn

Crop (variety)	Baby corn (HM-4)
Technology used	Drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Farm yard manure 12.5 tons, N- 150 kg, P_2O_5 - 60 kg, K_2O- 60 kg and $ZnSO_4$- 25 kg per ha under twice in a week through fertigation
Crop period	Round the year (3 crops in a year)

Table 6.5 Crop water requirement

Year-round cultivation	Crop water Fig. Amaranthus under shade net (PFDC, NAU, Navsari, Gujarat)requirement (mm)				Total water requirement (mm)
1st season (October-February)	Initial stage (20 days)	Developmental stage (30 days)	Middle stage (30 days)	Maturity stage (34 days)	196.2
	14.5	65.0	57.60	59.10	
2nd season (April-July)	Initial stage (20 days)	Developmental stage (25 days)	Middle stage (15 days)	Maturity stage (13 days)	285.5
	50.5	145.1	46.3	43.6	

Year-round cultivation	Crop water Fig. Amaranthus under shade net (PFDC, NAU, Navsari, Gujarat)requirement (mm)				Total water requirement (mm)
3rd season (August-November)	Initial stage (20 days)	Developmental stage (25 days)	Middle stage (15 days)	Maturity stage (11 days)	178.0
	23.4	95.7	28.1	30.8	

PFDC finding

About 83,334 plants can be accommodated in 1 hectare field by adopting 20 cm plant to plant and 60 cm row to row spacing with a seed rate of 22 kg ha^{-1} at planting depth of 2.5-3.0 cm. The yield of cob (13.25 t ha^{-1}), baby corn (2.25 t ha^{-1}) and fodder (63.33 t ha^{-1}) may be achieved by following biweekly fertigation schedule. High value of benefit cost ratios of 3.04, 3.68 and 1.86 are realizable (at the sale price of baby corn of Rs. 100 per kg and green fodder as Rs. 1/kg) under biweekly fertigation for crops grown during October-February, April-July and August-November, respectively. This cropiing schedule reduces payback period to only 0.58 year.

Fig. 6.3 Baby corn under drip fertigation at PFDC, IARI, New Delhi

6.2.4. Banana

Crop (variety)	Banana (Grand Naine)
Technology	Drip irrigation with fertigation, plastic mulch (100 micron)
PFDC	IIT, Kharagpur, West Bangal
Fertilizer dose and scheduling	Basal dose (1 kg Neem Cake, 10 kg FYM per pit. 439g Urea, 200g 20:20:20, 95g 00:00:50 and 40g 12:61:00) Recommended dose of fertilizer through fertigation (160:48:240 :: N:P_2O_5:K_2O g plant^{-1}) was given through fertigation using water soluble fertilizers at 7 days interval
Crop period	September, 2010 to February 2015

PFDC finding

The estimated quantity of water applied to Banana plant is 1236 mm in open condition and 1115 mm under plastic mulch, respectively. The irrigation water requirement varies from 1.27 to 15.99 L day^{-1} plant^{-1} from early stage to peak demand period in open field condition and 0.53 to 14.17 L day^{-1} plant^{-1} for plastic mulch covered condition. Irrigation should be given in alternate days with online drip irrigation system with drippers of 4 L h^{-1} discharge capacity. To get the maximum and sustainable yield, optimum dose of fertilizer (160:48:240 N: P_2O_5:K_2O g plant^{-1}) should be given through fertigation using water soluble fertilizers at 7 days interval. Fifty percent of plant area should be mulched with 50 μ black plastic film for weed control, conserve soil moil moisture and preventing soil nutrient leaching during heavy rain. Planting should be done 2 m x 2 m planting geometry. The maximum yield (64.49 and 50.07 t ha^{-1}) and bunch weights (25.43 and 20.20 kg) may be obtained for main crop and ratoon crop, respectively through drip with mulch for getting B.C. ratio of 2.56.

Fig.6.4 Banana under drip fertigation at PFDC, IIT, Kharagpur

Crop (variety)	Banana (Grand Naine)
Technologies used	Drip with fertigation and sleeving material
PFDC	NAU, Navsari, Gujarat
Fertilizer dose and scheduling	Recommended dose of fertilizer : 300:90:200 g NPK/Plant at 15 days interval after three month of planting through drip system.
Crop period	2014-16

Table 6.6 crop water requirement:

Months	CWR (L $Plant^{-1}$ day^{-1})
October	6.00
November	6.75
December	7.75
January	8.25
February	9.50
March	11.75
April	13.50
May	16.75
June	18.0 / rain
July	rain
August	rain
September	rain

PFDC finding

Fertilizer dose of 180:90:120 g NPK/plant (i.e. 60 % of N and K of RDF) of which 40 % NK and cent percent P applied in two equal splits at monthly interval after one month of planting as soil application. While, remaining 60 % NK applied in 6 equal splits at 15 days interval after three month of planting through drip system. The drip irrigated banana at a crop geometry of 2.4 m x 1.2 m for farmers of South Gujarat situated in Heavy Rainfall Zone (AES III) are advised to cover their fully emerged fruit bunch with either 16 micron plastics (transparent or blue plastic) or PP non-woven film for getting better quality fruits (minimum load of bacteria and fungus) and premium price as well. Under this fertigation practice fruit yield of 96 to 100 t/ha and net income was found higher under transparent plastic of Rs. 35112/ha, followed by blue plastic film of Rs. 31640/ha and PP non woven film of Rs. 28168/ha as compared to control treatment i.e., without sleeving.

Fig. 6.5 Banana under drip fertigation at PFDC, NAU, Navsari

6.2.5. Banana(Intercropping)

Crop (variety)	Banana (Grand Naine)
Intercrops (varieties)	Onion(Puna red), Galic(Local) and Cauliflower(Maharani)
Technologies used	Drip irrigation with fertigation
PFDC	NAU, Navsari, Gujarat
Fertilizer dose and scheduling	RDF: 300:90:200 g NPK/Plant 180:90:120 g NPK/plant (i.e. 60 % of N and K of RDF) of which 40 % NK and cent percent P applied in two equal splits at monthly interval after one month of planting as soil application. While, remaining 60 % NK applied in 6 equal splits at 15 days interval after three month of planting through drip system.
Crop period	2010-2012

Table 6.7 crop water requirement

Months	CWR (L $Plant^{-1} Day^{-1}$)
October	6.00
November	6.75
December	7.75
January	8.25
February	9.50
March	11.75
April	13.50
May	16.75
June	18.00 / rain
July	rain
August	rain
September	rain

PFDC finding

For optimum growth and yield the crop geometry should be 2.4 m x 1.2 m with spacing in intercrops at 10 cm line spacing. The equivalent yield of banana was affected significantly due to only individual effect of intercrops (Onion, Garlic and Cauliflower) and area (along the row, between the row and both side). The equivalent yield of banana under onion crop recorded (107 t/ha) 23 % significantly higher yield as compared to banana sole (87 t/ha). The same trend was observed for area of 58 % allocated to intercrop (along the row + between rows). The farmers of South Gujarat who want to adopt drip irrigation in banana planted during September - October are recommended to take onion as intercrop for realizing higher net income. Four rows of onion (*i.e.* 40 cm) should be planted on both sides of banana row by leaving about 20 cm space on all the sides of stem + 8 rows (80 cm) in between two row of banana or 8 rows (80 cm) of

Fig. 6.6 Banana under drip fertigation at PFDC, NAU, Navsari

onion only in between two rows of banana. This intercropping system also improves the land use efficiency. They are further advised to apply recommended doses of fertilizer as mentioned above in fertilizer dose and scheduling.

Crop (variety)	Banana (Grand Naine)
Technologies used	Drip irrigation and fertigation
PFDC	MPKV, Rahuri, Maharashtra
Fertilizer dose and scheduling	Recommended dose of fertilizer (200 : 40 : 240 g NPK/ plant)
Crop period	2003 and 2006

PFDC finding

Banana in medium black soils should be planted at 1.75m x 1.75m spacing for economical and quality production with early crop maturity. Daily drip irrigation to meet 60 % of pan evaporation value with fertigation with water soluble fertilizers at monthly interval is recommended. Total fertilizers are to be applied in 10 equal splits of 80 % of recommended dose (200: 40: 200 g/ plant /season).

Under water scarce situations a crop geometry of 1.25m x1.25m, irrigation at 40% pan evaporation., total fertilizers at a rate of 80% RDF is recommended as it may achieve up to 50 % water saving without any significant yield panalty.

Crop (variety)	Banana (Grand Naine and Dwarf Cavendish)
Technologies used	Drip irrigation, fertigation, soil solarisation and mulch
PFDC	Samastipur, Bihar
Fertilizer dose and scheduling	3Kg vermi compost , 80% RDF

Fig. 6.7 Banana crop under drip fertigation at PFDC, MPKV, Rahuri

PFDC finding

Vermi compost with 80 % recommended dose of fertilizer should be given to banana crop. The banana yield can be enhanced up to 91.15 t/ha with 20% water saving at closer spacing (2m x1.5m) by using soil solarisation, vermi compost, fertigation and plastic mulch along in comparison to traditional method.

Crop (variety)	Banana
Technologies used	Drip with fertigation
PFDC	TNAU, Coimbatore, Tamilnadu
Fertilizer dose	Recommended dose of fertilizer : Urea- 738, SSP-675 and MoP- 1697 kg/ha

Table 6.8 Fertigation Schedule

Weeks after planting	Number of dosage	Fertilizers (g/plant/ dose)		
		Urea	SSP	MoP
9 week–18 week	10	7.1	21.8	10.9
19 week–30 week	12	9.9	-	18.3
31 week–42 week	12	3.9	-	14.6
43 week–45 week	3	-	-	14.6

PFDC finding

Banana should be planted at a spacing of 1.8 m x 1.8 m and suggested fertigation schedule should be followed to obtain maximum yield.

Fig. 6.8 Banana crop under drip fertigation at PFDC, TNAU, Coimbatore

6.2.6 Bird of paradise

Crop (variety)	Bird of paradise (Dutch hybrid)
Technologies used	Drip with fertigation , mulching
PFDC	UAS, Bangalore, Karnataka
Fertilizer dose and scheduling	Recommended dose of fertilizer : 9:6:3 g NPK/plant/ month

PFDC finding

For early, higher yield (50 flowers/year) and good quality flowers in newly planted BOP, application of 1.20 litres of water per plant per day through drip and 9:6:3 g NPK/plant/month (60% of RDF) through fertigation is optimum under 50 micron plastics mulched condition up to the second year of planting of 6 leaf staged plants.

Fig. 6.9 Bird of paradise under drip fertigation at PFDC, Banglore

6.2.7. Bottle gourd

Crop (variety)	Bottle gourd (Pusa Samridhi)
Technologies used	Drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Recommended dose of fertilizer : N-150, P_2O_5-40, K_2O-200 kg/ ha Weekly fertigation frequency
Crop period	August to October

PFDC finding

The highest yield (31.7 t/ha) of bottle gourd in the crop geometry of 120 cm x 30 cm was recorded in weekly fertigation. Total amount of fertilizer was applied in 10 fertigations on weekly basis at the rate of 15 kg (N), 4 kg (P_2O_5) and 20 kg (K_2O) per ha per fertigation/. Total 210 litters stock solution was prepared for each fertigation and was injected using venturi injection system.

Fig. 6.10 Bottle gourds under drip fertigation at PFDC, IARI, New Delhi

6.2.8 Brinjal

Crop	Brinjal
Technologies used	Drip with fertigation, Low tunnel technology
PFDC	PAU, Ludhiana, Punjab
Fertilizer dose and scheduling	25 kg of N (55 kg of Urea) 25 kg of P_2O_5 (155 kg of Single Superphosphate) and 12 kg of K_2O (20 kg of Muriate of Potash) per acre. Apply all the fertilizers at transplanting. After two pickings, again apply 25 kg of N (55 kg of Urea) per acre.
Crop period	November to May

PFDC finding

Brinjal should be sown with rows spaced 60 cm apart and plants at 30-45cm apart in the row in drip irrigation and fertigation. Yield achievable under such system are up to 75 t/ha whereas in conventional system it rarely exceeds 44 t/ha. During winter protection of brinjal plants from low temperature with low tunnel technology gives early and high yield. For this nursery should be transplanted in first fortnight of November on raised beds at spacing of 90 cm between rows and 30 cm between plants. In first week of Dec., iron arches are fixed and covered with transparent non perforated plastic sheet of 50 micron thickness. When the temperature starts warming up, remove the polythene sheet in second fortnight of Feb. First irrigation should be given immediately after transplanting. During summer irrigate the crop at 4-6 days interval whereas during winter season irrigate at 10-14 days interval depending on soil type.

Fig. 6.11 Brinjal crop under drip fertigation at PFDC, PAU, Ludhiana

It requires 10-16 irrigations. By adopting drip irrigation technology we can save 44% water. Apply 10 tons of well rotten farmyard manure with 25 kg of N (55 kg of Urea) 25 kg of P2 05 (155 kg of Single Superphosphate) and 12 kg of K2 O (20 kg of Muriate of Potash) per acre. Apply all the fertilizers at transplanting. After two pickings, again apply 25 kg of N (55 kg of Urea) per acre.

Crop	Brinjal
Technologies used	Drip with fertigation
PFDC	TNAU, Coimbatore, Tamilnadu
Fertilizer dose and scheduling	Recommended dose of fertilizer: 200: 150: 100 Kg of N, P, K per ha Through fertigation: 200: 37.5: 250 Kg of N, P, Kg per ha applied and 112.5 kg of P (703 Kg of Super Phosphate) applied as a basal dose

Table 6.9 Fertigation schedule

Stages of crop	Duration in days	Name of Fertilizers	Number of dosage to be given	Fertilizer (Kg/ha/dosage)
First	Day of transplanting to 10th day	19 : 19: 19	3	13.17
		13 : 0 : 45	3	1.87
		Urea	3	8.53
Second	11th Day to 40th day	12 : 61 : 0	10	1.85
		13 : 0 : 45	10	6.67
		Urea	10	10.68
Third	41th day to 70th day	19 : 19 : 19	10	3.95
		13 : 0 : 45	10	5.00
		Urea	10	10.00
Fourth	71th day to 150th day	12 : 61 : 0	27	0.69
		13 : 0 : 45	27	2.47
		Urea	27	3.96

PFDC finding

Maximum yield of brinjal may be obtained through using drip fertigation technology (using the said fertigation schedules).

