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Fertigation: Enhancing Crop Yield with Precision Nutrient Management

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Abstract

Fertigation, the process of applying water and fertilizers simultaneously through irrigation systems, is transforming modern agriculture by improving crop yields and optimizing nutrient use efficiency. This article divides into the principles, advantages, and best practices of fertigation, emphasizing its significance in sustainable farming. By precisely delivering nutrients to the root zone, fertigation reduces nutrient loss, mitigates environmental impact, and fosters healthier crop development. The article also examines the compatibility of various water-soluble fertilizers with drip irrigation systems across different crops and soil types. This article helps to understand how fertigation enhances crop productivity, supports sustainable agricultural practices, and contributes to global food security.

INTRODUCTION

Irrigation plays an important role not only in improving the agriculture but overall economy and development. Water becoming increasingly scares due to various reasons viz; population growth, expansion of industrial area, inadequate water harnessing facility, skewed rainfall pattern etc. In most of the arid and semi-arid regions the problem of water scarcity is expected to be aggravated further. India has only about 4 per cent of the world's freshwater resources. Over the period, its availability is decreasing and India is fast approaching to a stage of water scarce country and decreasing per capita water availability. At the time of independence, India was a water surplus nation having 5000 m^3 (1951) per capita per annum water availability, now become a water deficit in large parts of the country having less than 1500 m^3 (2010) per capita per annum water availability and expected to shrink below 1000 m^3 before 2025. According to "2030 Water Resource Group" shows that global

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demand for water in 2030 is expected to exceed current reliable accessible water supplies by 40 % (INCID, 2009).

Irrigation potential of India is 93.7 m ha and is largest in the world. In spite of having high yielding varieties and advanced agronomical package the overall food grain production from irrigated area is very low. The food grain production is stagnated to more or less to 250 mt for last ten years, needs to be increased 350 mt by 2030 (Pawar *et al.* 2013). One of the reasons for low productivity in grains and vegetables is insufficient water and nutrient management practices being followed. Under such circumstances advance technologies like micro irrigation coupled with fertigation is inevitable. This has a tremendous scope to increase both water and nutrient use efficiency in limited water resource condition.

Globally the USA leads in area under micro irrigation followed by India. In India drip irrigation in crop is the need of hour, faster it spreads at farmers level greater are benefits to all stakeholders. However, the growth of pressurized irrigation in different states in India is limited, to water deficit states only.

Drip irrigation which is the most popular and widely adopted micro irrigation technique has a distinct characteristic that allows water soluble fertilizers (WSF) application i.e. fertigation which is not shared by any other conventional method. The fertigation allows applying the nutrients exactly and uniformly to the wetted root volume, where the active roots are concentrated.

Next water fertilizer plays an important role in increase of agriculture productivity. The fertilizer use efficiency in conventional practices in the country is very low. The current trend depicts that the productivity of soil in relation to application of fertilizer is declining (Report of fertilizer industry for twelfth plan 2012). The fertilizer use efficiency in India is very low to the tune of 30-50% in N, 10-20% in P and 70-80% in K under different methods of application, which can be double in N and P and upto 90-95 % in K under fertigation.

Fertigation is a sophisticated and efficient method of applying fertilizers, in which the irrigation system is used as the carrier and distributor of crop nutrients. The water-soluble fertilizer seems to be more economical and can be applied through fertilizer tank, ventury injector and fertigation pump as per the crop growth stages. Fertigation technology proved to be very beneficial in poly houses and green houses for high value horticulture crops. The potential of fertigation is wide enough to cover fruits, vegetables, flowers, cash crops, plantation crops, tuber crops, spices and oilseeds.

Introduction of this technology for major cereals, rice, wheat and maize in large scale would be the culmination of the long saga of adaptation and adoption. Application of Water-Soluble Fertilizer through drip irrigation system i.e. fertigation can be a better alternative to save the fertilizer and increase productivity at a time.

Different Methods of Irrigation:

Irrigation is a vital agricultural practice, and several methods are employed to ensure efficient water distribution to crops. Surface irrigation is one of the oldest and most commonly used methods, including techniques like border irrigation, where water is allowed to flow across the field in strips; furrow irrigation, which involves channeling water between crop rows; and check basin irrigation, where water is retained in small, leveled plots surrounded by embankments. Subsurface irrigation delivers water below the soil surface, directly to the root zone, reducing evaporation losses. Drip irrigation is another efficient method, where water is delivered in small, precise amounts directly to the base of each plant through a network of tubes, ensuring minimal wastage. Sprinkler irrigation mimics natural rainfall by spraying water over the crops through a system of pipes and nozzles, providing uniform coverage. Each irrigation method has specific applications depending on the crop type, soil characteristics, and water availability, with the goal of optimizing water use and enhancing crop yields.

