Review article

Fertigation - the key component of precision farming

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Abstract

The importance of fertigation in increasing productivity with efficient and reduced consumption of water and nutrients with practically no pollution is emphasized. The concept of fertigation, including the concepts of wetted soil volume and the resultant root volume and their optimization are discussed. The necessity, principles, chemistry and interactive effects, advantages and limitations of fertigation are explained. The precautions to be taken are also enlisted. The response of different crops to fertigation in terms of yield, use efficiency of water and nutrients etc. are reviewed hereunder.

Keywords: Effective forage space, Fertigation, Fertilizer compatibility, Fertilizer-irrigation water efficency Nutrient and water use, Precision farming, Root volume

Introduction

Fertile and productive soils are the most important components responsible for the development of stable societies and civilizations right from ancient days. As the central pillar of ecosystem functionaries, healthy soils ensure not only the growth of plants which are needed for food, fibre and feed for animals but for water and energy security also. Soil fertility refers to the capacity of a soil to supply the essential nutrients to the plants - the primary producers - in correct quantity, at correct time in balanced proportion according to the crop requirement (Singh and Singh, 2015). The world's population continues to grow rapidly, but the productive cropped land area is decreasing very rapidly due to industrialization and urbanization (Oliver and Gregory, 2015).

The need to supply enough food for a growing world population stimulated interest to increase input efficiency utilizing varieties with high yield potential along with improved water and fertilizer use efficiency. This has got practical significance in terms of increasing scarcity for water on one hand since the demand for water is increasing at an alarming rate, while on the other hand, precision farming was initiated to improve the fertilizer use efficiency using newly available technologies by different rates and combinations as needed for the crop. Precision farming and protected cultivation plays a major role in increasing the productivity from the decreasing cropped area with high water and fertilizer use efficiency utilizing latest technologies. The importance of these aspects have been reviewed by many workers (Keller and Bliesner, 1990; Mondal and Tewari, 2007)

What is fertigation?

One of the features of precision farming is to have maximum possible use efficiency of applied inputs

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especially water and fertilizers. Hence the fertilizers are dissolved at appropriate concentrations in water and applied through irrigation water by micro irrigation systems. This practice is known as fertigation, where the nutrients and water in required quantity at correct time are placed in the root zone so that maximum absorption of applied nutrients and water is assured to achieve more crop per drop of water.

A large range of fertilizer products are suitable for fertigation depending on their physico chemical properties. Solid fertilizer sources are typically less expensive. Four main factors to be considered in selecting fertilizers for fertigation are:

a. Plant type and stage of growth
b. Soil conditions
c. Water quality, and
d. Fertilizer availability and price (Kafkafi and Tarchitzky, 2011)

Fertilizers with high purity and solubility containing low salt levels and with an acceptable pH should be selected, and it must fit in the farm management program in terms of cost.

Need and essentiality of fertigation

The uneven growth is seen in fertilizer consumption across states and crops culminating in inadequate and imbalanced fertilizer application often resulted in increased use of fertilizer and dependence on import of fertilizers. Further the decline in crop response to applied fertilizer due to imbalanced fertilizer application weakens the relationship between fertilizer use and yield potential. This also attenuates the need for balanced application of fertilizer in water soluble form as per the stage wise requirement of the crop in the active root zone in order to achieve maximum use efficiency of both water and fertilizer (NCPAH, GOI, 2017).

Principles of fertigation

The fertigation system aims at maximizing yield by optimizing water and fertilizer use efficiency with reduction in quantity of fertilizer, water and labour, and minimizing pollution. The discharge rate of water should optimize the wetted soil volume in order to assure optimum root volume. This in turn will definitely help in maximum biomass production and economic yield. Such practices usually extend the crop duration and hence the yield, naturally by consuming more quantity of nutrients and water with minimal loss of these inputs. Because of application of small quantity of nutrient and water with more frequency, losses beyond the root volume are minimized thereby improving the use efficiency. The concentration of nutrients in irrigation water should be in such a way so as to maintain the required soil solution concentration in the wetted root zone. If the concentration exceeds the above limit, buildup of salinity can be anticipated, while influx towards the root surface will not occur if it is below this level, which in turn hinders the nutrient uptake (Bar-Yosef, 1999).