Crop (variety)	Brinjal (Navkiran)
Technologies used	Drip with fertigation
PFDC	SKRAU, Bikaner, Rajasthan
Fertilizer dose	Recommended dose of fertilizer (NPK= 80:80:60 kg/ha)
Crop period	Rabi(Season)

Table 6.10 Fertigation schedule

Crop Stage	Fertigation Schedule	Basal dose (kg/ha)	Nutrients through Fertigation (kg/ha)			Fertilizers for fertigation (Kg/ha)		
		FYM	N	P_2O_5	K_2O	Urea	MAP	MOP
Initial	Full dose of FYM and N, P_2O_5, K @ 20kg/ha	15000	20	20	20	34.86	32.7	33.33
Development	N,P_2O_5 @ 30 Kg And K2O @ 20Kg/ha in six spilt doses at an interval of 10 days		30	30	20	52.36	49.2	33.33
Middle & Maturity	do		30	30	20	52.36	49.2	33.33

Table 6.11 Crop water requirement

S.N	Crop Stage	Days	Crop water requirement (mm)
1	Initial	45	55.12
2	Crop Development	45	125.84
3	Mid Season	60	330.45
4	Last Season	60	306.83
	Total	210	818.24

PFDC finding

For efficient utilization of fertilizers, 125 per cent of the recommended doses of fertilizer should be applied through drip in split doses to get higher yields.

Fig. 6.12 Brinjal under drip fertigation at PFDC, Bikaner

Crop (variety)	Brinjal (Swarn pratibha)
Technologies used	Drip with fertigation, Mulch
PFDC	RAU, Samastipur, Bihar
Fertilizer dose	100% RDF (N- 120Kg; P_2O_{5-} 80Kg and K_2O- 80Kg/ha) Nitrogen through fertigation -120 kg N per ha
Crop period	2012-2015

PFDC finding

Brinjal should be transplanted in the crop geometry of 80 cm x 70 cm in rabi season. To obtain the maximum yield (33.2 t/ha), 100% RDF (N - 120Kg; P_2O_{5-} 80Kg and K_2O-80Kg/ha) should be applied. Phosphoric and potassic fertilizers should be applied as basal dose and nitrogenous fertilizer through drip fertigation. Application of plastic mulching and fertigation increased the yield about 60% than the traditional method. Maximum water use efficiency, fertilizer use efficiency and BC ratio of 33.28 kg/ m^3, 67.68 kg per kg fertilizer applied and 1.86, respectively could be obtained under drip fertigation technology.

Fig. 6.13 Brinjal under drip fertigation at PFDC, Samastipur

Crop (variety)	Brinjal (Surat Ravaiya)
Technologies used	Drip with fertigation and mulching
PFDC	NAU, Navsari ,Gujarat
Fertilizer dose and scheduling	Recommended dose of fertilizer (RDF)- 80:50:50 NPK kg/ha out of which 16:50:50 NPK kg/ha applied a basal and 64 N kg/ha was applied in 4 equal splits at monthly interval from the date of transplanting.
Crop period	November to April

PFDC finding

Irrigation system should be have lateral spacing of 1.8 m, dripper spacing of 1.2 m with dripper discharge of 8 Lph, crop transplanted in paired row planting (0.6 x 0.6 x 1.2 m). Crop water demand and operation duration of drip irrigation system from Nov to Jan. 1.5 hr (i.e. 3 lit/day/plant), Feb. to March 2.5 hr (i.e. 5 lit/day/plant) and April to June 3.0 hr (i.e. 6 lit/day/plant). Irrigation scheduling should be every alternate days. Recommended dose of fertilizer 80:50:50 NPK kg/ha out of which 16:50:50 NPK kg/ ha should be applied in basal and 64 N kg/

ha should be applied through fertigation in 4 equal splits at monthly interval from date of transplanting. Black plastic mulch 25 μ thickness, 45 % coverage of crop geometry should be maintained. Adoption of this package of practices could also save 40 % water and 20 % fertilizer N. The farmers of South Gujarat growing brinjal (Surati ravaiya) are recommended to adopt this technology for higher yield (40%) and net profit (44%).

Fig. 6.14 Brinjal crop under drip fertigation at PFDC, NAU, Navsari

6.2.9 Broccoli

Crop (variety)	Broccoli (Pyrate)
Technologies used	Drip irrigation and fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Recommended dose of fertilizer (RDF) : N-120kg/ha, P-60 kg/ha and K-60 kg/ha Fertigation was scheduled at weekly interval started after 15 days of transplanting
Crop period	October - March

PFDC finding

Broccoli crop may be grown with drip irrigation, following the crop geometry of paired row planting of 30 cm x 30 cm. Maximum yield achievable is 18 t/ha. The same amount of fertilizer application through fertigation may result more than 22% higher yields than conventional fertilizer application. Yield at par with conventional fertilization method may be achieved with only 60% of fertilizers if applied through fertighation.

Fig. 6.15 Broccoli crop under drip fertigation at PFDC, IARI, New Delhi

Crop (variety)	Broccoli (KTS-1)
Technologies used	Drip irrigation with fertigation
PFDC	AAU, Guwahati, Assam
Fertilizer dose and scheduling	Recommended dose of fertilizer- 80:60:60 NPK Kg/ha
Crop period	2013-2016

PFDC finding

The highest yield (18.86 t/ha) and BC ratio (3.28) may be obtained by applying NPK : 80 :60:60 Kg/ha with black polyfilm with daily fertigation and irrigation scheduling. Irriagtion system should be operated daily of 2 minutes duration. Total water demand per plant for the crop season will be 26.9 litres.

Fig. 6.16 Broccoli crop under drip fertigation at PFDC, Guwahati

6.2.10. Cabbage

Crop (variety)	Cabbage (Ramkrishna)
Technologies used	Drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Weekly fertigation frequency of N-180, P_2O_5-100, K_2O-150 kg/ha applied in 20 weeks up to end of middle stage
Crop period	October to February

PFDC finding

Irrigation system having 16 mm diameter lateral pipe with dripper discharge 2 Lph at spacing of 30 cm. Daily operation time of 4 minutes in initial (40 days) and 5 minutes in developmental (60 days), 12 minutes in middle (40 days) and 15 minutes in maturity stage (15 days) in drip system will be sufficient to meet crop water demand. Soil matric potential in the range of -25 to -32 kPa at 30 cm depth should be as an index for drip irrigation scheduling in sandy loam soils. Maximum yield of cabbage (75 t ha^{-1}) could be observed by applying irrigation water once in 2 days and fertigation once in a week, which was 68.8 % more than the national average. Irrigation water use efficiency of 25.77 kg/ m^3 could be achieved in drip fertigation technology with payback period of 3 cropping seasons.

Fig. 6.17 Cabbage crop under drip fertigation at PFDC, IARI, New Delhi

Crop (variety)	Cabbage (Pusa drum Head)
Technologies used	Drip irrigation with fertigation
PFDC	SKRAU, Bikaner, Rajasthan
Fertilizer dose and scheduling	Recommended dose of fertilizer (RDF) NPK= 150:80:80 kg/ha
Crop period	Rabi(season)

Table 6.12 Fertigation schedule

Crop stage	Fertigation Schedule	Basal dose (kg/ha)	Nutrients through fertigation (kg/ha)			Fertilizers for fertigation (Kg/ha)		
		FYM	N	P_2O_5	K_2O	Urea	MAP	MOP
Initial	full dose of FYM and N @ 50kg/ha, P_2O_5 & K_2O @ 20kg/ha	15000	50	20	20	100.2	32.7	33.3
Development	N @ 50 Kg, P_2O_5 & K_2O @ 30Kg/ha in four spilt doses at an interval of 10 days		50	30	30	95.9	49.2	49.8
Middle and Maturity	do		50	30	30	95.9	49.2	49.8

Table 6.13 Crop water requirement

S.No.	Crop Stage	Days	Crop water requirement (mm)
1	Initial	30	74.1
2	Crop Development	35	77.81
3	Mid Season	50	145.24
4	Last Season	30	142.03
	Total	145	439.18

PFDC finding

Recommended doses of fertilizer should be applied through drip in split doses to get higher yields (22.3 t/ha). Fertigation gives 36.64 per cent higher yield than the conventional system (surface).

Fig. 6.18 Cabbage crop under drip fertigation at PFDC, Bikaner

Crop (variety)	Cabbage (Green Express)
Technologies used	Drip irrigation with fertigation, Mulch 25 micron thickness
PFDC	AAU, Guwahati, Assam
Fertilizer dose and scheduling	Recommended dose of fertilizer - NPK : 120:60:60 kg/ha
Crop period	Rabi

PFDC finding

The drip irrigation with fertigation and plastic mulching of 25 micron thickness should be adopted by the farmers for cabbage cultivation for higher production (53.80 t/ha). Daily irrigation with fertigation should be maintained and system will be operated for 8 minutes daily using dripper of 2 Lph discharge. Water demand per plant is 26.9 litres for total cropping period.

Fig. 6.19 Cabbage crop under drip fertigation at PFDC, Guwahati

6.2.11. Capsicum

Crop (variety)	Capsicum (Orobelle)
Technology	Drip with fertigation, Mulching with black polyethylene mulch (25-50 micron)
PFDC	Dr. YSPUH&F, Solan, Himachal Pradesh
Fertilizer dose	Recommended dose of fertilizer -160 kg of 19:19:19 (N:P:K), 240 kg of urea and 180 kg of MOP
Crop period	March-October

Table 6.14 Fertigation scheduling

Growth stage	Days after planting	No of fertigation	Total quantity of fertilizer(Kg)			Quantity of fertilizer per fertigation(kg)		
			NPK (19:19:19)	Urea (46:0:0)	MoP (0:0:60)	NPK (19:19: 19)	Urea (46:0:0)	MoP (0:0:60)
Vegetative	2-25	10	2	5	2	0.20	0.50	0.20
Flowering	26-40	7	3	5	3	0.43	0.71	0.43
Fruit Set	41-55	7	10	15	10	1.43	2.14	1.43
Fruit Growth and Development	56-80	13	20	40	30	1.54	3.08	2.31
First Harvest	81-130	26	40	65	50	1.54	2.50	1.92
Second Harvest	131-180	26	45	60	45	1.73	2.31	1.73
Last Harvest	181-230	26	40	50	40	1.54	1.92	1.54

PFDC finding

One drip lateral should be placed between two rows with dripper discharge of 2 Lph at dripper spacings of 30 cm. Fertigation should be done on alternate days from vegetative to final harvest with the help of venturi as per schedule given in the table above. A total of 160 kg of 19:19:19, 240 kg of urea and 180 kg of MOP will be required for the whole season to get the yields of 5.78 kg/plant for a benefit cost ratio exceeding 4.

Fig. 6.20 Capsicum crop drip fertigation and mulching at PFDC, Solan, HP

Crop (variety)	Capsicum (Indira)
Technologies used	Drip with fertigation
PFDC	IGKV, Raipur, Chhattisgarh
Fertilizer dose and scheduling	Recommended dose of fertilizer-N:P:K: 160:112:144 kg /ha given through fertigation using water soluble fertilizers at 7 days interval

Table 6.15 Crop water requirement

Months	CWR (Litre plant^{-1} day^{-1})	
	Non Mulch	Plastic Mulch
October	0.50	0.38
November	0.86	0.57
December	1.02	0.62
January	1.15	0.84
February	1.25	0.77
March	1.02	0.65

PFDC finding

Planting should be done at 60 cm x 45 cm spacing in drip irrigation system. Irrigation should be given twice a week with online drip irrigation system having drippers of 2L h^{-1} discharge capacity. Fifty percent of plant area should be mulched with 25 micron silver polyhtene film to avoid weed growth, conserve soil moil moisture and prevent soil nutrient leaching during heavy rain. To get the maximum & sustainable yield, optimum dose of fertilizer (160:112:144 NPK ha^{-1}) should be given through fertigation using water soluble fertilizers at 7 days interval. The high yields up to 27.00t ha^{-1}may be obtained under drip fertigation and plastic mulch.

Fig.6.21 Capsicum crop drip fertigation & mulch at PFDC, IGKV, Raipur

Crop (variety)	Capsicum
Technology	Drip irrigation with fertigation
PFDC	GBPUAT, Pantnagar, Uttarakhand
Fertilizer dose and scheduling	NPK =375:400:90 kg per ha (20 % N + Full P as basal and remaining in 21 splits @ 8 splits at 7 days interval and 13 splits at 15 days interval)
Crop period	2015-2016

PFDC finding

Capsicum should be transplanted at crop geometry of 60cm x50cm. B:C ratio (3.04) under polyhouse with water productivity 38.83 l/kg in comparison to shade net with water productivity (44.47 l/kg) and B:C ratio (2.90) and open condition with water productivity (60.31 l/kg) and B:C ratio (2.20), respectively is achievable. The fertilizers dose i.e. NPK @ 375:400:90 kg/ha should be applied for the maximum yield (9.94 kg/m^2) of capsicum.

Crop (variety)	Capsicum (Yellow Orbella)
Technologies used	Drip with fertigation, poly house
PFDC	NAU, Navsari, Gujarat
Fertilizer dose and scheduling	Recommended dose of fertilizer -240:120:120 kg NPK/ha + 10 t/ha bio compost. N & K was applied through drip in 10 equal splits at an interval of 15 days starting from 15 days after transplanting and whole amount of P was applied as basal at the time of planting in addition to common dose of bio compost @10 t/ha
Crop period	2008-2010

PFDC finding

Drip irrigation system having lateral spacing of 1 m, dripper spacings 1m with dripper discharge of 8 Lph should be installed. Irrigation scheduling through drip @ 1 to 1.25 l/plant during winter and 1-2.5 l/plant during summer on alternate day should be adopted. Recommended dose of fertilizer of 240:120:120:: NPK kg/ha + 10 t/ha bio compost should be applied. N & K should be applied through drip in 10 equal splits at an interval of 15 days starting from 15 DAP and whole amount of P should be applied as basal at the time of planting in addition to a basal dose of @10 t/ha compost. Capsicum (Yellow Orbella) should be preferably grown in naturally ventilated poly house instead of fan and pad cooling system poly house and open field conditions. For achieving higher fruit yield and net profit, two spray of GA_3 @ 100 mg/l at flower initiation and 10 days after first spray are recommended.

Fig. 6.22 Capsicum crop drip fertigation & mulch at PFDC, Navsari

Crop	Capsicum
Technologies used	Drip irrigation fertigation
PFDC	CIAE, Bhopal, MP
Fertilizer dose	Recommended doses of fertilizers 320:150:360 NPK kg/ha applied in capsicum crop in 14 split doses of equal amounts applied weekly

Table 6.16 Fertigation scheduling

Date / Interval	Fertilizers applied (kg/ha)		
	Urea	17:44:00	00:00:50
1	33.04	24.22	31.45
2	33.04	24.22	31.45
3	33.04	24.22	31.45
4	33.04	24.22	31.45
5	33.04	24.22	31.45
6	33.04	24.22	62.56
7	33.04	24.22	62.56
8	33.04	24.22	62.56
9	33.04	24.22	62.56
10	33.04	24.22	62.56
11	19.04	24.22	62.56
12	19.04	24.22	62.56
13	19.04	24.22	62.56
14	19.04	24.22	62.56
	406.56	339.08	720.29

PFDC finding

Water Soluble Fertilizers namely Urea (46:00:00), Urea phosphate (17: 44: 00) and Sulphate of Potash (00: 00: 50) should be applied every 15 days interval. About 25 % of recommended dose of N (55 kg/ha) should be applied as a basal and 17% N (76kg/ha) should be applied with Urea Phosphate and remaining part of fertilizers should be applied in split doses at different growth stages. To get the maximum yield (99.4 t/ha) under polyhouse, RDF should be given through fertigation using water soluble fertilizers at 15 days intervals. The capsicum would perform better under 100% drip fertigation.

