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Drip Fertigation for Enhancing Crop Productivity:
Learnings from AICRP on Irrigation Water Management

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AICRP on Irrigation Water Management
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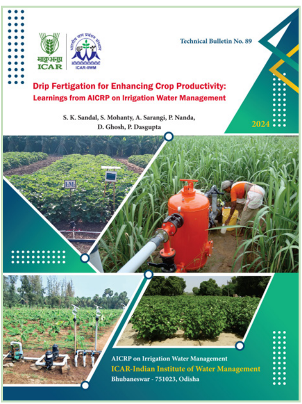

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MESSAGE

Fertigation studies using pressurized or micro irrigation have been an important mandate of All India Coordinated Research Project (AICRP) on Irrigation Water Management (IWM). For the last two decades, AICRP on IWM scheme has been playing a pivotal role in conducting fertigation trials in several crops across the Country. In the recent years, focus is on coordinated fertigation trials across different agro-ecological regions and soil conditions, considering a common set of fertilization treatments with an objective to standardize fertilization schedules for different crops grown in different parts of the Country.

I appreciate the efforts of the scientists of AICRP on IWM and the ICAR-IIWM for bringing out such a bulletin showcasing significant finding of different Centres. The bulletin is a compilation of various fertigation schedules developed under AICRP on IWM centres operating in different States. The technology demonstrated enhanced crop and water productivity fetching higher economic gains. Now, this has become more relevant in conditions of scarce water resources and erratic climatic pattern. I am sure that this bulletin will serve as a technical guide for farmers and other stakeholders *viz.*, planners, policy makers to adopt fertigation using micro-irrigation to improve and sustain their livelihood vis-à-vis conserve natural resources.

Dated the 6th May, 2024
New Delhi

(Suresh Kumar Chaudhari)

PREFACE

Nutrient supply to crops is a pivotal contributory factor for sustainable food production. Fertigation is a proven strategy of nutrient application along with irrigation for effective water and fertilizer use in a standing crop. Fertigation is found most effective with drip irrigation among the micro-irrigation systems. Apart from high crop productivity, precise and timely crop nutrition to the active root zone, fertigation also leads to better quality of produce and significant fertilizer cost savings. Cultivated crop area can be substantially increased as fertigation limits water and nutrient use while improving water and nutrient use efficiencies. Fertigation is also an eco-friendly way of nutrient application to plants because it controls leaching of nutrients especially nitrogen in form of nitrate ion and checks groundwater pollution. Fertigation provides opportunity for efficient use of micronutrient solutions, which are otherwise difficult to apply precisely to the soil. Other advantages of fertigation include higher resource conservation in form of energy, labour and time. When fertigation is applied with drip irrigation, crop foliage can be kept dry thereby preventing growth of plant pathogens. Soil compaction is avoided due to reduced surface traffic during irrigation and nutrient application in crops. Fertigation also checks development of soil salinity due to controlled application of fertilizers through irrigation water.

The bulletin is a comprehensive compilation of drip fertigation studies undertaken under AICRP on Irrigation Water Management (IWM) over the last 10-15 years. It covers findings from crops grown under different soil textural classes and agro-ecological regions of India. Co-ordinated fertigation trials were evaluated based on a common set of fertilization treatments with a vision to standardize fertilization for crops across different parts of India. The bulletin introduces some practical findings on fertigation which can be beneficial for researchers, extension workers and farmers for growing various field and horticultural crops.

Authors

CONTENTS

1. Fertigation

Intensification of agricultural production to meet growing market demand requires the simultaneous application of irrigation water and fertilizers. Fertigation is an attractive technology in modern irrigated agriculture which increases yield and fertilizer use efficiency. Fertigation combines irrigation water with fertilizer, and is well recognized as the most effective and convenient means of maintaining optimal nutrient levels and water supply according to the specific needs of each crop and type of soil. The technique applies both water and fertilizer at a low rate to the vicinity of plant root zone as per crop needs and according to crop developmental phase, resulting in higher yields and better quality of produce.

The effects of climate change on crop growth especially high value cash crops like vegetables with higher and frequent water requirement has started showing alarming signals in terms of output. The prolonged dry spell, uneven rainfall distribution in terms of frequency and intensity are promoting diversification to irrigated agriculture. Growing more crops per drop of water use is the key to mitigating the water crisis and the main ways of efficient water use are to increase its beneficial uses, avoid water losses, decrease non-beneficial uses and increase water productivity. In such aspects, drip irrigation system can reduce the total requirement of irrigation water along with increasing the water use efficiency. It is a type of micro-irrigation system that has the potential to save water and nutrients by allowing water to drip slowly to the roots of plants either from above the soil or buried below the surface. The drip irrigation results in 50-60 per cent saving of irrigation water and 20-25 per cent higher crop yield as compared to surface irrigation.

