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IMPROVING WATER AND FERTILIZER USE EFFICIENCY USING MICROIRRIGATION

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ABSTRACT

This manuscript presents importance of fertigation, types of fertilizers, their solubility and compatibility problems, fertigation system design and types of fertigation equipment. The research work carried out on fertigation with drip in fruits, vegetable, field crops and rose in India and abroad is also presented in this manuscript. Extensive work carried out by the author and his research group in the Precision Farming Development Centre project at IIT Kharagpur is also presented in this paper. The study shows that the use of micro irrigation significantly improves the water and fertilizer use efficiency.

Keywords: *Water use efficiency, Fertigation, Precision farming, Microirrigation.*

INTRODUCTION

Improving food grain productivity and sustainability of the production system is essential to maintain food security for the growing global population. As of today, about a billion populations have limited/no access to food. By 2050, the global food production needs to be increased by 70-110 percent at 2.4 percent per year to meet the food demand of 9 billion population (Alexandratos and Bruinsma, 2012; Ray et al., 2012; Zhou and Butterbach-Bahl, 2014). On the other hand, shrinking and degrading natural resources like land, water, energy and environment pose serious threat to enhancing global food production. With the advent of climate change, availability of water resources is going to be limited for future agricultural production, which poses a challenge to food production of the world in general and of developing countries in particular, which are highly vulnerable to climate change (Misselhorn et al., 2012). Further to address the environmental impacts of agricultural intensification aimed at minimizing yield gap, efforts should be made to decrease overuse of inputs like water and nutrients while maintaining and/or improving the food grain productivity (Mueller et al., 2012). Hence, it is highly essential to develop and implement resources (water and nutrients) in efficient manner to ensure the global food security in a sustainable manner. Drip irrigation, a precise water management technology which reduces evaporation, seepage and percolation losses, can be applied in rice fields in water scarce condition. Moreover through the drip irrigation, water soluble N fertilizers can be precisely applied directly in crop root zone which can reduce costs and environmental hazards (Shock, 2013). Subsurface drip irrigation is a highly precise method of water application, which enables monitoring the placement and application rate of water-soluble fertilizers in plant root zone (Thompson et al., 2000; Darwish et al., 2006). Precision N management through drip fertigation can reduce overall fertilizer application rates and thereby minimize adverse environmental impact. Researchers have demonstrated drip-irrigated crop response to N fertilizer leading to higher water use efficiency (Hanson and May, 2004; Wang et al., 2009) in crops such as wheat (Gao et al., 2014); cotton (Enciso et al., 2005) and corn (El-Wahed and Ali, 2013). However, research on use of drip irrigation on rice production is very limited. Drip irrigation or subsurface drip irrigation is a precise water and fertilizer management technology which can be used to improve resource use efficiency without affecting yield. Higher water and nitrogen use efficiencies through drip irrigation compared to conventional methods of irrigation have been reported by various researchers in vegetable crops, plantation crops, horticultural crops and high value cash crops. Fertigation is precise application of plant nutrients with irrigation system in the crop root zone according to the crop demand during crop growing season. In fertigation, fertilizer application is made in a small and frequent dose that feed within scheduled irrigation interval matching the plant water use to avoid leaching. Table 1 provides details of saving in the use of fertilizers and increase in yield (Anonymous 2001). Application of fertilizers and chemicals through drip or sprinkler system known as fertigation or chemigation, water soluble fertilizers can be effectively and efficiently applied through drip irrigation system. Reduced labour, equipment and energy costs and higher fertilizer use efficiency are the major benefits of fertigation. The success of drip irrigation, to a good degree, is due to the improved supply of nutrients at the desired location.

Table 1: Saving in fertilizer and increase in crop yield due to fertigation as compared to conventional method of fertilizer application

S. No.	Crop	Saving in fertilizer, %	Increase in yield, %
1	Okra	40	18
2	Onion	40	16
3	Broccoli	40	10
4	Banana	20	11
5	Castor	60	32
6	Cotton	30	20
7	Potato	40	30
8	Tomato	40	33
9	Sugarcane	50	40

GENERAL POINTS CONSIDERATION FOR FERTIGATION

The following points should be considered in operation of fertigation/ chemigation system.

i) The fertilizers/chemicals to be used should be water soluble.

ii) The fertilizers/chemicals should be injected at the upstream end of the filters to ensure that any undissolved particles of the fertilizers/chemicals are removed before entering in to the system.

iii) The irrigation system should be pressurized before starting the process of fertigation and chemigation.

iv) The system should be equipped with the anti-siphon device to protect the water supply from contamination of the fertilizers/chemicals. For this purpose, it is important to provide check and vacuum relief valves (anti-siphon devices) for preventing the chemical from draining or siphoning back into the irrigation well or to other water supply source. The vacuum and check valves must be located between the pump and the point of chemical injection. If water is blend from the main irrigation supply into the chemical supply tank, the connecting line too must be equipped with a check valve to prevent the supply tank from overflowing and contaminating the adjacent area with chemical solution.

v) The coefficient of uniformity (CU) of water application of irrigation system should be between 80 per cent and 90 per cent. This is important to ensure uniform application of chemicals to the area that is being fertilized or treated with herbicides or pesticides. Non uniform systems would results in poor placement of the chemicals.

vi) The size of the pump or rate of chemical injection into the sprinkler system should be checked closely so as to ensure desired application rate of the chemical. The rate of injection also depends on requirement: a) for continuous injection b) the entire volume of chemical is injected in the beginning or at the end of the irrigation set. Intermittent injection requires the system to be flushed intermittently.