The nutrient requirement in terms of quantity and ratio may vary with respect to each crop, variety as well as with the growth stage of the crop. Accordingly the quantity and combination of fertilizers used may also vary in fertigation. In precision farming systems, the nutrients and water supply are optimized for each growth stage according to the requirement so as to enable the plant to optimize all physiological activities realizing in optimizing the highest possible yield. Thus, nutrient prescriptions can be arrived at based on the targeted yields.

This can be achieved by experimentation to identify the optimum requirement of each nutrient at specified time periods for different species of crops. In brief, as indicated in Table 1, optimization of nutrient supply according to the requirement of the crop during different growth stages is done for realizing the potential yield of the crop in fertigation systems without wastage of nutrient and water supplied.

Table 1. Daily consumption rate of nitrogen, phosphorus and potassium (kg ha^{-1} day^{-1}) of different vegetables grown under drip irrigation after emergence or planting (Scaife and Bar-Yosef, 1995).

Days planting/	Tomato greenhouse			Tomato industry			Eggplant			Broccoli			Melon		
emergence	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
1-10	1.00	0.10	2.00	0.10	0.02	0.10	0.05	0.01	0.00	0.02	0.00	0.01	0.15	0.03	0.10
11-20	1.00	0.10	4.00	0.50	0.05	0.30	0.10	0.01	0.00	0.07	0.01	0.02	0.20	0.03	0.25
21-30	1.00	0.10	3.50	1.00	0.16	2.00	0.20	0.01	0.30	1.08	0.12	0.74	0.35	0.07	0.60
31-40	2.50	0.20	3.50	2.80	0.19	2.30	0.25	0.01	0.80	1.22	0.13	0.91	0.90	0.18	1.45
41-50	2.50	0.40	5.50	4.50	0.75	8.00	3.20	0.02	4.90	1.75	0.20	1.35	1.30	0.25	3.00
51-60	2.50	0.60	6.00	6.50	0.80	8.50	2.90	0.08	7.20	1.04	0.13	3.04	2.50	0.25	6.00
61-70	2.50	0.30	4.00	7.50	1.80	9.00	0.25	0.09	1.30	3.02	0.36	4.34	4.30	0.35	7.00
71-80	2.50	0.30	6.00	3.50	0.50	4.50	0.25	0.05	0.50	3.41	0.46	3.95	2.40	0.45	8.00
81-90	1.50	0.30	0.10	5.00	0.50	9.20	0.25	0.05	0.50	2.79	0.38	4.09	1.20	0.43	7.50
91-100	1.50	0.10	0.10	8.00	0.89	9.00	0.25	0.05	0.50	2.09	0.32	3.13	1.00	0.27	3.50
101-110	1.00	0.10	0.10	-	-	-	0.25	0.09	2.00	0.93	0.18	2.74	0.50	0.13	1.00
111-120	1.00	0.10	1.00	-	-	-	1.20	0.15	3.00	0.20	0.09	0.96	0.30	0.07	0.05
121-130	1.50	0.20	1.00	-	-	-	2.40	0.27	3.00	0.18	0.09	0.48	-	-	-
131-150	1.50	0.35	1.30	-	-	-	2.60	0.31	3.00	0.15	0.04	-	-	-	-
151-180	4.00	0.50	3.80	-	-	-	2.30	0.38	1.60	-	-	-	-	-	-
181-200	2.00	0.30	3.00	-	-	-	1.90	0.35	1.60	-	-	-	-	-	-
TOTAL	450	65	710	393	59	520	290	33	380	202	26	165	151	25	385
Variety	F-144			VFM82-1-2			Black Oval			Woltam			Galia		
Date em./pl.	25 Sep**			27 Mar*			10 Sep**			30 Aug**			14 Jan		
Harvest	Selective			18 Jul			selective			17 Jan			Selective		
Plants/ha	23,000			50,000			12,500			33,000			25,000		
Soil	Sandy			clay			sandy			loam			Sandy		
Yield (Mg ha^{-1})	195			160			51			13			56		