Irrigation systems are selected based on their water use efficiency, which varies with the soil properties and crop characteristics rather than the application system itself. In flood irrigation, the water is directed and controlled by constructed basins, borders, and/or furrows. During flood irrigation, the applied water percolates through the plant root zone, resulting in losses of applied nutrients to leaching. On the other hand, low-volume irrigation systems apply water only to the soil around the plants; therefore, agrichemicals can be more effectively applied with such systems. Because the infiltrating water dispenses the fertilizer in the soil, fertilizer distribution depends on the water flow pattern in the particular soil. Under flood irrigation, most of the water movement is due to gravity, resulting in excessive drainage. More nutrients may be needed for flood-irrigated fields than those irrigated with low-volume systems, which retain the applied water, and hence the nutrients, in the plant root zone.

Micro irrigation offers greater potential for precise water management as compared to surface irrigation. Drip irrigation maintains a favourable soil water regime and restricts the fluctuation of soil water within narrow range. This system recharges the root–zone and maintains the uniformity of seed–zone moisture throughout the planting area for a longer period as compared to conventional methods of irrigation. The drip irrigation system has an edge over surface irrigation since the soil moisture spreads horizontally as well as vertically and maintains soil moisture at field capacity during the growing period with frequent light irrigations. The drip irrigation systems apply controlled and precise amounts of water to the field, hence, the negative impacts (*i.e.* surface runoff, soil erosion, deep percolation, and nutrient loss) are avoided. More nutrients may be needed for flood-irrigated fields than those irrigated with low-volume systems, which retain the applied water, and hence the nutrients, in the plant root zone.

The regulated supplies of water through drippers not only affect the plant root and shoot growth parameters but also the fertilizer use efficiency and nutrient uptake. High irrigation water application efficiency associated with negligible deep percolation in drip irrigation systems makes them ideal for fertigation. Prescribed chemical application, reduced application cost, minimum operator hazard, no soil compaction and less plant injury are among the important advantages of fertigation through drip irrigation systems compared to foliar fertigation via above-ground sprays. Fertigation allows the landscape to absorb up to 90% of the applied nutrients, while granular or dry fertilizer application typically result in absorption rates of 10% to 40%.

Deficiency of N, P and K is a major production constraint in most of the soils, which have inherent constraints like P fixation, rapid hydraulic conductivity, faster infiltration rate, leaching of basic cations and low CEC. Thus, the cultivated crops in these soils require large quantity of nutrients to support 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. 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.

Pressurized irrigation systems offer the ability to use high-frequency fertigation. High irrigation water application efficiency associated with negligible deep percolation in drip irrigation systems makes them ideal for fertigation. Because drip irrigation systems apply controlled and precise amounts of water to the field, negative impacts (*i.e.*, surface runoff, soil erosion, deep percolation and nutrient loss) are avoided. In a fertigation system, the timing, amounts, concentrations and ratios of the nutrients are easily controlled. Due to this improved control, crop yields are larger than those produced by a simple fertilizer application and irrigation system. Since, pressurized irrigation systems generate a concentrated and space-limited root system within the wetted soil volume, fertigation is essential to ensure optimum plant nutrition. Combined application of plant nutrients and water through fertigation avoids excessive leaching of nutrients from the soil volume where roots are actively taking up nutrients and thus minimizes groundwater contamination. Furthermore, by adopting fertigation, crops may be grown to their maximum potential on infertile, shallow soils and inert media.

In fertigation techniques, the plant nutrients exist mostly in soil solution and nutrients concentration is highly variable with profile water distribution in soil as compared to conventional system where the plant nutrients are present mostly on soil exchange complex. This leads to frequent application of NPK fertilizers during fertigation to reduce leaching losses, over or underfeeding of plant, etc. By adopting fertigation, it is possible to save the fertilizers to a tune of 30 per cent and increasing the productivity about 40 per cent. The commercially available water-soluble fertilizers (WSF) used for fertigation are Urea, 19:19:19, 18:18:18, 12:61:0, 17:44:0, 0:0:50, 13:0:45, etc. As the N and K requirement increase and P requirement decreases with crop growth stage from early growth to flowering, drip irrigation-based fertigation provides a scope of varied application of nutrient as per crop growth stage.

Simultaneous use of micro irrigation and fertilizer application (fertigation) opens new possibilities for controlling water and nutrient supply to crops besides maintaining the desired concentration and distribution of nutrients and water into the soil. The advantages of supplying mineral nutrients to crop roots using fertigation include reduced delivery costs (no need to broadcast fertilizer, leading to less soil compaction in the inter-row areas, less fuel usage and lower labour requirements), greater control over where and when nutrients are delivered, leading to greater fertilizer use efficiency, more control over crop behaviour through targeted application of specific nutrients during particular stages of crop development and potential for reduced fertilizer losses (due to immobilization within or leaching below the root zone) by supplying small amounts often.