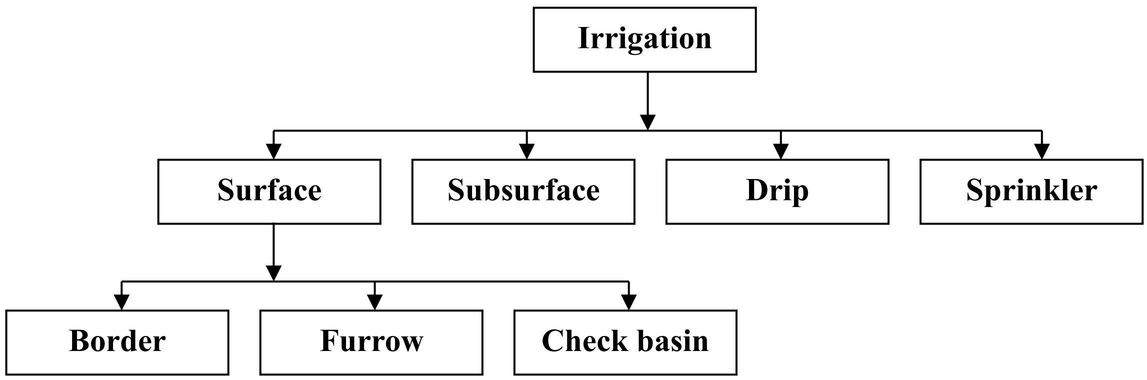

Figure 1. Different Methods of Irrigation

Drip Irrigation: Drip irrigation is a precise method of watering crops by applying water slowly, either on the soil surface, above it, or directly beneath it, near or into the plant's root zone using drippers. This technique is renowned for its efficiency, as it significantly reduces water wastage by delivering water exactly where it's needed, making it the most effective method among micro-irrigation systems. Drip irrigation is classified into two main types:

- ***Surface Drip Irrigation:*** Water is applied directly on the soil surface through a network of pipes and drippers, targeting the root zone.
- ***Sub-surface Drip Irrigation:*** Water is delivered beneath the soil surface through buried drip lines, directly irrigating the root zone and further minimizing evaporation losses.

Growth of Micro-irrigation technology in India

- 1970s: Introduction of drip irrigation systems with inline and online emitters and microtubes, marking the beginning of micro-irrigation in India.

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- **1980s:** Advancement with pressure-compensating drippers and emitters, ensuring uniform water distribution across varied terrains.
- **1990s:** Expansion of micro-irrigation techniques to include micro-sprinklers, misters, foggers, and bubblers, catering to diverse agricultural needs.
- **2000s:** Automation of drip systems combined with fertigation, allowing for precise water and nutrient delivery, optimizing crop growth and resource use.
- **2010s:** The decade saw the integration of smart irrigation technologies, including sensors and IoT (Internet of Things) based systems, enabling real-time monitoring and control of irrigation, thus further improving water use efficiency and crop management.
- **2020s:** The focus has shifted towards sustainable and climate-resilient irrigation practices, with widespread adoption of advanced micro-irrigation systems incorporating AI and machine learning for predictive analytics, ensuring optimal irrigation scheduling and resource conservation in response to changing environmental conditions.

Key Features of drip irrigation system:

- ***Low-Rate Water Supply:*** Water is delivered at a slow and controlled rate to minimize waste and ensure efficient usage.
- ***Extended Watering Duration:*** Water is supplied over a long period, promoting deeper soil moisture penetration.
- ***Frequent Watering Intervals:*** The system delivers water at regular intervals to maintain consistent soil moisture levels.
- ***Direct Root Zone Application:*** Water is applied directly to the plant's root zone, maximizing the effectiveness of irrigation.
- ***Pressurized Delivery System:*** Water is distributed through a pressure-controlled system, ensuring uniform application across all plants.
- ***Fertilizer Integration:*** Often, fertilizers are mixed with the irrigation water, allowing for precise nutrient delivery directly to the plants.