Crop (variety)	Capsicum (Indra)
Technologies used	Micro irrigation with fertigation, polyhouse and mulching
PFDC	MPKV, Rahuri, Maharastra
Fertilizer dose	Before flowering (N: P_2O_5: K_2O: Ca: Mg): 8.0 : 2.8: 4.0: 2.8: 0.2 Kg ha^{-1} After flowering (N: P_2O_5: K_2O: Ca: Mg) ::6.0: 3.0: 15.0 :3.0 :0.3 kg ha^{-1}
Crop period	2011-12 to 2012-13 (234 days)

PFDC finding

The average daily water requirement of capsicum varies from 0.42 to 0.89 litres per plant or 1.57 to 3.33 litres per m^2 area. In naturally ventilated polyhouse, to obtain higher production of capsicum (October planting) with better quality and net returns, scheduling of daily drip irrigations @ 0.70 of crop evapo-transpiration and alternate day fertigation @ 100% of recommended dose through water soluble fertilizers (before flowering: 8.0:2.8:4.0:2.8:0.2 Kg ha^{-1} and after flowering : 6.0:3.0:15.0:3.0:0.3 kg ha-1 $N:P_2O_5:K_2O:Ca:Mg$) should be followed. Maximum gross income of Rs. 4,39,609/= net income of Rs.2,31,409/= and B:C ratio of 2.11 would be expected from capsicum.

6.2.12. Carnation

Crop (variety)	Carnation (Pingu)
Technologies used	Drip irrigation with fertigation, Polyhpuse
PFDC	RAU, Samastipur, Bihar
Fertilizer dose and scheduling	RDF: N -140 g/m^2; P_2O_5 - 80g/m^2; K_2O -120g/m^2. Total FYM, 50% N, total P_2O_5 and K_2O were applied as basal dose; and remaining 50% N through fertigation.

PFDC finding

Pingu responded maximum number of branches (9.80), minimum days for bud initiation (89.83 days) and flowering (164.83 days) and maximum diameter (7.83cm) of flower, flower stalk (60.22cm) and girth (4.43 mm) of flower stalk as well as maximum number of flowers per plant (8.72) or 281 per m^2 area and benefit-cost ratio of 2.60 in the polyhouse.

Fig.6.23 Carnation under polyhouse at PFDC, RAU, Samastipur

Crop (variety)	Carnation (Dona, Malaga, Charment and Farida)
Technologies used	Drip irrigation with fertigation, Polyhouse
PFDC	UAS, Bangalore, Karnataka
Fertilizer dose and scheduling	Recommended dose of fertilizer @ 200:80:160g NPK / m^2 at fortnightly interval along with use of Azatobacter (@250g/ha)

PFDC finding

Irrigation through drip system by installing two 16 mm lateral pipes per bed with either inline (integrated) or online dripper of 4 lph capacity spaced at every 30 cm needs to be provided. Daily irrigation for 30-40 min in red sandy loam condition during first 30 days, 60-80 min during 31 to 90 days and 120-150 min after 91 days to provide about 6-8 l/m^2, 10-12 l/m^2, 12-16 l/m2 of water in red sandy loam soil. Raised beds of 1m width, 0.3m height, rooted carnation cuttings should be planted at a plant density of 33 plants/m^2 at a spacing of 20cm x 15cm. The most suitable cultivars of carnation for protected cultivation among standard types is IAHS-23 (173 flowers/m^2) followed by IAHS-22 (170 flower/m^2). WSF through drip fertigation @ 200:80:160 g NPK/ m^2 at fortnightly interval along with use of Azatobacter (@ 250g/ha) expected to yields of 31,300 flowers /100 m^2 (that is 313 flowers/m^2/year). Managing the temperature between 24-30^{0}C during day time by lowering or raising the side curtain will help in managing / reducing the bud splitting disorder.

Fig. 6.24 Carnation under polyhouse at PFDC, UAS, Bangalore

Crop (varieties)	Carnation (Yellow dotcom, Gaudina, Garuda, Firato)
Technologies used	Drip irrigation with fertigation
PFDC	MPKV, Rahuri, Maharashtra
Fertilizer dose and scheduling	Planting to pinching (N : P: K:: 3.70:1.32:2.90) Pinching to harvesting (N : P: K::3.75:1.20:4.50) During harvesting (N:P:K :: 3.90:1.20:5.60)
Crop period	24-36 months

PFDC finding

The annual water requirement of carnation per plant is 31.39 litres with maximum yield/plant/year (8.97). Carnation planting density should be 15cm x 15cm and daily irrigation through drip @ 0.60 PE should be flowed for producing the good quality flowers with maximum economic benefit (B:C ratio of 2.60).

6.2.13. Cashew

Crop (variety)	Cashew (Ullal-I)
Technologies used	Drip with fertigation
PFDC	UAS, Bangalore, Karnataka
Fertilizer dose and scheduling	400:100:100 g NPK /tree/year in the form of WSF through fertigation in four splits/year

PFDC finding

Cashew variety 'Ullal-I' spaced at 10m x 10m and supplied with 10 l water/plant/day in initial stage (for first 2 years and 20 l/day/ for 3rd year) and supplied with 400:100:100 g NPK/tree/yr in the form of WSF through fertigation in four splits/year is recommended to get higher yield of 17 kg of nuts/plant and also quality scion material.

6.2.14. Cauliflower

Crop (variety)	**Cauliflower (Indam 9803)**
Technologies used	Drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Fertilizer dose - 180 kg ha^{-1} N, 120 kg ha^{-1} P_2O_5 and 150 kg ha^{-1} K_2O. Weekly twice fertigation frequency (Nov. to Feb.) started 1 week after planting and stopped 2 weeks prior to harvesting.
Crop period	October to February

PFDC finding

Drip system having 16 mm lateral, dripper spacing of 30 cm with dripper discharge 2.0 Lph, one lateral for one row of cauliflower (crop spacing of 60 cm x 30 cm), paired row (lateral spacing 1.2 m, one lateral for two rows of crop). Water requirement at initial, developmental, middle and maturity stage is 1.7 (35 days), 1.6 (30 days), 2.3 (40 days) and 3.2 (15 days) litre/m^2/day, respectively. Fertilizer dose of 180 kg ha^{-1} N, 120 kg ha^{-1} P_2O_5 and 150 kg ha^{-1} K_2O should be applied through fertigation. Weekly twice fertigation frequency (Nov. to Feb.) started 1 week after planting and stopped 2 weeks prior to harvesting should be maintained. Optimum yield (60 t ha^{-1}) expected by applying daily irrigation. Irrigation water use efficiency of 24 kg/ m^3 with payback period of 3 cropping seasons is expected.

Fig. 6.25 Cauliflower under drip fertigation at PFDC, IARI, New Delhi

Crop (variety)	Cauliflower
Technologies used	Drip irrigation with fertigation,
PFDC	BAU, Ranchi, Jharkhand
Fertilizer dose and scheduling	Recommended dose of fertilizer - 120:60:50 NPK kg/ha Basal dose DAP-23.4 Kg/ha (N), DAP-60 Kg/ha (P), FYM 8 t/ha.
Crop period	May-September

Table 6.17 Crop water requirement

Plant Growth Stage	WR, liters/ plant/ days	WR, liters/ m2/day	System Operating time (in minutes)
Transplanting	0.73	3.65	37
Vegetative	1.05	5.25	53
Curd initiation	0.96	4.8	48
Harvest/ Maturity	0.9	4.5	45

Table 6.18 Fertigation schedule

Crop growth stages	Fertilizer applied, kg/ha	
	N (Urea + KNO3)	K (KNO3)
Vegetative	19.32	-
Vegetative	19.32	12.47
Flowering	19.32	12.47
Flowering	19.32	12.47
Flowering	19.32	12.47
Harvesting	-	-

PFDC finding

Crop geometry of 50cm x 40 cm should be followed by using 2.4 Lph dripper discharge to get the highest yield with mulch. Water productivity of 0.37 kg / litre could be achieved with drip irrigation system.

Fig. 6.26 Cauliflower under drip fertigation at PFDC, BAU, Ranchi

Crop (variety)	Cauliflower (Snowball)
Technologies used	Drip irrigation with fertigation
PFDC	AAU, Guwahati, Assam
Fertilizer dose and scheduling	Recommended dose of fertilizer -80:60:60 NPK kg/ha FYM :10 ton Daily fertigation with irrigation
Crop period	2012-2015

PFDC finding

Irrigation system having dripper discharge of 2 Lph should be operated for 8 minutes to meet the crop water demand. Crop water demand per plant for the whole season will be 19.2 litres. Highest yield (34.80 t/ha) could be achieved through drip fertigation by applying 80:60:60 NPK kg/ha daily with irrigation and 25 micron black polyfilm mulch.

Fig. 6.27 Cauliflower under drip fertigation at PFDC, AAU, Guwahati

Crop (variety)	Cauliflower (Madhuri)
Technologies used	Drip irrigation with fertigation, Mulching
PFDC	IGKV, Raipur, Chhattisgarh
Fertilizer dose and scheduling	Recommended dose of fertilizer-60:80:40 NPK kg/ha applied through fertigation at 7 days interval.

Table 6.19 Crop water requirement

Months	Crop water requirement (L plant^{-1} day^{-1})	
	Non mulched crop	Plastic mulched crop
September	2.96	2.01
October	3.11	2.56
November	3.66	2.92
December	4.88	3.44
January	5.41	4.34
February	5.11	4.24

PFDC finding

To get the maximum and sustainable yield, optimum dose of fertilizer (60:80:40 NPK ha^{-1}) should be given through fertigation using water soluble fertilizers at 7 days interval. Planting should be done 60cm x 40cm planting geometry. Irrigation should be given twice a week with online drip irrigation system having drippers of 2L h^{-1} discharge capacity. Fifty percent of plant area should be mulched with 25 micron silver polythene mulch film to avoid weed growth, conserve soil moisture and prevents soil nutrient leaching during heavy rain. The maximum yield (30.03t ha^{-1}) and BC ratio (6.80) could be achieved under drip fertigation and plastic mulch.

Fig. 6.28 Cauliflower under drip fertigation at PFDC, IGKV, Raipur

6.2.15. Chilli

Crop	Chilli
Technologies used	Drip irrigation with fertigation
PFDC	TNAU, Coimbatore, Tamilnadu
Fertilizer dose	Recommended dose of fertilizer N:P:K =120:80:80 Kg/ha 120:20: 80 Kg of N, P, K/ha was applied through fertigation and 60 kg P (375 kg Super phosphate) was applied as basal dose

Table 6.20 Fertigation schedule

Stages of crop	Duration in days	Name of Fertilizers	Number of dosage to be given	Fertilizer (Kg/ ha/dosage)
First	Day of transplanting to 10th day	19 : 19:19	3	7.0
		13 :0: 45	3	3.0
		Urea	3	5.0
Second	11th day to 40th day	12: 61: 0	10	1.0
		13:0:45	10	5.3
		Urea	10	6.1
Third	41th day to 70th day	19:19:19	10	2.1
		13:0:45	10	4.4
		Urea	10	5.7
Fourth	71th day to 90th day	12:61: 0	27	0.4
		13: 0:45	27	2.0
		Urea	27	2.0

PFDC finding

Drip fertigation technology should be used to get maximum yield following the fertigation schedule given above.

Crop /Variety	Chilli
Technology	Drip irrigation with fertigation
PFDC	PAU, Ludhiana, Punjab
Fertilizer dose and scheduling	Recommended dose of fertilizer – 98.25 kg urea, 40 kg Mono Ammonium Phosphate and 40 kg Muriate of Potash per ha

Table 6.21 Operation duration of drip irrigation system

Month	Time of irrigation (minutes)
March	31
April	61
May	137
June	110
July	60
August	60

PFDC finding

Drip irrigation in chilli results not only increases in yield but also save 46% of water as compared to conventional method of irrigation. Water should be applied at an interval of two days. While irrigating with drip irrigation, transplant two rows of chilli on 80cm wide bed with row to row distance of 60cm and plant to plant distance of 45cm. Provide 40cm space between the two beds. The chilli crop should be irrigated with one lateral pipe per bed having drippers spaced at 30cm and discharge of 2.2 litres per hour. Fertigation could save 20% of fertilizer. Apply 7.9 kg Urea, 3.2 kg Mono Ammonium Phosphate and 3.2 kg Muriate of Potash (white) per acre during first month of the transplanted crop in seven equal doses with every second irrigation (four days interval). The remaining amount of fertilizer 31.4 kg of Urea, 12.8 kg of Mono Ammonium Phosphate and 12.8 kg of Muriate of Potash (white) per acre should be applied in 21 equal doses with every second irrigation. Maximum yield of 30 t/ha could be obtained with drip fertigation in comparison to 20 t/ha in conventional irrigation.

Crop	Chilli
Technologies used	Drip irrigation with fertigation, Mulch
PFDC	GBPUAT, Pantnagar, Uttarakhand
Fertilizer dose and scheduling	Recommended dose of fertilizer - 120:64:64 NPK kg /ha Fertigation frequency twice in a week

PFDC finding

Chilli should be planted in paired row following the crop geometry of 60cm x50cm. Recommended dose of fertilizer (120:64:64 NPK kg /ha) should be applied twice in a week using fertigation and mulching to obtain the yield of 17.99 t/ha with B:C ratio of 3.17 as compared to conventional method (soil application of fertilizers) which gives 10.93 t/ha with B:C ratio of 2.64. The percentage yield improvement under fertigation could be 64.5% over control.

6.2.16. Coconut

Crop	Coconut
Technologies used	Drip with fertigation
PFDC	TNAU, Coimbatore, Tamilnadu
Fertilizer dose and scheduling	First year : N: P: K :: 108: 250: 225 (Sept-Oct.) g/tree Second year : N: P: K ::108: 250: 225(May-June), 239: 500: 450 (Sept.-Oct.) g/tree Third year: N: P: K :: 239: 500: 450 (May-June), 478: 1000: 900(Sept-Oct.) g/tree Fourth Year : N: P: K :: 369: 750: 667 (May-June), 717 : 1250: 1333 (Sept-Oct.) g/tree
Crop period	Perennial

PFDC finding

Drip fertigation technology should be used to maximize the yield of coconut by following the developed fertigation schedule.

