EFFECT OF TRICKLE IRRIGATION AND FERTIGATION ON SOIL PROPERTIES AND NUTRIENT UPTAKE BY TOMATO

Thesis submitted in part fulfilment of the requirements for the degree of
Doctor of Philosophy in Soil Science and Agricultural Chemistry
to the Tamil Nadu Agricultural University, Coimbatore.

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1991

CERTIFICATE

This is to certify that the thesis entitled **"EFFECT OF TRICKLE IRRIGATION AND FERTIGATION ON SOIL PROPERTIES AND NUTRIENT UPTAKE BY TOMATO"** submitted in part fulfilment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY IN SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the Tamil Nadu Agricultural University, Coimbatore is a record of **bona fide** research work carried out by **Thiru A.R.MOHAMED HAROON** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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Dedicated to

MY PARENTS

To whom I owe everything for what I am

ABSTRACT

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EFFECT OF TRICKLE IRRIGATION AND FERTIGATION ON SOIL PROPERTIES AND NUTRIENT UPTAKE BY TOMATO

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Degree : DOCTOR OF PHILOSOPHY (Agriculture) IN SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

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Trickle irrigation has the greatest potential in increasing the yields of crops with significant savings in water and nutrients as compared to other conventional methods. Restricting the active root zone of plants due to the limited area of wetting makes it necessary to apply nutrients through trickle irrigation and this is known as 'fertigation'. A glasshouse and two field experiments were conducted to study the effect of fertigation of single or combinations of major nutrients (N, P and K), and different levels of trickle irrigation with different methods of N application (soil application vs. fertigation) on the

changes in soil chemical properties, yield and nutrient uptake by tomato.

The results of the glasshouse experiment revealed that fertigation with half N or full N or full N & K decreased the soil pH and increased the soil EC at both 45 and 75 DAT while fertigation with NPK increased the soil pH and lowered the soil EC at all the three stages as compared to soil application of fertilisers. In all the three stages, fertigation with N alone (half or full N) recorded higher NH_4-N, $NaHCO_3$-P and NH_4OAc-K (45 and 75 DAT) contents of soil than soil application of fertilisers. In both the soils studied, higher $NaHCO_3$-P and NH_4OAc-K contents of soil were recorded in surface than subsurface soil.

Increased fresh fruit yields of tomato were recorded under fertigation of full N (40 per cent), half N (28 per cent), fertigation of NPK (19 per cent) and comparable fruit yield under simultaneous fertigation of N & K, with that of soil application of fertilisers. Loamy sand gave higher fruit yield of tomato due to the fertigation of nutrients than sandy clay loam. Fertigation with either half N, full N or full NPK, increased the relative nutrient use efficiency to the extent of 6.0 to 12.0, 0.8 to 2.3 and 5.0 to 15.0 per cent for N, P and K respectively than soil application of fertilisers.

In the field experiments daily trickle irrigation at 4 L recorded higher values of soil pH, NH_4-N content of soil with lower values of soil EC. Trickle irrigation at 4L in alternate days recorded higher soil EC and NH_4OAc-K content of soil. Lower values of soil EC, water soluble cations and anions, and NH_4OAc-K content of soil were recorded at just below the emitter. Higher values of soil EC, divalent cations and $NaHCO_3$-P contents of soil were recorded at 15 cm away across the lateral, while HCO_3 and NO_3-N contents of soil were higher at 30 cm away across the lateral. The contents of monovalent cations, Cl, NO_3-N and $NaHCO_3$-P were higher at 22.5 cm away along the lateral (mid point between two emitters).

Surface soil recorded higher values of water soluble Ca, Mg and K, NH_4-N, $NaHCO_3$-P and NH_4OAc-K contents than subsurface soil. Application of N @ 150 kg ha^{-1} through soil + fertigation recorded higher NH_4-N while same quantity of N applied through soil alone recorded higher NH_4OAc-K content of soil.

Compared to furrow irrigation, different levels of trickle irrigation increased the total fresh fruit yield of tomato to the extent of 25 to 57 and 30 to 62 per cent in the case of CO 3 and Rupali varieties respectively, besides saving of water to the extent of 11 to 37 per cent. In experiments I and II, daily trickle irrigation at 2 L recorded higher water use efficiency of 8.2 and 7.2 kg m^{-3} of fresh fruit yield of tomato with total water requirements of 394 and 438 mm respectively. Almost for the same quantity of water applied, daily application was found to be better than alternate day.

Application of N @ 150 kg ha^{-1} through soil + fertigation recorded 34 per cent higher tomato fruit yield in experiment II and 7 per cent higher relative N use efficiency in experiment I as compared to soil application alone. Fertigation of N @ 120 kg ha^{-1} recorded 17 per cent higher fruit yield of tomato with 20 per cent N savings as that of soil application alone in experiment II. In both experiments higher total uptake of K, Ca, Mg and Na were recorded at daily trickle irrigation at 4 L or 2 L while soil + fertigation of N @ 150 kg ha^{-1} recorded higher total uptake of P, K, Ca and Mg.

From this study, it was found that daily trickle irrigation at 2 L per emitter placed 0.45 m apart, and application of N through soil + fertigation were efficient in increasing the total fresh fruit yield of tomato.

ACKNOWLEDGEMENTS

ACKNOWLEDGEMENTS

I wish to place on record my heartfelt and sincere gratitude to my Chairman **Dr.P.Kandaswamy**,Ph.D., Professor and Head of the Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, for his expertise guidance, constant encouragement, constructive criticism and undaunted support throughout the course of this study.

My advisory committee members **Dr.P.P.Ramaswami**, Ph.D., Professor and Head of the Department of Soil Science and Agricultural Chemistry, A.C & R.I., Killikulam, **Dr.M.Murugesan** Ph.D., Professor and Head of the Department of Agricultural Statistics, **Dr.D.Chandrasekaran**, Ph.D., Professor and Head of the Department of Soil and Water Conservation Engineering, **Dr.(Mrs.) Seemanthini Ramadas**, Ph.D., Professor and Head of the Department of Olericulture have always inspired me by their valuable suggestions, keen interest and helpful criticism throughout the course of this study. I express my heartful thanks to them.

I am thankful to **Dr.U.S.Sree Ramulu**, Ph.D.(Calif.), Professor of Soil Science and Agricultural Chemistry, Water Technology Centre, for the encouragement and help rendered during the course of this study. It is my pleasure to thank **Dr.M.Rangarajan**, Ph.D., Dean, Agricultural College and Research Institute for his personal interest in the early completion of my thesis work.

I am pleased to thank my friends and colleagues **Dr.V.Velu**, **Dr.A.Saravanan**, **Mr.C.Udayasoorian** and **Mr.N.Meyyazhagan** for their help and support during the final stage of thesis preparation. My thanks are also due to **Dr.H.Hameed Khan**, **Dr. D.Clarson** **Dr.P.Govindaraju**, **Mr.T.Arumugam**, **Mr.A.Velayutham**, **Mr.D.Jawahar** and **Dr.P.Paramasivam** for their help and encouragement for the completion of the study.

I thank **Mr.Ramasamy Naicker** for his help in the experimental part of the programme and **M/S. SRI PAPPU ELECTRONICS**, Coimbatore, for the neat typing of the thesis.

Atlast but not the least, to my wife **Mrs.Shamshunissa** and daughter **Khairunissa** whose generous sacrifices and forbearance had enabled me to complete this work. I am thankful to them.

Finally, I acknowledge the **Indian Council of Agricultural Research**, New Delhi, for supporting my study programme with Senior Fellowship grant.

COIMBATORE

13th, December 1991 **(A.R.MOHAMED HAROON)**

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PLATE

Abbreviations Used

alt.	-	Alternate
appln.	-	Application
d	-	Day
DAT	-	Days after transplanting
e	-	emitter
EC	-	Electrical conductivity
Exp.	-	Experiment
Fertig.	-	Fertigation
ls	-	Loamy sand
scl	-	Sandy clay loam
*	-	Significant at P = 0.05
**	-	Significant at P = 0.01
NS	-	Not Significant

INTRODUCTION

CHAPTER 1

INTRODUCTION

"In irrigation just enough is the best"

-Hillel (1982)

The above statement clearly spells out that only measured quantity of water should be applied at a rate calibrated to meet the continuous requirements of the crop, not less and certainly not more.

This precise scheduling of irrigation is possible under trickle or drip irrigation where water is applied at frequent intervals but in small quantities, directly to the active root zone of the crop.

Though research with trickle irrigation was reported as early as 1860, the present day trickle irrigation technology had its beginning in the early 1960's after Blass (1964) who observed the vigorous growth of a tree near a leaking faucet. The availability of low cost plastic pipe lines came in handy for the rapid expansion of area under trickle irrigation.

Realising the scope of trickle irrigation, area under trickle irrigation grew rapidly in other parts of the World in the late seventies (Bucks et al., 1982). But in India, till mid eighties the concept of trickle irrigation was tested on experimental basis in different parts of the country (Sivanappan, 1985, and Menzel and Obe, 1990). In India, trickle irrigation is mostly practiced with perennial or wide-spaced crops and in areas where water is a scarce commodity. The high initial installation cost of trickle irrigation is the major bottleneck for its expansion in area. But with yield increase upto 60 per cent in most of the vegetables, the initial installation cost can be got back in one year (Menzel and Obe, 1990).

Trickle irrigation has the greatest potential for the efficient use of water and fertilisers, the two major inputs in agriculture. Many workers have pointed out that to have a sustainable effect of trickle irrigation on crop growth, it should be viewed as a 'total nutritional as well as water supply' system (Townsend, 1978, and Menzel and Obe, 1990). This becomes obvious in the sense, the limited area of wetting under trickle irrigation reduces the active root zone and also the foraging area of plants to draw water and nutrients from the soil. Thus applying nutrients through trickle irrigation (fertigation) becomes prerogative for increasing the yield of most of the crops under trickle irrigation.

Fertigation offers greater flexibility in applying nutrients in proper quantity and in frequencies as needed by the crop in its different growth stages. The fertiliser savings under trickle fertigation were reported to the extent of 50 per cent as compared to conventional methods (Haynes, 1985). But applying higher concentrations of nutrients to the limited area of wetting may bring changes in soil properties like soil pH and EC to an extent to affect crop growth.

Most of the published work on trickle irrigation from abroad and few from other parts of the country dealt elaborately the design and maintenance aspects of it. In management aspect, the efficiency of trickle irrigation was compared with other irrigation systems or scope of trickle irrigation for perennial and wide spaced crops alone were studied. On fertigation aspects especially for row crops, very few references are available. In modern agriculture, it seems difficult to increase productivity without the proper knowledge of optimum dose of fertiliser and water for a particular set of conditions (Biswas and Naresh Prasad, 1990).

The importance of vegetables especially tomato in supplying nutrients, vitamins and minerals in human diet needs no more explanation. Tomato is one of the important vegetables grown throughout the World under field and glasshouse conditions.

Hence, in order to find out the effect of fertigation of major nutrients and irrigation water requirements with fertigation of N to tomato under trickle irrigation, this study was planned with the following objectives:

1. To find out the effect of fertigation of single or combinations of major nutrients (N,P and K) on changes in soil chemical properties at different growth stages of tomato in two texturally different soils.

2. To find out the effect of fertigation of single or combinations of major nutrients on shoot, fruit yield and nutrient uptake by tomato in the two texturally different soils.

3. To find out the effect of different trickle irrigation levels and methods of N application (soil application vs. fertigation) on changes in soil chemical properties, at different distances and depths from the emitter.

4. To find out the effect of different trickle irrigation levels and methods of N application on shoot, fruit yield and nutrient uptake by tomato.

5. To arrive at the optimum irrigation water requirements and frequency of application to tomato under trickle irrigation.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Trickle irrigation is growing rapidly in terms of land area and economic impact. It truly involves interdisciplinary participation by the agricultural and hydraulic engineers, and soil and plant scientists.

Trickle irrigation offers greater flexibility in scheduling irrigation and fertiliser application as per the requirement of the crop in its different growth stages. It is proved beyond doubt that trickle irrigation not only increases the yields of most of the agricultural crops but also improves the fertiliser use efficiency at times, beyond the levels attainable in conventional irrigation system. Trickle irrigation had its beginning in the early 1960's and from the review articles published (Black, 1976 a & b; Maillard, 1976; Bresler, 1977; Shoji, 1977; Bucks et al., 1982; Elfving, 1982; and Haynes, 1985) the scope of trickle irrigation can be understood.

In this chapter, the literatures pertaining to the different management aspects of trickle irrigation especially fertigation of major nutrients, nutrient mobility and water use are reviewed. Attempts are also made to distinguish trickle irrigation with that of conventional irrigation system from a soil scientist's point of view. The modifications or changes that are necessary in the present cultural practices for the successful, at the same time cost-effective, implementation of trickle irrigation are also pointed out. The design and maintenance aspects of trickle irrigation are not dealt in this chapter, as they are beyond the objectives of this study.

2.1. THE CONCEPT OF TRICKLE IRRIGATION

Trickle irrigation differs from conventional irrigation methods in that smaller volume of water are applied to plants at more frequent intervals, and only to a portion of the rootzone. A trickle irrigation system consists of emitters which distribute the water for irrigation. These are usually attached to laterals to which water is delivered through the submains or mainlines. The trickle emitter is essentially a water energy reducer. It acts generally as a resistor which dissipates the energy of water flowing through it and thus reduces the flow rate to a given discharge (Bucks et al., 1982).

De Tar et al.(1983) concluded trickle irrigation as a convenient tool for irrigation experiments. Small areas can be used as test plots with distinct lines between irrigated and non-irrigated treatments. The system offers excellent control of moisture levels and does not obstruct field operations.

2.2. FERTILISING/FERTIGATING CROPS UNDER TRICKLE IRRIGATION

Crop growth and yields under trickle irrigation can be lower than those achieved under conventional irrigation methods if fertiliser placement is not modified to meet the needs of trickle irrigated crops (Miller et al., 1976). Fertilisers applied to the soil have to be close to the water source (emitter) in order to be used effectively by the crop. This implies the use of banded fertilisers applications or the addition of fertiliser nutrients to the irrigation water (fertigation). As high as 50 per cent of N requirement of brinjal was observed to be reduced under trickle irrigation over furrow irrigation (Jaime et al., 1987).