Chemistry of fertigation

In order to make suitable planning for supplying the required nutrients to the crop in right quantity in right time in appropriate proportion based on the physiological growth stage, the daily nutrient consumption rate for optimum yield during the growing cycle that results in maximum yield and quality should be assessed. The results of the work done by Scaife and Bar-Yosef (1995), is self-explanatory from Table 1. Effective fertigation requires an understanding of plant growth behavior including nutrient requirements and rooting patterns, soil chemical factors controlling the solubility and mobility of the nutrients and other factors like pH and salt index in soil as well as the interaction between fertilizers and irrigation water. The latter aspects are mainly governed by the chemical properties of fertilizers like concentration, form and chemical composition as well as the quality of water used. The solubility of fertilizer in water, super saturation of common ions (when more than one fertilizer material is used) and the resulting tendency for precipitation and clogging and compatibility should be primarily considered as criteria for selection of sources for fertigation (Imas, 1999). The chemical properties of common water soluble fertilizers used for fertigation, are presented

Table 2. Fertilizer evaluation for suitability to fertigation

Property	Ammonium nitrate	Ammonium sulphate	Potassium sulphate	Potassium chloride	Potassium nitrate	Phosphoric acid	Mono ammonium phosphate
Solubility	High	Medium	Low	Medium	Medium	High	Medium
Precipitation	Low	High	High	Low	Low	Low	High
Compatibility	Good	Poor	Poor	Medium	Medium	Medium	Good
Corrosion	Medium	Poor	Poor	Poor	Good	Poor	Medium

(Source: NCPAH, GOI, 2017)

Table 3. Compatibility chart of different water soluble fertilizers for fertigation

Fertilizers	Urea	Ammonium nitrate	Ammonium sulphate	Calcium nitrate	Mono ammonium phosphate	Mono potassium phosphate	Potassium nitrate
Urea		C	C	C	C	C	C
Ammonium nitrate	C		C	C	C	C	C
Ammonium sulphate	C	C		LC	C	C	LC
Calcium nitrate	C	C	LC		NC	NC	C
Mono ammonium phosphate	C	C	C	NC		C	C
Mono potassium phosphate	C	C	C	NC	C		C
Potassium nitrate	C	C	LC	C	C	C	

(NCPAH, GOI, 2017)

C: Compatible, LC:Limited Compatible: NC Not Compatible

in Table 2. Table 3 depicts the compatibility of different fertilizers used in fertigation. The corrosiveness due to presence of halides and residual acidity will adversely affect the durability of the fertigation system.

In addition to the above, use of calcium nitrate with any phosphate or sulphate, use of magnesium sulphate with mono and di ammonium phosphates and that of phosphoric acid with sulphates of iron, manganese, zinc and copper should be avoided as there is chance of either precipitation or toxicity. It is always advisable to have separate fertilizer tanks for compatible and incompatible fertilizers to avoid precipitation and clogging.

The quality of water used for fertigation as indicated by pH, salinity (measured by EC) and sodium hazards as indicated by sodium adsorption ratio (SAR) and Residual sodium carbonate (RSC), Mg/Ca ratio, concentration of boron and toxic metal ions are also to be considered as important factors in fertigation systems (BIS, 1986).

Interaction between fertilizers and irrigation water

The water with high content of carbonates and bicarbonates of calcium and magnesium as usually seen in tube well waters, results in precipitation in fertilizer tanks especially that of phosphates and clogging in the system due to increase in pH. On the other hand water with low pH and high content of iron and aluminium as in tropical climate can cause toxicity due to these elements in addition to precipitation of phosphorus. Hence it is mandatory to use water with near neutral pH for fertigation.

Advantages of fertigation

Fertigation assures uniform application of nutrients to the rhizosphere where the active roots are concentrated. Effective foraging space (EFS) of a plant is defined as the soil space which accounts for 80 per cent or more of root activity (Wahid, 2000). Therefore, it is possible to supply the nutrients in the EFS to assure almost complete absorption according to the crop demand throughout the growing season. Moreover, fertigation ensures higher and quality yield along with savings in time and labour which makes fertigation economically profitable (Singh, 2002). Fertigation involves not only the efficient use of the two most precious inputs, i.e. water and nutrients, but also exploits the synergism of their simultaneous availability to plants.Thus, losses of fertilizers are prevented and maximum absorption is assured since there is constant supply of soluble form of nutrients through irrigation water in small quantities. Moreover, the amount of fertilizer to be applied can be significantly reduced since the efficiency is the highest possible. This is because of application of soluble forms of fertilizers through micro irrigation system only to the wetted root zone. Easy and uniform application in soluble form through irrigation water assures reduction in labour cost, especially for top dressing.