The disadvantage includes, greater capital costs associated with the equipment needed to dissolve and inject the fertilizer into the irrigation water, higher operating costs associated with using technical grade fertilizers and chemical reactions between some types of fertilizers when mixed, potentially causing significant equipment blockages.

1.1 Behaviour of plant nutrients under fertigation

Nitrogen

Urea: Urea $[CO(NH_2)_2]$ does not carry an electric charge when dissolved in pure water. Once urea comes in contact with the soil, it is transformed very quickly (within 24-48 h after application) into ammonia (NH_3) and carbon dioxide (CO_2).

Ammonium: Ammonium (NH_4^+) carries a positive electric charge (cation) and is adsorbed to the negatively charged sites on clay and can also replace other adsorbed cations on the clay surfaces.

Nitrate: Nitrate (NO_3^-) carries a negative electric charge (anion). It cannot, therefore, bind to the clay particles of basic and neutral soils which carry negative charges. However, nitrate binds to positively charged ion and aluminum oxides present in acid soils.

Phosphorous

Phosphorous (P) in solution is subject to interactions with inorganic and organic constituents in the soil. The $H_2PO_4^-$ ion remains stable in the solution inside the irrigation line as long as the pH is kept low. Once it is released to the soil, it reacts very quickly with clay minerals like, montmorillonite and illite in basic soils, and with kaolinite clay, iron and aluminum compounds in acid soils.

Potassium

Potassium is present as a stable cation (K^+) in rocks, soils, and solution and has one positive active charge. Once the external concentration in the soil solution is increased by fertilizer additions, the K^+ ions split between three phases: (1) in soil solution, (2) in the clay pool of exchangeable cations and (3) in the inter clay particle space where it is "fixed." The rate of exchange between solution and adsorbed K^+ is high and an immediate equilibration is obtained. However, the "fixation" and "release" of K from the soil is slow and cannot match the rate of K^+ uptake by plant roots. Since the rate of K release from "fixed K position" is slower than the rate of K demand by a growing plant, additions of K in fertilizers are needed to match the plant K uptake during plant development.

1.2 Features of drip fertigation

- Irrigation system does the work and overfeeding and underfeeding is minimized.
- With precise application, the overall amount of chemicals applied is reduced as compared to the dry application.
- Increased nutrient absorption by plants and reduced leaching to the water table.

- Reduction in water usage due to increased root mass being able to trap and hold water.
- Application of nutrients at the precise time as needed and at the rate they are utilized.
- The localized wetting patterns produced by drip systems can induce limit to a nutrient uptake, making it necessary to apply the fertilizers through the drip fertigation system.
- The high efficiency of water application attained in drip irrigation systems is ideal for the high efficiency of applied nutrients in fertigation.
- Fertigation enhances fertilizer use efficiency by 40-60 percent, hence recommended doses of fertilizers may be reduced proportionally.
- Use of water-soluble fertilizers (WSF) may lead to leaching losses beyond surface layer, hence frequent split applications of WSF is desirable.
- The frequency of fertigation may increase with fertilizers doses in order to avoid leaching losses or toxicity if any.

1.3 Factors affecting fertigation schedule

The important factors which may affect the efficiency of fertigation technology are

- Soil texture
- Available NPK status in soil
- 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 or uniformity coefficient of installed drip irrigations

The drip irrigation and fertigation system can be installed in number of field crops depending upon crop spacing, soil texture, lateral spacing and climatic requirement mainly evapo-transpiration. The efficient fertigation schedule requires attention to three factors, *viz.*, a) plant growth stage wise nutrient requirement, b) nutrient delivery frequency and intervals to meet crop needs, and c) regulated water supply to minimize leaching of soluble nutrient below the effective root zone. When making a pre plant application of any nutrient, it is important that the fertilizer be placed within the wetting zone of the drip system. A crop specific fertigation schedule can be developed using growing degree days and crop growth pattern. Nutrient can be injected at various frequencies depending upon system design, soil type and grower preference. Frequent injection may be needed for sandy soil with poor water and nutrient capacity.

1.4 Characteristics of fertilizers suitable for fertigation

- High nutrient content readily available to plants
- Fully water soluble at field temperature conditions
- Fast dissolution in irrigation water
- No clogging of filters and emitters
- Low content of insoluble (<0.02%) particles
- Compatible with other fertilizers
- No drastic changes of water pH (3.5<pH>9.0)

1.5 Commonly available water soluble fertilizers

The commercially available water soluble fertilizers used for fertigation are Urea, 19:19:19, 18:18:18, 12:61:0, 17:44:0, 0:0:50, 13:0:45, etc. The nutrient distribution among these fertilizers is given in Table 1.