2.2.1. Need for Fertiliser Placement

Under trickle irrigation, when fertilisers are simply broadcasted over the entire soil area the nutrient supply may become limiting to plant growth. This is because nutrient reserves in the wetted volume of soil become depleted due to both plant uptake and the downward leaching of mobile ions such as NO_3 and K. Thus, banded fertiliser applications often give greater yields of row crops under trickle irrigation than do broadcast treatments.

The placement of bands of fertilisers is yet another important criterion. In a fine sandy soil, limited horizontal movement of trickle irrigation water prevented the utilization of fertilisers banded more than 10 cm away from the emitters. The maximum distance that fertilisers can be banded from emitters depend on the extent of lateral water movement which in turn depended upon the hydraulic conductivity of the soil and the rate of trickle discharge (Keng et al., 1979). Keng et al. (1989) compared the trickle fertigation with that of band/broadcast application of nutrients to sweet pepper and confirmed the need for either fertigation or band application over broadcast.

The positioning of trickle line and the fertiliser band in relation to the crop row is particularly an important consideration for mobile nutrients such as NO_3 and K. Miller et al. (1976, 1981) showed that if the trickle line was placed between the plant row and the fertiliser band, fertiliser N was moved away from the plants resulting in very low fertiliser use efficiency by tomato plants. In contrast, if the fertiliser band was placed between the plants and the trickle line, the fertiliser N was used relatively efficiently. Such a practice would, however, be less effective when immobile fertiliser nutrients such as P is applied.

2.2.2. Scope for Fertigation

Trickle fertilisation (fertigation) is an attractive concept, as it permits application of nutrients directly at the site of a high concentration of active roots and as needed by the crop. Scheduling fertiliser applications on the basis of need offers the possibility of reducing nutrient element losses associated with conventional application methods that depend on the soil as a reservoir of nutrients, thereby increasing nutrient use efficiency. Fertiliser savings through fertigation can be to the tune of 25 to 50 per cent (Haynes, 1985).

Fertilisers and other water amendments (herbicides, insecticides, fungicides etc.) applied through a trickle irrigation system can improve efficiency, save labour and increase flexibility in scheduling of applications to fit crop needs (Rolston et al., 1979). However, all chemicals must meet the following criteria (Bucks and Nakayama, 1980) for the successful maintenance of the trickle irrigation system. They must (i) avoid corrosion or clogging of any component of the system; (ii) be safe for field use; (iii) not decrease crop yield; (iv) be soluble or emulsifiable in water; and (v) not react adversely with salts or other chemicals in the irrigation waters.

2.2.2.1. Osmotic potential of nutrient solutions

Optimisation of levels of mineral nutrient application through trickle irrigation is closely related to osmotic potential (OP), usually expressed as electrical conductivity (EC), generated by the salts in the root medium solution. Increasing OP has a negative effect on plant growth and yield.

Testing several N fertilisers given with irrigation water, only urea did not increase appreciably the EC of the soil solution. A nutrient concentration in irrigation water generating an EC of 1.8 dS m^{-1} is recommended in the early growth period of tomato and of 2.0 dS m^{-1} after first fruit set (Hagin *et al*., 1990).

2.2.3. Efficiency of Fertigation over Fertilisation

Trickle fertigation offers greater flexibility in applying required quantity of nutrients at proper stages of the crop. For example, fertigation of N with balanced amount of K in early stage of citrus, prevented overly "sappy" soft growth. At flowering, lowering the N levels with increased levels of P, lead to heavier and more even fruitset. Fertigation with high levels of K during the period of fruit enlargement, gave good flavour, texture and shelf life. After harvest, fertigation with high levels of N assisted the citrus crop in the following year (Menzel and Obe, 1990).

High frequency application of N with trickle irrigation improved the efficiency of fertiliser use by potatoes more than two-fold over that of conventional fertiliser method (Rolston et al., 1979). Similarly Miller et al., (1976, 1981) found that utilisation of N by tomato was more when applied through the trickle system than when banded, and furrow irrigated or banded and trickle irrigated.

Locascio et al. (1977) compared the response of strawberries to basal soil incorporated fertilisers versus 50 or 100 per cent N and K applied through trickle system. Yields were significantly higher when fertilisers were injected through the trickle system. The inferiority of soil incorporated fertilisers was attributed to the leaching of fertiliser nutrients out of the rootzone below the trickle emitters during the growing season.

Compared to fertilisation, fertiliser savings under fertigation was found to be to the extent of 50 per cent and increased yields were reported in tomato (Goyal et al., 1985), pepper (Haynes, 1988), sweet pepper (Crespo-Ruiz et al., 1988) and peaches (Bussi et al., 1991). The positive effect of fertigation on plant growth, nutrient content and uptake were also reported (Haynes, 1988; Rubeiz et al., 1989 and Bussi et al., 1991)

2.2.4. Frequency of Fertigation

The success and efficiency of multiple fertiliser injection will depend, to a large extent, on the ability to match the external supply of nutrients to the physiological requirement of the plant at different growth stages. Fertigation of nutrients at almost every irrigation but in very great dilution, increased the fertiliser use efficiency far beyond the previously possible level (Menzel and Obe, 1990).

Dangler and Locascio (1990) found that the time of K application had less effect on tomato yields than the time of N application when both were applied through trickle irrigation. However, since a high N supply is known to encourage vegetative growth but stimulate the production of poor quality fruit, the N concentration in the fertiliser solution can be increased at vegetative stages of growth and restricted during the period of ripening (Levin et al., 1980).

But, Locascio et al. (1977) found no difference in yield of strawberries when N and K were applied either daily or at weekly intervals with the trickle irrigation. Multiple application of nitrogenous fertilisers through trickle irrigation did not appear to improve the efficiency of fertiliser uptake by tomatoes over a single injection (Miller et al., 1981).

2.2.5. Effect of Fertigation on Soil Properties

High concentrations of mineral nutrients applied by trickle irrigation may lead to localised salinity problems or changes in soil pH in the wetted zone. Changes in pH might not only affect root uptake but could significantly influence the solubility of mineral elements within the irrigated soil volume, possibly leading to deficiencies or toxic levels of certain elements.

Edwards et al. (1982) found that fertigation with ammonium nitrate at a rate of 33 kg ha^{-1} on 11 occasions over a 2 year period caused a decrease in soil pH from 6.2 to 3.7 in the zone wetted by emitters. Haynes (1988) observed decrease in soil pH was greater in fertigation on

N as urea followed by broadcast/fertigation and broadcast application in that order. The decrease in pH was greater in higher rate of urea application. In another study, Haynes (1990) concluded that fertigation with both ammonium sulphate and urea caused acidification in the wetted soil volume. Acidification was confined to the surface 20 cm of soil in the ammonium sulphate while it was upto a depth of 40 cm in urea due to its greater mobility. Increasing the trickle discharge rates reduced the downward movement of urea and encouraged its lateral spread in the wetted soil. As a consequence, acidification was confined to the surface 20 cm soil.

Generally, increased level of N through fertigation results in increased soluble salt concentration in soil below the trickle emitters (Papadopoulos, 1987). Haynes (1988) also reported increased levels of soluble salts below the trickle emitters due to the fertigation of N as compared to broadcast application of N, but within noninjurious level to plants.

2.2.6. Crop Response to Fertigation

Increased nutrient use efficiency with fertigation of nutrients through trickle irrigation should permit reduced fertiliser usage. Kafkafi and Bar-Yosef (1980) reported the successful cropping of tomatoes with trickle-fertilisation on a highly calcareous desert soil where control of nutrient level was more difficult than sand dunes. Stark et al.(1983) found a linear relationship among total N uptake by tomato with fertigation of N upto 300 kg ha^{-1}. When NPK were applied through trickle irrigation, the highest tomato yield was obtained with 75 per cent of the normal recommended dose (Singh et al., 1989).

Keng et al.(1989) reported that yields of sweet pepper were higher when N and K were fertigated through trickle irrigation. But the fruit yield of cucumber was highest when N alone was fertigated through trickle irrigation than fertigation of N & K, NPK and control. The absence of response to K or P and K addition with N was attributed to higher levels of P and K in soil (Rubeiz, 1990). Dangler and Locascio (1990) concluded that the total tomato fruit yields were higher when 50 per cent N was fertigated as N & K or N than fertigation of N at 75 to 100 per cent level.

2.2.7. Fertigation of Major Nutrients

2.2.7.1. Nitrogen

Nitrogen, the plant nutrient most commonly deficient for crop production, is often applied in trickle irrigation system. Nitrogen source selection should be based on its possible reactions with the irrigation water and the soil. Haynes (1985) observed the following points in using nitrogenous fertilisers in trickle irrigation system:

(i) The prolonged use of NH_4 containing fertilisers in trickle system can have very detrimental effects on soil fertility in the wetted soil volume. This is because nitrification of the applied NH_4 causes soil acidification.

(ii) Injection of anhydrous ammonia or aqua ammonia will cause the pH of the irrigation water to rise with the possibility that insoluble salts of Ca and Mg would precipitate.

(iii) Urea is a fertiliser well suited for injection into trickle irrigation since it is highly soluble and dissolves in non-ionic form so that it does not react with other substances in the water.

(iv) Nitrate salts are characteristically soluble and are well suited for use in trickle irrigation.

A nitrogen concentration of about 200-250 mg N L^{-1} in the growth medium solution was found to be adequate (Hagin et al., 1990). From the various experiments conducted, the optimum concentration of N for tomato to be applied through trickle irrigation was found to be 240 mg L^{-1} on a coarse textured soil (Bar-Yosef et al., 1980) and 180 mg L^{-1} on a sandy loam soil (Papadopoulos, 1987). In a detached culture 200 mg N L^{-1} (Tsikalas and Manios, 1985) and 213 mg N on rockwool (Sonneveld and Van der Wees, 1988) was adequate for tomato.

Distribution of nitrogen in soil after fertigation

The initial distribution of N added to the soil from trickle emitters is likely to differ markedly depending upon the source of N applied.

AMMONIUM

Nitrification is generally rather rapid in most agricultural soils. However, if the soil is kept relatively wet below the emitter, nitrification will be considerably decreased as nitrification process requires oxygen.

Bacon and Davey (1982) studied the effects of irrigation and fertiliser application on NH_4 concentration in chromic luvisol in an orchard. During irrigation NH_4 concentration rose from 7.1 to 13.5 ppm in the surface 6 cm depth of soil extending upto a distance varying from 30 to 65 cm from the outlet. Ammonium concentration decreased rapidly as the soil dried out and 8 hours after the end of irrigation, it had fallen from 13.5 to 8.5 ppm. As there was no change in the NO_3 concentration in this region during the 8 hour period the NH_4 was being immobilised rather than nitrified. Haynes (1990) reported that during a fertigation cycle, applied NH_4 was concentrated in the surface 10 cm of soil immediately below the emitter and little lateral movement occurred.

UREA

Urea is relatively mobile in soils and it is not strongly adsorbed by soil colloids. It therefore tends to be more evenly distributed within the wetted profile than does applied ammonium. Haynes (1990) reported that fertigated urea and nitrate were more evenly distributed down the soil profile below the emitter and had moved laterally in the profile to 15 cm radius from the emitter.

NITRATE

The highly mobile NO_3 ion moves with the wetting front of the irrigation application and tends to accumulate at the periphery of the wetted soil volume and at the soil surface midway between emitters (Haynes, 1985). The bulk of any form of N applied to the soil is likely to eventually be transformed to NO_3-N.

2.2.7.2. Phosphorus

Phosphorus has not generally been recommended for application in trickle irrigation system because of its tendency to cause clogging and its limited movement in the soil. If irrigation water is high in Ca and Mg, precipitates of insoluble calcium and magnesium phosphates may result from the application of inorganic phosphate (Bucks et al., 1982). But the addition of H_3PO_4 to the irrigation water maintained a low pH and prevented the precipitation of insoluble salts, thus allowing the introduction of P through trickle irrigation systems (Mikkelsen and Jarrel, 1987).

The recommended P concentration in irrigation water of glasshouse grown tomatoes in The Netherlands was 1.0 m. mol P L^{-1} (31 mg P L^{-1}) (Sonneveld and Van der Wees, 1988). The resulting P concentration in the root environment was 0.5 m. mol L^{-1} indicating considerable precipitation of phosphates. Voogt and Sonneveld (1989) recommended that the P_2O_5 concentration in the standard nutrient solution for tomatoes should be raised from 1.0 to 1.25 mM. The intended corresponding concentration in the root environment should be raised from 0.5 to 0.7 mM.

Distribution of phosphorus in soil after fertigation

The extent of movement of P in the soil from the emitter depends upon the P absorption capacity of the soil. However the distance of P movement was found to be proportional to the application rate since movement resulted from saturation of adsorption sites on the soil near the point of application and subsequently mass flow with the soil water. Generally the applied P was confined to the soil volume directly surrounding the emitter.

O'Neill _et al_. (1979) found that P was delivered to greater soil volume when applied as H_3PO_4 acid through a trickle system than triple super phosphate applied as a soil amendment beneath each emitter.

Bacon and Davey (1982) studied the distribution of Bray No.1-P in the sandy clay loam soil of a Chromic Luvisol that had been under trickle irrigation for five years. The results revealed that trickle irrigation caused both horizontal and vertical movement of native soil P near the outlet and that P fertiliser applied 50 to 80 cm away from the outlet, remained near the soil surface and above the root zone. Phosphorus when applied as urea phosphate moved in a calcareous loam soil to a depth of 30 cm (Mikkelsen and Jarrel, 1987).

Goyal *et al.* (1989) fertigated tomato through trickle irrigation and observed considerable movement of P throughout the soil profile possibly because of slow rates of calcium phosphates precipitation due to the lower pH of the irrigation water and the possible presence of Mg and HCO_3 in solution and to the predominant movement of fertiliser solutions through soil macropores.

In general, if a more or less uniform concentration of P in the rooting volume is desired, then a basal soil incorporated dressing will be required. Under normal agricultural conditions, the distribution of P within the rooting zone is not uniform since applied P characteristically accumulates close to the soil surface. Placement of small quantities of superphosphate near the trickle outlet is a satisfacotry alternative to broadcasting (Bacon and Davey, 1989).