The saving of energy and labour, flexibility with respect to time of application of nutrients, convenient use of soluble fertilizers and fertilizer solutions containing micronutrients in correct quantity, controlled supply and monitoring of water and nutrient supply are additional advantages of fertigation. The expensive investment of fertilizer injection system, and safety devices are the limiting factors for fertigation (Imas, 1999).

Consequently, recommendations have to be developed for the most suitable fertilizer formulation (including the primary, secondary and micro nutrients) according to the type of soil, physiological stage, climate and other factors. Special attention should be given to the pH, nutrient mobility in soil and salinity conditions.Planning the irrigation and nutrient supply to the crops according to their physiological stage and consideration of the soil and climate characteristics, results in quality produce both in terms of food security and nutritional security.

Precautions for fertigation

1. The fertilizers should be fully dissolved in water before fertigation.
2. The selected fertilizers should be fully compatible with each other.
3. The quality of irrigation water should be properly checked and managed before mixing.
4. Incorrect application may lead to salinity problem, crop damage, leaching of nutrients and pollution of ground water.
5. The time needed to distribute the fertilizer should be less than the time needed to supply enough water to the field; otherwise salinity may arise.
6. Over irrigation should be avoided.
7. The ratio NH_4/NO_3 of nitrogen sources should be such as to have a nitrogen mixture with 80% of nitrates and 20% of ammonium to regulate pH.

Yield under fertigation as a function of water and nutrient use efficiency

The texture of the growing media is an important factor deciding the movement of nutrients and water in fertigation. In order to assure the uniform supply of water and nutrients to the crop through fertigation, the quantity should be such that mobility of ions both through convective and diffusive gradient flow is sufficient to meet the requirement of the plant.

The limited migration of strongly adsorbed ions in soil implies that the distance between the emitters strongly affect the nutrient availability to the plants. In general, for mobile nutrients, with low buffering capacity, low rates may be sufficient so as to have dual advantages of meeting the crop needs along with minimizing the leaching losses. On the other hand, for nutrient with restricted mobility, the concentration as well as the frequency of application might be more to assure the reach of nutrients to the root surface.

Soil root volume effects

For a given soil emitter discharge rate, increasing the frequency of fertigation reduces the change in nutrient concentration in soil solution as a function of time. The size of root volume depends on the initial soil water content. Confined root systems improve the carbon economy of the plants because of the allocation of more carbohydrates to fruit production. The other advantage of a confined root system is the easy and effective control of salt content in root zone.

Table 4. Irrigation salinity classification

Effects	EC (dS m^{-1})	TDS (mg L^{-1})
No effects noticed	0.75	500
Can have detrimental effects on sensitive crops	0.75-1.5	500-1000
Can have adverse effects on many crops	1.5 - 3	1000-2000
Can be used for tolerant crops	3 - 7.5	2000-5000

Reducing the salinity hazards

The total soluble salt concentration in irrigation water for fertigation should be controlled so as to restrict the salinity in the root zone towards the safe limits, which in turn is crop specific. The following are the details of ratings of water (Table 4) and soil (Table 5) with reference to salinity as given by (NRCS, USDA, 2017).

Table 5. Soil salinity classification

Soil	EC (dS m^{-1})
Sensitive	>0.9
Moderately sensitive	>1.4
Moderately tolerant	>2.5
Tolerant	>4

In comparison to flood irrigation/sprinkler irrigation, water with comparatively higher salinity can be used in drip system because of the efficient displacement of the salts to the periphery of the wetted soil volume as well as the reduced salt concentration due to increased frequency of irrigation. The influx of ions from the periphery of the wetted soil volume is restricted due to increased concentration of nutrient ions in the root volume. Higher nitrate (NO_3^-) in the root volume may restrict the movement of chloride (Cl^-) and similarly, higher K^+ may reduce the inflow of Na^+.

Yield increase under fertigation

The percentage yield increase and water saving through fertigation has been established in many crops, and is summarized in Table 7. The substantial increase in fertilizer use efficiency under fertigation for major nutrients was also confirmed (Table 6).

Studies conducted to achieve highest fertilizer use efficiency and realized potential yield in different crops under fertigation system are reviewed hereunder.