Table 1: Distribution of nutrients in water soluble fertilizers

Grade	19:19:19	17:44:0	0:52:34	13:0:45	12:61:0	0:0:50
Total nitrogen by wt (%)	19	17	0	13	12	0
Ammonical N (%)	4.5	0	0	0	12	0
Amide N (%)	10.5	0	0	0	0	0
Nitrate N (%)	4.0	0	0	13	0	0
Water soluble P_2O_5 (%)	19	44	52	0	61	0
Water soluble K_2O (%)	19	0	34	45	0	50

1.6 Fertigation units

- Venturi system – A venturi of ¾ inch size. It discharges 750 to 1000 ml water per minute and attached with pressurized irrigation system
- Fertilizer tank system- A fertilizer tank of 20-30 litre capacity is attached. The discharge rate is 3 to 3.5 litre per minute and is attached with pressurized or gravity fed irrigation system.
- Fertilizer injection pumps
- Water storage tank

1.7 Fertigation process in the field

The total fertilizer quantity of water-soluble fertilizers calculated is divided into 8-10 equal parts and each part is applied at 5-7 days intervals. The fertigation my be done either on continuous basis from start of irrigation to its finish or in three stage application. In three stage application, irrigation starts without fertilizers and injection begins when the ground is wet. Injection cuts out before the irrigation cycle is completed since remainder of the irrigation cycle allows the fertilizer to be flushed out of the system.

2. Salient findings of fertigation experiments

2.1 Palampur, Himachal Pradesh; Soil texture: Silty Clay Loam

The experiments conducted under open conditions, on fertigation technology showed that application of conventional fertilizers as basal and water-soluble fertilizers through fertigation in 7-10 splits at 7-10 days intervals during crop growth resulted in 52.7%, 36.4% and 15.9% increase in marketable yield and 27.8%, 27.8% and 32.3% benefit-cost ratio (B:C) over conventional methods in capsicum, broccoli and onion, respectively (Table 2). Under protected conditions, the experiments conducted on fertigation technology showed that application of conventional fertilizers as basal and water-soluble fertilizers through fertigation in 10-12 splits at 7 days intervals during crop growth resulted in 21.4%, 13.9%, 19.4%, 2.7% and 7.7% increase in marketable yield and 28.3%, 21.3%, 24.2%, 1.9% and 29.8% increase in B:C ratio over conventional methods in capsicum, cucumber, tomato, strawberry and marigold crops, respectively (Table 2).

2.2 Bathinda, Punjab; Soil Texture: Loamy Sand

The experiments conducted under open conditions on fertigation technology showed that application of conventional fertilizers as basal and water-soluble fertilizers through fertigation in 12-20 splits at 4-7 days intervals during crop growth resulted in 37.7%, 60.9%, 60.0% and 67.0% increase in marketable yield and 55.0%, 72.7%, 41.2% and 45.0% increase in B:C ratio over conventional methods in roundgourd, okra, tomato and brinjal, respectively (Table 3).

2.3 Pantnagar, Uttrakhand; Soil Texture: Sandy Loam

The experiments conducted under open conditions on fertigation technology showed that application of conventional fertilizers as basal and water-soluble fertilizers through fertigation in 7 splits at 10 days intervals during crop growth resulted in 14.96% and 9.52% increase in marketable yield over conventional methods in mentha and vegetable pea, respectively. There was 4.6% and 2.6% increase in B:C ratio over fertigation methods in mentha and vegetable pea, respectively (Table 4).

2.4 Chalakudy, Kerala; Soil Texture: Sandy Clay Loam

The experiments conducted under open conditions on fertigation technology showed that application of conventional fertilizers as basal and water-soluble fertilizers through fertigation in 10-35 splits at 6-7 days intervals during crop growth resulted in 110.9% and 16.4% increase in marketable yield and 118.2% and 23.1% increase in B:C ratio over conventional methods in chilli and banana, respectively (Table 5).

2.5 Junagadh, Gujarat; Soil Texture: Clay Loam

The experiments conducted under open conditions on fertigation technology showed that application of conventional fertilizers as basal and water-soluble fertilizers through fertigation in 8-12 splits at 6-9 days intervals during crop growth resulted in 27.3%, 35.3% and 15.4% increase in marketable yield and 14.8%, 26.9% and 18.5% increase in B:C ratio over conventional methods in cotton, wheat and greengram, respectively (Table 6).

