Review Article

NUTRIENT DYNAMICS AND MOISTURE DISTRIBUTION UNDER DRIP IRRIGATION SYSTEM

ABSTRACT

A rational nutrient and water use can play a much higher synergic and supplementary effect on plant productivity. Therefore, understanding water and nutrient interaction is of paramount importance for sustainable crop production. Among the various irrigation methods, micro irrigation systems arethe most efficient and increasingly adopted worldwide.Drip systems are typically designed to wet only the soil zone occupied by the plant roots and to maintain this zone at or near an optimum soil moisture level.Fertigation is the most efficient method of fertilizer application, as it ensures application of the fertilizers directly to the plant roots as per crop demand. The knowledge of moisture distribution pattern helps in the effectiveness of drip irrigation. The volume and pattern of soil wetted from a point source is primarily a function of many factors like soil texture, application rate, total volume of water applied and irrigation regime. Nutrient dynamics is broadly defined as the way nutrients are taken up, retained, transferred, and cycled over time and distance in an ecosystem. Drip irrigation ensures uniform distribution of water and nutrients as compared to conventional methods. Thus the study of soil moisture distribution and nutrient dynamics has the potential to ensure that the optimum combination of water and nutrients is available at the root zone, satisfying the plants total and temporal requirement of these two key inputs.

Keywords : Drip irrigation,fertigation, nutrient dynamics, moisture distribution, root zone

1. INTRODUCTION

Water is a major factor involved in nutrient availability to plants. It is the vehicle through which nutrients move from soil to access plant roots for uptake. Although water and nutrient have their own functions, one can supplement or constrain the other by controlling, restricting or checking functions in plants. If soil water becomes limiting, nutrient availability to the plants gets affected. The nutrient and water interaction may be either positive or negative, depending upon crop growth stages, amounts, combinations and balances [1]. A rational nutrient and water use can play a higher synergic and supplementary effect on plant productivity. Therefore, understanding water and nutrient interaction is of paramount importance for sustainable crop production.

Among the various irrigation methods used for water application, micro irrigation systems particularly, drip and sprinkler methods seemthemost efficient and increasingly adopted worldwide. Applying plant nutrients by dissolving them in irrigation water (termed as fertigation) particularly with the drip system is themost efficient way of nutrient application[2].

2.WATER AND NUTRIENT AVAILABILITY TO THE PLANT

Nutrients, move via mass flow and diffusion in soil water to the root surface. Root interception is a third way in which plant obtain soil nutrient.Many mobile nutrients, such as calcium (Ca), magnesium (Mg), nitrate-N (NO_3-N), and sulphate (SO_4) are transported to the root by mass flow.Phosphorus (P) and potassium (K) are two nutrientsthat move by diffusion.Micronutrients are generally supplied to plant roots by diffusion in soil[1]. Therefore, low soil moisture conditions reduces micronutrient uptake. Plants require smaller quantities of micronutrients as compared to macronutrients, thus drought stress effects on micronutrient deficiency are not as serious as for macronutrients. However, iron (Fe) and zinc (Zn) deficiencies are frequently associated with high soil moisture conditions[3].

3. DRIP IRRIGATION

In drip irrigation, water is applied close to plants so that only part of the soil in which the roots grown is wetted, unlike surface and sprinkler irrigation, which involves wetting the whole soil profile. In this method of irrigation, a dense root system is developed in the zone adjacent to the dripper, resulting in direct and therefore more efficient water use by the plant. Drip systems are typically designed to wet only the soil zone occupied by the plant roots and to maintain this zone at or near an optimum soil moisture level [2].

4.FERTIGATION

Fertilizer application through micro irrigation system *i.e.* fertigation is the most advanced and efficient practice of fertilization. It combines the two main factors in plant growth and development, water and nutrients. Fertigation is the most efficient method of fertilizer application, as it ensures application of the fertilizers directly to the plant roots as per crop demand [4]. It enables the application of water-soluble fertilizer and other chemicals along with irrigation water uniformly and more efficiently in the root zone of crop. Agronomic efficiency of nutrients was also significantly higher for drip fertigation treatments compared to soil application of nutrients with drip and basin irrigation [5].