Tomato

A field experiment was conducted during the summer seasons of 1999–2000 and 2000–2001 at Hebbal, Bangalore to study the effect of fertigation with sources and levels of fertilizer and methods of fertilizer application on growth, yield and fertilizer use efficiency of hybrid tomato in red sandy loam soil. The total dry matter (TDM) production and fruit yield of tomato was 19.9% higher in drip irrigation (71.9 Mg ha^{-1}) over furrow irrigation (59.50 Mg ha^{-1}). Fertigation with 100 per cent Water Soluble Fertilizers (WSF) increased the fruit yield significantly (79.2 Mg ha^{-1}) and increased fertilizer use efficiency (226.48 kg yield kg^{-1} NPK). Fertigation resulted in lesser leaching of NO_3-N and K to deeper layer of soil (Hebbar et al., 2004).

In contrast, other studies revealed that the yield under fertigation can be improved with good quality fruit production of tomato even with 60 percent of

Table 6. Fertiliser use efficiency in fertigation (%)

Nutrient	Soil application	Drip + soil application	Drip + fertigation
N	30-50	65	95
P_2O_5	20	30	45
K_2O	60	60	80

(Source: Biswas, 2010)

Table 7. Recommended dose of major nutrients and yield under fertigation

Crop	Yield (Mg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
Apple	25	100	45	180
Banana	40	250	60	1000
Citrus	30	100	60	350
Grapes	20	170	60	220
Mango	15	100	25	110
Papaya	50	90	25	130
Pineapple	50	185	55	350
Cabbage	70	370	85	480
Carrot	30	125	55	200
Cauliflower	50	250	100	350
Cucumber	40	70	50	120
Egg plant	60	175	40	300
Okra	20	60	25	90
Onion and garlic	35	120	50	160
Spinach	25	120	45	200
Tomato	50	140	55	190

(Source: Biswas, 2010)

recommended dose of fertilizer (RFD 150: 60: 90 kg NPK ha^{-1}). The recorded yield was 86.4 Mg ha^{-1}, while the soil application of recommended dose of fertilizer could only achieve 66 Mg ha^{-1} (Gupta et al., 2014).

Hybrid cucumber

An experiment on assessment of effect of fertigation on hybrid cucumber with 4 levels of irrigation, *viz*., 100%, 80% and 60% ET through drip and flood irrigation; and 4 levels of fertilizer application, *viz*., 100, 80 and 60 per cent recommended NPK through fertigation and 100% recommended NPK as manual application was concluded with the following results. Drip irrigation and fertigation had significant influence on growth and yield attributes of cucumber hybrid SH-CH-1. The combined effect of drip irrigation and fertigation (80% ET through drip + 80% recommended NPK through fertigation produced highest yield (144.4 Mg ha^{-1}) which was found to be 68.1 per cent more than that of the traditional method of irrigation and fertilizer (70:30:30 kg NPK ha^{-1}) application. It could also save 37.8 per cent water and 20 per cent fertilizers with highest B/C ratio (5.99:1) (Gupta et al., 2014).

At the same time there are reports indicating the lower yields in poly house which can be improved by manipulating the fertigation schedules such as a yield of 54.43 Mg ha^{-1} obtained with 100 per cent RDF treatment (150:70:160 kg NPK ha^{-1}) in ventilated polyhouse for cucumber using the gynoecious variety Sandhya (F_1 hybrid) (Pushpendra and Hardaha, 2016).

Sweet pepper

Drip irrigation with 100 per cent evaporation replenishment of water along with supplementation of 100 per cent recommended N and K through fertigation recorded 61.09 per cent yield increase over conventional fertilization in bell pepper along with significantly higher ascorbic acid content and the highest cost benefit ratio of 1: 1.72 at Jorhat, Assam (Brahma et al., 2010)

Hybrid bitter gourd

Reports from TNAU confirmed a yield of 37.5 Mg ha^{-1} in hybrid bitter gourd by fertigation of recommended dose of fertilizers in water soluble form along with micro nutrients in comparison with that of soil application of recommended dose of fertilizers which yielded only 25.66 Mg ha^{-1}. Significant increase in quality parameters like vitamin C content was also noticed by fertigation (Meenakshi et al., 2007)

Potato

Field experiments conducted for 3 consecutive seasons at Potato Research Station, SDAU, Deesa (Gujarat) showed that drip fertigation of 100 per cent of recommended dose of N and K at 9, 16, 23, 30, 37, 43, 51, 58 and 65 days after planting markedly increased growth attributes like plant emergence and plant height and ultimately gave significantly higher quality tubers (">75 g grade" potato tuber) and total tuber yield of potato over conventional method. Further, this method improved crop productivity, water and nutrient use efficiency along with net return and benefit-cost ratio, which were much higher than conventional method (275:140:275 kg N: P_2O_5: K_2O ha^{-1}) (Chongtham et al., 2016).