Fig. 6.29 Coconut under drip fertigation at PFDC, TNAU, Coimbatore

Table 6.22 Fertigation schedule

Age (Years)	Fertilizer dose for coconut (g/tree)					
	May-June			September-October		
	Urea	SSP	MOP	Urea	SSP	MOP
First year	-	-	-	108	250	225
Second year	108	250	225	239	500	450
Third year	239	500	450	478	1000	900
Fourth year on wards	369	750	667	717	1250	1333

Crop (variety)	Coconut (Poona)
Technologies used	Drip irrigation with fertigation
PFDC	UAS, Bangalore, Karnataka
Fertilizer dose and scheduling	500:320:1200 g NPK/palm/year through fertigation at monthly intervals
Crop period	Perennial

PFDC finding

Dripper located in three locations in the basins and application of 500:320:1200 g NPK/palm/year in monthly intervals would be desirable and economical as it resulted in three fold increase in the yield from 9 nuts/palm under rainfed to 28 nuts/palm due to drip irrigation besides improvement in the copra quality.

Crop	Coconut
Technology	Drip irrigation with fertigation
PFDC	KCAET, Tavanur, Kerala
Fertilizer dose and scheduling	N: P_2O_5: K_2Oat 1:0.5:2 kg Palm^{-1} Year^{-1}) was applied in split doses. Among them, Phosphorous was applied manually while Nitrogen and Potassium requirements were met via fertigation every month
Crop period	Perennial

PFDC finding

Drip irrigation should be used to apply 16 Litre water per plant per day for the first year, 32 Litre water per plant per day for the second year and 50-60 Litre water per plant per day for the consecutive years. Basal application of Phosphorous should be ensured in 6 split doses at an interval of 2 months. Nitrogen and Potassium should be applied through fertigation at monthly intervals. In low lying areas where the water table is high, fertigation can be done after the recession of water table or two applications can be combined.

Fig. 6.30 Coconut under drip fertigation at PFDC, Tavanur

6.2.17. Coffee

Crop (variety)	Coffee (Robusta)
Technologies used	Drip with fertigation
PFDC	UAS, Bangalore, Karnataka
Fertilizer dose and scheduling	Recommended dose of fertilizer -240:240:240 kg NPK/ha in the form of WSF

PFDC finding

Drip irrigation with fertigation to apply water 10 litre per day per plant with 240:240:240 kg NPK/ha in the form of water soluble fertilizers through fertigation in 4 equal splits should be adopted to get higher yield of about 1240 kg/ha/year.

6.2.18. Cotton

Crop (variety)	Cotton (RCH-602 BG II)
Technologies used	Surface and subsurface drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Recommended dose of fertilizers - 300 kg N, 100 kg P_2O_5 and 250 K_2O following weekly fertigation frequency
Crop period	June to December

PFDC finding

Cotton (var. RCH-602 BG II) seeds should be sown in the field in the month of June with row to row distance of 120 cm and plant to plant distance of 30 cm. Total amount of irrigation water should be applied as 30 cm to maximum yield of 2.47 t/ha applying 300 kg N, 100 kg P_2O_5 and 250 K_2O fertilizers through fertigation in weekly fertigation frequency by placing the lateral at 15 cm depth.

Fig. 6.31 Cotton crop under drip fertigation at PFDC, IARI, New Delhi

6.2.19. Cowpea

Crop (variety)	Cowpea (Red Gold)
Technologies used	Drip irrigation with fertigation
PFDC	IGKV, Raipur, Chhattisgarh
Fertilizer dose and scheduling	Recommended dose of fertilizer -25:50:25 NPK kg/ha applied through fertigation using water soluble fertilizers at 7 days interval

PFDC finding

Planting should be done 60 cm x 45 cm planting geometry. Irrigation should be given twice a week with online drip irrigation system with drippers of 2L h^{-1} discharge capacity. Fifty percent of plant area should be mulched with 25 micron silver polythene mulch film to avoid weed growth, conserve soil moisture and prevents soil nutrient leaching during heavy rain. To get the maximum & sustainable yield, optimum dose of fertilizer (25:50:25NPK ha^{-1}) should be given through fertigation using water soluble fertilizers at 7 days interval.

Fig. 6.32 Cowpea under drip fertigation at PFDC, IGKV, Raipur

6.2.20. Cucumber

Crop (variety)	Cucumber
Technologies used	Drip irrigation with fertigation, polyhouse
PFDC	SKRAU, Bikaner, Rajasthan
Fertilizer dose	Recommended dose of fertilizer- 120:80:100 NPK kg/ha

Table 6.23 Fertigation schedule

Crop Stage	Fertigation Schedule	Fertilizer for fertigation (kg/ha)		
		Urea	MAP	MOP
Crop establishment	full dose of FYM and N, P2O5 and K2O applied in three split doses at 4 days interval	9.20	48.07	16.66
Vegetative stage	N,P2O5 and K2O @ 40 Kg, 25Kg/ha and 30 kg/ha in four spilt doses at an interval of 5 days	74.40	48.07	50
Flower initiation to first picking	N,P2O5 and K2O @ 40 Kg, 20Kg/ha and 20 kg/ha in four spilt doses at an interval of 5 days	76.90	38.46	33.33
Harvesting stage	N,P2O5 and K2O @ 30 Kg, 10 Kg/ha and 40 kg/ha in equal doses at an interval of 5 days	60.20	19.23	66.66
		220.70	153.83	166.65

PFDC finding

Recommended doses of fertilizer should be applied for efficient utilization of fertilizers through drip in split doses to get higher yields (154 t/ha). Fertigation through drip expected to give 46.38 per cent higher yield of Cucumber than the traditional system (surface).

Fig. 6.33 Cucumber under drip fertigation in polyhouse at PFDC, Bikaner

Crop	Cucumber
Technologies used	Drip irrigation with fertigation, Green house
PFDC	UAS, Bangalore, Karnatka
Fertilizer dose	Recommended dose of fertilizer - 60:50:80 NPK Kg/ ha

PFDC finding

European cucumber should be cultivated by following the crop geometry of 120cm × 45cm and 60:50:80Kg NPK ha^{-1} in the form of water soluble fertilizer through drip fertigation under naturally ventilated polyhouse conditions to obtain higher yield of 175.65 t /ha.

Fig. 6.34 Cucumber under drip fertigation in polyhouse at PFDC, Bangalore

Crop	Cucumber
Technologies used	Drip irrigation with fertigation, Polyhouse
PFDC	GBPUAT, Pantanagar, Uttarakhand
Fertilizer dose	Recommended dose of fertilizer - 50:25:25 NPK kg/ha

PFDC finding

Drip fertigation should be used in polyhouses to grow cucumber. Recommended dose of fertilizer (50:25:25 NPK kg/ha) should be applied following the crop geometry of 60 cm x50 cm with mulch to get maximum yield (10.52 kg/m^2). The percentage yield improvement in polyhouse condition is expected to 283.94 % as compared to open field condition with fertigation.

Crop (variety)	Cucumber (Ninja)
Technologies used	Drip irrigation with fertigation
PFDC	IGKV, Raipur, Chhattisgarh
Fertilizer dose and scheduling	Recommended dose of fertilizer- 100:50:50 NPK kg/ ha applied through fertigation using water soluble fertilizers at 7 days interval

PFDC finding

Planting should be done 60 cm x 40 cm planting geometry. Irrigation should be given twice a week with online drip irrigation system with drippers of 2 L h^{-1} discharge capacity. Fifty percent of plant area should be mulched with 25 micron silver polythene mulch film to avoid weed growth, conserve soil moisture and prevents soil nutrient leaching during heavy rain. To get the maximum & sustainable yield, optimum dose of fertilizer (60:80:40 NPK ha-1) should be given through fertigation using water soluble fertilizers at 7 days interval.

Fig. 6.35 Cucumber under drip fertigation with mulch at PFDC, Raipur

Crop (variety)	Cucumber Salad (Hilton F1)
Technologies used	Drip irrigation with fertigation, NVPH, plastic mulching
PFDC	KCAET, Tavanur, Kerala
Fertilizer dose and scheduling	Recommended dose of fertilizer - 175:125:300 NPK kg/ ha

PFDC finding

Cucumber should be planted following the crop geometry of 90 cm × 90 cm and daily irrigation of 2 Litre per plant per day. Fertigation found to have better performance in terms of average fruit weight (20.31 kg) and number (932) per bed.

Fig. 6.36 Cucumber under drip fertigation in polyhouse at PFDC, Tavanur

6.2.21. Dutch Roses

Crop (variety)	**Dutch Roses** (First Red and Gold Strike)
Technologies used	Drip irrigation with fertigation, Greenhouse
PFDC	IIT, Kharagpur, WB
Fertilizer dose and scheduling	Recommended dose of fertilizer -36:72:30 g NPK/plant/year given twice in a week through fertigation
Crop period	December to January (11months)

PFDC finding

Sawtooth shape greenhouse with top and side ventilation opening of 60% of floor area having 4.5 m central height is suitable for rose cultivation in sub-humid sub-tropic regions. Application of shadenet of 75% and 50% shading intensity in summer and winter season respectively, beneath the roof of greenhouse is recommended for better micro climate inside the greenhouse. Greenhouse temperature and relative humidity must be in the range of 28 to 35 °C and 65 to 70% respectively for greater and quality flower production. Soil solarization with formalin and transparent poly film should be done one month before planting. Planting should be done at 0.5 m × 0.3 m planting geometry for greater yield. Irrigation should be given in alternate days with online drip irrigation system with drippers of 2 L h^{-1} discharge capacity. A total of 999.51 mm and 1210.94 mm of water is required to grow Dutch rose crop under greenhouse and open field condition respectively. To get the maximum & sustainable yield, optimum dose of water soluble fertilizer (36:72:30 g N:P:K/plant/year)should be given twice in a week through fertigation. Fogging should be done during peak summer hours for 15-20 minutes period.

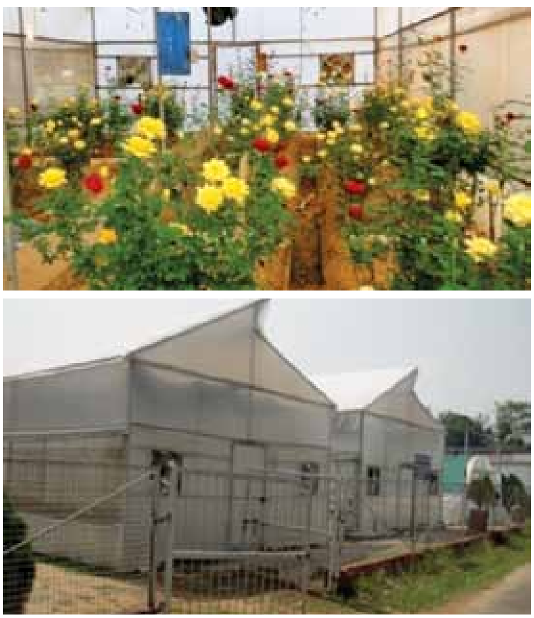


Fig. 6.37 Dutch roses under drip fertigation in polyhouse at PFDC, IIT, Kharagpur

6.2.22. Fig

Crop (variety)	Fig (Poona)
Technologies used	Drip irrigation with fertigation
PFDC	UAS, Bangalore, Karnataka
Fertilizer dose and scheduling	Recommended dose of fertilizers-300:200:200 NPK g / plant / year

PFDC finding

Fig should be planted following the crop geometry of 5 m x 5 m with the application of recommended dose of fertilizers (300:200:200 g NPK/plant/year) in plants aged more than five years in the form of water soluble fertilizers through fertigation along with soil application of 20 g of Zinc Sulphate (Zn SO4) to get higher yield.

Fig. 6.38 Fig under drip fertigation at PFDC, Bangalore

6.2.23. Garlic

Crop (variety)	Garlic (G 50)
Technologies used	Drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Recommended dose of fertilizer (N-130, P_2O_5-75, K_2O-70 kg/ ha) out of which 30 % N, 60 % P_2O_5, 40 % K_2O applied as basal dose and remaining through fertigation. Weekly fertigation frequency (28 times), started after 2week and stopped 2 weeks prior to harvesting. 3.25 kg N, 1.05 kg P_2O_5 and 1.5 kg K_2O applied per fertigation per ha
Crop period	October to April

PFDC finding

Drip system having head works including venturi having 60 Lph injection rate, 16 mm diameter lateral pipe; lateral to lateral spacing 120 cm and dripper to dripper spacing: 30 cm, dripper discharge 2.2 Lph should be installed to sow 5 rows of garlic per lateral with crop spacing of 10 cm x 15 cm. Water should be applied at initial, developmental, middle and maturity stage is 2.2 (15 days), 3.1 (25 days), 2.1 (90 days) and 4.2 litre/ m^2 area (60 days), respectively. Expected yield (16.8 t ha^{-1}) could be obtained by applying 51.3 cm of water following daily irrigation frequency. Expected irrigation water use efficiency of 3.27 kg/ m^3 with payback period of 3 cropping seasons is achievable under this technology.

Fig. 6.39 Garlic under drip fertigation at PFDC, IARI, New Delhi

Crop	Garlic
Technologies used	Drip irrigation with fertigation
PFDC	SKRAU, Bikaner, Rajasthan
Fertilizer dose	Recommended dose of fertilizer (N:P:K= 60:40:100 kg/ha)

Table 6.24 Fertigation schedule with crop growth stages

Crop growth stages	Fertigation Schedule	Amount of fertilizer, kg			
		FYM	N	P_2O_5	K_2O
Initial	Full dose of FYM @ 20000kg/ha and N, P_2O_5 and K_2O @ 20, 20 and 40 kg/ha, respectively	20000	20	20	40
Development	N, P_2O_5 and K_2O in four spilt doses at an interval of 10 days		20	20	30
Middle and maturity	N and K_2O in four spilt doses at an interval of 10 days		20	0	30

PFDC finding

Drip fertigation technology should be used for efficient utilization of fertilizers. Recommended doses of fertilizer should be applied through drip in split doses to get higher yields (174.4 q/ha). Savings of 25 percent of fertilizer could be achieved besides 33.33 per cent higher yield over 100 per cent recommended doses of NPK applied through traditional system i.e. surface irrigation.

