Nitrogen and potassium dynamics in fertigation systems

SINGH A.K., **CHAKRABORTY D., MISHRA P. and SINGH D.K.**

Water Technology Centre, Indian Agricultural Research Institute, New Delhi-110012, India

Abstract

Water and nutrients are the two key inputs in agriculture but their use efficiency is low and their injudicious use leads to environmental degradation. Among the various techniques of water application, drip or trickle irrigation is the most efficient method of delivering water to the root zone. Applying fertilizers through irrigation water, particularly through the drip system, termed as fertigation, also provides the most effective way of supplying nutrients to the plant roots. In fact, the supply can be tailored to meet the precise requirement of the plant depending on its growth stage. A considerable amount of work has been done on drip irrigation and also on fertigation, but studies on the dynamics of nutrients in soil after their exit from the emitter are very few. In this paper, results of two separate experiments conducted to study the fate of nitrogen and potassium in soil applied through fertigation have been presented.

In both the experiments, water-soluble fertilizer was applied through a drip system (T_1). In the second treatment (T_2), the fertilizer was applied on soil but water was applied through drip system while in the third treatment (T_3) fertilizer was applied on the soil with conventional irrigation method (check basin/furrow). In the experiment in which nitrogen dynamics were studied, the crop was broccoli while potassium dynamics were studied in radish.

In the experiment on nitrogen dynamics, it was observed that in the fertigation treatments, ammonium form of nitrogen dominated in the upper soil layers. Almost all the nitrogen applied remained confined to the root zone. In the conventional method of irrigation, the nitrate-nitrogen dominated and a significant amount was leached out. Leaching losses were also observed when the fertilizer was applied on soil and water through a drip system. In the second experiment, in which potassium dynamics were studied, it was observed that in fertigation treatments, potassium was confined to the root zone of the radish crop, while it moved in significant quantities beyond the root zone in the conventional method (furrow irrigation). Movement beyond the root zone was also observed in the soil-based fertilizer application with water through a drip system but to a lesser degree.

Keywords: fertigation, nitrogen, potassium, broccoli, radish, water use

Introduction

Sustainability of any production system requires optimal utilization of resources be it water, fertilizer or soil. Apart from the economic considerations, it is also well known that the adverse effect of injudicious use of water and fertilizers can have far reaching implications on the environment. There is, therefore, a need for technological options that will help in minimizing the use of the precious resources and maximizing crop production without any detrimental impact on the environment. Drip irrigation also referred to as trickle irrigation or microirrigation, represents a definite advancement in irrigation technology with very wide implications (Sivanappan *et al*., 1972; Magar and Firake, 1991). It is a technique in which water is applied in precise amounts at a rate which matches the plant requirement and also maintains an optimum soil water status around the vicinity of plant roots. This technology has the greatest potential where water is either very expensive or scarce or the soils are sandy, rocky or the terrain is undulating and difficult to level. Poor quality water can also be used without significant yield reductions (Nightingale *et al*., 1991). As water, labour and land preparation become costlier, this technique of water application is bound to replace conventional systems. Drip irrigation has another advantage because it can also be used to apply any water soluble fertilizer or chemical in precise amounts, as and when required to match the plant needs (Clothier and Saucer, 1988; Bar-Yosef and Sagiv, 1992; Bafna *et al*., 1993), directly into the root zone of the crop which is referred to as Fertigation or Chemigation. This provides a means of improving nutrient use efficiency as the fertilizer applied remains confined to the root zone of the crop.

Considerable amount of work has been conducted on drip irrigation in recent years but studies on the nutrient movement and distribution using drip irrigation are very few. The information on the nutrient dynamics under drip fertigation would be very useful in desiging efficient fertigation systems. In addition to nitrogen, the single most important plant nutrient, potash, a nutrient considered adequate in soils all over the world, has now been reported to be deficient in vast areas in recent years. Bar-Yosef and Sagiv (1985) showed that at the time of maximum nutrient uptake rate by several crops grown under drip irrigation, K must be supplied through the water even when it is in sufficient concentration (as exchangeable ion) in the soil. The fact that in India, the entire requirement of potassic fertilizers are imported signifies the importance of improving the potassium use efficiency through appropriate application methods. In this paper, results of experiments on the movement and distribution of nitrogen and potassium under drip fertigation have been presented and compared with conventional irrigation methods.