Advantages of drip irrigation system over flood irrigation

Sr. No.	Particulars	Drip Irrigation	Flood/ conventional method
1.	**Water saving**	High, between 30 to 60%	Less. High rates of evaporation, surface run off and percolation
2.	**Conveyance loss**	Negligible	High seepages and leakages
3.	**Irrigation efficiency**	80 – 90 %	30 - 50 %
4.	**Input cost**	Less spent on labour, fertilizers, pesticides and tilling	Comparatively higher
5.	**Weed problem**	Almost nil	High

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6.	**Suitable water**	Even saline water can be used	Only normal water can be used
7.	**Diseases and pests**	Relatively less	High
8.	**Fertilizer use efficiency**	Very high since supply is regulated	Heavy losses due to leaching
9.	**Water logging**	Nil	About 8.5 million ha in India
10.	**Water control**	Can be regulated easily	Not much control

Fertigation:

Fertigation is the practice of applying fertilizers through an irrigation system, delivering nutrients directly to the plant's root zone where they are most needed. This method ensures accurate and uniform distribution of nutrients across the wetted area, optimizing plant growth and enhancing overall efficiency.

Need of Fertigation / Why fertigation is important?

- **Uneven Fertilizer Consumption**: There is a significant disparity in fertilizer usage across different states and crops, leading to uneven growth.
- **Nutrient Mining**: Continuous nutrient extraction from the soil without replenishment leads to soil fertility depletion.
- **Declining Crop Response**: Crops are showing reduced responsiveness to traditional fertilizer applications.
- **Soil and Water Pollution**: Indiscriminate fertilizer use is contributing to environmental pollution.
- **Increased Fertilizer Use Efficiency**: Fertigation enhances fertilizer efficiency, leading to reduced wastage and cost savings.

Advantages of Fertigation

- **Eliminates Manual Application**: Reduces labour by automating fertilizer distribution.
- **Quick and Convenient**: Fertilizers are applied effortlessly along with irrigation.
- **Uniform Application**: Ensures consistent nutrient distribution across all plants.
- **High Efficiency and Fertilizer Savings**: Minimizes waste and maximizes nutrient uptake.
- **Reduced Leaching and Groundwater Pollution**: Nutrients are delivered precisely where needed, minimizing runoff.
- **Enhanced Penetration and Distribution**: Particularly effective for P and K fertilizers.
- **Tailored Nutrient Supply**: Fertilizer amounts can be adjusted according to the crop's growth stage.
- **Controlled Dosing**: Provides precise control over nutrient application.
- **Multiple Applications**: Herbicides, pesticides, and even acids can be applied through the system.

- **Reduced Nutrient Volatilization**: Nutrients are less likely to evaporate from the soil surface.
- **Cost Savings**: Decreases labor and energy expenses.
- **Trace Element Application**: Micronutrients can be easily applied alongside major nutrients.

Limitations of Fertigation

- **Emitter Clogging:** There is a risk of drip emitters becoming clogged, which can disrupt the irrigation process.
- **Potential Drinking Water Contamination:** If not managed properly, fertigation systems could contaminate water supplies.
- **Corrosive Chemicals:** Some fertilizers and chemicals can be corrosive to metal parts of the irrigation system.
- **Insoluble Fertilizers**: Not all fertilizers are suitable for fertigation; insoluble fertilizers can cause blockages.
- **Phosphate Precipitation:** Phosphate fertilizers may precipitate in the system, leading to clogging of pipelines and drippers.

Drip fertigation system:

A drip fertigation system integrates both irrigation and fertilization, ensuring that crops receive precise amounts of water and nutrients directly at the root zone. The various components of drip fertigation system are depicted in Fig. 2.