2.2.7.3. Potassium

Potassium seems to cause few, if any, clogging problems in trickle irrigation system. Common K sources, such as potassium sulphate, potassium chloride and potassium nitrate are readily soluble in water. These fertilisers move freely into the soil and some of the K ions are exchanged on the clay complex and are not readily leached away.

Recommendations on rates of K application through trickle irrigation for tomato go upto 350 mg K L^{-1} (Sonneveld and Van der Wees, 1988). The amounts of K required for production of evenly ripened and high quality fruit considerably exceed those required for maximum yields. The anion accompanying K may influence the root medium solution. The rate of uptake of K as sulphate is lower than that of chloride or nitrate forms (Marschner, 1986). Bussi et al.(1991) reported that fertigation of K did not increase fruit production of peaches when the initial soil K level was high.

Distribution of potassium in soil after fertigation

Potassium is less mobile than nitrate, but distribution in the wetted volume may be more uniform due to interaction with binding sites (Kafkafi and Bar-Yosef, 1980). However, Uriu et al. (1977) demonstrated that there was some movement after the K ions became concentrated in the soil near the emitter. Like NH_4, the K ion is adsorbed onto the cation exchange sites on soil colloids so that the extent of movement is dependent upon the cation exchange capacity of the soil and the rate at which K is applied. Most workers have detected considerable lateral and downward movement of trickle applied K (Goode et al., 1978;

Keng *et al.*,1979) and Kafkafi and Bar-Yosef,1980). Goyal *et al.* (1989) attributed the lesser movement of K after fertigation to large plant uptake of K.

Generally, crop response to fertigation of nutrients through trickle irrigation has been excellent, and frequent nutrient applications have improved the fertiliser application efficiency. Reductions upto 50 per cent in total fertiliser application using trickle irrigation as compared with surface broadcasting have been reported with no yield reductions.

2.3. IRRIGATION SCHEDULING UNDER TRICKLE IRRIGATION

Generally, one would anticipate greater savings in water requirements under trickle irrigation for widely spaced crops versus closely spaced crops, for sandy soil versus heavy-textured soil and for an inefficient existing irrigation system versus an efficient trickle system (Bucks *et al.*, 1982).

Bar-Yosef and Sagiv (1982) reported that tomato fruit yield responded linearly to increasing total water application rate through trickle irrigation upto 80 percent of the accumulated evaporation from U.S. class A Pan. Padmakumari and Sivanappan (1985) concluded that kapos yield of cotton cv. MCU 5 ranged between 1.95 to 2.58 t ha^{-1} in trickle irrigation to 37.5 per cent with free water evaporation (E_o) at E_p=3cm and 75 per cent E_o at E_p=1 cm respectively. Trickle irrigation at 100 per cent E_o increased vegetative growth and reduced yields.

El-shafei (1989) concluded that in a sandy soil, trickle irrigation at the rate of 80 per cent E_p was required to avoid yield loss of tomato and the soil water potential at 15 cm depth should be -10 to -20 kPa. Lindsay et al.(1989) found no significant difference in the total fruit yield of tomato among different methods used for scheduling trickle irrigation. But the direct methods like measurement of soil moisture status using either tensiometer or neutron probe required significantly less irrigation water than the indirect prediction methods using climatic data. Sanders et al.(1989) reported that trickle irrigation to 70 per cent ET terminated 7 days before harvest produced responses similar to conventional furrow irrigation.

Singh et al. (1989) found that with increased quantity of water application, the fertiliser rate to be applied for the optimum yield also increased. The highest tomato yield was obtained with 75 per cent of recommended level of NPK with trickle irrigation at ET_{50} level. But trickle irrigation at ET_{100} level required full dose of NPK for the highest tomato yield. Pratap Singh et al. (1990) found that trickle irrigation at 0.5 IW/ETP resulted in the highest yield of tomato compared to other ratios and surface irrigations/planting method. Levinson and Adato (1991) reported that trickle irrigation of avocado at 0.46 pan coefficient recorded 63 per cent more fruits than trickle irrigation at 0.64 pan coefficient.

2.3.1. Irrigation Quantity

When both irrigation amount and frequency were varied using trickle irrigation, the quantity of water applied had a large effect on yield than frequency. The highest production with trickle irrigation occurred at seasonal water applications nearly equal to or slightly greater than the measured ET under furrow irrigations. Most studies confirmed that the irrigation method does not significantly change the seasonal ET of the crop where the objective was maximising yield per unit land area. Therefore, any reduction in water requirements for trickle irrigation over another method should come primarily from an improvement in on - farm irrigation efficiency. On - farm efficiency for trickle irrigation can theoretically approach 90 to 95 percent (Bucks et al., 1982).

Total water requirements (ET_m) after transplanting of a tomato crop grown in the field for 90 to 120 days was 400 to 600 mm, depending on the climate (Doorenbos and Kassam, 1979). But under trickle irrigation, the irrigation water requirement of tomato was found to be reduced to 283 mm (Sivanappan et al., 1972), 400 mm (Kafkafi and Bar-Yosef, 1980), 218 mm (Bengal et al., 1986) and 290 mm (Chartzoulakis and Michelakis, 1988).

Comparing furrow or conventional irrigation, water requirement under trickle irrigation was 25 to 30 per cent for vegetables (Sivanappan, 1985) and 10 per cent less for water melons (Srinivas et al., 1989). From the experiments conducted with brinjal (Jaime et al., 1987), papaya (Padmakumari and Sivanappan, 1989) and autumn cabbages (Rubeiz et al., 1989), it can be concluded that water requirement under trickle irrigation was around 50 per cent as that of the conventional irrigation system. In several cases apart from reduced water requirements, increased yields upto 31 per cent were reported (Sivanappan et al., 1972).

2.3.2. Irrigation Frequency

Several studies reported increased yields for increased frequency for optimum irrigation quantity (Bucks et al., 1982). Bar-Yosef et al. (1980) found that increasing irrigation frequency from one to three irrigations per day on a sandy soil, increased the tomato fruit dry-matter yield. However, less frequent irrigation tended to increase yields of cabbage, cantaloupe and grapes. Shallow-rooted onions gave higher yields with daily than with weekly trickle irrigations (Bucks et al., 1982).

The optimum irrigation frequency will in general depend on the type of crop, soil and water quality. Possible reasons for applying trickle irrigation on other than a daily schedule include the need for deeper watering on a deep-rooted crop, improving aeration in the effective crop root zone in fine textured soils, and moving salts farther away from the plant. On the other hand, daily or more frequent applications can provide optimum soil moisture for shallow-rooted crops, reduce deep percolation losses on coarse-textured soil and improve the usage of saline irrigation water (Bucks et al., 1982).

2.3.3. Water Use Efficiency

Many studies have shown improved water use efficiency for trickle irrigation as compared to conventional irrigatın techniques, although carefully controlled conventional irrigation can sometimes produce water use efficiencies equal to trickle irrigation (Sammis et. al., 1980). Increased water use efficiency appeared to result both from reduced water losses by the irrigation system or through the soil, and from more efficient plant use.

The water use efficiency for harvested yield of fresh tomatoes was 10 to 12 kg m^{-3} (Doorenbos and Kassam, 1979). Bengal et al. (1986) reported water use efficiency of tomato as 7.87 and 4.65 q $ha^{-1}cm^{-1}$ in trickle and furrow irrigation respectively. Chartzoulakis and Michelakis (1988) reported the water use efficiency of tomato as 47.7 and 27.8 kg m^{-3} under trickle and furrow irrigation respectively. Comparing other irrigation systems, higher water use efficiency under trickle irrigation was reported for different vegetables (Sammis et. al., 1980; Sivanappan, 1985; Foster et al., 1989; Sanders et al., 1989 and Tekinel et al., 1989).

2.4. TRICKLE IRRIGATION AS DIFFERENT FROM OTHER IRRIGATION SYSTEMS

2.4.1. Salt Accumulation and Movement

Salt movement in the soil under trickle irrigation is more complex than with conventional irrigation, where primary salt movement is downward with the bulk water flux. But under trickle irrigation, salt movement in soil is associated with the flux of water (Elfving, 1982).

Salt tends to accumulate at the wetting front, between emitters where flux reaches zero, and at the surface, where evaporation occurs (Sing *et al.*, 1978). With repeated water replenished, trickle irrigation creates a continuous flushing action in a small volume of soil producing large salt gradients over short distances within the wetted volume. Trickle irrigation strategy should be designed to maintain a large enough leached soil volume to permit sufficient root development while minimising root contact with highly saline conditions (West *et al.*, 1979). This approach should limit effects on plant growth due to uptake of sodium or chloride salts or to osmotic pressure.

Singh (1978) studied the salt distribution in a loamy sand where it was trickle irrigated with saline waters. Salts were concentrated in the surface 15 to 20 cm of soil at the mid point between the emitters and towards the wetting front. Kumar (1979) concluded that the salt distribution in the soil profile in the lateral/radial direction as well as in the vertical direction was progressively increasing as the distance from plant or water source increased. The maximum salt concentration measured in terms of EC of the soil solution was noticed at 15 cm radius from the plant and at 30 cm depth for all levels of saline water and emitters. There was no change in soil pH due to the application of saline waters.

Bielorai (1985) found that under trickle irrigatin of citrus using single line and two lines of trickle per tree, the initial EC of soil (1.5 dS m^{-1}) increased to 4 dS m^{-1} and 6 dS m^{-1} at the soil surface and 3.5 dS m^{-1} at the wetting front at a distance of 0.7 m from the trickle line in single line and two lines per tree treatments respectively. Electrical conductivity of about 2 dS m^{-1} was found midway between the two laterals of two lines per tree treatment. Chloride, Na and NO_3-N distribution patterns in the soil profile followed the EC patterns. The highest accumulation occurred in the upper layer of the soil profile. Under trickle irrigation, the EC of the soil increased near the emitter and at the edges of the wetting zone (Goyal et al., 1989). Kranjac - Berisarljevic (1988) reported that most of the soluble salts remained at the soil surface when saline water was applied through trickle and furrow irrigation. Increasing the water volume, moved the salts farther from the irrigation source in both trickle and furrow irrigation, although trickle irrigation gave a greater variation in salt distribution in the soil profile than furrow irrigation. Over irrigatin with 125 per cent ETM (Maximum evapotranspiration) did not affect salt accumulation or distribution, whereas the treatment of 50 per cent of ETM resulted in a very high salt accumulation in the top soil. Salts remaining in the soil were mainly Cl and Na salts followed by Ca and Mg salts, with very small amounts of HCO_3 and K salts.

2.4.2. Non-uniform Nutrient Distribution

The effect of uneven nutrient distribution under trickle fertigation viz., accumulation of P close to the emitter (Goldberg et al., 1971) and rapid movement of NO_3 to the periphery of wetted volume is not great as plant can adapt to this spatial variability of nutrients through two major mechanisms. Firstly, the rate of nutrient uptake per unit weight or length of roots in the nutrient enriched area can be increased (Dasberg et al., 1981) and secondly, localised root proliferation can occur in the zones of soil high in nutrients (Haynes, 1985).

Under arid soil conditions, the whole root system may develop in the trickle irrigated zone since there is little water available beyond that soil volume (Bar-Yosef, 1977; Levin et al., 1979; and Levin et al., 1980).

2.4.3. Modifications in Plant Spacing

Conventional crop spacings may not be the most efficient for trickle irrigation. Alteration of planting system can reduce the number of trickle lines required with no loss in productivity.

Singh (1978) showed equivalent yield from single and double row planting geometrics for four vegetables; the double row system reduced the number of trickle lines by half. With triple-row units, pipe costs were cut by 75 per cent; but by reducing water use by 75 per cent over the single-row system, yields were reduced by 26-52 per cent for the different crops. In a loamy sand, when the wetted zone extended beyond 20 cm on either side of the lateral, Singh (1978) proposed two-row configuration of planting of vegetables.

Phene and Beale (1976) compared a double row planting system for sweet corn, which reduced pipe requirements by 40 per cent with a conventional single row system. Yield and water use were similar for the two planting systems. In a similar trial with potatoes, however, the twin-row system received approximately 30 per cent less water and produced 43 per cent less marketable yield (Phene and Sanders, 1976).

Tsipori and Shimshi (1979) found that trickle irrigation with single lateral per row of tomato plants recorded lesser yield compared to single lateral per four row of plants. The yields of the rows adjacent to the trickle line increased with line discharge to an extent to compensate the lower yield of the outlying rows. Sanders *et al.* (1989) reported that placement of trickle line on the plant row was more favourable than placement in the furrow between the beds for yield and yield characteristics of tomato. Singh *et al.* (1989) found that trickle lateral spacing of 1.2 m and NPK application on the total area basis resulted in higher marketable tomato yield.

2.5 CONCLUSIONS

From the above review, it can be concluded that: i) Through trickle fertigation, fertiliser savings can be achieved to the tune of 25 to 50 per cent. Moreover, fertigation offers flexibility in deciding the quantity and time of nutrient application.

ii) In trickle irrigation, as only a limited area is wetted, fertigation of nutrients may effect changes in soil pH and other properties of the wetted area to a certain extent, adversely affecting crop growth. Hence care has to be taken to apply judicious quantity of nutrients in proper form to suit the requirement of crop in different growth stages.

iii) In order to attain higher yield and fertiliser use efficiency by different crops under trickle fertigation, the interaction effect of nutrient to be applied with that of chemical constituents of irrigation water has to be clearly understood.

iv) The irrigation method does not change seasonal ET of the crop. Therefore any reduction in water requirement or improvement in water use efficiency under trickle irrigation should come primarily from either improvement in on-farm irrigation efficiency, or through the limited area of wetting and from more efficient plant use.

v) Irrigation quantity has a significant effect on yield than irrigation frequency under trickle irrigation. But, for the same irrigation quantity, increasing irrigation frequency increased the crop yields.

vi) In case of saline waters under trickle irrigation, salts tend to accumulate at the wetting front, between emitters where flux reaches zero, and at the surface where evaporation occurs. Hence trickle irrigation strategy should be designed to maintain a large enough leached soil volume to permit sufficient root development while minimising root contact with highly saline conditions.

vii) Plants are able to adapt to the non-uniform nutrients distribution within the wetting zone, either by increasing the nutrient uptake per unit weight or length of roots in the nutrient enriched area or by localised root proliferation in the zone of soil with high nutrient concentration.

viii) Studies on changes in plant geometrics (spacings) in order to save the cost of lateral lines without reduction in yield are needed especially for row crops.