Materials and Methods

The studies were carried out on the experimental farm of the Water Technology Centre, Indian Agricultural Research Institute, New Delhi, India situated at 28° 38' N latitude and 77° 10' E longitude and at an altitude of 228.7 meters above mean sea level. The soil is sandy loam classified as Typic Ustocrept with the average pH and EC of the 1:2.5 soil water suspension ratio being 7.51 and 0.48 dSm^{-1}, respectively. The organic carbon content was 0.32 percent. The available N, P and K status of surface soil was 120, 20 and and 170 kg ha^{-1}, respectively. Nitrogen movement was studied in Sprouting Broccoli (*Brassica oleracea* var. *italica* L.) variety-Packman, sown in the nursery on 20th October, transplanted in the field on 23rd November, and harvested on 10th February. The plant to plant spacing was 30 cm while the row to row spacing was 60 cm. The recommended fertilizer dose was 200:120:150 of N:P:K kg ha^{-1}. For Potassium studies, radish (*Raphanus Sativus L.* cv. *Pusa Chetaki*) was sown at a spacing of 45 cm x 15 cm on March 28, 2000. The recommended dose of fertilizer was 120 kg of N, 75 kg of P and 100 kg of K and harvested on May 18, 2000. The marketable yield was taken as the total fresh weight at harvest. The following three treatments, replicated four times, were adopted for the study:

T_1 : Fertigation with fertilizer applied along with irrigation water in the drip system;
T_2 : Drip irrigation with fertilizer applied on soil; and,
T_3 : Conventional irrigation [Check basin (Broccoli) and Furrow (Radish)]

In drip system, water was applied every alternate day based on the evapotranspiration demand of the crop computed from historical weather data. For check basin/furrow treatment, water was applied on the basis of soil moisture tension value (0.03 MPa approximately) measured by tensiometers installed in the field at 25 cm depth for broccoli and 15 cm depth for radish. All necessary measures were taken to keep the crop pest free.

During the crop growth period in broccoli, observations were taken on soil moisture content, ammonium and nitrate concentrations in the various soil layers. Sampling was done from 0-5, 5-10, 10-20, 20-30, 30-50, 50-70 and 70-90 cm depth of the profile at the emitting point, and 15, 30, 45 and 60 cm horizontally away from the emitting point. The drip line was placed mid-way between the two rows of Broccoli plants. Water content of the soil samples was determined gravimetrically. Nitrate-and Ammonical-N was determined in the soil samples collected from the above depths initially, before and after each fertigation and fertilization using Tecator Automated 5020 Flow Injection Analyzer.

To study the potassium movement (both horizontal and vertical) under different treatments, soil samples were collected from 0-5, 5-10, 10-20, 20-30, 30-40 cm depth of soil profile at the plant, 10 and 22.5 cm horizontally away from the plant. In case of T_1, the soil samples were collected before and after each fertigation and in case of T_2 and T_3 at 7 DAS, 19 DAS and 31 DAS and at harvest. Concentration of Potassium (K) in the collected soil samples was evaluated using Flame Photometer method.

Results and Discussion

Soil water movement and distribution

Innumerable studies have been conducted on the soil water uptake and movement under drip and conventional irrigation systems. It has been established that considerable savings in water use can be achieved through drip systems and our results also indicate that at least 30 percent savings in water use can be achieved without affecting the yield. Results on this aspect are not being presented in this paper.

Nitrogen movement and distribution

NO_3-N and NH_4-N movement and distribution at different stages for T_1, T_2 and T_3 treatments are presented here under different subheads.