Pigeon pea

Field experiments from Agricultural College and Research Institute, Madurai, Tamil Nadu, India revealed that drip fertigation with 100% recommended dose of fertilizer through water soluble fertilizers + foliar feeding with 0.5% $ZnSO_4$, could record the highest yield, mainly due to greater and consistent availability of nutrients, growth hormones and soil moisture which led to better crop growth, physiological characters and seed yield components, reflected on the seed yield

(Manikandan and Sivasubramaniam, 2015).

Banana

Field experiments were conducted on clay loam soil in western Maharashtra for three consecutive years (2007-2010) to study the response of drip fertigation on growth, yield, quality and economics of banana cv. Grand Naine. The experiment comprised of 100, 80 and 60 per cent water soluble fertilizers applied through drip irrigation in two schedules and results were compared with three control treatments. The study indicated the beneficial effects of drip irrigation in terms of 23 per cent increase in yield and 45.3 per cent water saving whereas drip with fertigation resulted into 24 to 46 per cent increase

Table 8. Fertilizer injection schedule for different vegetables

Crop	Typical bed spacing(m)	Rows per head	Total nutrient kg ha^{-1}		Crop development		Injection rate 7 days kg ha^{-1}	
			N	K_20	Stage	week	N	K_2O
Broccoli	2	1	150	150	1	2	7	7
					2	3	14	14
Cauliflower	1	2	175	150	1	1	14	12.25
					2	9	17.15	15.75
Cucumber	1.5	2	150	120	1	1	7	7
					2	2	14	10.5
					3	6	17.5	14
					4	1	14	10.5
Onion	2	6-10	150	150	1	2	7	7
					2	4	10.5	10.5
					3	4	14	14
					4	4	10.5	10.5
					5	1	7	7
					6	1	7	7
Pepper	1.2	2	175	160	1	2	7	7
					2	2	10.5	10.5
					3	7	17.5	17.5
					4	1	10.5	7
					5	1	7	7
Pumpkin	8	1	120	120	1	2	7	7
					2	2	10.5	10.5
					3	7	14	14
					4	1	10.5	10.5
					5	1	7	7
Tomato	6 feet	1	175	225	1	2	7	10.5
					2	2	10.5	14
					3	7	17.5	21
					4	1	10.5	14
					5	1	7	10.5
Water melon	8 feet	1	150	150	1	2	7	7
					2	2	10.5	14
					3	4	17.5	17.5
					4	3	10.5	10.5
					5	2	7	7

(Source: NCPAH, GOI, 2017)

in banana yield with equal amount of water saving as compared to conventional method. The results revealed that drip fertigation significantly increased growth, yield contributing and quality characters as compared to conventional fertilizers. Fertigation as per the growth stages proved superior as compared to uniform splits for all the characters including yield. The 100 per cent recommended dose of fertilizer through drip as per crop growth stages showed 46.22 per cent increase in yield (83.62 Mg ha^{-1}) (Pawar and Dingre, 2013).

Citrus

The economic feasibility of fertigation and mulching on 4-year-old Assam lemon was evaluated with three levels of fertigation applied at 120, 100 and 80 per cent of recommended dose of fertilizer through drip. Soil application of fertilizers with recommended dose was used for comparison. Among the different fertigation levels, 120 per cent of recommended dose recorded the highest yield with 22.05 percentage increase over conventional method with highest fruit weight, volume and juice content (Barua, 2013).