Though the effect of trickle fertigation of N, mostly with the wide spaced crops have been studied by the earlier workers as indicated above, still not much work has been done on the effect of simultaneous fertigation of more than one nutrient especially with row crops like vegetables and also its effect on the changes in soil properties within the wetted volume, which needs further study.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

The details of glasshouse and field experiments conducted to study the effect of fertigation and different levels of trickle irrigation with methods of N application for tomato are presented in this chapter. The techniques adopted in soil and plant sample collection, with methods of analysis are also given in this chapter.

3.1. GLASSHOUSE EXPERIMENT

A glass house experiment was conducted during July-October 1988 with two texturally different soils viz., loamy sand (Typic Ustifluvent) and sandy clay loam (Typic Haplustalf), collected from Millet Breeding Station, Tamil Nadu Agricultural University, Coimbatore. The main objective of the experiment was to find out the effect of fertigation of single or combination of major nutrients on soil properties, nutrient mobility, yield and nutrient uptake by tomato.

3.1.1. Physical and Chemical Properties of Initial Soil (Table 1)

Loamy sand

The loamy sand used in the study belongs to coarse loamy, mixed,isohyperthermic Typic Ustifluvent. The

Table 1. Physical and chemical properties of initial soil used in the study

Properties	Glasshouse Experiment		Field Experiment
	Loamy sand	Sandy clay loam	Sandy clay loam
1. Mechanical analysis			
i) Clay (Per cent)	3.4	25.9	28.4
ii) Silt (Per cent)	13.5	17.5	12.6
iii) Fine sand (Per cent)	59.1	42.9	43.5
iv) Coarse sand (Per cent)	23.8	12.8	16.1
Taxonomical classification	Typic Usti-fluvent	Typic Haplu-stalf	Typic Haplu-stalf
2. Physical properties			
i) Apparent specific gravity (Mg m^{-3})	1.53	1.47	1.51
ii) Absolute specific gravity (Mg m^{-3})	2.41	2.47	2.35
iii) Maximum water holding capacity (Per cent)	24.53	32.82	33.17
iv) Total pore space (Per cent)	38.60	46.50	47.50
v) Volume expansion on wetting (Per cent)	1.20	4.60	7.40
vi) Hydraulic conductivity (cm h^{-1})	5.47	3.95	3.66

contd.,

Table 1. Contd.,

vii)	1/3 bar moisture (Per cent)	9.60	20.40	18.20
viii)	15 bar moisture (Per cent)	4.40	11.50	8.40
3. Chemical properties				
i)	Moisture (Per cent)	2.8	3.2	3.15
ii)	Total N (Per cent)	0.086	0.116	0.120
iii)	Total P (Per cent)	0.035	0.055	0.070
iv)	Total K (Per cent)	0.119	0.275	0.321
v)	Total Ca (Per cent)	0.507	0.257	0.268
vi)	Total Mg (Per cent)	0.273	0.106	0.221
vii)	pH	7.50	7.60	8.20
viii)	Electrical conductivity (dS m^{-1})	0.70	0.90	0.60
ix)	Organic carbon (Per cent)	0.29	0.40	0.62
x)	Alkaline-$KMnO_4$-N (ppm)	123	194	182
xi)	NH_4 - N (ppm)	45	60	42
xii)	NO_3 - N (ppm)	4.8	3.9	2.6
xiii)	$NaHCO_3$-P(ppm)	7.2	6.8	6.2
xiv)	NH_4OAc-K (ppm)	230	330	340
xv)	Cation exchange capacity (c.mol (p^+) kg^{-1})	10.8	18.6	20.2

contd.,

Table 1. contd.,

xvi) Exchangeable Ca (c.mol (p^+) kg^{-1})	4.95	9.95	11.8
xvii) Exchangeable Mg (c.Mol (p^+) kg^{-1})	2.92	4.52	5.8
xviii) Exchangeable K (c.Mol (p^+) kg^{-1})	0.22	0.22	0.35
xix) Exchangeable Na (c.mol (p^+) kg^{-1})	0.60	0.60	0.82
xx) Water soluble Ca (c.mol (p^+) kg^{-1})	-	-	0.35
xxi) Water soluble Mg (c.mol (p^+) kg^{-1})	-	-	0.22
xxii) Water soluble K (c.mol. (p^+) kg^{-1})	-	-	0.08
xxiii) Water soluble Na (c.mol.(p^+) kg^{-1})	-	-	0.68

apparent specific gravity of the surface soil was 1.53 Mg m^{-3} while absolute specific gravity was 2.41 Mg m^{-3} with 24.5 per cent water holding capacity. The hydraulic conductivity of surface soil was 5.47 cm h^{-1} with 9.6 and 4.4 per cent moistures at 1/3 bar and 15 bar soil moisture tension respectively.

The surface soil of loamy sand was neutral in pH with safer levels of soluble salt concentration. The organic carbon content and alkaline $KMnO_4$ distilled N content of the soil were low. But the $NaHCO_3$ extractable P (Olsen's) content of the soil was medium in status while NH_4OAc extractable K content was high. The soil had a cation exchange capacity of 10.8 c.mol (p^+) kg^{-1}.

Sandy Clay loam

The sandy clay loam used in the study belongs to fine, mixed, isohyperthermic Typic Haplustalf. The apparent specific gravity of surface soil was 1.47 Mg m^{-3} while the absolute specific gravity was 2.40 Mg m^{-3} with 32.8 per cent water holding capacity. The hydraulic conductivity of the soil was 3.95 cm h^{-1} with 20.4 and 11.5 per cent moisture at 1/3 bar and 15 bar soil moisture tension respectively.

The surface soil of sandy clay loam was neutral in pH with safer levels of soluble salt concentration. The organic carbon content was low. The alkaline $KMnO_4$ distilled N and $NaHCO_3$ extractable P content were medium in status while NH_4OAc extractable K content was high. The surface soil had a cation exchange capacity of 18.6 c.mol (p^+) Kg^{-1}.

3.1.2. Soil Bag Preparation

The two texturally different soils viz., loamy sand and sandy clay loam were air dried and approximately 25 kg soil was filled in thick gauge polythene bags to get a cylindrical shape of dimension of 30 cm diameter at the surface with 25 cm depth.

The soil bags were arranged on the concrete slabs provided in the glasshouse. The laterals of 12 mm diameter made of low density polyethylene were drawn over them with one emitter of 4 L h^{-1} flow rate each for a soil bag. Individual laterals were used to apply different fertigation treatments. Altogether there were 5 laterals for imposing five fertigation treatments. In each bag single 25 days old tomato seedling was transplanted at the centre. The lateral line with emitter was placed just 5 cm away from the seedling. In both textural classes of soil, moisture content was raised to 1/3 bar soil moisture tension before taking up transplanting. The laterals were fed through a container placed 10 feet above the ground level. Sufficient number of soil bags were maintained to draw plant and soil samples at different stages of plant growth and also to record shoot and fruit yield at harvest.

3.1.3. Treatment Details

The experiment was conducted in factorial RBD design with five replications. The test crop was tomato (Rupali - F_1 hybrid) developed by Indo-American Hybrid Seeds, Bangalore.

Factor I (Soils)

1. Loamy sand
2. Sandy clay loam

Factor II (Fertigation)

The recommended level of nutrients for the test crop tomato (Rupali) was 220:250:250 kg ha^{-1} of N, P_2O_5 and K_2O respectively. From this per plant nutrient requirement was worked out. The NPK were applied as urea, single superphosphate and muriate of potash respectively, for soil application and as urea, phosphoric acid (H_3PO_4) and muriate of potash respectively in fertigation treatments. As per the treatment schedule given below the basal soil application of fertilisers was applied 5 cm away around the root zone of seedlings. In the same way, top dressing was done at 45 days after transplanting (DAT). In fertigation treatments, per plant fertiliser dose was divided into 10 equal splits and applied through irrigation water at weekly intervals from 15 days after transplanting.

The treatment wise application of above level of nutrients was as follows:

(kg ha^{-1})

Fertigation	Soil application						Fertigation		
	Basal			Top dressing					
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1. Half N	100	250	125	-	-	125	120	-	-
2. Full N	-	250	125	-	-	125	220	-	-
3. Full N & K	-	250	-	-	-	-	220	-	250
4. Full NPK	-	-	-	-	-	-	220	250	250
5. Soil appln.	100	250	125	120	-	125	-	-	-

In all the fertigation treatments, the total quantity of nutrients applied was same.

Irrigation

From the second day after transplanting, irrigation was applied through trickle system as follows:

Phenological stage	DAT	Water application	Number of irrigations	Total water applied
		(L/plant)		(L/plant)
i) Till preflowering stage	45	0.5	28	14
ii) Flowering to harvest	46-115	1.0	58	58

Whenever the soil moisture content was above 1/3 bar soil moisture tension, irrigation was withheld for a day. A total quantity of 72 L per plant was added in 86 irrigations during the crop growth period of 115 days. The composition of irrigation water used in the study is given in Table 2.

3.1.4. Soil Sample Collection

Soil samples were collected at three stages viz., 45th day, 75th day after transplanting and at post-harvest. At every stage, after removing the plant from the soil bag with least disturbance, using core sampler, soil samples were taken at two depths viz., 0-10 cm and 10-20 cm from the opposite half of the soil bag where the emitter was placed. Soil samples were air dried and passed through 2 mm sieve and the fine earth obtained was used for soil chemical analysis viz., soil reaction, soluble salt concentration (EC) and inorganic fractions of N besides $NaHCO_3$-P and NH_4OAc-K.

3.1.5. Plant and Fruit Sample Collection

The plant samples were collected at three stages viz., 45th day and 75th day after transplanting and at post-harvest. In all the stages, the individual plant from each soil bag was uprooted. Then the root portion was removed, shoot portion was air dried and then oven dried at 60 ± 5 C.

The fully ripened fruits were harvested once in four days and fresh fruit weight was recorded on individual plant basis. From individual pickings, fruit samples were drawn, cut into pieces and oven dried at 60 ± 5°C. After drying, samples from all the pickings were pooled, ground in a Wiley mill.

The ground shoot and fruit samples were used for analysing the nutrient content. The standard methods used for estimating different nutrient contents are listed at the end of this chapter.

3.1.6. Computations

From the dry matter of shoot, fruit yield and their respective nutrient contents, nutrient uptake at stages and at harvest was computed.

3.2. FIELD EXPERIMENTS

Two field experiments were conducted during June - September 1988 (Experiment I) and January - April 1989 (Experiment II) at field No.54 of Tamil Nadu Agricultural University Orchard, Coimbatore. The main objective of the experiments was to study the effect of different irrigation levels and methods of N application under trickle irrigation on yield and nutrient uptake by tomato apart from studying the changes in soil chemical properties.

3.2.1. Physical and Chemical Properties of Initial Soil

The surface soil of the experimental site was sandy clay loam in texture belonging to fine, mixed, isohyperthermic Typic Haplustalf. The apparent specific gravity of the surface soil was 1.51 Mg m^{-3} while absolute specific gravity was 2.35 Mg m^{-3} with 33.2 per cent maximum water holding capacity. The hydraulic conductivity of the core sample was 3.66 cm h^{-1} with 18.2 and 8.4 per cent moisture at 1/3 bar and 15 bar soil moisture tension.

The surface soil was slightly alkaline in pH, with safer levels of soluble salt concentration. The organic carbon content, alkaline $KMnO_4$-N, $NaHCO_3$ extractable P were medium in status while NH_4OAc extractable K was high. The cation exchange capacity of the soil was 20.2 c.mol (p^+) kg^{-1}.

The exact values of soil physical and chemical properties are given in Table 1, of this chapter.

3.2.2. Quality of Irrigation Water

The irrigation water used in the field experiment was slightly alkaline in pH and marginal in quality as far as soluble salt concentration was concerned. The chloride content and Sodium Adsorption Ratio (SAR) were below the harmful level with no Residual Sodium Carbonate. The detailed composition of the irrigation water used in the study is given below.

Table 2. Analysis of irrigation water used in the study (Mean values)

Composition/Parameters	Glasshouse Experiment	Field Experiment
1. Soil pH	7.80	8.30
2. Electrical conductivity (dS m^{-1})	0.39	1.20
3. Calcium (c.mol(p^{+}) kg^{-1})	1.52	1.52
4. Magnesium (c.mol(p^{+}) kg^{-1})	0.48	3.68
5. Sodium (c.mol(p^{+}) kg^{-1})	2.37	7.13
6. Potassium (c.mol(p^{+}) kg^{-1})	0.10	0.20
7. Carbonate (c.mol(p^{-}) kg^{-1})	-	1.60
8. Bicarbonate (c.mol(p^{-}) kg^{-1})	2.40	3.20
9. Chloride (c.mol(p^{-}) kg^{-1})	1.16	5.08
10. Sodium Adsorption Ratio (SAR)	1.08	1.17
11. Residual sodium carbonate	0.40	-

3.2.3. Trickle Irrigation Lay-out

In both field experiments, 40 mm dia. high density polyethylene(HDP) pipes were used as mainline, 12 mm dia. low density polyethylene (LDP) pipes were used as laterals with 4 L h^{-1} pressure compensating emitters. The irrigation water was pumped into the main line using 0.5 HP single phase motor.

In experiment I, from the mainline, laterals were drawn at 1.5 m spacing. The laterals were placed on centre of the ridges formed with dimension of 10 cm at the top with 40 cm at the bottom with height of 20 cm. Within the laterals, emitters were placed at 0.45 m intervals. As per this lay-out, there will be 14815 emitters per hectare.

In experiment II, from the mainline, laterals were drawn at 1.2 m spacing. The laterals were placed on the centre of the ridges of same dimensions as used in experiment I. The emitters were placed 0.45 m apart within the lateral. In this configuration, there will be 18518 emitters per hectare. The system was operated at a pressure of 1.2 kg cm^{-2}, and with a pressure of 0.6 - 0.7 kg cm^{-2} at emitter point. To test the uniformity in emitter flow rate, distribution efficiency (Appendix I) was worked out (Wu et al., 1986).

The sketch of the different components of the trickle irrigation system used in experiments I and II are given in the figures 1 and 2 respectively.