NO_3-N movement and distribution

The distribution of nitrate-N throughout the profile varied both horizontally and vertically from the emitting point. Before the first fertigation, the nitrate nitrogen was observed to be uniformly distributed throughout the profile. When the soil samples were taken 24 hours after first fertigation, the peak NO_3-N concentration below the emitter (16.16 g/g of dry soil) was found to be in 30-50 cm depth whereas for locations 15 cm, 30 cm and 45 cm away from the emitter, the peak was within 10-20 cm depth. The peak concentration was maximum for the point 15 cm from the emitter (32.13 g/g of dry soil) and observed in the 10-20 cm layer. At a distance of 60 cm from emitter the peak (14.3

g/g of dry soil) was again found within 30-50 cm depth. For the point below the emitter, the NO_3-N distribution at first decreased steadily upto a depth of about 25 cm followed by a sudden increase in the peak concentration in 30-50 cm layer. For 15 and 30 cm horizontal distance from the source there was a decrease in NO_3-N concentration from surface to 10 cm depth, then a steep increase in concentration upto a depth of 15 cm (32.13 and 19.87 g/g of dry soil) followed by an almost uniform distribution within 15-25 cm and then a decrease in NO_3-N concentration up to 90 cm. For a layer 60 cm away from the emitting point, the concentration gradually increased to a depth of 10-20 cm (17.19 g/g of dry soil) and then decreased up to 30-50 cm layer. Beyond this depth, the concentration was found to be uniform through the profile up to 70-90 cm depth. Again, the decrease in NO_3-N concentration from the respective peak concentrations, for all the specified horizontal distances from the emitting point, is steeper for the point immediate to the emitting point than the locations horizontally away from the emitting point.

In samples taken 24 hours before 2nd fertigation, the distribution of NO_3-N was found to follow a definite pattern (increase in concentration upto a depth, then steep decrease followed by a uniform decrease) for each distance from emitter. For all distances from emitting point, the NO_3-N is found to be minimum in the upper 0-10 cm (0.59 to 2.01 g/g of dry soil) and 10-20 cm (0.6-2.98 g/g of dry soil) layer. The concentration below 10-20 cm depth was found to decrease with increase in distance from emitter. The peak concentrations for the point immediate to the emitter and 15 cm from the emitter (26.45 and 18.03 g/g of dry soil) were found in 20-30 cm depth whereas for 30, 45 and 60 cm horizontal distance from emitter, the peak concentrations were 13.41, 15.02 and 11.12 g/g of dry soil, respectively and found in 30-50 cm depth.

Twenty four hours after 2nd fertigation, the distribution of NO_3-N was almost similar to that at 24 hours after 1st fertigation. The only difference was that the peak NO_3-N concentration for the soil profile at a distance of 30 cm from emitting point was in 20-30 cm layer rather than 10-20 cm layer as found at 24 hours after first fertigation. The concentration at surface layer (0-5 cm) was more for the point near the emitter and the point 15 cm away from the emitter (15.47 and 18.62 g/g of dry soil, respectively). It was less for 30 cm from the emitter (9.45 g/g of dry soil) and almost same (7.49 and 6.07 g/g of dry soil) for points 45 cm and 60 cm distance from emitter, as compared to that found 24 hours after 1st fertigation.

The peak concentration of NO_3-N, was again located at the same depth 24 hours before 3rd fertigation as was observed before 2nd fertigation, but the concentrations were higher at all the points. The concentrations in 50-70 cm depth also increased for all the sampling points as compared to the sampling after the 2nd fertigation but the concentration below 70 cm remained almost the same.

The distribution of NO_3-N throughout the profile under study 24 hours after 3rd fertigation followed the same trend as 24 hours after 1st and 2nd fertigations. The peak NO_3-N concentrations for the points 15 and 45 cm from the emitting point were found at a lower depth (20-30 cm) but for other points the peaks were found at the same depth as observed earlier.

The peak NO_3-N concentration for the point immediately below the emitter 24 hours before the 4th and last fertigation was more (29.73 g/g of dry soil) as compared to the previous values. The peak concentration of the point 15 cm from the emitter (31.08

g/g of dry soil) was significantly higher and more than the point near the emitter. This peak concentration was located at the 30-50 cm layer.