Advantages of Fertigation

- *Synchronization with plant requirement:* In drip fertigation, fertilizer application is synchronized with plant need which varies from plant to plant. The amount and form of nutrient supply is regulated as per the need of critical stages of plant growth.
- *Economics:* Saving in amount of fertilizer, due to better fertilizer use efficiency and reduction in leaching. Reduction in labour and energy cost by uniform water and nutrient distribution.
- *Balanced nutrient availability:* Optimization of nutrient balance in soils by supplying the nutrients directly to the effective root zones as per the requirement.
- *Higher yield:* Greater yield and quality of produce is obtained.
- *Higher fertilizer use efficiency:* Ensures a uniform flow of water and nutrients. Timely application of small but precise amounts of fertilizers directly at the plant roots zone, this improves fertilizer use efficiency and reduces nutrient leaching below the root zone. Improves availability of nutrients and their uptake by crop.
- *Safer application method*: It eliminates the danger affecting roots due to higher dose.

Limitations of Fertigation

- *High initial investment:* The drip and fertigation equipment components are expensive.
- *Relatively higher maintenance cost:* The maintenance cost of drip and fertigation system is higher.
- *Clogging of drip emitter:* Good quality water is very essential. Due to precipitation of chemicals, clogging of drip emitters may cause a serious problem.
- *Availability of water soluble fertilizers& its compatibility:* It needs water soluble fertilizers; the availability of these types of fertilizers is limited. Adjustment of fertilizers to suit the need is not easy.
- *Subsidy in drip system:* Area under micro irrigation is increasing mainly because of subsidy in micro-irrigation, if subsidy is withdrawn, the area under micro-irrigation may also reduce. So same may be the fate of fertigation.
- *Overdosing:* Due to fear of yield loss, because of relatively lower dose of fertilizers in fertigation, farmers have the tendency to add additional fertilizers and irrigation water by traditional methods too. This may result in crop loading (sugar cane) lower yield and lower profits.

TYPES OF FERTILIZERS

A large range of fertilizers, both solid and liquid, are suitable for fertigation depending on the physicochemical properties of the fertilizer solution. For large scale field operations, solid fertilizer sources are typically a less expensive alternative to the commonly used liquid formulations. The solubility of these fertilizers does vary greatly.

The main fertilizers/chemicals used for fertigation are:

Nitrogen: Nitrogen is usually applied through the system as anhydrous ammonia, aqua ammonia, ammonium phosphate, urea, ammonium nitrate, calcium nitrate or several other mixtures. Careful consideration must be made for the pH in irrigation water since some nitrogen sources, particularly aqua ammonia and anhydrous ammonia, will increase pH. The increased pH can result in precipitation of insoluble calcium and magnesium carbonates that can clog the drip system. Urea and urea-ammonium nitrate mixture are highly soluble and usually do not cause large pH shifts.

Phosphorus: Phosphoric acid is soluble and with low pH water has no clogging problems. Sulfuric acid injection together with phosphoric acid may be sufficient to prevent precipitation of calcium and magnesium especially as the phosphoric acid boundary passes. Inorganic phosphate, orthophosphate and glycero phosphate have also been used to supply phosphorus.

Potassium: Potassium can be applied as potassium chloride and potassium nitrate. These potassium sources are soluble and have few precipitation problems. The Potassic fertilizers are water soluble and quick acting such as potassium chloride or muriate of potash, potassium sulphate, potassium magnesium sulphate, also known as Sulphate of potash magnesia.

The K ions are absorbed in the soil and thus remain available, and largely protected against leaching. However, split application is advisable where higher leaching losses may be expected. Some immobilization into clay lattice layers reduces availability but strong fixation into completely unavailable forms is limited to a few special soil types.

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 preferred. Soluble dry fertilizers containing N, P and K in different combinations are also available in the market.

Micronutrients: Manganese, zinc, iron, copper, etc., may be applied as soluble salts through the irrigation system. These should each be injected separately and apart from other fertilizers and chemicals to avoid chemical interaction and precipitation. Iron, copper, zinc and manganese may react with salt in irrigation water and result in precipitation. However, the more soluble chelated forms such as iron or zinc EDTA (ethyl-enediamine tetra acetate dihydrate) usually cause little clogging problem.

SOLUBILITY OF FERTILIZERS

The quantity of fertilizer that can be dissolved in unit quantity of water is called the solubility. Normally nitrogen and potassic fertilizers do not have solubility problem. However, phosphatic fertilizers such as DAP & SSP do not readily dissolve in water. The solubility is greatly affected by the temperature variations. The solubility decreases with decrease in temperature. Table 2 to 7 provides the solubility limit (g/l) of nitrogenous, potassic and phosphatic and micro nutrient fertilizers.