Fig. 6.40 Garlic crop under drip fertigation at PFDC, Bikaner

6.2.24. Gerbera

Crop (variety)	Gerbera (Savannh)
Technologies used	Drip irrigation with fertigation, Polyhouse
PFDC	MPKV, Rahuri, Maharashtra
Fertilizer dose and scheduling	Recommended dose of fertilizer -N:P:K : 4.26: 2.13: 5.13 g/m²/ week Fertigation frequency weekly once in 52 splits/ year

PFDC finding

Adopting drip fertigation technology 1140 mm /year i.e. 102.51 lit/plant/year should be applied to achieve water use efficiency of 229 flowers /m^3 water. Maximum no. of flowers/ m^2 /year i.e. 261.17 could be obtained in weekly fertigation under semi-controlled polyhouse. Daily schedule of irrigation at 60 per cent pan evaporation and weekly fertigation with water soluble $N:P_2O_5:K_2O$ fertilizer 3.40:1.71:4.11gm^{-2} by drip irrigation is recommended.

Fig. 6.41 Gerbera crop under poly house at PFDC, Rahuri

Crop (varieties)	Gerbera (Gold spot, Ibiza, Rendavouz and Rosabella)
Technologies used	Drip irrigation with fertigation, Polyhouse
PFDC	UAS, Bangalore, Karnataka
Fertilizer dose and scheduling	Recommended dose of fertilizer -12:8:25 g NPK/m²/week through fertigation with foliar application of micro nutrients of 2 ml per litre of water

PFDC finding

Crop geometry of 30cm x 30cm should be adopted for greenhouse gerbera to get yield of 200 to 250 flowers/m²/year. Water soluble fertilizers (12:8:25 g NPK/m²/week) through fertigation along with foliar application of micro nutrients (2 ml per litre of water) at weekly interval should be followed to get maximum flower yield of 216 flowers/m² with at least 45-50 cm stalk length and 8-10 cm diameter flower. Fully grown ray and disc florets should be harvested by bending the flower stalk to about 40^0 from the centre or tip of the plant twice / thrice a week starting from 45-50 days after planting the tissue culture rooted plants for realizing the net profit of Rs. 540/m² under naturally ventilated greenhouse.

Fig. 6.42 Gerbera crop under poly house at PFDC, UAS, Bangalore

6.2.25. Gladiolus

Crop	Gladiolus
Technologies used	Drip irrigation with fertigation
PFDC	NAU, Navsari, Gujarat
Fertilizer dose and scheduling	Recommended dose of fertilizer -N:P:K:: 200:100:100 kg ha^{-1} 10 equal splits at an interval of 7 days from 30 days after planting. Full dose of P (100 kg/ha) should be applied as basal in addition to FYM @10 t/ha

PFDC finding

Using drip irrigation system 576 mm of water should be applied which resulted in the savings of 24 % over control. Paired row planting (20 cm x 20 cm x 60 cm) on raised bed with drip irrigation and fertigation with N and K @ 200:100 kg/ha in 10 equal splits at an interval of 7 days starting from 30 days after transplanting could result in highest yield (no. of spikes- 5.7 lakhs/ha, No. of corms- 5.9 lakhs/ha and Cormels yield-4.7 t/ha). By adopting this practice, farmers can get higher yield and net profit as compared to conventional method of irrigation.

Fig. 6.43 Gladiolus crop under drip fertigation at NAU, Navsari

Crop	Gladiolus
Technologies used	Drip irrigation with fertigation
PFDC	GBPUAT, Pantnagar, Uttarakhand
Fertilizer dose and scheduling	Recommended dose of fertilizer -N:P:K:: 400:100:100 kg/ha

PFDC finding

Optimum crop geometry for Gladiolus should be 20cm x 20cm under drip fertigation with crop water demand of 140 mm. Maximum yield attributes with 20 percent savings of water could be obtained by applying recommended dose of fertilizer through fertigation as plant height (97.28 cm), no. of spikes/plant (3.11), no. of florets/ spike (18.33) and vase life (8 days).

6.2.26. Guava

Crop (variety)	Guava (Allahabad safeda)
Technologies used	Drip irrigation with fertigation, Mulch (100 micron thickness)
PFDC	CISH, Lucknow, UP
Fertilizer dose	Recommended dose of fertilizer – N:P:K:: 350:240:200 g/plant

Table 6.25 Fertigation schedule

Months	**Fertilizer applied (g per plant)**		
	16:46:00 (DAP)	**46:00:00 (Urea)**	**0:00:50 (SOP)**
January	0	0	0
February	125.0	0	0
March	0	125.0	100.0
April	0	0	0
May	0	150.0	0
June	125.0	0	150.0
July	0	0	0
August	0	0	0
September	150.0	200.0	0
October	125.0	125.0	150.0
November	0	0	0
December	0	0	0
Total	**525.0**	**600.0**	**400.0**

PFDC finding

Irrigation water should be applied 2 to 3 litres during 1st year of age up to 14 to 16 litres per day per plant during 5th year of age and above. High density plant geometry (2 m x 1 m) should be followed for guava (Allahabad safeda) accommodating 5000 trees ha-^{1} to be irrigated using drip irrigation system. Water productivity, number of fruits per tree and individual fruit weight are expected as 16.92 kg m^{-3}, 27.3 tree^{-1} and 107.2 g fruit^{-1}, respectively. Improvement in fruit quality in terms of high TSS (12.1 °brix) and ascorbic acid (169.2 mg 100 g 1) would also possible.

Fig. 6.44 High density Guava under drip, mulch and fertigation at PFDC, Lucknow

Crop	Guava
Technologies used	Drip irrigation with fertigation
PFDC	CIAE, Bhopal, MP
Fertilizer dose and scheduling	Recommended dose of fertilizer -Urea (46:00:00), Urea phosphate (17:44:00) and Sulphate of Potash (00:00:50) Fertigation scheduling - 1st year: 2 split dose 2nd year onwards: 3 split dose (quarterly) Farm Yard Manure: 10-50kg/ plant/ year

PFDC finding

Dip fertigation should be adopted in Guava to get maximum yield (11.09 t/ha). Farmers not only get higher yield but also get better quality fruit.

Fig. 6.45 Guava under drip and fertigation at PFDC, Bhopal

Crop (variety	Guava (Allahabad Safeda)
Technologies used	Drip irrigation with fertigation, Plastic mulch (100 micron thickness)
PFDC	IIT, Kharagpur, WB
Fertilizer dose and scheduling	Recommended dose of fertilizer: 360g N, 480g P, 360g K per plant per year at 15 days interval Farm Yard Manure -50 kg per plant per year

PFDC finding

Drip system should be used to apply 1126 mm of water for matured plant to produce good Guava fruits planted at a spacing of 5m × 5m using online drip irrigation system of 4 L h^{-1} dripper discharge following alternate day irrigation. Forty percent of plant canopy area should be mulched with 100 μ/ 50 μ black plastic films. Eighty percent of recommended dose of water soluble fertilizers (290:384:290 g/plant N: P_2O_5:K_2O) should applied through fertigation at 15 days interval to obtain highest yield (35.66 t/ha). Fruit yield of 27 per cent could be higher in fertigation in comparison to same amount of solid fertilizer application by conventional means.

Fig. 6.46 Guava under drip, fertigation and mulch at PFDC, IIT, Kharagpur

6.2.27. Kinnow

Crop	Kinnow
Technologies used	Drip irrigation with fertigation,
PFDC	CCS, HAU, Hisar, Haryana
Fertilizer dose and scheduling	Recommended dose of fertilizer - 98 g N, 45g P_2O_5 and 15g K_2O per plant/year of age
Crop period	Perennial

PFDC finding

Kinnow plants should be planted at a spacing of 6m x 6m to get maximum number of fruits (910.0), fruit yield per plant (114.00kg) by applying 98g N, 45g P2O5 & 15g K2O per plant/year of age.

Fig. 6.47 Kinnow plant under drip fertigation at PFDC, CCS, HAU, Hisar

6.2.28. Leafy Vegetables

Crops	Fenugreek, Coriander, Spinach, Amaranthus
Technologies used	Mini sprinkler with fertigation, Shade net
PFDC	NAU, Navsari, Gujarat
Fertilizer dose and scheduling	Leafy vegetables Recommended dose of fertilizers Fenugreek 40:40:00 Coriander 20:20:00 Spinach 40:00:00 Amaranthus 60:50:50 Full quantity of P applied as basal. N and K applied in two equal splits at an interval of 10 days starting from 10 days after sowing
Crop period	Seasonal

PFDC finding

Mini sprinkler at spacings of 2m x 2m should be installed to apply 40 mm irrigation water. Leafy vegetables should be sown inside the shade net house to obtain the highest yield of leafy vegetable / m^2 (coriander: 1876 g, fenugreek: 11599 g, spinach: 4403 g and Amranthus: 6460 g) under net house recorded higher values over control (Coriander: 166 g, Fenugreek: 00 g, Spinach: 3667 g and Amranthus: 6509 g). The highest net return of 33.39 Rs./m^2 is expected under shade net house. Farmers of South Gujarat having different shade net house (%) are advised to prefer the following leafy vegetables to be grown during summer season for getting higher yield and net income.

Fig. 6.48 leafy vegetables under drip fertigation in shadnet at PFDC, Navsari

Table 6.26 Recommended shade factor for growing leafy vegetables

Crops	Ideal shade net house (Summer season)
Fenugreek	75
Coriander	75
Spinach	30
Amranthus	30 % or open field

6.2.29. Litchi

Crop (variety)	Litchi (Shahi)
Technologies used	Drip irrigation with fertigation
PFDC	RAU, Samastipur, Bihar
Fertilizer dose and scheduling	Recommended dose of fertilizer -100% N through fertigation and P, K as basal dose
Crop period	Perennial

PFDC finding

Litchi should be under drip fertigation

to get maximum fruit length of 3.53 cm, fruit weight 25.1 g and yield per plant 20.5 kg through application of 100 % N through drip with mulch. Expected increase in yield would be 17.28 % more in comparison to control. Minimum fruit cracking of 2.5 % is also possible in comparison to 17.16 % than in the conventional practice.

Fig. 6.49 Litchi under drip fertigation at PFDC, RAU, Samastipur

6.2.30. Mango

Crop (variety)	Mango (Amrapalli and Mallika)
Technologies used	Drip irrigation with fertigation, LLDPE mulching
PFDC	OUAT, Bhubaneswar, Odisha
Fertilizer dose and scheduling	Nitrogen twice in a month
Crop period	Perennial

PFDC finding

Irrigation scheduling for mango should be done on daily basis and volume of water to be applied at 24.5 litre/day/plant in winter season and 52.8 lit / day /plant in hot /summer season. Maximum yield of 9.6 t/ha is expected when applying 80 % nitrogen through drip fertigation using LLDPE mulching.

Fig. 6.50 Mango under drip fertgation technology at PFDC, Bhubaneswar

Crop	**Mango**
Technologies used	Drip irrigation with fertigation
PFDC	CIAE, Bhopal, MP
Fertilizer dose and scheduling	Recommended dose of fertilizer- Urea (46:00:00), Urea phosphate (17: 44: 00) and Sulphate of Potash (00: 00: 50) 1st year: 2 split dose (February and October) 2nd year onwards: 3 split dose (February, June and October) Every year: FYM as a basal application

Table 6.27 Fertigation schedules

Year	**Fertigation**	**Fertilizer applied, kg/plant**			
		N	**P**	**K**	**FYM**
1st	Feb-09	0.10	0.15	0.2	**10**
	Oct-09	0.10	0.05	0.1	
		0.20	**0.20**	**0.30**	

Year	Fertigation	Fertilizer applied, kg/plant			
		N	P	K	FYM
2nd	Feb-10	0.15	0.2	0.3	10
	Jun-10	0.15	0.1	0.2	
	Oct-10	0.10	0.1	0.1	
		0.40	**0.40**	**0.60**	
3rd	Feb-11	0.20	0.3	0.4	30
	Jun-11	0.20	0.2	0.3	
	Oct-11	0.20	0.1	0.2	
		0.60	**0.60**	**0.90**	
4th	Feb-12	0.40	0.4	0.6	40
	Jun-12	0.20	0.2	0.3	
	Oct-12	0.20	0.2	0.3	
		0.80	**0.80**	**1.20**	
5th	Feb-13	0.60	0.6	0.8	50
	Jun-13	0.20	0.2	0.35	
	Oct-13	0.20	0.2	0.35	
		1.00	**1.00**	**1.50**	
6th year onward	Feb-14	0.60	0.6	0.8	50
	Jun-14	0.20	0.2	0.35	
	Oct-14	0.20	0.2	0.35	
		1.00	**1.00**	**1.50**	

PFDC finding

Farmers should adopt mango cultivation with drip fertigation technology following the fertigation schedule given above in the table to obtain the maximum yield (3.04 t/ha).

Fig. 6.51 Mango under drip fertgation technology at PFDC, CIAE, Bhopal

Crop (variety)	**Mango** (Dashehari)
Technologies used	Drip irrigation with fertigation, Mulch of 100 micron thickness
PFDC	CISH, Lucknow, UP
Fertilizer dose	Recommended dose of fertilizer - 1000:500:1000 g/ plant

Table 6.28 Fertigation schedule and crop water requirement

Fertilizer applied through fertigation (g per plant)				Water requirement (Litre /plant)
Month	**16:46:00 (DAP)**	**46:00:00 (Urea)**	**0:00:50 (SOP)**	
January	0	0	0	691.2
February	0	0	150.0	753.0
March	0	0	250.0	1035.9
April	300	0	350.0	1927.3
May	0	0	450.0	2417.3
June	0	0	250.0	244.4
July	0	450.0	150.0	-
August	400.0	250.0	0	-
September	0	450.0	150.0	-
October	400.0	250.0	150.0	1694.3
November	0	425.0	100.0	1371.6
December	0	0	0	868.4
Total	**1100.0**	**1825.0**	**2000.0**	

PFDC finding

Mango planting at a spacings of 9m x 6m under drip system, following the fertigation schedule and application of estimated amount of water (table 6.28) should give higher yield of 5.90 t ha^{-1} and quality in terms of TSS (25.8° Brix), firmness (0.84 kg cm^{-2}) and reduced cumulative physiological losses (5.45 %).

Fig. 6.52 Mango under drip fertgation technology at PFDC, Lucknow

6.2.31. Maize

Crop (variety)	Maize(Spring)
Technologies used	Drip irrigation with fertigation
PFDC	PAU, Ludhiana, Punjab
Fertilizer dose and scheduling	Recommended dose of fertilizer - 200 kg Urea, 80 kg of Mono Ammonium Phosphate (MAP) and 40 kg Muriate of Potash (white) per ha Fertigation started 12 days after sowing of maize and applied 25 % of the fertilizers in four equal splits during first month on weekly basis. Remaining fertilizers applied in equal splits on weekly basis up to first week of May

Table 6.29 Operation duration of drip system

Month	Operation duration of irrigation system , minutes
February	22
March	64
April	120
May	130

PFDC finding

Drip irrigation system should be installed and beds needs to be prepared of 80 cm covering with U.V stabilized plastic film (black) of 25 micron thickness (23 grams per m²). Maize should be sown following the crop geometry of 60 cm row to row and 20 cm plant to plant by dibbling. One lateral pipe should used to irrigate two rows of maize having drippers at a spacing of 30 cm with discharge of 2.2 litres per hour. Expected maximum yield in drip fertigation system is 6 t/ha (33.3 % more than conventional) with 40% savings of water and 20% fertilizer.