5.MOISTURE DISTRIBUTION UNDER DRIP IRRIGATION

Moisture distribution pattern is one of the basic requirements for efficient design and management of an irrigation system. The knowledge of moisture distribution pattern helps in the effectiveness of drip irrigation [6].This will ensure precise placement of water and fertilizer in the active root zone. In the design of drip irrigation system, the volume of soil wetted by a single emitter is important. This must be known in order to determine the total number of emitters required to wet a large volume of soil to ensure that the plant's water requirement will be met.

The volume and pattern of soil wetted from a point source is primarily a function of many factors like soil texture, application rate, total volume of water applied and irrigation regime [7].The volume of water applied per irrigation also affects the width and depth of the wetted soil volume and therefore the optimal emitter spacing.

5.1. Water movement in soil

The movement of water into the soil is very important for effective utilization for optimum crop growth and production as it affects the extent of wetted soil volume and concentration of different nutrients and salts in the root zone. The pattern of movement and distribution of soil water resulting from drip sources can be more different from those resulting from the more conventional modes of irrigation[8]. The water movement depends on the following factors in a drip-irrigated field [9].

- Soil constants such as liquid limit, plastic limit and porosity

- Soil moisture content prior to irrigation
- Hydraulic conductivity
- Soil and Water temperature
- Rate of infiltration into the soil
- Rate of discharge of emitter
- Spacing of emitters
- Level of water table
- Duration of water application
- Evaporation and root suction

5.2 Effect of soil texture on soil moisture distribution

The study of sub surface drip irrigation (SDI) with a drip line buried depth of 30 cm in sandy soil revealed that the wetting pattern was elliptical in shape with the wetted depth larger than the wetted radius, disributing 94 per centof the applied water below the emitter. For silty soil, the wetting pattern was roughly spherical [10].

Soil wetting patterns under trickle revealed that the maximum wetted width and depth was found in sandy soil followed by silt clay loam and loam soil for all volumes of irrigation water applied under trickle irrigation [11].The wetting front for sandy and clayey soils was studied and the vertical wetting front was found to be greater in sandy soil as compared with clayey soil (36.07% more), while the horizontal wetting front was found to be greater in clayey soil as compared with sandy soil (13.08% more)[12].

The soil surface wetting pattern under trickle source irrigation was studied and theresults revealed that the soil surface wetted area is directly proportional to the soil surface silt content, and increases approximately at the same ratio as the increase in silt content [13].

5.3 Effect of drip line spacing on soil moisture distribution

Three-dimensional water flow for lettuces under drip irrigation in sandy loam soil with laterals spaced at 65 cm and drippers spaced at 40 cm was monitored. The results showed that the impact of the compact soil layer was to reduce penetration of the wetting front to 25 cm depth, while there was homogeneous spread with the radial influence extending to 25 cm after irrigation and 30 cm after 24 hours [14].

Drip lines for SDI in sandy loam soil were buried at a depth of 0.25 m with laterals spaced at 0.91 and 1.82 m, and drippers spaced at 0.30 m. It was found that water moved laterally to the midpoint of both lateral spacings and vertically integrated to 0.53 m. Cotton yield and irrigation water use efficiency were 3.44 Mg ha^{-1}, 1.764 kg m^{-3} and 3.22 Mg ha^{-1}, 0.980 kg m^{-3}for 0.91 and 1.82 m lateral spacing, respectively which were statistically at par[15].

5.4 Effect of drip line placement depth on soil moisture distribution

The moisture distribution pattern of SDI in sandy soil indicated that a dripper line at 15 cm depth was better than 10 cm. At a depth of 15 cm the average moisture content was 10.6% up to a soil depth of 43 cm, whereas for a drip line at a depth of 10 cm the average moisture content was observed to be 9.4% up to a soil depth of 39 cm[16].