FERTIGATION SYSTEM DESIGN

In drip irrigation the wetted soil volume is limited; the root system is confined and concentrated. The nutrients from the root zone are depleted quickly and continuous application of nutrients along with the irrigation water is desired.

Factors crucial for effective fertigation design include (i) estimation of available nutrients in soil, (ii) estimation of amount of fertilizer required, (iii) frequency of fertigation, (iv) fertilizer tank capacity, (v) irrigation water requirement, (vi) capacity of drip system, (vii) injection duration, (viii) estimation of concentration of nutrients in irrigation water and (ix) injection rate.

Fertigation/ Chemigation Devices

There are several equipment available for the application of fertilizers /chemicals through the sprinkler irrigation systems. The choice of a particular method depends on: flow rate, operating pressure, type of fertilizers/chemicals to be used, concentration of the fertilizers/chemicals, time of operation and power source.

Pressurized fertigation tank

The pressurized chemical tank is generally made of corrosion resistant enamel-coated or galvanized cast iron, stainless steel or fiber glass. This should withstand the network working pressure. The diverted water is mixed with solid soluble or liquid fertilizers in the pressure tank. A pressure differential is created by throttling the water flow in the control head and diverting a fraction of the water through a tank containing the fertilizer solution. A gradient of 0.1 to 0.2 bar (1 – 2 m) is required to redirect an adequate stream of water through a connecting tube of 9 – 12 mm diameter. Once the solid fertilizer had been fully dissolved, continuous dilution by water gradually decreases the concentration of the chemical solution. The tank should have enough capacity to store the required quantity. This device is cheap and simple to use. A wide dilution ratio can be attained without external source of energy.

Limitations: Nutrient or chemical concentration in the irrigation water cannot be precisely regulated. Prior to each application, the tank has to be refilled with fertilizer. Valve throttling generates pressure losses, and the system cannot be straight forwardly automated.

Venturi Injector

The fertilizer solution is injected in to the system by suction generated by water making water-to flow through a constricted passageway called venturi. The high flow velocity of water in the constriction reduces water pressure below the atmospheric pressure, so that the vacuum is created and fertilizer solution is sucked from an open tank into the constriction through a small diameter tube. Venturi is made of corrosion-resistant materials such as copper, brass, plastic and stainless steel. Venturi devices require excess pressure to allow for the necessary pressure loss. Maintaining a constant pressure in the irrigation system guarantees uniform long-term nutrient concentration.

Table 2: Solubility of Nitrogenous Fertilizers

Types of Fertilizer	Nitrogen Content (%)	Solubility(g/L)
Ammonium Sulphate	21	750
Urea	46	1100
Ammonium Nitrate	34	1920
Calcium Nitrate	15.5	1290

(Source:http://www.ncpahindia.com/articles/article17.pdf; Oct 09, 2012.)

Table 3: Characteristic of Nitrogenous Fertilizers Suitable for Fertigation

Fertilizers	Grade	Formula	pH(1g/L at 20^0C)
Urea	46-0-0	$CO(NH_2)_2$	5.8
Potassium Nitrate	13-0-46	KNO_3	7.0
Only Fertigation grade			
Ammonium Sulphate	21-0-0	$(NH_4)_2SO_4$	5.5
Urea Ammonium nitrate	32-0-0	$CO(NH_2)_2.NH_4NO_3$	

Ammonium Nitrate	34-0-0	NH_4NO_3	5.7
Mono Ammonium Phosphate	12-61-0	$NH_4H_2PO_4$	4.9
Calcium Nitrate	15-0-0	$Ca(NO_3)_2$	5.8
Magnesium nitrate	11-0-0	$Mg(NO_3)_2$	5.4

Table 4: Solubility of Potassic Fertilizers

Fertilizer	K content (%)	Solubility (g/L)
Potassium Sulphate	50	110
Potassium Chloride	60	340
Potassium Nitrate	44	133

Table 5: Characteristic of Potassic Fertilizers Suitable for Fertigation

Fertilizers	Grade	Formula	pH (g/L at 20^{0}C)	Other Nutrients
Potassium Chloride@	0-0-60	KCl	7.0	46% Cl
Potassium Nitrate	13-0-46	KNO_3	7.0	13% N
Potassium Sulphate#	0-0-50	K_2SO_4	3.7	18% S
Potassium Thiosulphate*	0-0-25	$K_2S_2O_3$	-	17% S
Monopotassium Phosphate	0-52-34	KH_2PO_4	5.5	52% P_2O_5

@ Only white, # only Fertigation grade, * Liquid.