Fig. 6.53 Spring maize under drip fertigation at PFDC, Ludhiana

6.2.32. Mosambi

Crop	Mosambi
Technologies used	Drip irrigation with fertigation
PFDC	SKRAU, Bikaner, Rajasthan
Fertilizer dose	Recommended dose of fertilizer - 288:200:240 NPK g/plant 75 kg FYM application incorporates per plant in last week of December
Crop period	Perennial

Table 6.30 Fertigation schedule

Water soluble fertilizers	Rate of fertigation g/plant/15 days	Total fertigation
	100%	
Urea + Water soluble fertilizer 17:44:0 grade + Muriate of potash	45.81 + 45.45 + 40	10

Table 6.31 Water requirement per month

Age/month	Water requirement per month in Litre (Data per day)							
	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year
Jan	2.83	5.75	7.16	7.79	8.44	10.44	11.43	9.40
Feb	4.43	8.13	10.12	11.01	11.94	14.77	16.17	16.88
Mar	7.36	14.94	18.59	20.23	21.93	27.13	29.71	35.90
Apr	11.18	21.97	27.35	29.76	32.26	39.91	43.70	41.65
May	14.61	29.67	36.93	40.18	43.56	53.89	59.00	79.36
Jun	14.37	28.25	35.16	38.26	41.48	51.31	56.18	71.58
Jul	10.94	22.21	27.64	30.08	32.61	40.34	44.17	46.45
Aug	9.21	18.70	23.28	25.33	27.46	33.97	37.19	34.48

Age/month	Water requirement per month in Litre (Data per day)							
	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year
Sep	8.45	16.61	20.67	22.49	24.38	30.17	33.03	26.64
Oct	7.22	14.66	18.25	19.86	21.53	26.63	29.16	29.30
Nov	4.50	8.84	11.01	11.97	12.98	16.06	17.58	21.18
Dec	3.13	6.37	7.92	8.62	9.35	11.56	12.66	12.70
Avg. water	**8.19**	**16.34**	**20.34**	**22.13**	**23.99**	**29.68**	**32.50**	**35.46**

PFDC finding

For efficient utilization of fertilizers, recommended doses of fertilizer should be applied through drip in split doses to get higher yields (162.4 q/ha). Expected enhancement in yield about 52.84 per cent higher than the traditional system (surface).

Fig. 6.54 Mosambi under drip fertigation at PFDC, SKRAU, Bikaner

6.2.33. Okra

Crop (variety)	**Okra (Versa improved)**
Technologies used	Drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Recommended dose of fertilizer- N-120, P_2O_5-100, K_2O-120 kg/ha Weekly fertigation frequency
Crop period	February to May

PFDC finding

Drip system having head works including filters and venturi injector, 16 mm diameter inline lateral pipe at 30 cm dripper spacing of 2.0 Lph dripper discharge, 120 cm lateral spacing should be installed. Crop geometry of 60cm x 30cm for single row and 30cm x 30cm should be maintained. In a total crop period of 96 days, irrigation interval of 2 days with weekly fertigation should be maintained to apply estimated water demand of 47 cm.

Fig. 6.55 Okra crop under drip fertigation at PFDC, IARI, New Delhi

Maximum expected yield in surface drip (30.5 t/ha) and subsurface drip system (34.5 t/ha) could be achieved. Drip irrigation system could save 50 % water with irrigation water use efficiency of 6.48 kg/ m^3 with payback period of 2 to 3 cropping seasons.

Crop	Okra
Technologies used	Drip irrigation with fertigation, Mulch
PFDC	TNAU, Coimbatore, Tamilnadu
Fertilizer dose and scheduling	Recommended dose of fertilizer = 200:100:100 NPK kg/ha 75 kg of P (469 Kg of Super Phosphate) should be applied as a basal dose 200: 25: 100 NPK kg/ha was applied through fertigation

Table 6.32 Fertigation schedule

Stages of crop	Duration in days	Name of Fertilizers	No. of dosage given	Fertilizer (Kg/ha/ dosage)
First	Day of transplanting to 10 day	19 :19:19	3	8.8
		13:0:45	3	3.7
		Urea	3	9.8
Second	11-40	12:61:0	10	1.2
		13:0:45	10	6.7
		Urea	10	10.8
Third	41-70	19:19:19	10	2.6
		13:0:45	10	5.6
		Urea	10	10.4
Fourth	71-100	12:61:0	27	1.2
		13:0:45	27	6.7
		Urea	27	10.8

PFDC finding

Okra should be grown with drip fertigation technology with mulching to enhance the yield.

Fig. 6.56 Okra crop under drip fertigation & mulching at PFDC, TNAU, Coimbatore

Crop (variety)	Okra (Arka Anamika)
Technologies used	Drip irrigation with fertigation, Mulch
PFDC	KCAET, Tavanur, Kerala
Fertilizer dose and scheduling	Recommended dose of fertilizer - 55:35:70 NPK kg/ ha

PFDC finding

Okra should be grown under plastic mulch and fertigation to get better yield than the conventional method. Basal application of Phosphorous and fertigation of Nitrogen and Potassium in 16 split doses at 3 days interval should be followed.

Fig. 6.57 Okra crop under drip fertigation & mulching at PFDC, KCAET, Tavanur

Crop	Okra
Technologies used	Drip irrigation with fertigation
PFDC	BAU, Ranchi, Jharkhand
Fertilizer dose and scheduling	Recommended dose of fertilizer -100:60:50 NPK kg/ha Basal dose DAP-18.7 Kg/ha (N), DAP-48 Kg/ha (P), MoP-20 Kg/ha (K), FYM 6400Kg/ha.

Table 6.33 Fertigation scheduling

Fertigation stages	N (Urea + KNO_3)	K (KNO_3)
Vegetative	15.46	4.99
Vegetative	15.46	4.99
Flowering	15.46	4.99
Flowering	15.46	4.99
Flowering	15.46	-
Harvesting	-	-

Table 6.34 Crop water requirement

Plant growth stage	Water requirement (litres/plant/days)	Discharge Rate	System operating time (in minutes)
Germination	0.17	2.4Lph	9
Vegetative	0.38		19
Flowering	0.68		34
Harvesting	0.64		32

PFDC finding

Drip fertigation should be adopted to get highest yield of okra (13 t/ha) in comparison to conventional method of irrigation (furrow) and fertilizer application (basal), which will be 18.5 % more than the conventional method. Irrigation water should be applied in the tune of 0.17 litre/plant/day at initial stage to 0.68 litre/plant/day at peak crop growth stage.

Fig. 6.58 Okra crop under drip fertigation & mulching at PFDC, Ranchi

6.2.34. Onion

Crop (variety)	Onion (Kharif) (AFDR, N-53)
Technologies used	Drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Recommended dose of fertilizer- 160 kg ha^{-1} nitrogen (N), 115 kg ha^{-1} phosphorous (P_2O_5) and 95 kg ha^{-1} potassium (K_2O) Alternate day fertigation by applying 4.3 (N), 1.77 (P_2O_5) and 2.2 (K_2O) kg/ha per fertigation (26 times fertigation, 3 litres of stock solution per fertigation event)
Crop period	August to November

PFDC finding

Irrigation system should be installed including inline drip system having lateral spacings of 1.2 m, accommodating 6 rows per bed leaving 30 cm furrow at row to row and plant to plant spacings of 15 cm and 10 cm, respectively. Urea, muriate of potash (KCl) and single super phosphate (SSP), mono potassium phosphate (MKP) should be used to supply N, K_2O and P_2O_5, respectively. Thirty per cent (30 %) N, 60 % P_2O_5 and 40 % K_2O should be applied as basal dose at the time of sowing of crop. Phosphorous could be applied in the form of SSP in basal dose and remaining 40 % will be applied in the form of MKP with fertigation. Alternate day fertigation by applying 4.3 (N), 1.77 (P_2O_5) and 2.2 (K_2O) kg/ha per fertigation (26 times, 3 litres of stock solution per fertigation event) expected to give maximum yield (30 t/ha) of onion. Amount of water should be applied as but adequate rainfall in the crop season only 124 mm irrigation water will be needed through drip thus, kharif onion could be one of the options to rice. Drip irrigation leads to 45% saving of irrigation water with 60 % increase in yield as compared to the conventional surface irrigation method.

Fig. 6.59 Kharif onion under drip fertigation at farmers field (PFDC, IARI, New Delhi)

Crop (variety)	Onion (Arka Lalima)
Technologies used	Drip irrigation with fertigation
PFDC	UAS, Bangalore
Fertilizer dose and scheduling	Recommended dose of fertilizer - 100:60:100 kg NPK/ha

PFDC finding

Cultivation of onion (Arka Lalima hybrid) at a spacing of 20cm x 15cm on raised beds by providing 100:60:100 NPK kg/ha in the form of water soluble fertilizers through fertigation at weekly interval starting from 15 days after transplanting upto 15 days before final harvest of the crops should be done in obtaining yield of 63.66 t/ha of superior quality bulbs.

Fig. 6.60 Onion under drip fertigation at PFDC, UAS, Bangalore

Crop	Onion
Technologies used	Drip irrigation with fertigation
PFDC	PAU, Ludhiana, Punjab
Fertilizer dose and scheduling	Recommended dose of fertilizer - 80 kg Urea, 32.8 kg Mono Ammonium Phosphate and 33.6 kg Muriate of Potash (white) per ha

PFDC finding

Recommended dose of fertilizer i.e. 80 kg Urea, 32.8 kg Mono Ammonium Phosphate and 33.6 kg Muriate of Potash (white) per ha should be applied during first month of the transplanted crop in seven equal doses with four days interval. The remaining amount of fertilizer 317.5 kg of Urea, 131.25 kg of Mono Ammonium Phosphate and 135.2 kg of Muriate of Potash (white) per ha should be applied in equal doses during the rest of crop season in 20 equal doses with every second irrigation. Onion should be grown under drip irrigation fertigation system to get maximum yield (51 t/ha), which 45.1% more than in the conventional method (28 t/ha). Adoption of drip irrigation technology saved 44% water and 20% fertilizer.

Crop (variety)	Onion (Nasik red)
Technologies used	Mini sprinkler
PFDC	NAU, Navsari, Gujarat
Fertilizer dose and scheduling	Recommended dose of fertilizer -125:50:50 NPK kg/ha

PFDC finding

The mini sprinkler should be laid out at the spacing of 2.5 x 2.5 m with a pressure of 1.5 kg/cm^2. The depth of irrigation should be 50 mm. The farmers of South Gujarat heavy rainfall zones (AES III) are advised to adopt mini sprinkler system of irrigation along with fertigation for their onion crop to get about 23 per cent higher net income along with saving of about 20 per cent in fertilizer and 42 per cent in water over surface method. The 50 per cent N as urea should be applied at the time of planting and remaining 50 per cent in three equal splits at 30, 45 and 60 days after transplanting through mini sprinkler.

Crop (varieties)	**Onion (rabi)** (Pusa Red, Agrifound light Red and L-28)
Technologies used	Drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Recommended dose of fertilizer- N-160, P_2O_5-115, K_2O-95 kg/ha) was applied, out of which 30 % N, 60 % P_2O_5, 40 % K_2O applied as basal dose and remaining through fertigation. Weekly fertigation frequency, fertigation started after 1 week and stopped 15 days prior to harvesting.
Crop period	December to May

PFDC finding

Irrigation system having 16 mm diameter lateral pipe with dripper discharge of 2.2 Lph, laterals spacing of 100 cm, drippers spacing of 30 cm, laterals placed at 10-15 cm depth, 5 rows of onion per lateral with crop spacing of 10 cm x 15 cm should be installed in onion crop. Daily operation duration of drip system should be 15 min. in initial (15 days) and 30 min. in developmental (35 days), 60 min. in middle (70 days) and 75 min. in maturity

Fig. 6.61 Rabi onion under drip fertigation at PFDC, IARI, New Delhi

stage (35 days) of crop. Expected maximum yield (40.7 t ha^{-1}) with daily irrigation and weekly fertigation by applying a total of 53.7 cm water in the entire crop season should be achieved. Irrigation water use efficiency of 8.57 kg/ m^3 should be obtained in Pusa Red under deficit water supply situations.

Crop (variety)	Onion
Technologies used	Drip irrigation with fertigation
PFDC	IGKV, Raipur, Chhattisgarh
Fertilizer dose and scheduling	Recommended dose of fertilizer - 100:50:50 NPK kg per ha

PFDC finding

The maximum yield (26.08 t ha^{-1}) was obtained under drip fertigation (80% RDF) and plastic mulch with planting geometry 15cm x 10 cm. Irrigation should be given twice a week with online drip irrigation system with drippers of 2L h^{-1} discharge capacity. Fifty percent of plant area should be mulched with 25 micron silver polythene mulch film to avoid weed growth, conserve soil moil moisture and prevents soil nutrient leaching during heavy rain. To get the maximum and sustainable yield, optimum dose of fertilizer (100:50:50NPK ha^{-1}) should be given through fertigation using water soluble fertilizers at 7 days interval.

Fig. 6.62 Onion under drip fertigation at PFDC, IGKV, Raipur

6.2.35. Pea

Crop	Pea
Technologies used	Drip irrigation with fertigation
PFDC	PAU, Ludhiana, Punjab

PFDC finding

Seed should be sown in proper soil moisture condition and first irrigation should be given after 15 days of sowing. Next irrigation should be given at flowering and then at fruit set if necessary. The total number of irrigations required will be 3-4 depending upon the soil type and weather conditions. Expected maximum yield in drip fertigation system would be 20 t/ha (45 % more than conventional) with 50% savings of water.