The depth of wetting increased with the depth of placement of laterals [17]. Soil water dynamics studied under subsurface drip irrigated onions in sandy loam soil showed an elliptical shape wetting pattern when the drip laterals were placed deeper than 15 cm, and the wetted depth was observed to be larger than the surface wetting which caused high water content below the drippers [18].

Effect of SDI depth on soil water content distribution at different times after irrigation in sandy loam soil was studied and theexperiment revealed that SDI at 35 cm depth could achieve higher efficiency rates with limited water to maximize yield, as the soil moisture content with laterals at 35 cm depth was more uniform in comparison to that at 5 cm and 20 cm depth [19].

5.5 Effect of discharge rate of dripper on soil moisture distribution

A study about point-source trickle irrigation in sandy soil revealed that the soil moisture decreased with the depth under the point of application, and also in the horizontal direction as the moisture was mostly stored within 0.2 m of the point source. The maximum wetted depth of 0.84 m was observed under the point source when irrigation was terminated for the 7 lph application rate, while the minimum wetted depth was 0.72 m for the 3.0 lph application rate [20].

Wetting patterns under trickle source irrigation in loamy sand soil in Tunisia, using two discharge rates of emitters i.e. 1.5 and 4 lph was studied. The study observed that vertical movement of soil moisture was greater with the higher discharge rate i.e. 40 cm at 1.5 lph after 6 h water application whereas it was 52.5 cm at 4 lph after 6 h water application. However, after 3 h water application, the maximum wetted radius (30 cm) was observed with the lower discharge rate (1.5 lph), and the minimum (22 cm) at the higher discharge rate (4 lph)[21].

The shape of the wetted soil volume for silt and clay soils, with different flow rates of 2, 4, 8, 16, and 24 lph and different operating times of trickle source irrigation for squash and grape crops were observed. The study revealed that the depth of wetted soil after soil-water redistribution was almost double the depth just after irrigation, but wetted soil width did not increase significantly. Higher emitter discharge rates increased wetted soil width but decreased wetted soil depth [22].

5.6 Effect of emitter spacing on soil moisture distribution

A study about wetting patterns for overlap zones under double point sources of drip irrigation,revealed that the wetting front increased with shorter emitter spacings.The results revealed that the selection of a shorter emitter spacing to increase the wetted area for improving water content and water use efficiency [23].

The effect of emitter spacing under drip irrigated sugarcane was studied and it was observed that at emitter spacings of 30 cm, the wetted depth was 33.5 cm while at emitter spacings of 40 cm, the wetted depth was 31.5 cm [24].

5.7 Effect of irrigation regime on soil moisture distribution

An experiment was done to study the effect of irrigation scheduling on moisture distribution under drip irrigated limes in Rajasthan for a loamy sandy soil. The experiment consisted of three irrigation levels, *i.e.* I1 (ETc – Evapotranspiration coefficient), I2 (0.7 ETc) and I3 (0.4 ETc) and two lateral spacings of 20 cm and 40 cm with a dripper discharge of 4 lph. The soil moisture in the profile increased with increasing irrigation levels. The moisture content was higher at the 20 cm lateral spacing as compared with the 40 cm spacing. The vertical distribution of moisture content was observed to be lower at the surface and increased with increase in depth for all irrigation levels. The results revealed that soil moisture decreased laterally, but increased vertically at each irrigation level. In addition, a higher increase in soil moisture was observed between 15 and 30 cm depth and thereafter it showed a uniform increase up to 60 cm [25].

An experiment consisting of combinations of three levels of irrigation (0.3,0.6 and 0.9 PE) through drip system and three levels of fertilizer (100, 50 and 150% recommended dose) supplied through drip irrigation were done. The moisture content of the soil was more at 15 cm depth both at 15 and 30 cm radial distances, in all irrigation levels [26].