The peak NO_3-N concentrations for all the points 24 hours after 4th and last fertigation were found at a depth of 30-50 cm except for the point 15 cm from the source which was found in 20-30 cm soil layer and was significantly higher (32.75 g/g of dry soil).

At harvesting i.e., 8 days after last fertigation maximum NO_3-N concentration was found within 30-50 cm layer (Figure 1). The peak values for the points below the emitter (27.16 g/g of dry soil) and 15 cm from emitter (29.15 g/g of dry soil) was much higher than those of other points (ranging from 12.74 to 14.26 g/g of dry soil).

There were marked differences in the distribution of nitrate nitrogen t in the soil profile among fertigation (T_1), drip irrigation (T_2) and check basin (T_3) treatments (Figure 1). For the drip fertigation treatments, the nitrate nitrogen concentration, at 24 hours following fertigation, was less in upper 0-10 cm layer with a peak concentration in 30-50 cm layer for the point immediate to the source (emitting point) and 10-20 cm for other points at different distances from the source. For the fertigation treatments, the maximum NO_3-N concentration 19-20 days after each of the fertigations was found to be in 20-30 cm layer.

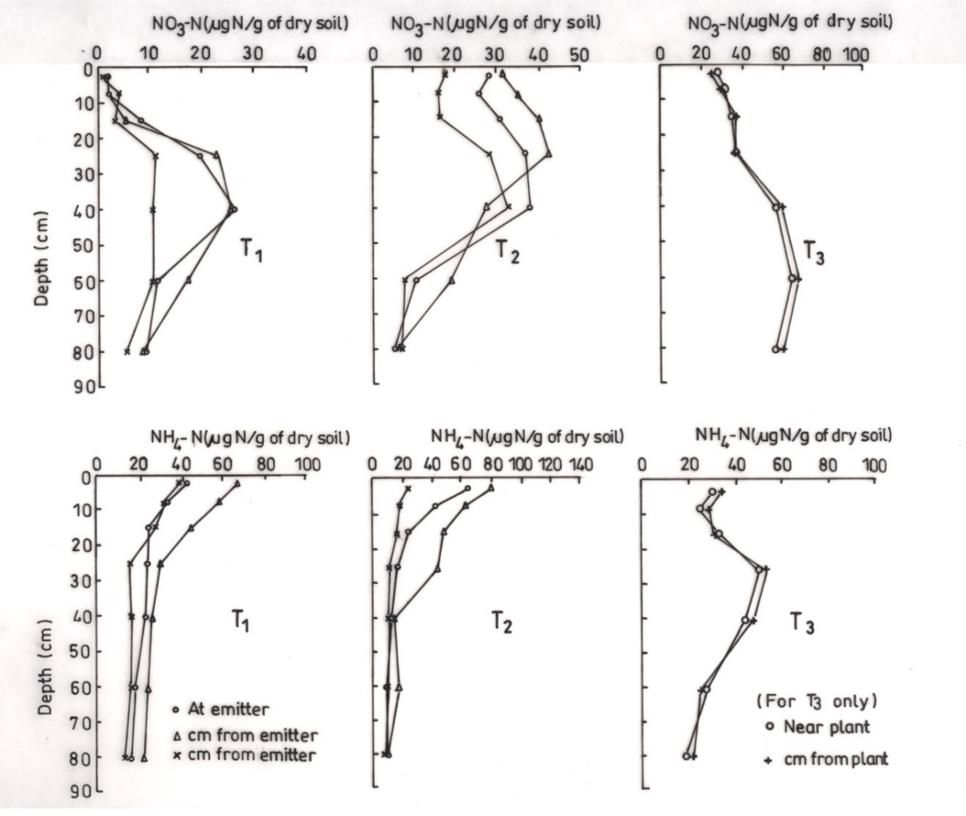

Figure 1 Distribution of NO_3-N and NH^4-N in soil profile at harvest for (T_1) fertigation, (T_2) drip irrigation with soil application of fertilizer and (T_3) check basin treatment.