Table 6: Characteristics of Phosphorus Fertilizers Suitable for Fertigation

Fertilizers	Grade	Formula	pH (1g/ L at 20^{0}C)
Phosphoric acid	0-52-0	H_3PO_4	2.6
Mono- potassium Phosphate	0-52-34	KH_2PO_4	5.5
Mono ammonium phosphate	12-61-0	$NH_4H_2PO_4$	4.9

Table 7: Solubility of Micro-nutrient Fertilizers

Fertilizer	Content (%)	Solubility (g/L)
Solubor	20B	220
Copper Sulphate	25 Cu	320
Iron Sulphate	20 Fe	160
Magnesium Sulphate	10	710
Ammonium Molybdate	54	430
Zinc Sulphate	36	965
Manganese Sulphate	27	1050

Common head losses are above 33% of the inlet pressure. Double stage venturi injectors have lower pressure loss and pipe diameter. It can be adjusted by valves and regulators. The suction rates vary from $0.1\ \mathrm{L\,h^{-1}}$ to $200\,\mathrm{L\,h^{-1}}$. Venturi injectors are installed on the line or on a bypass.The injection rate depends upon the pressure loss, which ranges from 10% to 75% of the system's pressure and is controlled by the injector type and operating conditions. The injection rate can be controlled by

- Changing the flow through the venture injector
- Controlling the system operating pressure
- Adjusting the control valve at discharge side
- Using the metering valve

Advantages: Cheap open tanks may be used for storing the fertilizers/chemical. A wide range of suction rates can be created by changing the diameter of the venturi dimensions of converging and diverging sides; and valves. It has simple operation and low wear. It requires easy installation and mobility. It is compatible with automation. It provides uniform nutrient concentration.

Limitations: There is a significant pressure loss. The injection rates are affected by pressure fluctuations.

Injection Pumps

Hydraulic Pumps: These are versatile, reliable feature low operation and maintenance costs. A diaphragm or piston movement injects the fertilizer solution into the irrigation system. Water-driven diaphragm and piston pump combine precision, reliability and low maintenance costs.

Hydraulic pump used in fertigation can be automated. A pulse transmitter is mounted on the pump. The movement of the piston or diaphragm spoke sends electrical signals to the controller that measures the delivered volume. Measurement can also be performed by small fertilizer-meters installed on the injection tube. The controller allocates fertilizer solution according to a preset program.

In glasshouses, simultaneous application of a multi-nutrient solution is routine practice. When the distinct chemical compounds in the fertilizers are incompatible and cannot be combined in a concentrated solution due to the risk of decomposition or precipitation, two or three injectors are installed inline one after another, in the control head. The application ratio between the injectors is coordinated by the irrigation controller. In high valve crops grown in glasshouses on detached media, the irrigation water is mixed with fertilizers in a mixing chamber (mixer).

Electric Pump: Electric pumps are inexpensive and reliable. Operation costs are low. They can be readily integrated into automatic systems. A wide selection of pump is available from small low-capacity to massive high-capacity pumps. The injection pressure is the range of 1 – 10 bars. Electric piston pumps are exceptionally precise and appropriate for accurate mixing in constant proportions of several stock solutions.

Variable speed motors and variable stroke length allow for a wide range of dosing from 0.5 to 300 $\mathrm{Lh^{-1}}$ at the working pressure of 2 – 10 bars.