5.8 Effect of duration of water application on soil moisture distribution

The effects of emitter rate on drip irrigation water distribution patterns in sandy loam soil were studied[27]. This study showed that low antecedent soil water content and low application rates increased the relative horizontal to vertical water spreading and this increase was attributed to the longer irrigation time instead of flow rates.

Wetted soil width and depth depends on the duration of water application and both of these increase with time [28]. A greater wetted depth was observed compared to wetted width for loamy sand mixed soil.

6. Nutrient dynamics

Nutrient dynamics is broadly defined as the way nutrients are taken up, retained, transferred, and cycled over time and distance, in an ecosystem [29].The plant available soilnutrients are highly variable, due to complex nature of soil nutrient dynamics, which are strongly influenced by root–soil interactions. Plants can uptake only a limited portion of total amount of nutrients for their growth and development depending on the chemical formulation of soil minerals and interaction with other influencing parameters[30].

When we consider nutrient distribution pattern under different irrigation methods, it is seen that nutrients will undergo leaching in surface irrigation methods, localization of nutrients takes place in drip irrigation andan uniform distribution of nutrients was found under drip fertigation.

7. NUTRIENT–MOISTUREINTERACTIONS UNDER DRIP IRRIGATION

7.1. Nitrogen

More amount of residual N was observed at 0-90 cm soil depth when supplied with higher N rates and irrigated at high soil moisture tension in sub surface drip irrigated cauliflower. But when irrigated at low soil moisture tension nitrogen was lost beyond root zone [31].

Total nitrogen uptake in drip irrigation was 8.11 per cent higher than that of furrow irrigation at the highest level of applied nitrogen (120 kg N ha^{-1}) in tomato[32].

An experiment was conducted in which drip fertigated cotton received five different nitrogen rates (0,60,120,180 and 240 kg N ha^{-1}), while only one rate (180 kg N ha^{-1}) was applied to the surface irrigated cotton. Nitrogen recovery ranged between 48 and 55 per cent in drip- fertigated cotton and 43 per cent for the surface irrigated cotton. The overall average of total N uptake for cotton ranged between 145 for control and 417 kg N ha^{-1} for the highest N rate under drip fertigation. It is clear that increasing N rates under drip fertigation resulted in an increase of N uptake by the corresponding treatments [33].

Fertigation treatment maintained high concentration of NO_3^- N at shallow depth than deeper layer[34]. The available nitrogen was increased steadily with increased distance from the dripper along and between the laterals up to a distance of 30 cm. The peak available soil nitrogen (207 kg N ha^{-1}) was recorded in the depth of 15-30 cm at a distance of 30 cm from the dripper[35].

In the study conducted on tomato, four levels of nutrients (l_1- 75 per cent RD of N and K, l_2- 100 per cent RD of N and K, l_3- 125 per cent RD of N and K, l4- 150 per cent RD of N and K) constituted the main plot treatments and two fertigation intervals (i_1- fertigation once in four days, i_2- fertigation once in eight days) constituted the sub plot treatments. The two control treatments were, control 1 (KAU ad hoc POP for precision farming) and Control 2 (KAU POP for conventional farming).The treatment l_3 recorded the highest N, P and K uptake and it was statistically on par with l_4[36].

Fertigation treatments improved the N and K status of soil, while N status improved and K decreased in soil application [37]. Effect of interaction between irrigation and nitrogen (N) rates on fruit yield, root characteristics and N uptake was studied. Tomatoes were irrigated at 100% (W_1), 80% (W_2), and 60% (W_3) of reference crop evapotranspiration (ET_0) and N fertilizer was supplied at 240 kg N ha^{-1}, 180 kg N ha^{-1}, and 120 kg N ha^{-1} under drip fertigation. With the application of the irrigation and N fertilizer rates, plant N uptake increased from 28.7 to 94% in 2015 and from 14 to 92.3% in 2016. The water use efficiency (WUE) of the irrigation and N rates varied from 25.4 to 37.2 kg m^{-3} and from 20.8 to 36 kg m^{-3}[38].