2.6 Bhavanisagar, Tamil Nadu; Soil Texture: Sandy Loam

The experiments conducted under open conditions on fertigation technology showed that application of conventional fertilizers as basal and water-soluble fertilizers through fertigation in 7-18 splits at 10-40 days intervals during crop growth resulted in 100.0%, 38.9%, 56.8%, 101.3% and 68.4% increase in marketable yield over conventional methods in turmeric, banana, coconut, tomato and jasmine, respectively (Table 7).

2.7 Madurai, Tamil Nadu; Soil Texture: Sandy Clay Loam

The experiments conducted under open conditions on fertigation technology showed that application of conventional fertilizers as basal and water-soluble fertilizers through fertigation in 6-16 splits at 7-15 days intervals during crop growth resulted in 78.5%, 100.0%, 50.0%, 41.4%, 74.1% and 75.0% increase in marketable yield over conventional methods in sugarcane, groundnut, redgram, onion, rice and brinjal, respectively (Table 8).

2.8 Sriganganagar, Rajasthan; Soil Texture: Sandy Loam

The experiments conducted under open conditions on fertigation technology showed that application of conventional fertilizers as basal and water-soluble fertilizers through fertigation in 6-12 splits at 2-14 days intervals during crop growth resulted in 23.0%, 11.5%, 16.0%, 7.8% and 7.1% increase in marketable yield over conventional methods in tomato, bittergourd, *Bt* cotton, sugarcane ratoon and cotton, respectively (Table 9). The experiments conducted under protected conditions showed 55.3% increase in marketable yield and 8.6% increase in B:C ratio over conventional methods in chilli; and 2.7% and 11.6% increase in marketable yield in spongegourd and summer squash, respectively.

Plate 2.1. Cucumber (Palampur)

Plate 2.2. Marigold (Palampur)

Plate 2.3. Banana (Bhavanisagar)

Plate 2.4. Banana (Chalakudy)

Plate 2.5. Cotton (Sriganganagar)

Plate 2.6. Peas (Pantnagar)

Table 2: Results of fertigation experiments at Palampur Centre, Himachal Pradesh; Soil Texture: Silty clay loam

Crop	FYM (t/ha)	Conventional fertilizers (kg/ha) (Basal)			Water soluble fertilizers (kg/ha/split) (Fertigation)				No. of splits	Interval (Days)	Yield (t/ha) and B:C ratio (brackets)	
		Urea	SSP	MoP	Urea	19:19:19	12:61:0	0:0:50			Conventional	Fertigation
Open conditions												
Capsicum	10	54.3	117.2	29.2	9.6	31.0	3.5	-	7	10	7.4 (3.20)	11.3 (4.09)
Broccoli	10	81.5	156.2	22.9	20.1	31.0	7.9	-	7	10	6.6 (2.41)	9.0 (3.08)
Onion	10	140.0	240.0	40.0	16.0	25.0	4.0	-	10	7	20.7 (2.66)	24.0 (3.52)
Protected conditions												
Capsicum	10	80.0	176.0	44.0	9.8	32.9	4.2	-	10	7	14.0 (3.21)	17.0 (4.12)
Cucumber	10	120.0	160.0	60.0	12.0	30.0	-	23.0	10	7	49.0 (1.64)	55.8 (1.99)
Tomato	10	102.0	141.0	25.0	63.0	81.0	36.0	-	12	7	63.8 (3.10)	76.2 (3.85)
Strawberry	10	44	250	16	8.1	-	-	3.7	12	7	3.7 (4.13)	3.8 (4.21)
Marigold	10	60	120	30	5.0	30.0	-	-	10	7	16.8 (2.42)	18.1 (3.14)

Table 3: Results of fertigation experiments at Bathinda Centre, Punjab; Soil Texture: Loamy Sand

Crop	FYM (t/ha)	Conventional fertilizers (kg/ha) (Basal)			Water soluble fertilizers (kg/ha/split) (Fertigation)				No. of splits	Interval (Days)	Yield (t/ha) and B:C ratio (brackets)	
		Urea	SSP	SoP	Urea	19:19:19	17:44:0	0:0:60			Conventional	Fertigation
Roundgourd	-	-	312.0	38.0	22.6	-	-	3.1	12	4	11.4 (4.0)	15.7 (6.2)
Okra	40	62.0	78.0	19.0	11.2	-	4.1	3.8	15	5	6.9 (1.1)	11.1 (1.9)
Tomato	-	-	391.0	-	20.4	-	-	3.90	20	7	41.5 (1.7)	66.4 (2.4)
Brinjal	-	-	391.0	-	24.3	-	-	3.21	14	7	43.7 (4.0)	73.0 (5.8)

Table 4: Results of fertigation experiments at Pantnagar centre; Soil Texture: Sandy Loam