RESPONSE OF DRIP FERTIGATION IN VEGETABLE AND FRUIT CROPS

The effect of depth of drip lateral spacing was significant on lint yield and seed mass in cotton (Enciso et al., 2005). The lateral at 0.3 m depth was superior to 0.2 m depth. The deeper lateral depth might have resulted in greater root volume in early developmental stages, allowing the plant to extract a higher amount of soil water during water stress sensitive stages. Ayers et al. (1999) reported higher cotton yields (134 and 132 Mg ha^{-1}) in the drip plots compared to the furrow plots (65 and 85 Mg ha^{-1}). The cotton could extract between 40 and 60% of total water requirement from shallow ground water under subsurface drip irrigation system compared to 40% extraction of water in furrow irrigation system. The application of similar quantity of water through drip irrigation led to 32% increase in cotton seed yield as compared to check-basin method of irrigation. The yield in drip irrigation was 12% higher even after 25% reduction in water application as compared to check basin irrigation. The drip irrigation maintains optimum soil water availability in crop root zone resulting in higher dry matter partitioning to cotton bolls as reported by Aujla et al. (2005). They stated the beneficial effects of drip under normal sowing can be realized by 25-50% water and 25% N saving without any loss in yield. Along with water use, drip irrigation was able to improve ANUE in cotton. The ANUE was 32% higher in drip irrigation compared to check basin irrigation at similar N and water application. Increase in ANUE with lower N application in drip irrigation improved distribution of fertilizer with minimum leaching beyond root zone or runoff have been reported by Bharambe et al. (1997). Similarly higher yields in cotton under drip irrigation system have been reported by Radin et al. (1992) and Cetin and Bilgel (2002). Ünlü et al. (2011) reported higher (48–57%) cotton yield under deficit irrigation (50-70% of full irrigation) compared to continuous stress condition, though they were lower than full irrigation. The maximum estimated cotton yield was noted at irrigation water input of 400 mm. The yield variability below 400 mm of irrigation water was ascribed to environmental factors over the years and stress due to less than optimum water input. The WUEs of the fresh water (FW) and brackish water (BW) treatments were similar and about 11% higher than saline water (SW) treatment. The WUE was also significantly influenced by N application rate with highest being in N 480 (40 kg N hm^{-2}). In the FW and BW treatments, both WUE increased with increase in N application rate from 0 (N_0) to 360 kg N hm^{-2} (N_{360}). On an average, total N uptake was 20% higher in the FW treatment and 16% higher in the BW than SW treatment. The ANR in the FW treatment was 8% and 32% higher than BW and SW treatments, respectively. Cetin and Uygan (2008) evaluated different drip line spacing's (1 m and 2 m) and irrigation scheduling criterions (based on percentage canopy cover and percent wetted area) on yield and WUE of tomato. Maximum yield was obtained with the drip line spacing 1 m and irrigated with water amount based on percentage of canopy cover. The irrigation scheduling criterion based on percentage of canopy cover was precise due to the variation in amount of irrigation water applied according to percentage of canopy cover. The majority of soil wetted by irrigation might have shaded under canopy which led to lower evaporation loss. The maximum irrigation water use efficiency (IWUE) of 22.3 kg m^{-3} was obtained from 2 m lateral spacing and the percentage of canopy cover criteria. Furthermore, IWUE improved with decline in irrigation volume (Howell, 2006). Machado et al. (2003) compared yield and root distribution among surface and subsurface drip irrigation (at two different depths) of tomato cultivars. Yields were 88 and 114 t ha^{-1} (with surface), 108 and 128 t ha^{-1} (subsurface at 20 cm depth), 105 and 125 t ha^{-1} (subsurface at 40 cm depth) for the first and second year, respectively. Lower phosphorus availability in surface drip irrigation might have led to reduction in the yield. Deep placement of fertilizer led to better availability and uptake of phosphorus in subsurface drip irrigation. The depletion of available soil moisture was quite low in drip irrigation treatments compared to furrow irrigation, as frequent applications of irrigation water resulted in optimal soil-water environment for proper growth of the tomato crop. As a result, drip irrigation recorded 68-77% higher WUE than that of furrow irrigation with 3.7-12.5% higher fruit yield. Along with water, nitrogen application through the drip fertigation in 10 equal splits and at 8-days interval resulted in 20-40% of N savings and 8-11% higher N uptake as compared to the furrow irrigation with two equal splits of N application in tomato as reported by Singandhupe et al. (2003). The higher moisture content due to frequent irrigations might have aided better N uptake. Split application of nitrogen in drip irrigation was matched with crop demand which favored growth and produced maximum fruit yield. The placement of nitrogen just near the base of plant resulted in better utilization and reduced leaching. Dalvi et al. (1999) revealed that drip irrigation in tomato scheduled at every second day frequency, led to better root elongation compared to daily irrigation with irrigation at 0.79 ET. It saved water to the tune of 21% and increased yield up to 27% as compared to traditional method of cultivation. Tiwari et al. (1998) reported higher fresh yield of okra crop under drip irrigation compared to furrow irrigation. Based on the average yield of three years, all the drip irrigated at 40% deficit water supply resulted in 45% higher yield of okra as compared to furrow irrigation. Similar results were reported for Cabbage crop by Tiwari et al. (2003) who stated 54% higher yield at 40% reduced water application through drip irrigation compared to furrow irrigation. Maximum corn yield was obtained with 254 and 173 mm of water application through subsurface drip irrigation in two years in Nebraska. Excessive irrigation might have reduced the amount of oxygen in the crop root zone and increased possibility of nitrogen leaching. Linear relationships between relative evapotranspiration deficit and relative corn yield decrease were observed by Payero et al. (2008). The IWUE decreased sharply with increase in irrigation during both the seasons. The IWUE decreased in the areas where no irrigation resulted in positive yield. Subsurface drip irrigation systems reduced net irrigation requirement by 25%, while maintaining corn yields of 12.5 Mg ha^{-1}, as analyzed by Lamm and Trooien (2003) based on 10 years data. The results stated that irrigation needs to be scheduled to replace approximately 75% of actual evapotranspiration (ETa), which could limit leaching without reducing corn yield. The nonlinear relationship among corn yield and irrigation water applied asserts greater deep percolation losses with increase in irrigation amounts. Further, 7 day irrigation frequency led to higher IWUEs due to better storage of precipitation and reduction in deep percolation losses.

Maisiri et al. (2005) compared water productivity of low cost drip irrigation system and surface irrigation system for vegetable cultivation. Drip irrigation method used 7.87 m^3 of water which led to > 50% of water saving compared to surface irrigation method (23.88 m^3). The lower percentage wetted area in drip irrigation systems (up to 30%) compared to surface irrigation (100%) might be the major reason for difference in water use. This led to water productivity of 10.8 kg m^{-3} in drip irrigation and2.4 kg m^{-3} in conventional surface irrigation for vegetable cultivation. The lower water productivity in surface irrigation systems was due higher volume of water applied compared to drip irrigation. This was due to water saving in drip irrigation and application of N fertilizer through fertigation in drip system. The fertilizer was injected through the water supply directly (fertigation) to the plant root zone in split application according to crop demand throughout the growing season.

Significant interaction between irrigation and nitrogen application through drip irrigation on potato yield was reported by Badr et al. (2012). The reduction in yield by 27.3% and 44.6% was attributed to applying 40% and 60% less amount of water compared to full irrigation, respectively. Increasing N level under water stress condition was non-productive as excessive N led to reduced yield. The water use efficiency can be improved either by similar yield with lower water use or minimizing evaporation and other non-productive losses through reduced water application strategies such as deficit irrigation. The highest NUE was noted in 160 kg N ha^{-1} application level with full irrigation. However, NUE was inversely proportional to the amount of N applied as plants extracted more N from soil at lower N levels.