3.2.4. Planting Configuration

In experiment I, two varieties of tomato namely CO 3 and Rupali were used. Twenty five days old seedlings were planted, in two rows per lateral at 10 cm perpendicularly away on either side of the emitter. On the side of the ridge, seedlings were planted 15 cm above ground level. Laterals of 30 m length were used in which emitters were placed at 0.45 m intervals. Within a lateral, there were 60 emitters which were grouped into 6 blocks of 10 emitters each. Thus a treatment consisted of 4.5 m length of lateral with 10 emitters and 20 plants.

In experiment II, the same trickle lay-out of experiment I with same emitter spacing of 0.45 m but with reduced spacing (1.2 m) between laterals. A treatment consisted of 4.5 m length of lateral with 10 emitters and 30 plants. On each side of laterals there were 15 plants at a spacing of 0.3 m in between them. Every two rows of tomato plants were fed by a single lateral. The planting configuration used in experiments I and II is given in figures 1 and 2 respectively.

FIG.1 TRICKLE LAY-OUT AND PLANT CONFIGURATION
(Experiment 1)

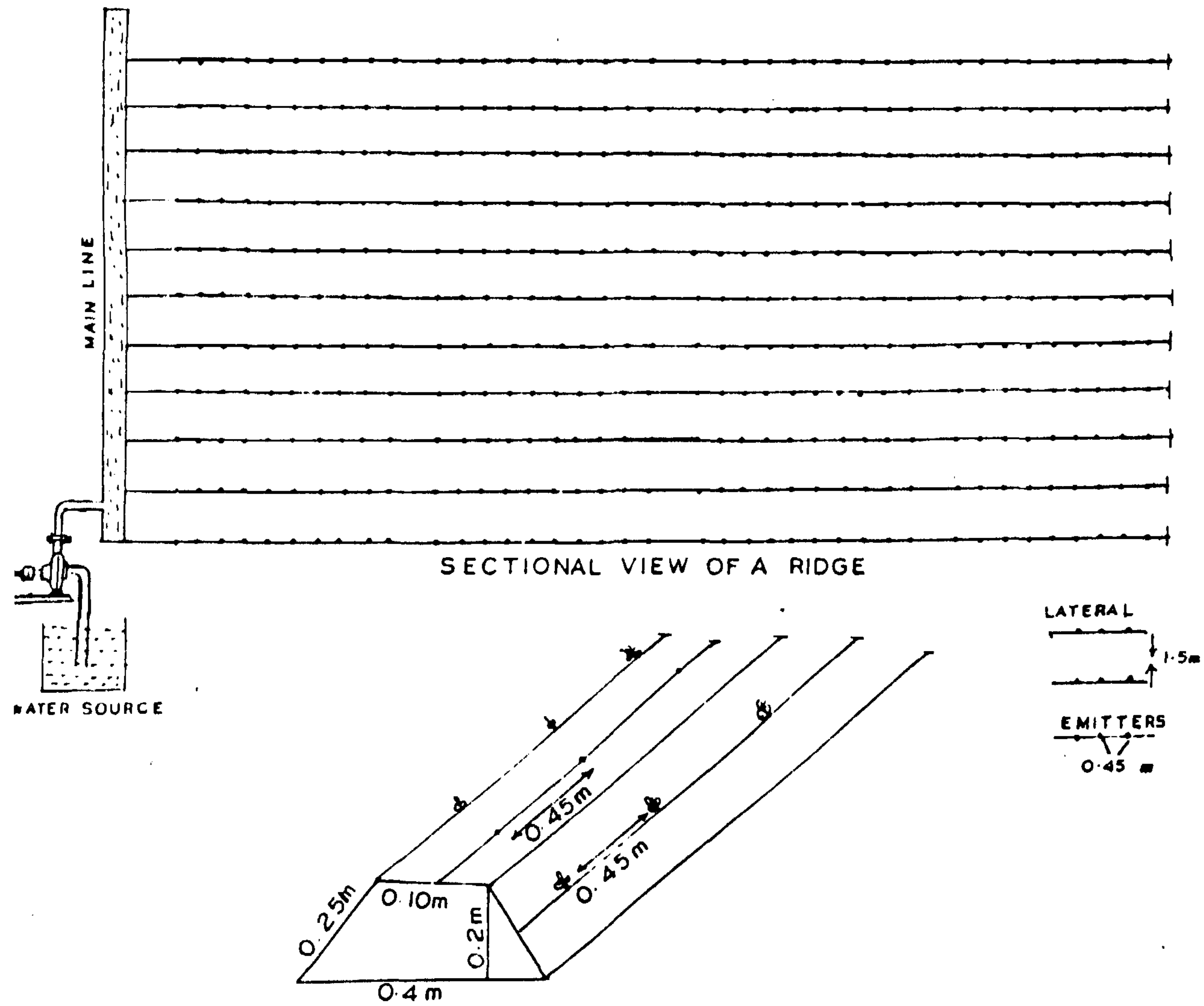
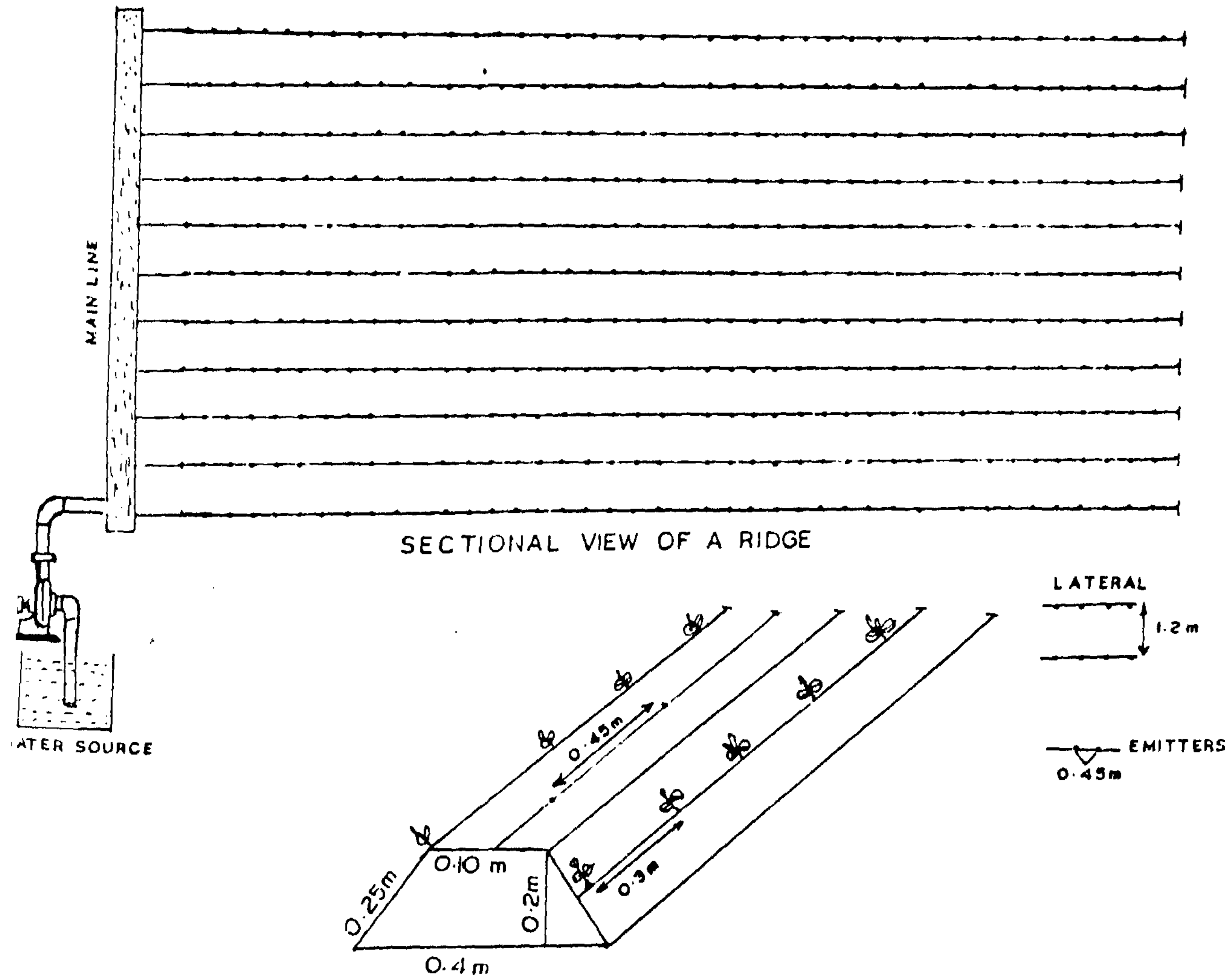


FIG.2 TRICKLE LAY-OUT AND PLANT CONFIGURATION
(Experiment II)



The details of trickle lay-out and planting configuration used in field experiments were as follows:

S.No.	Parameter	Experiment I	Experiment II
1.	Lateral spacing (m)	1.5	1.2
2.	Emitter spacing (m)	0.45	0.45
3.	No. of emitters per hectare	14815	18518
4.	Plant spacing (m)	0.45	0.30
5.	No. of plants irrigated by single emitter	Two	Three
6.	Plant population per hectare	29630	55555

3.2.5. Treatment Details

Experiment I

The experiment I was conducted during June-September, 1988 in split-plot design with three replications.

The main plot treatments consisted of nine combinations of three levels each of irrigation and methods of N application as follows:

Irrigation levels

I_1 - 4 L d^{-1} e^{-1}

I_2 - 2 L d^{-1} e^{-1}

I_3 - 4 L(alt.) $d^{-1}e^{-1}$

(d - day, e - emitter; (alt.) d - alternate day)

Methods of N application

N_1 - Soil application of N

N_2 - 30 kg N ha^{-1} through soil + 120 kg N ha^{-1} through fertigation

N_3 - 100 kg N ha^{-1} through soil + 120 kg N ha^{-1} through fertigation.

In sub plots, two varieties of tomato (*Lycopersicon esculentum* Mill.) viz., CO 3 and Rupali were grown as test crops.

Irrigation levels

The trickle irrigation system was operated at 1.2 kg cm^{-2} pressure and with a pressure of 0.6-0.7 kg cm^{-2} at emitter point. Then the average emitter discharge was 5.08 L h^{-1}. Hence when the system was operated for 50 minutes, the average discharge was 4.23 L per emitter.

The different rates of trickle irrigation imposed were as follows:

Trickle irrigation		Water added during crop growth		Rain-fall (mm)	Total water applied (mm)
Levels ($d^{-1}e^{-1}$)	Time (minutes/ day)	Quantity (mm)	No. of irrigations		
I_1 - 4 L	50	335	37	175	510
I_2 - 2 L	25	219	37	175	394
I_3 - 4 L (alt.)	50	247	23	175	422

As per the treatment requirement, laterals were detached from the main line after the expiry of stipulated time.

Before taking up planting, the moisture content of ridges was brought to 1/3 bar soil moisture tension level by applying water through trickle irrigation. After that, in first 14 days, in order to condition the tomato seedlings to trickle irrigation and also to have good establishment of seedlings, irrigation at 4 L d^{-1} e^{-1} was followed irrespective of the treatment. After 15th day onwards different trickle irrigation levels were imposed. Irrigation was stopped in last one week before pulling the plants.

Methods of nitrogen application

The methods and levels of N application for CO 3 and Rupali were as follows:

Treatment	CO 3			Rupali		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	kg ha^{-1}					
N_1 - Soil application						
i) Basal	75	100	75	100	250	125
ii) I top dressing	75	-	-	55	-	60
iii) II top dressing	-	-	-	65	-	65
Total nutrients applied	150	100	75	220	250	250

contd.,

contd.,

N_2 - (30S + 120F)						
i) Basal	30	100	75	30	250	125
ii) I top dressing	-	-	-	-	-	60
iii) II top dressing	-	-	-	-	-	65
iv) Fertigation of N	120	-	-	120	-	-
Total nutrients applied	150	100	75	150	250	250
N_3 - (100S + 120 F)						
i) Basal	100	100	75	100	250	125
ii) I top dressing	-	-	-	-	-	60
iii) II top dressing	-	-	-	-	-	65
iv) Fertigation of N	120	-	-	120	-	-
Total nutrients applied	220	100	75	220	250	250

In N_1 and N_2, for CO 3 same level of N was applied either through soil alone or soil + fertigation respectively. In N_1 and N_3, for Rupali same level of N was applied either through soil alone or soil + fertigation respectively. Top dressing was done at 30 DAT for CO 3 while I and II top dressings were done on 20 and 40 DAT respectively for Rupali. In soil application treatments, fertilisers were banded in between the lateral and plant row. For fertigation of N, 120 kg N ha^{-1} was applied in 10 equal splits at weekly intervals from 15th day after transplanting till 77th day. In both soil application and fertigation treatments, N was applied as urea while P_2O_5 and K_2O were applied as single superphosphate and muriate of potash respectively.

Conventional method

In order to find out the effect of trickle irrigation and fertigation of N with that of soil application of N with furrow irrigation, in an adjacent plot to the trickle irrigated area both varieties of tomato viz., CO 3 and Rupali were grown following the usual recommended practices.

Ridges were formed 0.75 m apart and along the sides of the ridges, 25 day old tomato seedlings were planted with plant spacing of 0.45 m. Per hectare plant population (29630) was same in both trickle irrigation and furrow irrigations. The recommended level of nutrients, viz., 150:100:75 and 220:250:250 kg $N:P_2O_5:K_2O$ ha^{-1} for CO 3 and Rupali respectively were applied in splits as given in N_1 (Soil application) treatment below the root zone of seedlings, along the side of the ridges. Altogether eight furrow irrigations of 5 cm depth each were given. Including rainfall received during crop growth period, total irrigation water requirement in furrow irrigation was 575 mm.

3.2.4.2. Experiment II

This experiment was conducted during January-April 1989, in split-plot design with three replications. The main plot treatments consisted of nine combinations of three levels each of trickle irrigation and methods of N application as follows:

Irrigation levels

I_1 - 4 L d^{-1} e^{-1}

I_2 - 2 L d^{-1} e^{-1}

I_3 - 4 L(alt.) d^{-1} e^{-1}

(d - day; e - emitter;
(alt.)d - alternate day)

Methods of N application

N_1 - Soil application of N

N_2 - 30 kg N ha^{-1} through soil + 120 kg N ha^{-1} through fertigation

N_3 - 120 kg N ha^{-1} through fertigation only.