Crop	VC (t/ha)	Conventional fertilizers (kg/ha) (Basal)			Water soluble fertilizers (kg/ha/ split) (Fertigation)		No. of splits	Interval (Days)	Yield (t/ha) and B:C ratio (brackets)	
		Urea	SSP	MOP	Urea	0:52:34			Conventional	Fertigation
Mentha herbage	3	-	-	-	27.9	12.2	7	10	23.4 (2.3)	26.9 (2.2)
Vegetable pea	-	49.5	58.8	9.3	-	10.3	7	10	10.5 (3.9)	11.5 (3.8)

Table 5: Results of fertigation experiments at Chalakudy Centre, Kerala; Soil Texture: Sandy clay loam

Crop	FYM (t/ha)	Conventional fertilizers (kg/ha) (Basal)			Water soluble fertilizers (kg/ha/split) (Fertigation)				No. of splits	Interval (Days)	Yield (t/ha) and B. C ratio	
		Urea	Rock P	MoP	Urea	19:19:19	20:20:0	0:0:60			Conventional	Fertigation
Chilli	20	-	113	-	12.22	-	-	2.34	10	7	6.4 (1.1)	13.5 (2.4)
Banana	37.5	-	1078	-	35.36	-	30.80	40.18	35	6	20.7 (1.3)	24.1 (1.6)

Table 6: Results of fertigation experiments at Junagadh Centre, Gujarat; Soil Texture: Clay loam

Crop	FYM (t/ha)	Conventional fertilizers (kg/ha) (Basal)			Water soluble fertilizers (kg/ha/split) (Fertigation)			No. of splits	Interval (Days)	Yield (t/ha) and B:C ratio (brackets)	
		Urea	SSP	MoP	Urea	Phosphoric acid (60% P)	MoP			Conventional	Fertigation
Cotton	10	130.4	78.1	62.5	32.6	5.2	15.6	12	9	2.2 (2.7)	2.8 (3.1)
Wheat	10	-	-	-	19.57	7.5	7.5	10	6	3.4 (2.6)	4.6 (3.3)
Greengram	-	-	187.5	-	4.08	-	-	8	6	1.3 (2.7)	1.5 (3.2)

Table 7: Results of fertigation experiments at Bhavanisagar centre, Tamil Nadu; Soil Texture: Sandy loam

Crop	FYM (t/ha)	Conventional fertilizers (kg/ha) (Basal)				Water soluble fertilizers (kg/ha/split) (Fertigation)					No. of splits	Interval (Days)	Yield (t/ha) and B:C ratio (brackets)	
		Urea	SSP	MoP	Others	Urea	19:19:19	12:61:0	0:0:50	others			Conventional	Fertigation
Turmeric	25	-	281	-	-	13	-	3.8	-	11	18	10	2.2	4.4 (3.2)

Banana	25	-	-	-	117	14	-	9	34	-	16	12	18.0	25.0 (2.9)
Coconut	25	-	-	-	60.9	43.8	-	11	84	-	12	30	3.7	5.8 (1.4)
Tomato	12.5	-	1172	-	-	15	9.2	-	-	35	14	10	7.5	15.1 (2.9)
Jasmine	10	75	187	80	-	9	13	27	16	-	7	40	3.8	6.4 (2.1)

Table 8: Results of fertigation experiments at Madurai, Tamil Nadu; Soil Texture: Sandy clay loam

Crop	FYM (t/ha)	Conventional fertilizers (kg/ha) (Basal)				Water soluble fertilizers (kg/ha/split) (Fertigation)					No. of splits	Interval (Days)	Yield (t/ha) and B:C ratio (brackets)	
		Urea	SSP	MoP	Others	Urea	19:19:19	12:61:0	0:0:50	others			Conventional	Fertigation
Sugarcane	25	61	98	19	-	31	-	10	-	8	14	10	27.0	48.2 (2.16)
Groundnut	12.5	-	312	-	-	5.4	-	-	-	12.5	10	7	1.3	2.6 (1.73)
Redgram	5	-	312	-	-	5.4	-	-	-	4.1	10	7	0.6	0.9 (2.11)
Onion	25	65	281	50	-	10	-	16	-	-	6	7	12.8	18.1 (1.94)
Rice	25	-	185	48	-	18	4.5	-	-	8.75	16	7	5.4	9.4 (1.28)
Brinjal	12.5	106	168	-	96	29	6.5	7	-	17	20	7	20.0	35.0 (1.48)

Table 9: Results of fertigation experiments at Sriganganagar, Rajasthan; Soil Texture: Sandy loam