Bhat et al. (2007) determined optimal fertigation schedule for arecanut and its impact on productivity and resource use efficiency. The ANUE with 50 and 75% of recommended NPK dose through fertigation was at par, though significantly superior over 100% NPK. Fertigation up to 75% NPK provided a higher ANUE than the soil application of 100% NPK which affirms higher production at lower application rates through drip fertigation. Drip fertigation at 75% of NPK dose also resulted in significantly higher WUE compared to other fertigation levels. Continuous replenishment of nutrients through frequent fertigation (10 and 20 days interval) near root zone could have enhanced nutrient transport by mass flow resulting in higher yield. Significant interaction between fertigation level and frequency of application indicated superior WUE at 75% NPK applied at 10 days interval over 100% NPK at similar interval. The WUE increased with increase in fertilizer application, which suggested synergistic effect of water and fertilizer on yield.

Erdem et al. (2010) studied response of drip irrigated broccoli to different water regimes and N fertilizer applications. The higher yield of broccoli in the spring season (6-11 t ha^{-1}) compared to autumn (3-5 t ha^{-1}) was due to difference in climatic conditions. The lower yield in autumn was attributed to lower temperature and excessive rain. The highest yield (11 t ha^{-1}) was recorded with irrigation at 125% of pan evaporation (Epan) and 200 kg N ha^{-1} application in spring and 4.55 t ha^{-1} at 125% of Epan with 250 kg N ha^{-1} application in autumn. Lower NUE in autumn (13-22%) compared to spring (37-73%) was ascribed to higher rainfall leading to leaching of applied N fertilizer.

Sharmasarkar et al. (2001) assessed N leaching under drip irrigation and flood irrigation in sugar beet. Lower NO3 concentrations in soil under flood irrigation could be due to greater solute leaching compared to drip irrigation. Higher N leaching in flood irrigation led to lower WUE and NUE compared to drip irrigation. The cumulative drainage in flood irrigation was more than three times higher than observed with drip irrigation. Higher irrigation frequency with smaller water amount which favored more efficient use of water in the coarse-textured soil led to least cumulative drainage in drip irrigation systems.

Recently, drip irrigation has been successfully applied in food grain crops such as rice and wheat. He et al. (2013) reported reduction in number of spikelets per unit area under drip irrigation compared to continuous flooded rice which lowered grain yield in drip irrigated rice. The lower grain yield in non-flooded treatments (drip and furrow irrigation with and/or plastic mulching) was attributed to higher plant density which might have affected source-sink relationship in non-flooded treatments. Drip irrigation with plastic mulching and furrow irrigation with plastic mulching had higher WUE than the furrow irrigation with non-mulching and continuous flooded treatments. In drip irrigated rice with plastic mulching, water consumption was reduced by 57–67% compared with the CF treatment. The reduction in seepage and evapotranspiration resulted in reduced water use. Also, drip irrigated rice with plastic mulching had reduced water use compared to furrow irrigation due to similar reasons as stated above. Gao et al. (2014) evaluated the effect of irrigation amount on seasonal evapotranspiration, grain yield, and water use efficiency of winter wheat using sub surface drip irrigation. Irrigation was applied at three levels, i.e. 1.0, 0.83, and 0.65 times the average ETo. Irrigation amount per application was 45 (D1), 37.5 (D2) and 30 mm (D3) which resulted in 440, 425, and 393 mm of cumulative water application as averaged over the three years, respectively. The maximum yield of winter wheat was recorded in D2 (37.5 mm per irrigation) treatment when irrigated at 0.83 ETo. Considering the grain yield and water applied, water use efficiency in D2 (1.83 kg m^{-3}), and D3 were greater than that in D1. Irrigation schedule D2 was suitable for winter wheat to achieve higher yield and water productivity.

RESEARCH STUDIES UNDER SUB-SURFACE DRIP FERTIGATION

Subsurface drip irrigation with different lateral spacing and variable rate of N fertigation is expected to have differential nitrogen dynamics in the crop root zone depth, which is likely to influence growth, water and N use efficiency, and hence the grain yield of wheat, rice and maize crops. Moreover, evaluating response of such precise irrigation technology under plausible climate change scenarios will assist in developing agro-adaptations for maintaining and/or improving rice grain yield is of vital importance to ensure food security. Agro-technology for improving water as well as N use efficiency is a concern for rice production as the crop is poorly water efficient, and moreover, availability of water resources is going to be scarce with the climate change and N loss through leaching or volatilization cause environmental pollution. In the present investigation, drip irrigation system with varying lateral spacing and fertigation levels has been evaluated for improving rice grain yield with high resource use efficiency.

RESEARCH STUDIES DONE AT IIT KHARAGPUR

Guava

Upreti (2013) conducted a field experiment at PFDC, IIT Kharagpur India to study the response of Guava crop under drip fertigation and plastic mulch. The highest yield, plant height, plant girth, canopy diameter, FUE and net income were obtained for 80 % of soluble fertilizers applied through with plastic mulch treatment as compared to other fertigation treatments.