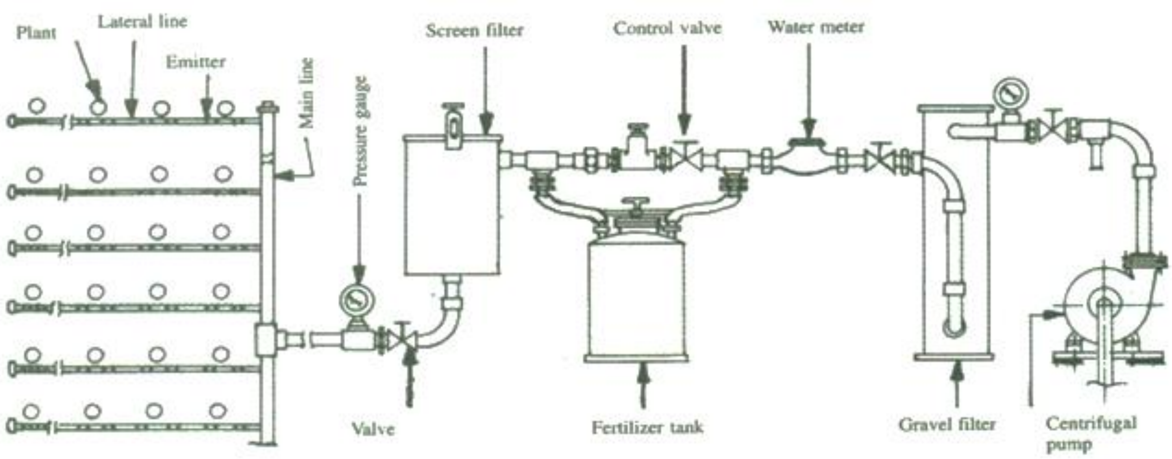

Fig. 2. Different components of drip irrigation system with fertigation and filtration units. (Source: Michael, 2010, pp.641)

- **Water Source:** This can be a well, pond, river, or any reliable water source that provides clean water for irrigation. The quality of the water is crucial to prevent clogging and ensure the longevity of the system.

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- **Pumping Unit:** The pump is used to pressurize the water from the source and distribute it through the system. The size and capacity of the pump depend on the size of the area being irrigated and the water requirements of the crops.
- **Filtration Unit:** Filters (such as screen filters, sand filters, or disc filters) are essential for removing particles, sediments, and debris from the water. Proper filtration prevents clogging of the drip emitters and ensures a consistent flow of water and nutrients.
- **Fertilizer Injector:** The fertilizer injector is the heart of the fertigation system. It accurately mixes fertilizers with the irrigation water and injects the solution into the irrigation lines. Common types include venturi injectors, pressure differential injectors, and positive displacement injectors.
- **Mainline, Sub-Main, and Laterals**: These are the pipelines that carry the water and nutrient solution from the pump and filtration unit to the crop rows. The mainline distributes water to the sub-mains, which then deliver it to the laterals (smaller pipes) that directly connect to the emitters.
- **Drip Emitters:** Emitters are devices placed along the lateral pipes that regulate the flow of water and nutrient solution to the plants. They can be placed on the soil surface (surface drip) or buried underground (subsurface drip). Emitters ensure that water is delivered slowly and directly to the root zone.
- **Pressure Regulators and Gauges:** These components maintain a consistent pressure within the system, preventing damage to pipes and ensuring even distribution of water and nutrients across all emitters. Pressure gauges help monitor the system's performance.
- **Control Valves:** Control valves are used to regulate the flow of water through different sections of the irrigation system. They can be manually operated or automated, allowing for precise control of irrigation schedules and fertigation cycles.
- **Backflow Prevention Device:** This device prevents the reverse flow of fertilizer solution into the water source, protecting the water supply from contamination. It is a crucial safety feature in any fertigation system.
- **Monitoring and Automation Systems:** Advanced drip fertigation systems often include sensors, timers, and automation controllers that monitor soil moisture levels, nutrient concentrations, and weather conditions. These systems help optimize irrigation schedules, reduce labor, and improve overall efficiency.

Table 3: Fertilizer use efficiency in fertigation (%)

Nutrient	Soil application	Drip + soil application	Drip + fertigation
Nitrogen	30-40	65	95
Phosphorus	20	30	45
Potassium	60	60	80

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Table 4: Crops suited for the drip fertigation:

Orchard crops	**:**	Grapes, Banana, Pomegranate, Orange, Citrus, Tamarind, Mango, Fig, Lemon, Custard Apple, Sapota, Guava, Pineapple, Coconut, Cashew nut, Papaya, Aonla, Litchi, Watermelon, Muskmelon etc.
Vegetables	**:**	Tomato, Chilly, Capsicum, Cabbage, Cauliflower, Onion, Okra, Brinjal Bitter gourd, Bottle gourd, Ridge gourd, Cucumber, Peas, Spinach Pumpkin etc.
Cash Crops	**:**	Sugarcane, Cotton. Arecanut, Strawberry etc.
Flowers	**:**	Rose, Carnation, Gerbera, Anthurium, Orchids, Jasmine, Lily, Mogra Tulip, Dahilia, Marigold etc.
Plantation	**:**	Tea, Rubber, Coffee, Coconut etc
Spices	**:**	Turmeric, Cloves, Mint etc.
Oilseed	**:**	Sunflower, Oil palm, Groundnut etc
Forest crops	**:**	Teakwood, Bamboo etc.