Cotton

The paired row planting (0.75 - 1.5 x 0.75 m) of Bt cotton in an Inceptisol with the application of water soluble fertilizers (N, P, K @ 90: 45: 45 kg ha^{-1} respectively) and apportioning them through drip irrigation (fertigation) in equal weekly splits at 11 to 30 DAP (NPK @ 18, 9, 4.5 kg ha^{-1}), 31 to 60 DAP (NPK @ 36, 22.5, 18 kg ha^{-1}) and 61 to 100 DAP(NPK @ 36, 13.5, 22.5 kg ha^{-1}) could help in increasing the yields, in saving of fertilizers up to 25 per cent along with maximum movement of nutrients in soil, when compared with that of conventional fertilizers (N, P, K @ 120: 60: 60 kg ha^{-1} respectively) with surface irrigation (Bhakare et al., 2015).

Bajra Napier hybrid

Paired row planting of bajra napier hybrid with irrigation at 100 per cent PE and fertigation at 125 per cent recommended dose of nitrogen recorded a green fodder yield of 368.17 and 349.83 Mg ha^{-1} respectively in Tamil Nadu (Alagudurai and Muthukrishnan, 2014).

Table 9. Fertigation schedule for banana (Nendran) rate for 1000 tissue culture plants- every 4th day

Table 9a. Full dose- 190:115:300 g/plant, 50% P- basal application

Period	No. of splits	Urea*	MAP*	MOP*
1-60 days	15	4.8	2.5	6.7
61-120 days	15	8.7	3.8	11.7
121-180 days	15	8.3	0	10
181-280 days	25	2.5	0	3.0

*fertilizer material (kg) per application

Table 9b. Sucker planting

Period	No. of splits	Urea	MAP	MOP
30-60 days	9	8.1	4.2	11.1
60-120 days	15	8.7	3.8	11.7
120-180 days	15	8.3	0	10.0
180-280 days	25	2.5	0	3.0

Table 9c. Fertigation schedule for banana (Grand Naine) for 1000 tc plants (Full dose 200:200:400 g/plant)

Period	No. of splits	Urea	MAP	MOP
1-60 days	15	4.6	4.4	11.1
61-120 days	15	5.5	6.6	15.5
121-180 days	15	8.7	0	13.3

Fertigation schedules of nutrients

Fertilizer injection schedules are developed by different agencies for various vegetables for fertigation by considering stage wise nutrient requirement and proportions. The schedule developed by Indian Institute of Horticulture Research, Bangalore for some important vegetables

Table 10. Fertigation schedule for vegetables

30 splits

Crop		Total (Kg ha^{-1})	Total NPK (kg ha^{-1}) Basal	Estb 6 doses	Veg 12 doses	Fruting 22 doses	19/19/19 kg ha^{-1} Estb 6 doses	Veg 12 doses	Fruting 22 doses	13:00:45 kg ha^{-1} Estb 6 doses	Veg 12 doses	Fruting 22 doses	Urea kg ha^{-1} Estb 6 doses	Veg 12 doses	Fruting 22 doses	12:61: 00 kg ha^{-1} stb E 6 doses	Veg 12 doses	Fruting 22 doses
Cabbage40 Mg ha^{-1}	N	211		42.20	84.4	84.4												
	P	49	24.5	4.90	9.8	9.8	25.8	25.8	25.8	28.0	232.7	232.7	81.1	75.30	141.1	0.00	8.00	8.00
	K	274		54.8	109.6	109.6												
Cauliflower 30 Mg ha^{-1}	N	150		30.0	60.0	60.0												
	P	60	30	6.0	12.0	12.0	31.6	31.6	31.6	26.7	173.3	173.3	52.2	39.1	88.0	0.00	9.80	9.80
	K	210		42.0	84.0	84.0												
Cucumber100 Mg ha^{-1}	N	175		35.0	70.0	70.0												
	P	125	62.5	12.5	25.0	25.0	65.8	65.8	65.8	55.6	238.9	238.9	48.9	42.3	109.8	2.00	20.50	20.50
	K	300		60.0	120.0	120.0												