Crop	FYM (t/ha)	Conventional fertilizers (kg/ha) (Basal)			Water soluble fertilizers (kg/ha/split) (Fertigation)				No. of splits	Interval (Days)	Yield (t/ha) and B:C ratio	
		Urea	SSP	MoP	Urea	19:19:19	12:61:0	0:0:50			Conventional method	Fertigation
Tomato	-	180	120	80	100	40	-	40	9	12	39.1	48.1 (3.4)
Bittergourd	-	100	40	40	80	32	-	32	12	11	36.6	40.8 (3.2)
Bt Cotton	-	150	40	20	120	32	-	16	6	2	2.5	2.9 (1.5)
Sugarcane ratoon	10	150	40	40	112.5	-	-	30	9	3	61.2	66.0 (2.1)
Cotton	-	150	40	20	150	40	20	-	6	14	2.4	2.6 (1.8)

3. Coordinated Fertigation Experiment

A coordinated fertigation experiment with common set of treatments was initiated from 2015 onward at AICRP on IWM centers *viz.*, Bathinda, Navsari, Palampur, Chalakudy, Madurai and Junagadh. The common set of treatments were

a) 100% N through fertigation
b) 100% N & K through fertigation
c) 100% N, P & K through fertigation
d) 25% NPK as basal and 75% NPK through fertigation
e) 75% N through fertigation
f) 75% N & K through fertigation
g) 75% N, P & K through fertigation
h) 19% NPK as basal and 56% NPK through fertigation
i) 100% NPK through Conventional fertilizers & method

The basic information such as soil textural class, initial NPK status (low/medium/high), recommended dose of fertilizer, conventional fertilizer and water soluble fertilizers in use, crop selected, crop duration, number of fertigation splits and intervals and optimum drip irrigation level from each centre was collected and accordingly, the fertilizer doses were calculated. The center-wise results are given in Tables 10 and 11.

3.1 Bathinda: At Bathinda on loamy sand soil, the maximum tomato and brinjal yields were obtained with 75% and 100% NK fertigation which were statistically higher than that obtained with 100% and 75% NPK fertigation. There was saving of 25% K, 25% P and no saving for N in loamy sand soil. The lowest yields were obtained with 100% NPK conventional method. The B:C ratio were also higher for 75% and 100% NK fertigation primarily due to use of conventional fertilizers for fertigation and the next best treatments with higher B:C ratio were 25% NPK basal + 75 NPK through fertigation and 19% NPK through basal and 56% NPK through fertigation. The lowest B:C ratio was obtained in 100% NPK through conventional method since the yields were also low in conventional treatment.

3.2 Palampur: At Palampur on silty clay loam soil, the treatment with 25% NPK as basal and 75% NPK through fertigation resulted in significantly higher broccoli yields as compared to 75% and 100% N, NK and NPK fertigation treatments. The treatment 25% NPK as basal and 75% NPK through fertigation was statistically at par with 19% NPK basal + 56% NPK fertigation, indicating saving of 25% NPK through fertigation. The 75% and 100% NPK fertigation treatments had the lowest B:C ratio which was primarily due to high cost of commercially available water-soluble fertilizers. The highest B:C ratio was obtained with 75% and 100% N fertigation where only urea was used for fertigation.

3.3 Navsari: At Navsari on clay soil, the treatment with 100% NPK through fertigation resulted in significantly higher cauliflower yield as compared to rest of the fertigation treatments. The treatment 25% NPK as basal and 75% NPK through fertigation had significantly higher cauliflower yield as compared to 19% NPK basal + 56% NPK fertigation. The B:C ratio was higher with 100% NPK through conventional fertilizers which was primarily due to low subsidized cost of conventional fertilizers as compared to NPK fertigation treatments.

3.4 Junagadh: At Junagadh on clay loam soil, the treatment with 25% NPK as basal and 75% NPK through fertigation had significantly higher cotton yield followed by 100% N, 100% NK and 19% NPK basal + 56% NPK fertigation treatments. All these treatments were also statistically at par with each other indicating 25% saving of fertilizers. The B:C ratio was higher with 25% NPK as basal and 75% NPK through fertigation primarily due to higher cotton yield which was followed by 100% N fertigation treatment where only urea was used through fertigation.

3.5 Chalakudy: At Chalakudy on sandy clay loam soil, the treatment with 19% NPK as basal and 56% NPK through fertigation had significantly higher chilli yield followed by 75% NK and 75% NPK fertigation treatments as compared to all the fertigation treatments. All these treatments were also statistically at par with each other indicating 25% saving of fertilizers. The B:C ratio was higher with 100% conventional fertilizer application primarily due to subsidized price of conventional fertilizers and next treatment with higher B:C ratio was 19% NPK as basal and 56% NPK through fertigation.