In sub plots, two varieties of tomato (_Lycopersicon esculentum_ Mill.) viz., CO 1 and CO 3 were grown as test crop.

Irrigation levels

In experiment II, the same trickle irrigation system used in experiment I was used with a change in lateral line spacing of 1.2 m. The mean average emitter discharge was 5.08 L h^{-1} with the system pressure of 1.2 kg cm^{-2}, with 0.6 - 0.7 kg cm^{-2} pressure at emitter point. Hence when the system was operated for 50 minutes, the average discharge was 4.23 L per emitter.

Before planting, the moisture content of the ridges was brought to 1/3 bar soil moisture tension. In the first 14 days irrespective of the treatment, trickle irrigation was given for 50 minutes daily to have better establishment of seedlings. From 15th day onwards the different trickle irrigation levels were imposed. Irrigation was stopped one week before uprooting the plants.

The different rates of trickle irrigation imposed were as follows:

Trickle irrigation		Water added during crop growth		Rain-fall (mm)	Total water applied (mm)
Levels ($d^{-1}e^{-1}$)	Time (minutes/ day)	Quantity (mm)	No. of irrigations		
I_1 - 4 L	50	666	70	46	712
I_2 - 2 L	25	392	70	46	438
I_3 - 4 L(alt.)	50	392	35	46	438

Methods of nitrogen application

In experiment II, for both the varieties of tomato viz., CO 1 and CO 3 same fertiliser schedule was followed as indicated below:

Treatment	Soil application						Fertigation		
	Basal			Top dressing					
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	Kg ha^{-1}								
N_1 (Soil application)	75	100	75	75	-	-	-	-	-
N_2 (30S + 120 F)	30	100	75	-	-	-	120	-	-
N_3 (120 F only)	-	100	75	-	-	-	120	-	-

In N_1 and N_2, total nutrients applied were 150:100:75 kg ha^{-1} of N: P_2O_5: K_2O while in N_3, 120:100:75 kg ha^{-1} of N, P_2O_5 : K_2O respectively. In N_3, 30 kg N ha^{-1} was reduced to find out the level of N economy under fertigation. In soil application of N, top dressing was done on 30th day after planting. Soil applied fertilisers were banded in between the lateral line and plant row while N, P_2O_5 and K_2O were applied as urea, single superphosphate and muriate of potash respectively.

The total quantity of N to be fertigated was split into 10 equal doses and applied at weekly intervals from 15th day after transplanting to 77th day.

3.2.6. Soil Sample Collection

After pulling the plants with least disturbance to soil, in each treatment, around a single emitter eight soil samples were taken using a core sampler viz., four distances from emitter and at two depths namely surface (0-15) and subsurface (15-30 cm). The four distances being, just below the emitter (0), perpendicularly 15 and 30 cm away from the emitter, and 22.5 cm away from the emitter along the lateral or the mid point between two emitters. The soil samples collected were air dried, and passed through 2 mm sieve and used for different soil analysis like soil reaction, soluble salt concentration (EC), water soluble cations and anions apart from inorganic fractions of N, $NaHCO_3$-P and NH_4OAc-K contents of soil.

3.2.7. Plant and Fruit Sample Collection

The fully ripened fruits were harvested at 3 days intervals. In experiment I, there were 11 pickings and in experiment II there were 9 pickings. After recording the fresh fruit weight treatment wise, samples were drawn, cut into pieces and dried in oven at 60 $\pm$ 5 C. From the loss in weight during drying, moisture content of fruits was worked out. The samples from all the pickings were pooled.

After the final picking of fruits, plants were pulled and fresh weight was recorded. Then the shoots were air dried, then oven dried at 60 ± 5 C. From the loss in weight, moisture content of shoots was worked out.

The fruit and shoot samples, after drying, were ground in a Wiley mill. The ground samples were used for the estimation of different nutrient contents.

3.2.8. Computations

From the dry matter weight of shoot and fruit with their respective nutrient contents, total nutrient uptake was computed.

The efficiency parameters namely water use efficiency and relative nitrogen use efficiency were computed considering the quantum of either water or N added.

3.2.9. Statistical Analysis

The data obtained from soil chemical analysis, plant analysis, yield and computed nutrient uptake in both glasshouse and field experiments were statistically scrutinised following the methods suggested by Panse and Sukhatme (1967). Simple correlations and multiple regressions were worked out to study the relationship between related parameters. Whenever the correlation coefficient was significant, regression equation was worked out.

contd.,

Total nitrogen	Kjeldahl's method	Piper (1966)
Soil reaction (pH)	1:2 soil water suspension using Elico pH meter.	Jackson (1973)
Soluble salt concentration (EC)	1:2 soil water suspension using Elico conductivity bridge	Jackson (1973)
Organic carbon	Chromic acid wet digestion	Walkley and Black (1934)
Available nitrogen	Alkaline $KMnO_4$ method	Subbiah and Asija (1956)
Available phosphorus	0.5 M $NaHCO_3$ pH 8.5	Olsen *et al.* (1954)
Available potassium	N NH_4OAc, pH 7.0, using flame photometer	Stanford and English (1949)
Cation exchange capacity	N NH_4OAc pH 7.0, method	Schollenberger and Dreibelbis (1930)
Exchangeable and Water soluble calcium	Versenate titration	Jackson (1973)
Exchangeable and Water soluble magnesium	Versenate titration	Jackson (1973)
Exchangeable and Water soluble potassium	Flame photometry	Toth and Prince (1949)
Exchangeable and Water soluble sodium	Flame photometry	Toth and Prince (1949)

Contd.,

Contd.,

NH_4 - N content of soil	Using 2 M KCl extract, steam distillation in microkjeldahl using MgO	Bremner and Keeney (1966)
NO_3 - N content of soil	Colorimetrically estimated using 2 M KCl extract, using chromotropic acid	Sims and Jackson (1971)
C. Irrigation water		
pH	Using pH meter (Elico)	Jackson (1973)
Soluble salt concentration	Using conductivity bridge (Elico)	Jackson (1973)
Calcium	Versenate titration	Jackson (1973)
Magnesium	Versenate titration	Jackson (1973)
Potassium	Flame photometry	Toth and Prince (1949)
Sodium	Flame photometry	Toth and Prince (1949)
Carbonate	N/10 H_2SO_4 using phenolphthalein indicator.	Jackson (1973)
Bicarbonate	N/10 H_2SO_4 using Methyl orange indicator.	Jackson (1973)
Chloride	Using standard $AgNO_3$ and K_2CrO_4 as indicator	Jackson (1973)

Contd.,

Contd.,

D. Plant analysis		
Nitrogen	Micro-kjeldahl method	Humphries (1956)
Phosphorus	Vanadomolybdo phosphoric yellow colour method	Jackson (1973)
Potassium Calcium Magnesium Sodium	Same procedures as adopted for exchangeable cation estimation but using triple acid mixture (HNO_3: H_2SO_4: $HClO_4$ = 9:2:1)	

EXPERIMENTAL RESULTS

CHAPTER 4

EXPERIMENTAL RESULTS

The results obtained from the glasshouse experiment to study the effect of fertigating single or combination of major nutrients for tomato and also that of two field experiments to study the effect of different irrigation levels and methods of N application on two varieties of tomato are described in this chapter.

4.1. GLASSHOUSE EXPERIMENT

A glasshouse experiment was conducted during July-October 1988 with two soils viz., loamy sand (Typic Ustifluvent) and sandy clay loam, (Typic Haplustalf) with tomato (Rupali) as test crop. The results obtained by fertigating single or combination of N, P and K on soil chemical properties, shoot, fruit yield and nutrient uptake are described below.

4.1.1. Effect of Fertigation on Soil Chemical Properties

4.1.1.1. Soil reaction (pH)

45th day (Table 3 and Fig. 3)

Of the two soils, sandy clay loam recorded significantly higher soil pH (7.88) than loamy sand (7.60). Between the two depths of sampling, subsurface soil recorded significantly higher pH (7.87) than surface soil

Table 3. Mean effect of fertigation on **Soil pH at 45 DAT**

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	7.25	7.40	7.75	8.20	**7.65**
Full N	7.36	7.65	7.65	7.90	**7.64**
Full N & K	7.45	7.80	7.65	7.85	**7.69**
Full NPK	7.60	8.05	8.05	8.00	**7.93**
Soil appln.	7.50	7.95	7.80	7.90	**7.79**
Mean	**7.43**	**7.77**	**7.78**	**7.97**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	7.33	7.98	7.50	7.80
Full N	7.51	7.78	7.51	7.78
Full N & K	7.63	7.75	7.55	7.83
Full NPK	7.83	8.03	7.83	8.03
Soil appln.	7.73	7.85	7.65	7.93
Mean	**7.60**	**7.88**	**7.61**	**7.87**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.02	0.04	S x D	0.03	0.05
Depth (D)	0.02	0.04	D x F	0.04	NS
Fertig. (F)	0.03	0.06	S x F	0.04	0.08
			S x D x F	0.06	0.12

(7.61). Among the different fertigation combinations, the pH ranged from 7.64 to 7.93. Fertigation with either half N or full N or N & K significantly lowered the pH than soil application of fertilisers (7.79) while fertigation of NPK significantly increased the soil pH.

In the interaction effect of soils and fertigation, in loamy sand, all the fertigation treatments were significantly different. Fertigation of NPK recorded higher pH while fertigation of half N recorded the least. In sandy clay loam, fertigation with either NPK or half N, both being on par, recorded significantly higher pH than rest of the treatments.

In surface soil of loamy sand fertigation with either half N or full N significantly decreased the pH than soil application of fertilisers which was on par with fertigation of N & K and NPK. In subsurface soil, fertigation of either half N or full N significantly lowered the soil pH while fertigation of NPK significantly increased the pH than soil application of fertilisers which was on par with fertigation of N & K. In sandy clay loam surface soil, fertigation of NPK significantly increased the pH while fertigation with full N or N & K significantly lowered the pH compared to soil application. In subsurface soil, fertigation of half N significantly increased the soil pH compared to other treatments.

Table 4. Mean effect of fertigation on **Soil pH at 75 DAT**

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	7.32	7.73	7.45	7.73	**7.56**
Full N	7.43	7.93	7.53	7.80	**7.68**
Full N & K	7.35	7.83	7.70	7.60	**7.61**
Full NPK	7.85	7.90	7.87	7.90	**7.88**
Soil appln.	7.48	8.00	7.62	7.93	**7.76**
Mean	**7.48**	**7.87**	**7.63**	**7.79**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	7.53	7.59	7.38	7.73
Full N	7.68	7.67	7.48	7.87
Full N & K	7.57	7.65	7.53	7.69
Full NPK	7.88	7.88	7.86	7.90
Soil appln.	7.74	7.78	7.55	7.97
Mean	**7.68**	**7.71**	**7.56**	**7.83**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.02	NS	S x D	0.03	0.05
Depth (D)	0.02	0.04	D x F	0.04	0.09
Fertig. (F)	0.03	0.06	S x F	0.04	NS
			S x D x F	0.06	0.12

Table 5. Mean effect of fertigation on **Soil pH of post-harvest soil**

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	7.31	7.78	7.57	7.76	**7.61**
Full N	7.35	7.74	7.75	7.78	**7.66**
Full N & K	7.33	7.84	7.61	7.74	**7.63**
Full NPK	7.98	7.76	7.83	7.88	**7.86**
Soil appln.	7.56	7.90	7.52	7.66	**7.66**
Mean	**7.51**	**7.80**	**7.66**	**7.76**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	7.55	7.67	7.44	7.77
Full N	7.55	7.77	7.55	7.76
Full N & K	7.59	7.68	7.47	7.79
Full NPK	7.87	7.86	7.91	7.82
Soil appln.	7.73	7.59	7.54	7.78
Mean	**7.65**	**7.71**	**7.58**	**7.78**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.02	0.04	S x D	0.03	0.05
Depth (D)	0.02	0.04	D x F	0.04	0.08
Fertig. (F)	0.03	0.06	S x F	0.04	0.08
			S x D x F	0.06	0.11

Among the fertigation treatments, the pH ranged from 7.61 to 7.86. Fertigation of NPK recorded significantly higher pH while other treatments were on a par.

In the interaction effect of soils and fertigation, in loamy sand, fertigation of NPK recorded significantly higher pH than soil application of fertilisers. The rest of the treatments were on par, and recorded significantly lower pH. In sandy clay loam, fertigation of NPK recorded significantly higher pH than fertigation of full N followed by rest of the treatments.

In loamy sand, surface soil, fertigation of NPK significantly increased the pH while other treatments significantly lowered it than soil application of fertilisers. At subsurface soil, though the fertigation treatments were on par, they recorded reduced pH as compared to soil application. In sandy clay loam, surface soil, fertigation of full NPK significantly increased the pH followed by fertigation of full N than soil application of fertilisers. In subsurface soil, all fertigation treatments which were on par recorded significantly higher pH than soil application of fertilisers.

4.1.1.2. Soluble salt concentration (EC)

45th day (Table 6 and Fig. 3)

Between the two depths of sampling, surface soil recorded significantly higher soil EC (1.4 dS m^{-1}) than

Table 6. Mean effect of fertigation on **Soluble salt concentration (EC) of soil at 45 DAT**

($dS\ m^{-1}$)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	1.4	1.1	1.4	0.7	**1.1**
Full N	1.4	0.8	1.5	1.2	**1.2**
Full N & K	1.7	0.9	1.8	1.1	**1.4**
Full NPK	0.9	0.6	0.9	0.7	**0.8**
Soil appln.	1.6	0.7	1.5	0.9	**1.2**
Mean	**1.4**	**0.8**	**1.4**	**0.9**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	1.3	1.0	1.4	0.9
Full N	1.1	1.4	1.5	1.0
Full N & K	1.3	1.5	1.8	1.0
Full NPK	0.8	0.8	0.9	0.7
Soil appln.	1.2	1.2	1.6	0.8
Mean	**1.1**	**1.2**	**1.4**	**0.9**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.03	NS	S x D	0.04	NS
Depth (D)	0.03	0.06	D x F	0.07	0.14
Fertig. (F)	0.05	0.10	S x F	0.07	0.14
			S x D x F	0.10	0.20

subsurface soil (0.9 dS m^{-1}). Among the fertigation treatments, EC of soil ranged from 0.8 to 1.4 dS m^{-1}. Compared to soil application of fertilisers, fertigation of NPK significantly lowered the EC while fertigation of N & K significantly increased it.