40 splits

Crop		Total (Kg ha^{-1})	Total NPK (kg ha^{-1}) Basal	Estb 6 doses	Veg 12 doses	Fruting 22 doses	19/19/19 kg ha^{-1} Estb 6 doses	Veg 12 doses	Fruting 22 doses	13:00:45 kg ha^{-1} Estb 6 doses	Veg 12 doses	Fruting 22 doses	Urea kg ha^{-1} Estb 6 doses	Veg 12 doses	Fruting 22 doses	12:61: 00 kg ha^{-1} stb E 6 doses	Veg 12 doses	Fruting 22 doses
Okra 30 Mg ha^{-1}	N	90		18.0	36.0	36.0												
	P	37.5	18.75	3.8	7.5	7.5	19.7	19.7	19.7	20.0	111.7	111.7	31.0	4.3	35.9	0.00	6.1	6.1
	K	135		27.0	54.0	54.0												
Capsicum	N	210		31.5	63.0	115.5												
	P	48	24	3.6	7.2	13.2	18.9	18.9	34.7	22.0	176.0	322.7	60.7	44.8	208.7	0.00	5.9	10.8
	K	276		41.4	82.80	151.8												
Bitter gourd	N	210		31.5	63.00	115.5												
	P	74	37	5.55	11.1	20.4	29.2	29.2	53.6	5.00	137.7	252.4	50.4	55.7	208.7	0.00	9.1	16.7
	K	225		33.75	67.5	123.8												
Snake gourd	N	210		31.5	63.00	115.5												
	P	74	37	5.55	11.1	20.4	29.2	29.2	53.6	5.00	137.7	252.4	50.4	55.7	208.7	0.00	9.1	16.7
	K	225		33.75	67.5	123.8												
Pumpkin	N	120		18.00	36	66.0												
	P	60	30	4.5	9.00	16.5	23.7	23.7	43.4	10.00	90.00	165.0	29.3	10.5	101.1	0.00	7.4	13.5
	K	150		22.5	22.5	82.5												
Ashgourd	N	120		18	36	66												
	P	60	30	4.5	9	16.5	23.8	23.8	43.11	10	90	165	29.3	10.4	101.1	0	7.4	13.5
	K	150		22.5	22.5	82.5												
Brinjal	N	175		26.25	52.5	96.3												
	P	40	20	3	6	11	15.8	15.8	38.60	41.7	193.3	354	50.5	17.1	166.8	0	4.9	9.
	K	300		45	90	165												
Yard long bean	N	170		25.5	51	93.5												
	P	105	52.5	7.9	15.75	28.9	41.4	41.4	76	46.7	189.2	346.8	38.3	15	160.9	0	12.9	23.7
	K	310		46.5	93	170.5												
	K	380		45.6	91.2	167.2												

50 splits

crop		Total NPK	Basal kgha^{-1}	Total NPK (kg ha^{-1}) Estb 6 doses	Veg 12 doses	Fruitig 22 doses	Last 10 doses	19:19:19 (kg ha^{-1}) Estb 6 doses	Veg 12 doses	Fruiting 22 doses	Last 10 doses	13:00:45 (kg ha^{-1}) Estb 6 doses	Veg 12 doses	Fruiting 22 doses	Last 10 doses	Urea (kg ha^{-1}) Estb 6 doses	Veg 12 doses	Fruiting 22 doses	Last 10 doses	12:61:00 (kg ha^{-1}) Estb 6 doses	Veg 12 doses	Fruiting 22 doses	Last 10 doses
Tomato	N	280		33.60	67.20	123.2	56.0																
100 Mg ha^{-1}	P	130	65	9.75	19.50	35.75	0.0	51.30	51.3	94.10	0.00	26.7	181.	331.8	168.9	51.8	52.5	225.4	43.5	0.00	16.0	29.30	0.00
	K	380		45.60	91.20	167.2	76.0																

are summarized in Table 8 (NCPAH, GOI, 2017).

Fertigation schedule has been developed by Kerala Agricultural University for some important vegetable crops (Sureshkumar and Geetha, 2015). The schedules are presented in Table 10. Fertigation schedules for banana (both for TC and sucker in Nendran and for TC in Grand Naine) are presented in Table 9. These recommendations were based on the nutrient removal in poly house fertigation systems. Care should be taken to maintain the pH near neutrality by lime application since the soil as well as the water can have acidic pH range under tropical humid climate.

The economic use of fertilizers and water for realizing the potential yield and for sustainable agriculture is the need for the hour. This is required to harvest more quantity produce with a competitive price which can be planned for seasons of high demand under protected cultivation system. The efficient use of water and fertilizers for more yield per unit area is necessary for food security and for keeping the soil and water in a pollution free environment. Fertigation is not an alternate way but the need of the hour and the best way to realize the potential yield with highest fertilizer and water efficiency and with minimum pollution with more control over factors of productivity.

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