Fig. 6.63 Pea under drip fertigation at PFDC, PAU, Ludhiana

Crop (variety)	Pea (Azaad P1)
Technologies used	Drip irrigation with fertigation, Mulch
PFDC	Dr. YSPUH&F, Solan, HP
Fertilizer dose and scheduling	Recommended dose of fertilizer: Urea -54: SSP -375: MOP-100 kg/ha

Table 6.35 Fertigation schedule

Growth stage of crop	Total quantity of fertilizer (Kg/ha)			Quantity of fertilizer for fertigation (kg/ha)			
	N	P	K	N PK 12.61.00	NPK 13.00.45	NPK 16.05.24	NPK 05.15.30
Germination	0	0	0	0	0	0	0
Vegetative	7.2	36.6	0	6.25 (for 4 weeks)	0	0	0
Flowering	16	3.75	36.9	0	6.25 (for 3 weeks)	6.25 (for 4 weeks)	0
Harvesting	2	6	12	0	0	0	2.65 (for 2 weeks)

PFDC finding

One drip lateral should be placed between two rows with dripper discharge of 2 Lph at 30cm dripper spacing. Fertigation should be done bi-weekly from vegetative to final harvest with the help of venturi as per schedule given in the above table. Mulching with black polyethylene mulch (25-50 micron) must be done to control weeds and conserve moisture. To maintain organic carbon (atleast1.5%) add sufficient quantity of well decomposed organic matter/vermi compost, preferably farm yard manure @ 4kg/m^2 or vermi compost @ 2 kg /m^2 to maintain soil fertility. Expected maximum yield in drip fertigation is 145q/ha (32% more than conventional method with saving of water & fertilizers.

Fig. 6.64 Pea under drip fertigation at PFDC, Solan

6.2.36. Potato

Crop (variety)	Potato (Kufri Jyoti)
Technologies used	Drip irrigation with fertigation
PFDC	UAS, Bangalore, Karnataka
Fertilizer dose and scheduling	Recommended dose of fertilizer: 125:125:150 NPK kg/ha Fertigation applied at fortnightly interval.

PFDC finding

Studies were carried out to evaluate systems of irrigation (Furrow, drip) and sources of fertilizers (Normal fertilizers and WSF) on productivity of potato when applied at fortnightly interval. Among the 8 treatments drip systems of irrigation as found to be superior compared to conventional

Fig. 6.65 Potato under drip fertigation at PFDC, UAS, Bangalore

furrow irrigation. Application of 125:125:150 kg/NPK/ha in the form of water soluble fertilizers through fertigation at fortnightly intervals in recommended for potato for getting maximum marketable yield of tubers and returns. Expected maximum yield is 20-25 ton/ha and water use efficiency is 9.7 liter/day/plant through drip irrigation and fertigation system.

Crop (Variety)	Potato (Kufri Bahar)
Technologies used	Drip irrigation with fertigation
PFDC	CCS, HAU, Hisar, Haryana
Fertilizer dose	Recommended dose of fertilizer: 125kg N, 50 kg P_2O_5, 100kg K_2O per hectare

PFDC finding

Potato cultivation conducted in drip irrigation & fertigation with crop geometry 60X20 cm. It is concluded that the dose of I_1F_1 i.e. Drip irrigation with 0.6 volume of water and 25% of RDF as basal +75% of RDF through fertigation at 23, 30, 37, 43, 51, 58, and 65 days after planting was found optimum for better growth and yield. The plant emergence was found maximum in the treatment I_1F_1 (98.00%), the maximum plant height (90 days after planting) of 58.33 cm. in the treatment of I_1F_1 and yield was estimated maximum 319.30 q/ha (38.37 kg/ plot) in the treatment of I_1F_1.

Fig. 6.66 Potato under drip fertigation at PFDC, CCS, HAU, Hisar

Crop (varieties)	Potato (Kufri Anand, Kufri Badsah, Kufri Bahar, Kufri Chipsona)
Technologies used	Drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Recommended dose of fertilizer (N-214.5, P_2O_5- 67.5, K_2O-434, CaO-50, MgO-90 kg/ha) was applied out of which 30% N, 60% P_2O_5, 40% K_2O, 80% CaO, 80 % MgO was applied as basal dose and remaining through fertigation. Fertigation frequency was weekly and started after 1 week and stopped 15 days prior to harvesting.
Crop period	October to February

PFDC finding

Drip irrigation system having 16 mm diameter lateral pipe with dripper discharge of 1.4 Lph, laterals placed at 15 cm soil depth, lateral to lateral spacing 60 cm and dripper to dripper spacing 30 cm. Daily operation duration of drip system was 5 min. in initial (25 days) and developmental (30 days), 8 min. in middle (45 days) and 7 min. in maturity stage (25 days) of crop. The total amount of water needed to irrigate 1 ha potato crop was

Fig. 6.67 Potato under drip fertigation at PFDC, IARI, New Delhi

estimated as 19.1 cm. Maximum yield (40- 45 t ha^{-1}) was obtained by applying alternate day irrigation and weekly fertigation. Payback period was estimated as 4 cropping seasons with irrigation water use efficiency of 30.15 kg/ m^3.

Crop	Potato
Technologies used	Drip irrigation with fertigation, Black mulch (25 μ)
PFDC	BAU, Ranchi, Jharkhand
Fertilizer dose and scheduling	Recommended dose of fertilizer 150:60:90 NPK kg/ha Basal dose DAP-23.4 Kg/ha (N), DAP-60 Kg/ha (P), MoP-45 Kg/ha (K), Farm Yard Manure 8000Kg/ha as Basal dose.
Crop period	October-February

Table 6.36 Fertigation schedule

Fertigation: stage wise	N (Urea + KNO_3)	K (KNO_3)
Vegetative	22.72	-
Vegetative	25.97	11.25
Tubering	25.97	11.25
Tubering	25.97	11.25
Tubering	25.97	11.25
Harvesting	-	-

Table 6.37 Crop water requirement

Crop Water Requirement of Potato		
Plant Growth Stage	**litter/plant/ days**	**litter/m^2/ day**
Germination	0.21	1.77
Vegetative	0.24	2.04
Flowering	0.33	2.76
Harvest	0.31	2.6

PFDC finding

This trail has conducted to study the effect of drip Irrigation and black plastic mulch (25 micron) on yield, water use efficiency of potato. The highest yield was observed for drip irrigation at 0.8 ET with mulch followed by drip irrigation at 1 ET with Mulch. The highest yield was found to be 24.5 t/ha. The cultivation of potato through drip irrigation with black plastic mulch (25 micron) increased the productivity and quality of produce with added benefit of water saving.

Fig. 6.68 Potato under drip fertigation at PFDC, Ranchi

Crop	Potato
Technologies used	Drip irrigation with fertigation
PFDC	PAU, Ludhiana, Punjab
Fertilizer dose and scheduling	Recommended dose of fertilizer 305:82:83.5 NPK Kg/ha, out of which 64.2 kg Urea: 16.5kg Mono ammonium phosphate and 16.7 kg Muriate of Potash (white) per hectare applied as basal dose. Remaining fertilizers fertigation at 4 days intervals

Table 6.38 Operation duration of drip system

Month	Operation duration of irrigation system , minutes
October	20
November	25
December	45
January	20

PFDC finding

One lateral pipe should used to irrigate one row of potato having drippers at a spacing of 30 cm with discharge of 2.2 litres per hour. This system, irrigation should be applied at two days interval at operation time given above table and fertigation done at 4 days interval 13 equal doses after germination of crop. Expected maximum yield in drip fertigation system is 44 t/ha (34 % more than conventional) with 39% savings of water and 20% fertilizer

6.2.33. Papaya

Crop (Variety)	Papaya (Taiwan786)
Technologies used	Drip irrigation with fertigation, Mulch
PFDC	NAU, Navsari, Gujarat
Fertilizer dose and scheduling	Recommended dose of fertilizer: 200:200:250 NPK g/plant. Alternate day fertigation

PFDC finding

Papaya (Taiwan 786) was planted at 2.5 x 2.5 m spacing and lateral lines of 16 mm diameter with online two drippers (8 lph) were placed 30 cm away on either side of papaya plant. The system was operated at 1.2 kg/ cm2 pressure on alternate day and fertigated @ 200:200:250 g/ plant. Nitrogen (N) was applied in the form of urea and potassium (K) as muriate of potash in 14 equal splits at an interval of 15 days starting from 30 days after planting. The whole amount of P was applied in the form of single super phosphate as basal. Drip irrigation schedule in winter 20-30 lit/plant/ alternate day and in summer 30-50 lit/plant/alternate day. Black plastic mulch of 50 micron, 20 % coverage also saves 40 % water. The farmers of South Gujarat growing papaya are recommended to adopt following package of practices for higher fruit yield and net profit.

Fig. 6.69 Papaya under drip fertigation at PFDC, Navsari

6.2.38. Paddy

Crop (Variety)	Paddy(Mahamaya)
Technologies used	Drip irrigation with fertigation
PFDC	IGKV, Raipur, Chhattisgarh
Fertilizer dose and scheduling	Recommended dose of fertilizer: 120:60:40 NPK kg/h Fertigation of water soluble fertilizers at 7 days interval.

Table 6.39 crop water requirement

Month	CWR (L Plant^{-1}Day^{-1})
July	4.0
August	3.8
September	4.1
October	4.4
November	3.5
December	2.4

PFDC finding

The maximum yield (6.36 tha^{-1}) was obtained under drip fertigation (80% RDF) and plastic mulch. Planting should be done 15cm x 10 cm planting geometry. Irrigation should be given twice a week with online drip irrigation system with drippers of 2L h^{-1} discharge capacity. To get the maximum & sustainable yield, optimum dose of fertilizer (120:60:40 NPK kg/ha) should be given through fertigation using water soluble fertilizers at 7 days interval.

Fig. 6.70 Paddy under drip fertigation at PFDC, IGKV, Raipur

6.2.39. Rosemary

Crop	Rosemary
Technologies used	Drip irrigation with fertigation
PFDC	UAS, Bangalore, Karnataka
Fertilizer dose and scheduling	Recommended dose of fertilizer: 80:32:32 NPK kg/ha (Water Soluble Fertilizer) along with 0.5 percent zinc and 0.5 per cent boron through fertigation at monthly intervals.

PFDC finding

Application of 80:32:32 kg NPK/ha in the form of WSF along with 0.5 per cent zinc and 0.5 per cent boron through fertigation at monthly intervals is recommended to get maximum essential oil yield is408 liter/ha and high returns of Rs. 1,06,967/ha of rosemary.

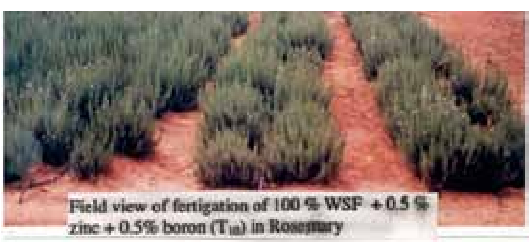


Fig. 6.71 Rosemary under drip fertigation at PFDC, Bangalore

6.2.40. Sapota

Crop (variety)	Sapota (Kalipatti)
Technologies used	Drip irrigation with fertigation
PFDC	UAS, Bangalore, Karnataka
Fertilizer dose and scheduling	Recommended dose of fertilizer: 320:130:360g NPK/tree/year

PFDC finding

Application of 80 per cent of the recommended dose of fertilizers (RDF: 320:130:360 g NPK/tree/year) through drip fertigation have shown higher productivity i.e. 10/15 ton/ha and quality of sapota fruits. The optimum water use efficiency is 34 l/day/ plant through drip.

Crop (variety)	Sapota (Baramasi)
Technologies used	Drip irrigation with fertigation, Mulch
PFDC	RAU, Samastipur, Bihar
Fertilizer dose and scheduling	Application of 100% of N through drip with mulch

PFDC finding

Maximum yield was observed 12.1 kg/ plant in treatment F_5 (Application of 100% of N through drip with mulch) and 6.5 kg/plant in treatment F_4 (Application of 100% of N through traditional method).In Comparison to control the yield was about 86.15% more in treatment F_5. The three years research data advocated that by applying 100% of N through drip about 90.78% more yield could be harvested over control practices.

6.2.41. Sweet corn

Crop (variety)	Sweet corn (Sugar 75)
Technologies used	Drip irrigation with fertigation
PFDC	NAU, Navsari, Gujarat
Fertilizer dose and scheduling	Recommended dose of fertilizer: 120:60:60 NPK Kg/ha Fertigation of N and K should be done in 5 equal splits starting from 30 day after sowing. Full dose of P should be applied as basal.

PFDC finding

Sweet corn at a row to row spacing of 60 cm and plant to plant 20cm during rabi season are advised to adopt drip method of irrigation along with fertigation of N and K @ 100% RDF (120: 60: 60 NPK kg/ha) for getting higher yield and net profit. Fertigation of N and K should be done in 5 equal splits starting from 30 DAS. Full dose of P should be applied as basal. The cob yield (12.52 t/ha) and fodder yield (9.51 t/ha) yields recorded .This implies that one could obtain almost similar cob and fodder yields with 30 per cent less water with 40 per cent fertilizer saving. Farmers of South Gujarat should be adopt this package of practices to get maximum yield.

Fig. 6.72 Sweet corn under drip fertigation at PFDC, Navsari

6.2.42. Tomato

Crop (Variety)	Tomato (Sun 7611)
Technologies used	Drip Irrigation with fertigation
PFDC	UAS, Bangalore, Karnatka
Fertilizer dose and scheduling	Recommended dose of fertilizer: 140 % 350:350:350 NPK kg /ha

PFDC finding

Transplantation of Sun 7611 at 60 cm x 45 cm with application of 140 per cent (350:350:350 kg NPK/ha) is recommended for the better yield of tomato. With this, through drip fertigation at fortnightly intervals starting from 15 days after transplanting of the saplings along with growth regulator GA_3 of 25 ppm concentration twice at weekly interval is recommended for getting maximum productivity (258 tons/ha.) and best quality tomato fruits of hybrid cv. SUN 7611 under cost effective greenhouse. The optimum water use for the tomato was 8-12 litters /sq.m /day.

Fig. 6.73 Tomato under drip fertigation in polyhouse at UAS, Bangalore

Crop (Variety)	Tomato(Avinash)
Technologies used	Drip Irrigation with fertigation
PFDC	SKRAU, Bikaner, Rajasthan
Fertilizer dose and scheduling	Recommended dose of fertilizer: 180:120:80 NPK kg/h

Table 6.40 Irrigation scheduling and water requirement

S.N	Crop Stage	Tomato	
		Days	Water applied (mm)
1	Initial	35	37.01
2	Crop Development	45	83.54
3	Mid Season	45	246.29
4	Last Season	25	179.93
	Total	**150**	**546.77**

Table 6.41 Fertigation scheduling of tomato

Crop Stage	Fertigation Schedule	Basal dose (kg/ha)	Nutrients through Fertigation (kg/ha)			Fertilizers for fertigation (Kg/ha)		
		FYM	N	P_2O_5	K_2O	Urea	MAP	MOP
Initial	Full dose of FYM and N, P_2O_5 and K_2O @ 60kg/ha, 40kg/ha and 20Kg/ha respectively	35000	60	40	20	113.12	65.56	33.33
Development	N,P_2O_5 and K_2O @ 60 Kg, 40Kg/ha and 30kg/ha in four spilt doses at an interval of 10 days		60	40	30	113.12	65.56	49.8
Middle & Maturity	do		60	40	30	113.12	65.56	49.8

PFDC finding

The optimum crop geometry for better yield should be 45 cm x 60 cm. With this the optimum dose should be 180:120:80 kg/h NPK for better yield. Tomato at 125% RDF shown better yield i.e. 575.08 q/ha. On the other hand the water use efficiency at 100% RDF shown better results i.e. 69.15 kg/ha-mm.