In the interaction effect of soils and fertigation, in loamy sand, fertigation of NPK recorded significantly lower EC than other treatments. In sandy clay loam, fertigation of NPK was on par with full N, and recorded significantly higher EC followed by soil application of fertilisers, fertigation of half N and NPK, in that order. In surface soil of loamy sand, fertigation of NPK significantly decreased the EC than soil application of fertilisers which was on par with fertigation of N & K and recorded significantly higher EC. In subsurface soil, fertigation of half N recorded significantly higher EC while soil application of fertilisers which was on par with fertigation of NPK recorded significantly lower EC. In sandy clay loam, fertigation of NPK significantly decreased the EC of soil while fertigation of N & K significantly increased it than soil application. In subsurface soil, fertigation of N & K was on par with full N, which recorded significantly higher soil EC while fertigation of half N which was on par with fertigation of NPK recorded significantly lower soil EC as compared to soil application of fertilisers.

75th day (Table 7)

Sandy clay loam recorded significantly higher EC (1.6 dS m^{-1}) than loamy sand (1.3 dS m^{-1}). Between the two depths of sampling, surface soil recorded significantly higher EC (1.6 dS m^{-1}) than subsurface soil (1.3 dS m^{-1}). The soil EC, among the fertigation treatments ranged from 1.0 to 1.8 dS m^{-1}. Fertigation of NPK significantly lowered the soil EC than soil application of fertilisers while fertigation of full N and half N which were on par, significantly increased it.

In the interaction effect of soils and fertigation, in both soils, fertigation of NPK significantly lowered the soil EC.

The interaction effect of fertigation with soils and depth of sampling was not significant.

Post-harvest soil (Table 8 and Fig. 4)

Between the two soils, sandy clay loam recorded significantly higher EC (1.4 dS m^{-1}) than loamy sand (1.2 dS m^{-1}). Of the two depths of sampling, surface soil recorded significantly higher EC (1.4 dS m^{-1}) than

Table 7. Mean effect of fertigation on **Soluble salt concentration (EC) of soil at 75 DAT**

($dS\ m^{-1}$)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	1.8	1.2	2.1	2.2	**1.8**
Full N	1.8	1.2	2.0	1.8	**1.7**
Full N & K	1.4	1.1	1.3	1.9	**1.4**
Full NPK	0.9	0.9	1.0	1.2	**1.0**
Soil appln.	1.9	0.7	1.5	0.9	**1.2**
Mean	**1.6**	**1.0**	**1.6**	**1.6**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	1.5	2.1	1.9	1.7
Full N	1.5	1.9	1.9	1.5
Full N & K	1.3	1.6	1.4	1.5
Full NPK	0.9	1.1	0.9	1.1
Soil appln.	1.3	1.2	1.7	0.8
Mean	**1.3**	**1.6**	**1.6**	**1.3**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.07	0.15	S x D	0.10	0.21
Depth (D)	0.07	0.15	D x F	0.16	0.33
Fertig. (F)	0.12	0.23	S x F	0.16	0.33
			S x D x F	0.23	NS

Table 8. Mean effect of fertigation on **Soluble salt** concentration (EC) of post-harvest soil

(dS m^{-1})

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	1.7	1.0	1.2	1.5	**1.4**
Full N	1.8	1.3	1.2	1.2	**1.4**
Full N & K	1.5	1.0	1.6	1.5	**1.4**
Full NPK	0.8	1.2	1.1	1.2	**1.1**
Soil appln.	1.2	0.9	2.0	1.9	**1.5**
Mean	**1.4**	**1.1**	**1.4**	**1.5**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	1.3	1.4	1.5	1.3
Full N	1.6	1.2	1.5	1.3
Full N & K	1.2	1.6	1.5	1.3
Full NPK	1.0	1.2	1.0	1.2
Soil appln.	1.1	1.9	1.6	1.4
Mean	**1.2**	**1.4**	**1.4**	**1.3**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.04	0.10	S x D	0.05	0.11
Depth (D)	0.04	0.07	D x F	0.08	0.17
Fertig. (F)	0.06	0.12	S x F	0.08	0.17
			S x D x F	0.12	0.24

subsurface soil (1.3 dS m^{-1}). Among the fertigation treatments, EC ranged from 1.1 to 1.5 dS m^{-1}. All the fertigation treatments lowered the EC compared to soil application of fertilisers.

In the interaction effect of soils and fertigation, in loamy sand, fertigation of full N recorded significantly higher EC while fertigation of NPK recorded the least. In sandy clay loam, soil application of fertilisers recorded significantly higher EC of soil followed by fertigation of N & K, half N, full N and NPK, the latter two were on par, and recorded the lower EC.

In loamy sand surface soil, fertigation of NPK significantly lowered the EC than soil application of fertilisers while fertigation of N & K, half N and full N which were on par among themselves, increased the EC significantly. In subsurface soil, fertigation of full N was on par with NPK and recorded higher EC than the soil application. In sandy clay loam, at both depths, fertigation treatments significantly lowered the EC than soil application of fertilisers.

4.1.1.3. Ammoniacal - nitrogen (NH_4-N) content of soil 45th day (Table 9)

Sandy clay loam recorded significantly higher NH_4 - N content (56.4 ppm) than loamy sand (47.5 ppm). Between

Table 9. Mean effect of fertigation on NH_4 - N content of soil at 45 DAT

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	39.1	61.2	59.2	56.0	**53.9**
Full N	36.9	50.3	50.8	56.0	**48.5**
Full N & K	39.7	46.3	56.0	70.9	**53.2**
Full NPK	56.0	33.9	56.0	67.1	**53.3**
Soil appln.	50.8	61.2	35.9	56.0	**51.0**
Mean	**44.5**	**50.6**	**51.6**	**61.2**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	50.2	57.6	49.2	58.6
Full N	43.6	53.4	43.9	53.1
Full N & K	43.0	63.5	47.9	58.6
Full NPK	44.9	61.6	56.0	50.5
Soil appln.	56.0	45.9	48.3	58.6
Mean	**47.5**	**56.4**	**48.0**	**55.9**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.8	1.7	S x D	1.2	2.3
Depth (D)	0.8	1.7	D x F	1.8	3.7
Fertig. (F)	1.3	2.6	S x F	1.8	3.7
			S x D x F	2.6	5.2

the two depths, subsurface recorded significantly higher NH_4-N content (55.9 ppm) than surface soil (48.0 ppm). Among the fertigation combinations, NH_4 - N content varied from 48.5 to 53.9 ppm. Fertigation of full N which was on par with soil application of fertilisers recorded significantly lower NH_4-N content than other treatments which were on par among themselves.

In the interaction effect of soils and fertigation, in loamy sand, soil application of fertilisers recorded significantly higher NH_4 - N content than fertigation of half N and rest of the treatments. In sandy clay loam, fertigation of N & K was on par with NPK and recorded significantly higher NH_4 - N content followed by fertigation of half N, full N and soil application of fertilisers in that order.

In loamy sand surface soil, soil application of fertilisers was on par with fertigation of NPK and recorded higher NH_4-N content than other fertigation treatments which were on par among themselves. In subsurface soil, soil application of fertilisers was on par with fertigation of half N and recorded significantly higher NH_4 - N content while fertigation of full NPK recorded the least. In sandy clay loam surface soil, fertigation of half N or full NPK or N & K which were on par among themselves, recorded significantly higher NH_4 - N content than soil application of fertilisers. In subsurface soil, fertigation of either NPK or N & K which were on par, recorded the highest NH_4 - N content than soil application of fertilisers which was on par with fertigation of full or half N.

75th day (Table 10)

Between the two soils, sandy clay loam recorded significantly higher NH_4 - N content (46.5 ppm) than loamy sand (41.5 ppm). Of the two depths, surface soil recorded significantly higher NH_4 - N content (46.5 ppm) than subsurface soil (41.9 ppm). Among the fertigation treatments, fertigation of full N recorded significantly higher NH_4 - N content (47.6 ppm) than fertigation of N & K which recorded the least (37.7 ppm).

In the interaction effect of soils and fertigation, in loamy sand, fertigation of full N recorded significantly higher NH_4 - N content than soil application of fertilisers whereas in sandy clay loam, fertigation of NPK was on par with soil application of fertilisers and fertigation of half N recorded significantly higher NH_4 - N content followed by fertigation of full N and NPK in that order.

In surface soil of loamy sand, fertigation of full N recorded significantly higher NH_4-N content while

Table 10. Mean effect of fertigation on NH_4 - **N content of soil at 75 DAT**

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	46.8	39.2	57.6	42.0	**46.4**
Full N	58.8	47.6	47.6	36.4	**47.6**
Full N & K	36.4	44.4	39.2	30.8	**37.7**
Full NPK	33.6	33.6	39.2	70.0	**44.1**
Soil appln.	46.8	28.0	58.6	47.2	**45.2**
Mean	**44.5**	**38.6**	**48.4**	**45.3**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	43.0	49.8	52.2	40.6
Full N	53.2	42.0	53.2	42.0
Full N & K	40.4	35.0	37.8	37.6
Full NPK	33.6	54.6	36.4	51.8
Soil appln.	37.4	52.9	52.7	37.6
Mean	**41.5**	**46.5**	**46.5**	**41.9**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	1.5	3.1	S x D	2.2	NS
Depth (D)	1.5	3.1	D x F	3.4	6.9
Fertig. (F)	2.4	4.9	S x F	3.4	6.9
			S x D x F	4.8	9.8

fertigation of full NPK and N & K which were on par among themselves, recorded significantly lower NH_4-N content. In subsurface soil, fertigation of either full N or N & K or half N, recorded the highest NH_4-N content. In sandy clay loam, fertigation of N & K recorded significantly lower NH_4-N content in both depths while in surface soil, soil application of fertilisers was on par with fertigation of N. In subsurface soil, fertigation of NPK recorded significantly higher NH_4-N content.

Post-harvest soil (Table 11)

Of the two soils, sandy clay loam recorded significantly higher NH_4 - N content (59.3 ppm) than loamy sand (52.8 ppm). Between the depths of sampling, surface soil recorded significantly higher NH_4 - N content (60.3 ppm) than subsurface soil (51.8 ppm). Among the fertigation treatments, NH_4 - N content varied from 52.8 to 59.6 ppm. Fertigation of half N recorded the highest NH_4 - N content which was on par with fertigation of full N and NPK, while soil application of fertilisers on par with fertigation of N & K recorded the lower NH_4 - N content.

In the interaction effect of soils and fertigation, in loamy sand, fertigation of half N recorded significantly higher NH_4-N content than soil application of fertilisers. In sandy clay loam, fertigation of NPK

Table 11. Mean effect of fertigation on **NH_4 - N content of post-harvest soil**

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	71.0	50.2	65.2	52.0	**59.6**
Full N	61.4	48.6	67.4	54.0	**57.9**
Full N & K	52.0	48.6	58.0	52.4	**52.8**
Full NPK	52.0	51.2	65.0	58.8	**56.8**
Soil appln.	48.4	44.4	63.0	57.6	**53.4**
Mean	**57.0**	**48.6**	**63.7**	**55.0**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	60.6	58.6	68.1	51.1
Full N	55.0	60.7	64.4	51.3
Full N & K	50.3	55.2	55.0	50.5
Full NPK	51.6	61.9	58.5	55.0
Soil appln.	46.4	60.3	55.7	51.0
Mean	**52.8**	**59.3**	**60.3**	**51.8**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	1.3	2.6	S x D	1.8	NS
Depth (D)	1.3	2.6	D x F	2.8	5.7
Fertig. (F)	2.0	4.1	S x F	2.8	5.7
			S x D x F	4.1	NS

recorded significantly higher NH_4-N content than fertigation of N & K.

The interaction effect of fertigation with soils and depth of sampling with respect to NH_4-N content of soil was not significant.

4.1.1.4. Nitrate-nitrogen (NO_3-N) content of soil

45th day (Table 12)

The individual effect of soils on NO_3-N content was not significant. Surface soil recorded significantly higher NO_3-N content (19.5 ppm) than subsurface soil (14.9 ppm). Among the fertigation treatments, NO_3-N content varied from 13.7 to 19.8 ppm. Soil application of fertilisers was on par with fertigation of N & K and recorded significantly higher NO_3-N content than others while fertigation of NPK recorded the lowest.

In the interaction effect of soils and fertigation, in loamy sand, soil application of fertilisers was on par with fertigation of half N and N & K which recorded significantly higher NO_3-N content than fertigation of N and NPK, the latter two being on par recorded the least. In sandy clay loam, fertigation of N & K which was on par with full N recorded significantly higher NO_3-N content than soil application of fertilisers, fertigation of half N and

Table 12. Mean effect of fertigation on **NO_3 - N content of soil at 45 DAT**

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	20.2	17.3	20.0	8.3	**16.5**
Full N	19.3	10.5	20.0	19.1	**17.2**
Full N & K	20.0	17.2	21.0	21.0	**19.8**
Full NPK	18.5	10.3	15.3	10.5	**13.7**
Soil appln.	21.0	18.5	20.0	16.3	**19.0**
Mean	**19.8**	**14.8**	**19.3**	**15.0**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	18.7	14.2	20.1	12.8
Full N	14.9	19.6	19.7	14.8
Full N & K	18.6	21.0	20.5	19.1
Full NPK	14.4	12.9	16.9	10.4
Soil appln.	19.8	18.2	20.5	17.4
Mean	**17.3**	**17.2**	**19.5**	**14.9**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.4	NS	S x D	0.6	NS
Depth (D)	0.4	0.8	D x F	0.9	1.8
Fertig. (F)	0.6	1.2	S x F	0.9	1.8
			S x D x F	1.2	2.5

NPK, the latter two being on par recorded the lowest NO_3 - N content.

In loamy sand at both depths, soil application of fertilisers recorded the highest NO_3-N content while fertigation of NPK recorded the least. In sandy clay loam, fertigation of N & K was on par with full N and recorded significantly higher NO_3-N content than fertigation of NPK which recorded the least.