In T_2, the NO_3-N distribution, 24 hours after each dose of fertilizer application decreased steadily without any peak NO_3 concentration within the profile under study. Here the maximum concentration was found in the upper 0-10 cm layer and decreased with depth. This trend was similar for all the sampling points at different distances from the emitter. The NO_3-N was observed to increase 18-20 days after following application of fertilizer with an uniform distribution with 0-30 cm depth and then followed a gradual decrease. This is true for all the locations in the soil profile. The NO_3-N concentrations as found in lower depths were more in this treatment as compared to other fertigation treatments, suggesting the possibility of some leaching losses of NO_3-N. The NO_3-N concentration was significantly higher in surface soil in this treatment than that in fertigation treatments and found to increase with each fertilizer application. In T_3 (check basin treatment), NO_3-N moved to deeper layer with the advance of the experiment and at the harvest, the NO_3-N peak was found in 70-90 cm layer, indicating maximum leaching loss.

The significant difference of NO_3-N movement and distribution observed between drip fertigation, drip irrigation and check basin treatments a few days following fertigation or fertilization was that the peak concentrations of NO_3-N in fertigation treatment was found at some depth in the profile (for the point near the emitter peak was formed at a greater depth than any other points following fertigation), whereas maximum NO_3-N concentration in T_2 treatments was found in the surface layer gradually decreasing down the profile. The peak concentration for the points near the emitting point and 15 cm from that in T_1 treatment was much more than that for other points. This range was not so large for T_2 treatment. For check basin treatment, the peak concentration moved to a much lower depth than other treatments with drip system, indicating loss of NO_3-N out of the root zone which was found to be 10-50 cm. In both T_2 and T_3 treatments, urea was applied but for T_2, the water was applied through drip whereas in T_3, the flood irrigation system was employed. This resulted in the difference in the quantum of water applied at a time between the two treatments following application of fertilizer. Hence, NO_3-N moved to a greater depth greater than 50 cm with water in check basin (T_3) but in T_2, it was confined within 50 cm depth.

NH_4-N movement and distribution

The NH_4-N concentration, 24 hours after each fertigation was found mostly in the upper 0-30 cm soil layer. As NH_4 is not mobile and is adsorbed to the soil matrix, its peak concentration (99.45 g/g of dry soil) was in the top 0-10 cm layer, decreased towards the deeper layers upto 40-50 cm layer and then maintained a constant value till 70-90 cm depth. For the point located close to the source, NH_4-N was concentration was greater in the 0-10 cm (66.09 g/g of dry soil) than any other point. At the point 15 cm from the emitter the variation in concentration of NH_4-N from top layer to the bottom layer of the profile studied was less than that for the point immediate to the source and this difference was significant. For other points, the distributions were uniform throughout the profile, indicating restricted movement of NH_4-N.

In T_2 treatment, NH_4-N was concentrated in 0-50 cm layer. In this treatment, the NH_4-N concentration was more in the 0-50 cm layer than found in fertigation treatments for both the points next to the emitter and 15 cm from the emitter. In samples taken 24 hours before the next urea application, NH_4-N was found more in the upper 50 cm layer than 24 hours after application, indicating urea hydrolysis.

In T_3 treatment (check basin), NH_4-N concentration peak was found in 30-50 cm depth 24 hours after urea application. But 20 days after application, its peak was observed at 20-30 cm depth. This indicated conversion of NH_4-N to NO_3-N in the deeper layers and was reflected in NO_3-N profiles.

The NH_4-N concentration in T_1 treatment was maximum in the surface layers i.e., between 0-40 cm layer with peak values in the surface layer, decreasing depth wise. At the start of the experiment, NH_4-N concentration in the deeper layer was less. But these differences increased towards the end of the experiment for all fertigation treatments both horizontally and vertically. In T_2 treatment, except for the point near the emitter, the NH_4-N concentration did not show any marked difference and was same throughout the profile. Figure 1 shows the distribution of NH_4-N in the soil profile at harvest in the various treatments.

In check basin treatment (T_3), the peak was always found between 20-50 cm depth with minimum NH_4-N concentration in the surface layer (0-10 cm) which was in sharp contrast to the drip irrigation and fertigation treatments, where maximum NH_4-N concentration was always found in the surface layers.