Banana

A field experiment was carried out in the lateritic sandy loam soils of Kharagpur, West Bengal, India, to investigate the response of Banana (*Musa Paradisica* L.) cv. Grand Naine at different levels of nitrogen, phosphorous and potassium nutrients applications through drip fertigation and plastic mulch. A randomized complete block design was used with four fertigation levels in conjunction with mulch and without mulch. The results of recommended dose of fertilizers application through drip either alone or in conjunction with black plastic mulch conditions were compared with other fertigation treatments in terms of growth and crop of yield.

Results of this study showed that both main and ratoon crops for 80 per cent of the recommended dose of fertigation (RDF) (i.e. 160 N: 48 P: 240 kg plant^{-1} year^{-1}) along with plastic mulch responded superior in respect of growth parameters; maximum plant height (201.6 & 178.3 cm), higher stem girth (60.6 and 52.2 cm), more no. of functional leaves (10-14 leaf/plant), highest yield (64.49 & 50.4 t ha^{-1}) and shortened the total crop duration by 13-38 days compared to other treatments in main and ratoon crops. This treatment also recorded higher levels of TSS (24.1 ^{0}brix), reducing sugar (13.53%) and non-reducing sugar (1.76%), pulp: peel ratio (2.34:1) and lower acidity (0.25 %) in fruits. The nutrient content in the leaf both in main crop and ratoon crops revealed that the treatment with 80 per cent of recommended dose of fertilizer with plastic mulch recorded higher of N, P and K contents over the other treatments. The highest nutrient conversion efficiency (57.58 t kg^{-1} nutrient), maximum net profit of Rs. 475148.52 per hectare and B:C ratio of 5.2 were obtained for the 80% RDF with plastic mulch treatment.

Potato

An Experiment was conducted at PFDC IIT Kharagpur to study the effect of fertilizer application through sub surface drip irrigation on potato crop. Result of this showed that the daily crop water requirement of potato (cv. Kufri Jyoti) is 0.22 L plant^{-1} at its initial growth stage and 0.32 L plant^{-1} at peak stage. About 220 mm of water is needed for irrigating one hectare of potato crop through drip irrigation. Basal dose of 120 kg, 60 kg K and 25% of 200 kg of N be given after bed preparation and remaining 3/4th of N be given at 10 days of interval through inline drip system. The maximum yield (26.74 t ha^{-1}) of potato was obtained for the lateral pipe at 7.5 cm below the soil surface in sandy loam soil with fertigation schedule of nitrogen applied at 10 days interval from 20 to 70 days after sowing.

Rose

An experiment was conducted from 2011 to 2015 at Field water management laboratory, IIT Kharagpur to study the influence of different levels of fertigation on vegetative growth, flowering characteristic and fertilizer-use efficiency of two hybrid varieties of rose (First red and Gold strike) under greenhouse and open field cultivation. There were ten treatments, eight under greenhouse and two in open field with three replications. Fertigation treatments were 140%, 120%, 100% and 80% of recommended dose of fertilizer with two varieties. In open field experiments, the conventional fertilizers were applied using conventional methods of fertilization (Basal and side dressing). The study revealed that Dutch rose cultivation under saw-tooth shape greenhouse with application of 120% recommended dose of soluble fertilizers resulted in greater plant height (66.5 cm), shoot length (45.1 cm), flower diameter (6.7 cm) for First Red variety whereas number of shoots per plant (16.9), number of flowers per m^2 (301.2) was more with Gold Strike variety.

The fertigation doses influenced the number of shoots per plant for both the varieties. The shoot length of rose flower increased significantly with increase in the dose of fertigation up to 120 % of RDF and thereafter decreased. Among two varieties the shoot length was found greater for First Red variety as compared to that of Gold Strike for the same level of fertigation. With the same level of fertigation, the shoot length was higher under greenhouse conditions.

Rice

Rajwade (2016) studied effect of subsurface drip irrigation system in which laterals kept at 40 cm and 60 cm spacing and four N fertilizer levels on growth and yield of dry and wet season rice. He determined the total water (rainfall + irrigation) productivity of the dry season drip irrigated rice (DIR) under four N fertilizer levels and lateral spacing's. Water productivity of the DIR varied from 0.26 kg grain per m^3 of water input (kg m^{-3}) in $S_{40}N_0$ to 0.64 kg m^{-3} in $S_{40}N_{75}$ during 2012-13 and from 0.16 kg m^{-3} in $S_{60}N_0$ to 0.60 kg m^{-3} in $S_{40}N_{100}$ during 2013-14. Averaged over the lateral spacing's, the water productivity significantly increased with increasing the N application level from N_0 to N_{75} and N_0 to N_{50} in the first and second year, respectively and further addition of N fertilizer did not bring any significant increase in water productivity in both years. At the normal N level (N100), the water productivity of DIR was 1.24 and 1.53 times that of puddled transplanted rice (PTR) during the first and second year, respectively. Total water inputs in DIR were 790 mm and 880 mm and in PTR were 1190 mm and 1266 mm in 2012-13 and 2013-14, respectively. This result stated about 32% saving of irrigation water in DIR compared to the conventional PTR as averaged over the two years.