3.6 Madurai: At Madurai on sandy clay soil, the treatment with 25% NPK as basal and 75% NPK through fertigation had significantly higher chilli and brinjal yields followed by 75% NPK fertigation treatment, both also being statistically at par with each other. The minimum yield was obtained with conventional NPK application followed by 75% and 100% N fertigation. The B:C ratio was higher with 25% NPK as basal and 75% NPK through fertigation primarily due to higher chilli and brinjal yields and minimum was obtained with 100% NPK conventional method.

Plate 3.1: Tomato crop (Bathinda)

Plate 3.2: Brinjal (Bathinda)

Plate 3.3: Broccoli crop (Palampur)

Plate 3.4: Cauliflower crop (Navsari)

Plate 3.5: Chilli (Chalakudy)

Plate 3.6: Cotton (Junagadh)

Table 10: Effect of NPK fertigation on marketable yield (t/ha) of crops

Treatments	Tomato (Bathinda)	Brinjal (Bathinda)	Broccoli (Palampur)	Cabbage (Palampur)	Cauliflower (Navsari)	Cotton (Junagadh)	Chilli (Chalakudy)	Chilli (Madurai)	Brinjal (Madurai)
100% N fertigation	59.4	55.8	4.9	18.4	24.4	1.8	9.3	12.7	48.2
100% NK fertigation	66.4	73.0	4.8	22.4	25.6	1.7	10.3	15.4	58.1
100% NPK fertigation	53.9	58.2	4.7	23.8	34.2	1.6	13.2	16.7	61.5
25% NPK basal + 75% NPK fertigation	61.3	74.4	6.0	28.9	27.1	2.0	14.7	19.1	70.7
75% N fertigation	58.9	53.0	4.9	20.0	25.2	1.5	12.3	11.7	46.1
75% NK fertigation	66.3	72.2	4.3	21.2	24.6	1.5	17.4	13.9	52.0
75% NPK fertigation	53.3	57.1	4.5	22.3	25.2	1.4	18.7	17.8	64.5
19% NPK basal + 56% NPK fertigation	62.0	71.3	5.8	23.5	25.9	1.7	23.2	15.0	56.0
100% NPK by conventional method	41.5	43.7	4.6	22.1	22.8	1.5	16.0	10.2	27.7

Table 11: Effect of NPK fertigation on benefit-cost ratio

Treatments	Tomato (Bathinda)	Brinjal (Bathinda)	Broccoli (Palampur)	Cabbage (Palampur)	Cauliflower (Navsari)	Cotton (Junagadh)	Chilli (Chalakudy)	Chilli (Madurai)	Brinjal (Madurai)
100% N fertigation	2.2	4.7	2.7	2.8	2.0	2.0	2.0	1.7	2.9
100% NK fertigation	2.4	5.8	2.5	3.1	1.9	1.9	2.3	2.0	3.3
100% NPK fertigation	1.9	4.5	0.8	1.3	1.6	1.6	2.7	2.0	3.3

25% NPK basal + 75% NPK fertigation	2.2	5.6	1.3	1.7	1.9	2.1	3.1	2.3	3.9
75% N fertigation	2.2	4.5	3.2	3.6	2.0	1.8	2.7	1.6	2.9
75% NK fertigation	2.4	5.9	2.7	3.3	2.0	1.8	3.8	1.8	3.0
75% NPK fertigation	2.0	4.6	0.9	1.3	2.0	1.5	3.9	2.2	3.6
19% NPK basal + 56% NPK fertigation	2.3	5.6	1.4	1.6	1.9	1.9	4.9	1.9	3.2
100% NPK by conventional method	1.7	4.0	2.5	3.3	2.2	1.7	5.2	1.5	2.1

4. Conclusions

Fertigation is an effective and convenient means of fertilizer application. It includes application of both water and fertilizer in the vicinity of plant root zone as per crop needs, consequently showing higher crop productivity and better quality of produce. This has been explored through experimentations in field, horticultural and cash crops in different agro-ecological regions under the AICRP on Irrigation Water Management (IWM) scheme. Standard commercially available water-soluble fertilizers were used for the fertigation experiments. Fertigation, in general, led to 30-70% increase in marketable yield compared to conventional fertilizer application. Coordinated fertigation experiments with common set of treatments were conducted in varying soil textural classes in some identified centres. Optimum fertigation schedule for loamy sand, sandy clay, clay loam and silty clay loam soils was 25% NPK applied as basal and 75% NPK applied through fertigation. Optimum fertigation schedule for clay soil was 100% NPK through fertigation. Optimum fertigation schedule for sandy clay loam soil was 75% P as basal and 75% NK through fertigation. Fertigation resulted in 26-61% higher economic returns over conventional fertilization.

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NOTES

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