The increase in NH_4-N concentration immediately in the vicinity of the emitter is a consequence of the hydrolysis of urea (Haynes, 1990). The consistently wet condition around the emitter also ensures that the conversion of NH_4-N to NO_3-N occurs some distance away from the emitter in a relatively drier zone, where more oxygen is available (Laher and Avnicmelech, 1980). This results in the peak concentration of NO^-_3N occurring below the soil surface in the layer (30-50 cm) and more than 15 cm away from the emitter. Ammonium ion is absorbed by the soil matrix and, therefore, the maximum concentration changes were confined to the top layer and around the emitter. There was no appreciable change beyond 30 cm away from the emitter up to the third fertilizer application. It is only after the third fertigation that the changes in NH_4-N content percolate down to deeper layers. NO_3-N ions, on the other hand, are considered very mobile. But unlike T_3 (check basin treatment) where the soil is comparatively drier, the higher soil water status in the root zone in T_1 and T_2 treatments restricts the mobility of NO_3 ions to the 20-30 and 30-50 cm layers. These results confirm to the observations of Dalbro and Dorph-Peterson (1976) and Haynes (1990), who have reported that solute penetration is more in an initially dry soil compared to an initially moist soil. Ghuman and Prihar (1980) who reported salt movement under different soil texture also supported these observations.

In T_1 and T_2, the amount of fertilizer applied was identical but as a result of higher amount of water applied in T_3, a significant amount of fertilizer was leached down which was reflected in the relatively lesser amounts of NH_4-N and NO_3-N being retained in the profile. The soil profile was relatively drier in T_3 compared to other treatments and this resulted in the conversion of NH_4-N to NO_3-N the latter being mobile was leached down.

It is often reported that nitrate ion being mobile has a tendency to more away from the emitter to the periphery of the water front (Dalbro and Dorph-Peterson, 1976) and not be available to the plant. The distribution of NO_3-N in the soil profile has shown that it neither accumulates at the periphery of the wetting zone nor is leached out from the root zone under drip systems. The design of the drip irrigation system coupled with the discharge rate can, therefore, optimize both water and fertilizer use by a crop.

Potassium (K) movement and distribution

Potassium movement, its horizontal and vertical distribution at harvest in various treatments has been presented in Figure 2. Under the fertigation treatment T_1, the distribution of Potassium varied both vertically and horizontally from the emitting point. Before first fertigation (7 DAS) itself the initial Potassium concentration indicated the decreasing trend with respect to the depth. However, before first fertigation the Potassium concentration was found to be fairly uniform with respect to horizontal distance from the emitter. After each fertigation, the similar trend was observed. Thus, in general, the potassium content was found to decrease irrespective of before or after fertigation with depth under all the fertigation treatments (Figure 2). In general, higher concentration of Potassium was found in the upper layers of the soil i.e. at 0-25 cm soil depth and lower concentration of potassium was found in the lower layers of the soil i.e. 25-40 cm soil depth. However, the peak quantity of Potassium under fertigation treatments was always found to be in the soil depth of 0-10 cm at the emitter, 10 cm and 22.5 cm from the emitter irrespective of before or after fertigation.

It can also be observed that at the emitter, higher quantity was deposited in the upper layers (0-25 cm depth of soil). But at 10 cm and 22.5 cm distance from the emitter slight decrease in the quantity of Potassium was observed in the upper layers (0-25 cm depth) of the soil. Thus, as the distance from the emitter increased the Potassium quantity was found to decrease. However, the Potassium at lower depths (25-40 cm) remained almost similar and equal to the initial Potassium concentration irrespective of the distance from or at the emitter.

K distribution pattern under T_2 treatment indicated lower concentration of Potassium in the 0-20 and 30-40 cm depth of soil and higher concentration in the middle layers of soil (i.e. 20-30cm) irrespective of the distance from the emitter. This can be explained in the light of the fact that regular application of irrigation water has taken down the soluble Potassium to the middle layers from the upper layers. However, there was not much difference of Potassium content between that present at emitter and 10 cm from the emitter. As the distance from the emitter increased to 22.5 cm, higher level of Potassium concentration was noticed. This may be due to the depletion of the available Potassium by the plants at the emitter and 10 cm from emitter more than that at 22.5 cm from the plant.