In general, the total water productivity of wet season rice was lower than the dry season rice. Averaged over lateral spacings, the N fertilizer treatment N_{100} gave the highest water productivity (0.47 kg m^{-3}) in the first year and the treatment N75 gave the highest value (0.30 kg m^{-3}) in the second year, but they were comparable.

In general, NUE with increasing N application rate in both years. The N fertilizer treatments N_{50}, N_{75} and N_{100} had comparable PE in first as well as the second year.

Rice –Okra-Green gram under subsurface drip

The water and nitrogen balance under Rice- Okra- Green gram crop rotation under subsurface drip and under flood irrigation study revealed that subsurface drip irrigation gave more yield and saved considerable amount of irrigation water as compared to furrow irrigation. Significant increase in yield registered under Okra and Green gram, however non-significant yield in Rice. However amount of irrigation water in surface irrigation was 1.8 times of that of subsurface drip irrigation that resulted in 4.07 t ha^{-1} rice yield.

Subsurface drip application in Okra crop resulted in greater yield and water use efficiency by 41.82 % and 40% as compared to that of furrow irrigation. Green gram also responded 19 % greater yield under subsurface drip.

SOIL MOISTURE DISTRIBUTION PATTERN UNDER DRIP IRRIGATION

The soil moisture movement under a drip emitter and its distribution depends on number of parameters such as soil type, rate of infiltration, hydraulic conductivity, rate of emitter discharge, quantity of water applied, antecedent soil moisture content, depth of water table and climatic factors. The discharge rate of a drip emitter and mode of water emission are the important factor that governs moisture distribution, size and geometry of wetted area. A high rate may cause deep drainage loss whereas a very low rate may contribute to evaporation loss.

Experiments were conducted to evaluate the soil moisture dynamics under subsurface drip for the Okra crop in four soil layers 0-20, 20-40, 40-60, and 60-90 cm. The study revealed that temporal variations of soil moisture in the root zone are affected by irrigation treatment (Fig.1). In 60-90 cm soil layer, the magnitude of change in soil moisture was minimum for different irrigation events. Fig. 1 shows depletion in soil moisture was relatively rapid in 0-20 cm layer whereas it was gradual 20-40 cm, 40-60 cm and 60-90 cm soil layers. The soil moisture variation within root zone of the crop was greatly influenced due to water extraction by roots and their growth. Soil moisture variation was more prominent in 0-20 cm soil profile this may also be due to evaporation. In addition to this some part of applied irrigation water may get percolated to the lower layers. Cumulative deep drainage throughout the Okra crop growing season was less than 1 mm for 20% maximum allowable deficit (MAD).

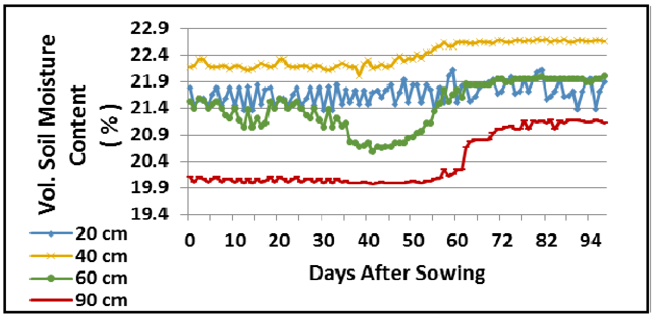

Fig. 1: Temporal variation of soil moisture in Okra crop root zone at 20% MAD

SUMMARY

The success of drip irrigation depends on improved water and fertilizer use efficiency. Hence fertigation assumes an important role. Various fertilizers, their solubility and their compatibility; various modes of fertilizer injection methods and the research findings of various investigators on fertigation to various field and fruit crops are presented in this manuscript.

- Application of N fertilizer at 75% of normal recommendation level produced similar grain yield as of the normal N level in DIR and this was comparable with the yield of conventional PTR in dry as well as wet season.
- About 25% N fertilizer i.e. 55 kg N ha^{-1} (25 kg ha^{-1} in wet season and 30 kg ha^{-1} in dry season) can be saved annually in DIR as compared to PTR without affecting the grain yield in rice-rice cropping system.
- The N fertilizer application at 50 or 75% of normal level resulted in similar water productivity, but significantly higher N use efficiency of rice as compared to normal N level in DIR.
- The drip irrigation saved significant volume of irrigation water during land preparation to tillering and flowering to maturity, overall 32% in the crop growing period, as compared to PTR with a minor yield reduction (8%) during dry season.
- The apparent N recovery with reduced N fertilizer level (75% of normal) in drip irrigation was considerably higher (72% in dry season and 64% in wet season) as compared to reported value (31-40%) in conventional PTR without much sacrificing the grain yield.
- Fertilizer applied with drip irrigation of 80 per cent of recommended dose along with plastic mulch was found to be optimum and economical for cultivation of Grand Naine banana.
- Fertilizer use efficiency was the highest for 120% recommended dose of fertilizer application through drip in Gold Strike variety of rose (205.7 No. of flowers/ kg fertilizer used/ year).
- Dutch rose cultivation under sawtooth shape greenhouse with application of 120% recommended dose of soluble fertilizers resulted in greater plant height, shoot length, flower diameter for First Red variety. However maximum number of flowers per m^2 (301.2) was for Gold Strike variety of rose.

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