Characteristics/criteria of suitability of water-soluble fertilizers for fertigation

1. **Solubility:**
   - Solubility is pre requisite for solid fertlizers used in fertigation.
   - Should be fully soluble in irrigation water.
   - Fast dissolution in irrigation water.
   - Minimum interaction with irrigation water.
   - Fertilizes such as Ammonium nitrate, Urea, Potassium chloride, MAP (12-61-00), Mono potassium phosphate (0-52-34) are soluble in water.
2. **Precipitation:**
   - Irrigation water contents calcium, magnesium and bicarbonates when fertilizes mix in water it gets precipitation in fertilizer tank results into clogging of system.
   - Problem concerned with P application
   - To avoid phosphoric acid is recommended
3. **Compatibility:**

   Liquid fertilizers are best suited for fertigation.

   Mixture of $(NH_4)_2SO_4$ and KCL considerably reduce the solubility due to formation of K_2SO_4.

Other forbidden mixtures are:

1. Calcium Nitrate and phosphates or sulphates
2. Magnesium sulphate with di- or mono ammonium phosphate
3. Phosphoric acid with Fe, Zn, Cu and manganese sulphates.

Table 5: Specification of some commercial fertilizers used for fertigation

Sr.No.	Fertilizer	Grade	pH*
1.	Urea	46% N	B
2.	Ammonium nitrate	34-0-0	A
3.	Calcium nitrate	16-0-0 (19% Ca)	B

4.	Diammonium phosphate	18-48-0	A
5.	Ammonium sulphate	21-0-0	A
6.	Potassium nitrate	13-45-0	B
7.	Potassium sulphate (SOP)	0-0-50	A
8.	Monopotassium phosphate (MKP)	0-52-34	B
9.	Potassium chloride (MOP)	0-0-60	N
10.	Mono ammonium phosphate (MAP)	12-61-0	A
11.	Orthophosphoric acid	0-52-0	A

Water soluble fertilisers: Water-soluble fertilizers are designed to dissolve quickly in water, making them ideal for fertigation systems where they can be applied efficiently through irrigation systems like drip or sprinkler irrigation. These fertilizers provide precise nutrient delivery directly to the root zone, which enhances nutrient uptake and reduces waste. Some commonly used commercial water-soluble fertilizers are,

1. Urea Phosphate (17% Nitrogen (N), 44% Phosphorus (P_2O_5))

2. Potassium Nitrate (13% Nitrogen (N), 44% Potassium (K_2O))

3. Calcium Nitrate (15.5% Nitrogen (N), 19% Calcium (Ca))

4. Monoammonium Phosphate (MAP) (12% Nitrogen (N), 61% Phosphorus (P_2O_5))

5. Mono Potassium Phosphate (MKP) (0% Nitrogen (N), 52% Phosphorus (P_2O_5), 34% Potassium (K_2O)

6. NPK Blends

- **19-19-19**: Equal parts of Nitrogen (N), Phosphorus (P_2O_5), and Potassium (K_2O)
- **20-20-20**: Balanced mix for all growth stages
- **12-32-16**: Higher phosphorus content for root development

7. Magnesium Sulfate (Epsom Salt) (9.8% Magnesium (Mg), 13% Sulfur (S))

8. Calcium Ammonium Nitrate (CAN) (15% Nitrogen (N), 26% Calcium (Ca))

9. Iron Chelates (e.g., Fe-EDTA, Fe-DTPA)

10. Micronutrient Mixes

- Zinc (Zn), Manganese (Mn), Copper (Cu), Boron (B), Molybdenum (Mo)

11. Ammonium Sulfate (21% Nitrogen (N), 24% Sulfur (S))

12. Potassium Sulfate (50% Potassium (K2O), 18% Sulfur (S))

Conclusion:

Fertigation presents a significant advancement in optimizing both crop production and resource management. It enhances crop productivity and quality by ensuring efficient use of water and nutrients, contributing to increased resource use efficiency and environmental safety. This method is particularly beneficial for managing crops in diverse field conditions, including those with undulating topography, as it promotes effective weed management and adaptability in operations. Its eco-friendly nature minimizes nutrient leaching, and crops exhibit high responsiveness to fertigation due to the precise

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supply of water and nutrients, leading to improved yields, better quality produce, and a higher return on investment. Overall, fertigation's precision enhances nutrient use efficiency, reduces waste, and lessens environmental impacts such as nutrient runoff and soil degradation.

Future thrust

- Needs to develop crop specific fertigation schedules including the basic nutrients and micro elements according to soil, climate, crop and their physiological stages.
- Promotion of technology by concerned stakeholder.
- Government is providing subsidy on conventional fertilizers; water soluble fertilizers may be considered under fertilizer subsidy regime of GOI.

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