The resultant Potassium distribution profiles under T_2 treatment indicated lower concentration of Potassium in the 0-20 cm depth and higher concentration in the lower layers of soil i.e. 20-40 cm soil depth irrespective of the distance from the emitter. However, the Potassium content was found to be lower near the plant compared to that present at 10 cm and 22.5 cm from the plant in the upper layers of the soil i.e. in the soil depth range of 0-20 cm. Within the depth range of 0-20 cm, the Potassium content was found to decrease with respect to depth where as that in the depth range of 20-40 cm was found to be fairly uniform with respect to depth (Figure 2). The presence of higher amount of Potassium beyond the crop root zone is not useful to crop and probably lead to more leaching loss of Potassium as a result of flood irrigation by way of furrow irrigation which ultimately resulted into lower yield under T_3 treatment compared to other treatments of the present study.

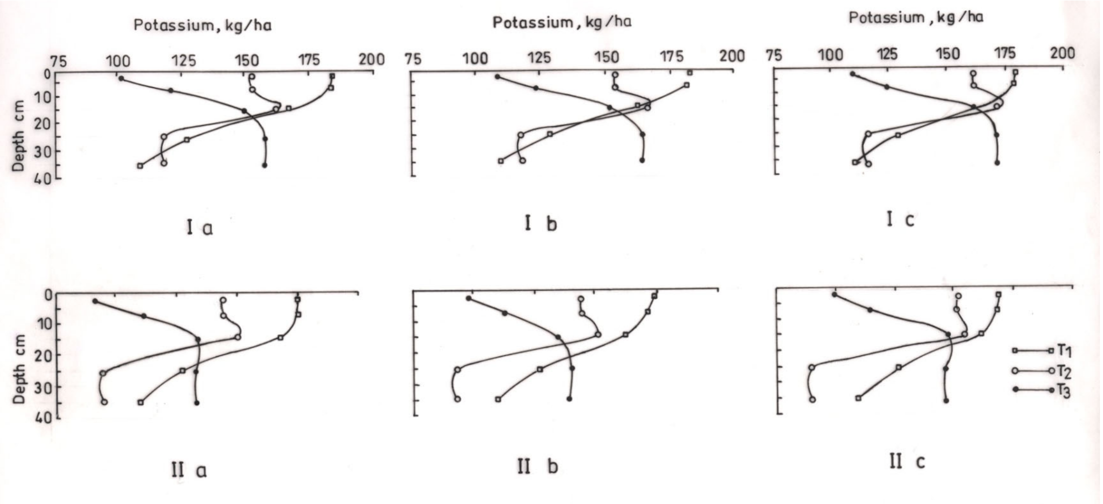

Figure 2 Distribution of potassium in soil under different treatments I: 31 days after sowing; II: at harvest; a, b, c refer to sampling points near the plant, 10 cm and 22.5 cm away from the plants, respectively T1: fertigation; T2: griip irrigation with soil application of fertilizer; and T3: furrow irrigation.

Yield and water use efficiency

Yields obtained in the various treatments along with the water use efficiency have been presented in Table 1. Fertigation has resulted in higher yields indicating that it is one technology that can enhance both the nutrient and water use efficiency.

Table 1 Yield and water use of broccoli and radish in various treatments.

Treatments	Broccoli			Radish		
	Yield kg ha^{-1}	Water applied mm	Water use efficiency kg ha^{-1} mm	Yield kg ha^{-1}	Water applied mm	Water use efficiency kg ha^{-1} mm
T1	4301	217	18.70	15200	205	74.15
T2	2343	217	10.87	11200	205	54.63
T3	1997	306	6.50	10300	310	33.23

Conclusions

The findings of the foregoing experiments have clearly established that fertigation is definitely advantageous over drip irrigation with soil application of fertilizer and check basin irrigation with broadcast application of fertilizer. Fertigation is, therefore, a technique which economises in water and fertilizer application and increases their use efficiency.

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