Crop (Variety)	Tomato
Technologies used	Drip Irrigation with fertigation, Polyhouse, Shadenet
PFDC	CIAE, Bhopal, Madhya Pradesh
Fertilizer dose and scheduling	Recommended doses of fertilizers 350:120:390 NPK kg/ha at 15 days of interval 25 % of recommended dose N (87 kg/ha) was applied as a basal and 17% N (47 kg/ha) was applied with Urea Phosphate and remaining part of fertilizers were applied as a split dose at different growth stages.

PFDC finding

Better yield (95.16 t/ha) in polyhouse would be obtained with application of 100 % drip fertigation as compared to shade net (73.26 t/ha) and open field (50.51 t/ha). In polyhouse condition water Soluble Fertilizers Viz., Urea (46:00:00), Urea phosphate (17: 44: 00) and Sulphate of Potash (00: 00: 50) were applied every 15 days interval. 25 % of recommended dose N (87 kg/ha) was applied as a basal and 17% N (47 kg/ha) was applied with Urea Phosphate and remaining part of fertilizers were applied as a split dose at different growth stages.

Crop (variety)	Tomato
Technologies used	Drip Irrigation with fertigation
PFDC	TNAU, Coimbatore, Tamilnadu
Fertilizer dose and scheduling	RDF 200: 62.5: 250 Kg/ha of N, P, K. 187.5 kg of P (1172 Kg of Super Phosphate) should be applied as a Basal dose.

Table 6.42 Fertigation scheduling of tomato

Stages of crop	Duration in days	Name of fertilizers	Number of dosage	Fertilizer (Kg/ha/dosage)
First	Day of transplanting to 10th	19 : 19: 19	3	21.93
		13: 0:45	3	9.26
		Urea	3	2.82
Second	11th to 40th	12:61:0	10	3.07
		13:0:45	10	16.66
		Urea	10	7.53
Third	41th to 70th	19 – 19 - 19	10	6.60
		13 - 0 – 45	10	13.90
		Urea	10	6.40
Fourth	71 th to 150 th	12 – 61 – 0	27	1.14
		13 - 0 – 45	27	6.17
		Urea	27	2.80

PFDC finding

Optimum growth and maximum yield of tomato could be obtained with recommended dose of fertilizers i.e. 200: 62.5: 250 Kg/ha of N, P, K with basal dose of 187.5 kg of P (1172 Kg of Super Phosphate).

Crop (variety)	Tomato (Hy. Namdhari)
Technologies used	Drip Irrigation with fertigation, Greenhouse
PFDC	NAU, Navsari, Gujarat
Fertilizer dose and scheduling	Recommended doses of fertilizers 250:125:125 NPK kg/ha

PFDC finding

The optimum crop geometry for the better yield of tomato should be (50 x 60 cm) under green house conditions. The fertilizer should be applied @ 125 % of recommended dose i.e. 250:125:125 NPK kg/ha for getting optimum yield in 20 equal splits at an interval of 10 days for N and K. Full dose of P should be applied as basal.

Fig. 6.74 Tomato under drip fertigation in polyhouse at UAS, Bangalore

Crop (varieties)	Tomato (Himshikar, Indam-2103)
Technologies used	Drip irrigation with fertigation
PFDC	IARI, New Delhi
Fertilizer dose and scheduling	Recommended doses of fertilizers (N-120, P2O5-60, K2O-50 kg/ha) out of which 30 % N, 60 % P2O5, 40 % K2O was applied as basal dose and remaining through weekly fertigation.
Crop period	October to April

PFDC finding

System head works including filters, venturi injector, 120 cm lateral spacing,16 mm diameter inline lateral pipe (buried at a depth of 20 cm) with 2.0 Lph dripper discharge and 30 cm dripper spacing, crop spacing (single row -120 cm x 30 cm, paired row -lateral spacing 120 cm, two rows of tomato at 40 cm x 30 cm) should be installed. To meet the crop water demand system should supply water at initial, developmental, middle and maturity stage 2.2 (35 days), 2.1 (45 days), 2.78 (70 days) and 4.57 litre/ m^2 area (30

Fig. 6.75 Tomato under drip fertigation at PFDC, IARI, New Delhi

days), respectively in rabi tomato. In a total crop period of 180 days, irrigation interval of 2-3 days in winter and daily in summer should maintain. Expected maximum yield with surface drip (55 t/ha) and subsurface drip system (72 t/ha) in summer and 60 t/ha in winter with 40-60 % saving of water with irrigation water use efficiency of 12.2 kg/ m^3 would be possible through this technology.

Crop (variety)	Tomato
Technologies used	Drip irrigation with fertigation, Polyhouse, Shade net
PFDC	GBPUAT, Pantnagar, Uttarakhand
Fertilizer dose	Recommended doses of fertilizers - 120:60:60 NPK kg /ha
Crop period	Annual

PFDC finding

Tomato should be transplanted at a crop geometry of 60cm x 50cm to get B:C ratio of 3.48 under polyhouse and water productivity 28.10 l/kg in comparison to shade net with water productivity (31.47 l/kg) and B:C ratio (2.61) and open condition with water productivity (36.64 l/kg) and B:C ratio (2.68), respectively. The recommended dose of fertilizer i.e. NPK @ 120:60:60 NPK kg/ ha should be applied for the maximum yield (16.12 kg/m^2) of tomato.

Crop (variety)	Tomato (Rajshree F1 hybrid)
Technologies used	Drip irrigation with fertigation,
PFDC	MPKV, Rahuri, Maharashtra
Fertilizer dose	Recommended doses of fertilizers: 225:250:250 Kg, NPK/ha
Crop Period	Annual

Table 6.43 Crop water requirement

Year	Quantity of water applied(cm)
1998	89.53
1998-1999	87.90
1999-2000	65.78
Average quantity of water applied	81.07

PFDC finding

The paired row planting i.e. 30-90 cm row to row and 45 cm plant to plant with lateral diameter 12 mm, lateral spacing 1.20 m, dripper spacing 0.45 m, average discharge 4 Lph should be installed to achieve uniformity coefficient 90 %. Water soluble fertilizers through drip at the rate 180 kg Nitrogen, 200 kg Phosphorus, and 200 kg potassium per hectare should be applied to get 75 t/ha yield. Savings of fertilizers by 20 % and increase in yield by 25 % with water-use-efficiency was maximum (0.95 t/ha-cm) is expected in this technology.

Crop (variety)	Tomato (Shaktiman)
Technologies used	Drip irrigation with fertigation, Mulch
PFDC	IGKV, Raipur, Chhattisgarh
Fertilizer dose and scheduling	Recommended dose of fertilizer - 120:80:100 NPK kg/ha at 7 days of interval

Table 6.44 Water requirement and irrigation scheduling

Month	No. of days	CWR (L $plant^{-1}$ day^{-1})	
		Mulch	Without Mulch
October	10	0.45	0.45
October	10	0.45	0.52
November	10	0.52	0.62
November	10	0.62	0.65
November	10	0.65	0.68

December	10	0.65	0.70
December	10	0.70	0.75
December	11	0.72	0.78
January	10	0.72	0.78
January	10	0.75	0.80
January	11	0.82	0.85
February	10	0.95	1.20
February	10	0.98	1.25
February	8	1.00	1.35
March	10	1.20	1.45
March	10	1.20	1.50

PFDC finding

Irrigation should be given twice in a week using online drip irrigation system with drippers of 2 l h^{-1} discharge capacity. Maximum yield (35.76 t ha^{-1}) could be obtained under drip fertigation and plastic mulching through application of recommended dose of fertilizer (120:80:100 NPK ha^{-1}). Fertilizers should be given through fertigation using water soluble fertilizers at 7 days of interval. Planting should be done 60 cm row to row and 45 cm plant to plant and fifty percent of plant area should be mulched using 25 micron silver polythene mulch film to avoid weed growth, conserve soil moisture and prevents soil nutrient leaching during heavy rain.

Fig. 6.76 Tomato under Drip fertigation and mulch at PFDC, IGKV, Raipur

Crop (variety)	Tomato (Avinash)
Technologies used	Drip irrigation with fertigation, Mulch
PFDC	RAU, Samastipur, Bihar
Fertilizer dose	FYM applied at the rate of 50 q/ha with half of Nitrogen and whole amount of $P_2 0_5$ and 75% of K_2O as basal dose. The remaining half of Nitrogen and K_2O through fertigation.
Crop period	Annual

Table 6.45 Fertigation Schedule of Tomato at different stages

Fertigation schedule	**Dose (kg/ha)**		
	N	**P**	**K**
Vegetative stage	-	-	-
Flowering(January)	10	-	-
Flowering and Fruiting (February)	15	-	10
Flowering and Fruiting (March)	20	-	10
Flowering and Fruiting (April)	15	-	-
Harvesting	-	-	-

PFDC finding

The row to row distance should be 80 cm and plant to plant should be 70 cm. The maximum plant height was 155.66 cm, average number of tomato fruits per plant was 51.30, average weight per fruit was 76.63 gram, average yield per plant was 3.93 kg and percentage increase over control was 85.38 with recommended dose of fertilizers i.e. 100% of Nitrogen through drip with mulch. Based on three years yield data it was found that by using plastic mulch with fertigation (100 % of RDF) in tomato crop the fruits yield can be significantly increase 68 percent.

Crop (variety)	Tomato (Heemshona)
Technologies used	Drip irrigation with fertigation
PFDC	Dr. YSPUH&F, Solan, Himachal Pradesh
Fertilizer dose and scheduling	Recommended Dose of fertilizers: 326: 475: 90 kg/ha (Urea: SSP: MOP)

PFDC finding

Mulching with black polyethylene mulch (25-50 micron) must be done to control weeds and conserve moisture. To maintain organic carbon (atleast1.5%) in medium fertility status of soil ones should add sufficient quantity of well decomposed organic matter or vermicompo^st, preferably FYM @ 4kg/m2 or vermicompost @ 2 kg /m2 to maintain soil fertility.

On other hand, for soils with low fertility status, the quantity of fertilizers should be increased by 25% and in soils with high fertility the quantity should be decreased by 25%. A drip lateral is to be placed between two rows with discharge of 2 lit./hr and drippers are to be at 30 cm spacing. Mulching is to be done with 30 micron black colored polyethylene.

Fertigation is to be done on alternate days from vegetative to final harvest with the help of venturi as per schedule given in the table above. Maximum yield of tomato would be obtained 510 q/ha in drip ferigation whereas in conventional **method it is 365 q/ha.**

Fig 6.77 Tomato under drip fertigation and mulch at PFDC, Solan

Table 6.46 Fertigation scheduling at different growth stages.

Growth stage of crop	Total quantity of fertilizer(Kg/ha)			Quantity of fertilizer for fertigation (kg/ha)			
	N	P	K	N:P:K 12:61:00	N:P:K 13:00:45	N:P:K 16:05:24	N:P:K 05:15:30
Germination	0	0	0	0	0	0	0
Vegetative	7.2	36.6	0	5 kg/ha (after 30 days of transplanting)	0	0	0
Flowering	16	3.75	36.9	0	5 kg/ha (within 31-50 days of transplanting)	5 kg/ha (within 51-80 days of transplanting)	0
Harvesting	2	6	12	0	0	0	5kg/ha (within 81-95 days of transplanting)

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Annexure-1

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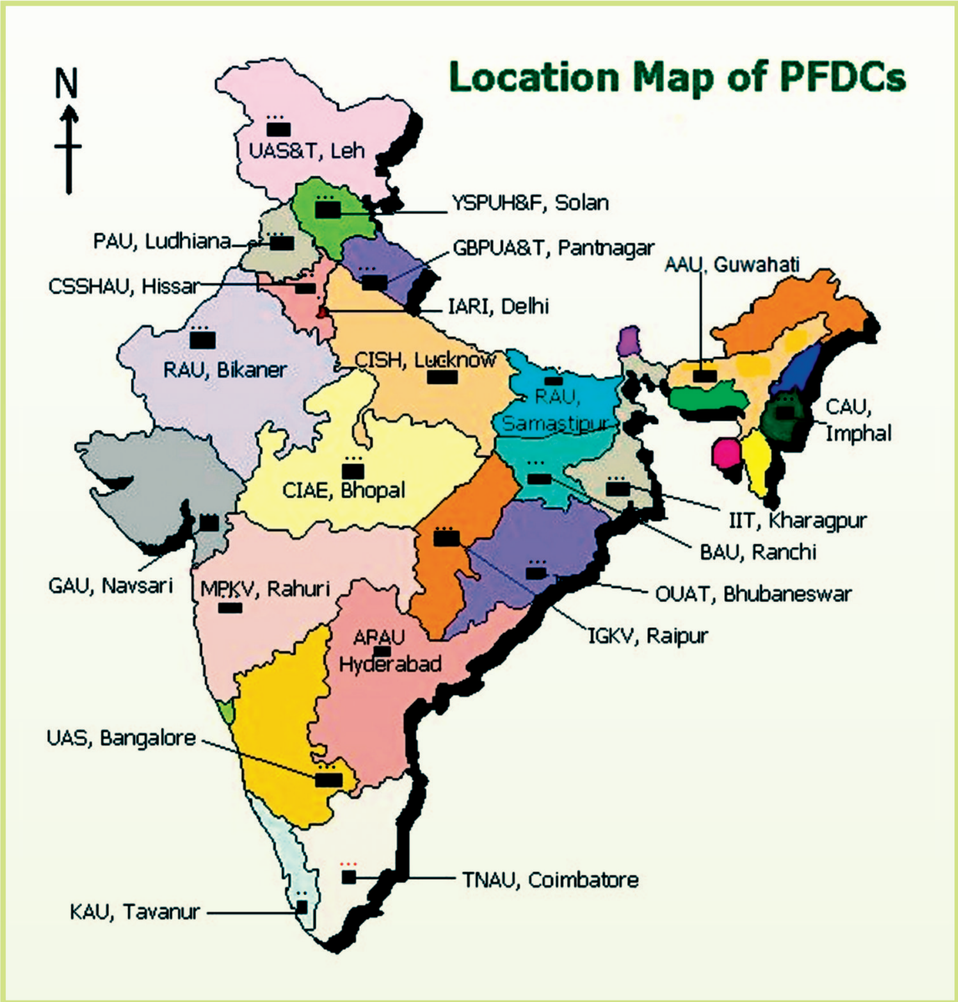

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