Seasonal dynamics of N, P, and K distribution in the soil of an apple orchard under fertigation was evaluated[39].The results revealed that the ammonium-N concentrations in the wetted soil volume strongly varied when the orchard was fertigated, probably because of its rapid oxidation to nitrates. Soil $N\text{-}NO_3$ concentration increased when fertigation was applied, despite partial leaching of unassimilated nitrogen in the winter and spring period. The highest concentration of nitrate-N was observed 20 cm away from the drip emitters.

7.2. Phosphorous

Application of DAP at the lower rate (33 kg P ha^{-1}) through fertigation resulted in almost the same wheat grain yield as obtained by the higher dose (44 kg P ha^{-1}) applied by broadcast method[40].

An experiment with corn plants resulted in greater biomass product and higher plant tissue P content when water and nutrients were applied continuously as compared with a 2 days intermittent application regime. P content of corn leaves was 25 per cent greater for the continuous treatment as compared with the pulsed treatment [41].Application of recommended dose of fertilizer at every irrigation (2 days' interval) upto 105 days recorded significantly higher uptake of phosphorus (12.58 kg ha^{-1}) by chilli than surface irrigation (8.53 kg ha^{-1})[42].

The highest available phosphorus in soil was confined to 0-15 cm of soil layer under all fertigation levels. The available phosphorous decreased with increase in distance and soil depth. The peak availability of phosphorous was recorded just below the dripper[34].

Significant changes in chickpea phenotypic and physiological traits in response to different P and water supply regimes was reported [43]. Compared with the unfertilized treatment, the stomata density and conductance, chlorophyll content, photosynthesis efficiency, biomass accumulation, and plant nutrient uptake were significantly improved under P drip fertigation. The results revealed that the P fertilizer form and irrigation regime providing chickpea plants with enough P and water, at the early growth stage, increased the stomatal density and conductance, which significantly improved the photosynthetic performance index (PIABS) and P use efficiency (PUE), and consequently biomass accumulation and nutrient uptake.

7.3. Potassium

Application of RDF at every irrigation (2 days interval) upto 105 days recorded significantly higher uptake of potassium (99.1 kg ha^{-1}) by chilli than surface irrigation (44.6 kg ha^{-1})[42].

Higher concentration of potassium was found in the upper layers of the soil i.e. at 0 to 20 cm soil depth and lower concentration of potassium was found in the lower layers of the soil i.e. 20 to 40 cm soil depth under fertigation. Peak quantity of potassium under fertigation treatment was always found to be in the soil depth of 0- 10 cm at the emitter [44].

The available K content was more in the surface layer under drip fertigation system due to entrance of K ions on soil exchange complex resulting in very small movement to deeper layer[45]. Dynamics of potassium nitrate (KNO$_3$) around a dripper are influenced by presence of plants. In the presence of maize, the soil water content, soil electrical conductivity, soil water solution and mass of KNO$_3$ decreased substantially more than when there was no maize. And the difference in the dynamics of KNO$_3$ with and without maize is attributed to the uptake of KNO$_3$[46].

Afterfertigation, the highest K concentration was recorded in 0-15 cm depth under emitter with a distance of 20 cm from dripper[35].

8.CONCLUSION

It could be clearly seen that drip irrigation requires less irrigation water with increased irrigation efficiency and ensure uniform distribution of water and nutrients as compared to conventional methods. Fertigation also increases the nutrient use efficiency, which leads to increase in yield and income. The right combination of water and nutrients is the key factor for high yield and the quality of produce. Thus the study of soil moisture distribution and nutrient dynamics has the potential to ensure that the optimum combination of water and nutrients is available at the root zone, satisfying the plants total and temporal requirement of these two key inputs.

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