75th day (Table 13)

Of the two soils, sandy clay loam recorded significantly higher NO_3-N content (20.2 ppm) than loamy sand (19.5 ppm). The individual effect of depths and fertigation with respect to NO_3-N content of soil was not significant.

In the interaction effect of soils and fertigation, NO_3-N content varied from 18.5 to 20.0 and from 18.5 to 20.8 ppm in loamy sand and sandy clay loam respectively. In loamy sand, fertigation of full N recorded significantly higher NO_3-N content than soil application of fertilisers. In sandy clay loam, fertigation of half N recorded significantly lower NO_3-N content than other treatments which were on par among themselves.

Table 13. Mean effect of fertigation on **NO_3 - N content of soil at 75 DAT**

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	19.2	20.5	15.9	21.0	**19.1**
Full N	21.0	18.9	21.0	20.5	**20.4**
Full N & K	20.0	19.3	20.5	21.0	**20.2**
Full NPK	19.6	19.3	20.5	21.0	**20.1**
Soil appln.	20.2	16.8	22.0	18.2	**19.3**
Mean	**20.0**	**19.0**	**20.0**	**20.3**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	19.8	18.5	17.5	20.8
Full N	20.0	20.8	21.0	19.7
Full N & K	19.7	20.8	20.3	20.2
Full NPK	19.5	20.8	20.1	20.2
Soil appln.	18.5	20.1	21.1	17.5
Mean	**19.5**	**20.2**	**20.0**	**19.6**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.3	0.6	S x D	0.4	0.9
Depth (D)	0.3	NS	D x F	0.7	1.4
Fertig. (F)	0.5	NS	S x F	0.7	1.4
			S x D x F	1.0	NS

The interaction effect of fertigation with soils and depths of sampling was not significant.

Post-harvest soil (Table 14)

Of the two soils, sandy clay loam recorded significantly higher NO_3-N content (22.4 ppm) than loamy sand (13.9 ppm). Comparing the two depths of sampling, subsurface soil with 20.2 ppm recorded significantly higher NO_3-N content than surface soil (16.1 ppm). Among the fertigation treatments, soil application of fertilisers (21.4 ppm) which was on par with fertigation of full N recorded significantly higher NO_3-N content while fertigation of half N (12.7 ppm) recorded the least.

In the interaction effect of soils and fertigation, in loamy sand, fertigation of full N was on par with soil application of fertilisers and recorded significantly higher NO_3-N content followed by fertigation of NPK which was on par with N & K and half N in that order. In sandy clay loam, soil application of fertilisers was on par with fertigation of N & K and N, recorded higher NO_3-N content while fertigation of half N which was on par with NPK and full N recorded the least.

In surface soil of loamy sand, soil application of fertilisers was on par with fertigation of full N and

Table 14. Mean effect of fertigation on NO_3 - **N content of post-harvest soil**

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	3.9	5.5	16.5	25.0	**12.7**
Full N	20.3	19.9	20.0	25.0	**21.3**
Full N & K	11.2	13.5	21.2	25.0	**17.7**
Full NPK	4.8	21.0	19.3	25.0	**17.5**
Soil appln.	21.6	17.1	22.0	25.0	**21.4**
Mean	**12.4**	**15.4**	**19.8**	**25.0**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	4.7	20.7	10.2	15.3
Full N	20.1	22.5	20.1	22.5
Full N & K	12.4	23.1	16.2	19.2
Full NPK	12.9	22.2	12.1	23.0
Soil appln.	19.4	23.5	21.8	21.1
Mean	**13.9**	**22.4**	**16.1**	**20.2**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.4	0.8	S x D	0.6	1.2
Depth (D)	0.4	0.8	D x F	0.9	1.9
Fertig. (F)	0.7	1.3	S x F	0.9	1.9
			S x D x F	1.3	2.7

recorded significantly higher NO_3-N content than fertigation of N & K. Fertigation of full NPK was on par with half N and recorded significantly lower NO_3-N content. In subsurface soil, fertigation of full N and NPK which were on par with each other, recorded significantly higher NO_3-N content followed by soil application of fertilisers, fertigation of N & K and half N in that order. In surface soil of sandy clay loam , soil application of fertilisers was on par with fertigation of N & K and full N and recorded significantly higher NO_3-N content, while fertigation of half N recorded the least. In subsurface soil, no significant difference was observed.

4.1.1.5. Sodium bicarbonate extractable phosphorus ($NaHCO_3$) 45th day (Table 15)

Between the two soils, loamy sand recorded significantly higher $NaHCO_3$-P (17.3 ppm) than sandy clay loam (13.4 ppm). Of the two depths of sampling, surface soil recorded significantly higher $NaHCO_3$-P (19.3 ppm) than subsurface soil (11.4 ppm). Among the fertigation combinations, $NaHCO_3$-P varied from 10.5 to 18.2 ppm. Fertigation of either full N or half N recorded significantly higher $NaHCO_3$-P while fertigation of NPK recorded the least.

Table 15. Mean effect of fertigation on **$NaHCO_3$-P content of soil at 45 DAT**

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	29.0	12.4	19.0	12.4	**18.2**
Full N	19.5	17.5	19.8	15.5	**18.1**
Full N & K	25.2	7.8	22.3	10.0	**16.3**
Full NPK	14.3	8.9	8.9	10.0	**10.5**
Soil appln.	25.2	13.3	10.0	6.1	**13.7**
Mean	**22.6**	**12.0**	**16.0**	**10.8**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	20.7	15.7	24.0	12.4
Full N	18.5	17.7	19.6	16.5
Full N & K	16.5	16.2	23.8	8.9
Full NPK	11.6	9.5	11.6	9.5
Soil appln.	19.3	8.1	17.6	9.7
Mean	**17.3**	**13.4**	**19.3**	**11.4**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.3	0.7	S x D	0.5	0.9
Depth (D)	0.3	0.7	D x F	0.7	1.5
Fertig. (F)	0.5	1.0	S x F	0.7	1.5
			S x D x F	1.0	2.1

In the interaction effect of soils and fertigation, in loamy sand, fertigation of half N was on par with soil application of fertilisers and recorded higher $NaHCO_3$-P followed by fertigation of full N, N & K and NPK in that order. In sandy clay loam, fertigation of full N was on par with N & K and recorded higher $NaHCO_3$-P followed by fertigation of half N, NPK and soil application of fertilisers, the latter two being on a par.

In loamy sand surface soil, fertigation of half N recorded significantly higher $NaHCO_3$-P content while fertigation of NPK recorded the least. In subsurface soil, fertigation of full N recorded significantly higher $NaHCO_3$-P while fertigation of NPK which was on par with N & K recorded the least. In surface soil of sandy clay loam, fertigation of N & K recorded higher $NaHCO_3$-P while soil application of fertilisers which was on par with fertigation of N & K recorded the least. In subsurface soil, fertigation of full N recorded significantly higher $NaHCO_3$-P while soil application of fertilisers recorded the least.

75th day (Table 16)

Loamy sand recorded significantly higher $NaHCO_3$-P (14.3 ppm) than sandy clay loam (11.2 ppm). Of the two depths of sampling, surface soil recorded significantly

Table 16. Mean effect of fertigation on $NaHCO_3$ -P content of soil at 75 DAT

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	27.7	9.5	19.8	13.1	**17.5**
Full N	26.6	11.8	18.8	7.0	**16.0**
Full N & K	20.7	7.8	14.0	8.3	**12.7**
Full NPK	8.9	6.1	8.4	5.1	**7.1**
Soil appln.	16.1	7.8	11.3	6.7	**10.5**
Mean	**20.0**	**8.6**	**14.4**	**8.0**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	18.6	16.4	23.8	11.3
Full N	19.2	12.9	22.7	9.4
Full N & K	14.3	11.2	17.4	8.1
Full NPK	7.5	6.7	8.6	5.6
Soil appln.	12.0	9.0	13.7	7.2
Mean	**14.3**	**11.2**	**17.2**	**8.3**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	1.0	1.9	S x D	1.4	2.7
Depth (D)	1.0	1.9	D x F	2.1	4.3
Fertig. (F)	1.5	3.1	S x F	2.1	NS
			S x D x F	3.0	NS

higher $NaHCO_3$-P (17.2 ppm) than the subsurface soil (8.3 ppm). Among the fertigation combinations, $NaHCO_3$-P varied from 7.1 to 17.5 ppm. Fertigation of either full N or half N recorded significantly higher $NaHCO_3$-P than fertigation of NPK which recorded the least. The interaction effect of soils x fertigation and soil x depth x fertigation were not significant.

Post-harvest soil (Table 17)

Of the two soils, loamy sand had significantly higher $NaHCO_3$-P (9.8 ppm) than sandy clay loam (8.5 ppm). Surface soil recorded significantly higher $NaHCO_3$-P (11.5 ppm) than subsurface soil (6.8 ppm). Among the fertigation combinations, fertigation with full N (11.3 ppm) or N & K recorded significantly higher $NaHCO_3$-P while fertigation of half N (6.7 ppm) recorded the least.

In the interaction effect of soils and fertigation, in loamy sand, fertigation of N & K recorded significantly higher $NaHCO_3$-P followed by fertigation of full N, NPK, half N and soil application of fertilisers with the latter two being on a par. In sandy clay loam, fertigation of full N was on par with NPK and recorded significantly higher $NaHCO_3$-P while fertigation of half N recorded the least.

Table 17. Effect of fertigation on $NaHCO_3$ -P content of post-harvest soil

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	9.1	5.2	7.4	5.2	**6.7**
Full N	18.5	5.8	12.6	8.4	**11.3**
Full N & K	16.2	11.3	9.2	5.9	**10.7**
Full NPK	11.5	7.4	12.4	6.5	**9.5**
Soil appln.	8.0	5.2	10.1	6.8	**7.5**
Mean	**12.7**	**7.0**	**10.3**	**6.6**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	7.2	6.3	8.3	5.2
Full N	12.1	10.5	15.6	7.1
Full N & K	13.8	7.6	12.7	8.6
Full NPK	9.4	9.5	12.0	7.0
Soil appln.	6.6	8.5	9.0	6.0
Mean	**9.8**	**8.5**	**11.5**	**6.8**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	0.3	0.5	S x D	0.4	0.7
Depth (D)	0.3	0.5	D x F	0.6	1.1
Fertig. (F)	0.4	0.8	S x F	0.6	1.1
			S x D x F	0.8	1.6

In surface soil of loamy sand fertigation of full N recorded significantly higher $NaHCO_3$-P while soil application of fertilisers which was on par with fertigation of half N recorded the least. In subsurface soil, fertigation of N & K recorded significantly higher $NaHCO_3$-P than fertigation of NPK followed by rest of the treatments which were on par among themselves. In surface soil of sandy clay loam, fertigation of either full N or NPK recorded significantly higher $NaHCO_3$-P while fertigation of half N recorded the least. In subsurface soil, fertigation of full N recorded significantly higher $NaHCO_3$-P while fertigation of either half N or N & K recorded the least.

4.1.1.6. Ammonium acetate extractable potassium (NH_4OAc-K) 45th day (Table 18)

Comparing the two soils, sandy clay loam had significantly higher NH_4OAc-K (642 ppm) than loamy sand (335 ppm). Of the two depths of sampling, surface soil recorded significantly higher NH_4OAc-K (507 ppm) than subsurface soil (470 ppm). Among the fertigation combinations, NH_4OAc-K varied from 423 to 565 ppm. Fertigation of half N recorded significantly higher NH_4OAc-K followed by soil application while fertigation of NPK recorded the least.

Table 18. Mean effect of fertigation on NH_4OAc-K content of soil at 45 DAT

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	370	300	750	842	**565**
Full N	480	260	670	460	**468**
Full N & K	360	250	690	590	**473**
Full NPK	290	252	460	690	**423**
Soil appln.	420	368	580	688	**514**
Mean	**384**	**286**	**630**	**654**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	335	796	560	571
Full N	370	565	575	360
Full N & K	305	640	525	420
Full NPK	271	575	375	471
Soil appln.	394	634	500	528
Mean	**335**	**642**	**507**	**470**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	6.0	11.0	S x D	8.0	16.0
Depth (D)	6.0	11.0	D x F	12.0	25.0
Fertig. (F)	9.0	18.0	S x F	12.0	25.0
			S x D x F	17.0	35.0

In the interaction effect of soils and fertigation, in loamy sand, soil application of fertilisers which was on par with fertigation of full N recorded significantly higher NH_4OAc-K followed by fertigation of half N, full N and N & K, in that order. In sandy clay loam, fertigation of half N recorded significantly higher NH_4OAc-K while fertigation of NPK whcih was on par with full N, recorded the least.

In loamy sand surface soil, fertigation of full N recorded significantly higher NH_4OAc-K while fertigation of NPK recorded the least. In subsurface, soil application of fertilisers recorded significantly higher NH_4OAc-K followed by fertigation of half N and the rest of fertigation combinations which were on par among themselves recorded the least. In both depths, fertigation of half N recorded significantly higher NH_4OAc-K while fertigation of NPK and full N recorded significantly lower NH_4OAc-K in surface and subsurface soils of sandy clay loam respectively.

75th day (Table 19)

Sandy clay loam recorded significantly higher NH_4OAc-K (603 ppm) than loamy sand (323 ppm). Of the two depths of sampling, surface soil recorded significantly higher NH_4OAc-K (587 ppm) than subsurface soil (338 ppm). Among the fertigation combinations, NH_4OAc-K varied from

Table 19. Mean effect of fertigation on **NH_4OAc-K content of** soil at 75 DAT

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	495	225	910	655	571
Full N	500	200	860	555	**529**
Full N & K	335	170	485	395	**346**
Full NPK	290	170	570	300	**333**
Soil appln.	620	220	805	490	**534**
Mean	**448**	**197**	**726**	**479**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	360	783	703	440
Full N	350	708	680	378
Full N & K	253	440	410	283
Full NPK	230	435	430	235
Soil appln.	420	648	713	355
Mean	**323**	**603**	**587**	**338**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	8.0	17.0	S x D	12.0	NS
Depth (D)	8.0	17.0	D x F	19.0	38.0
Fertig. (F)	13.0	27.0	S x F	19.0	38.0
			S x D x F	27.0	54.0

333 to 571 ppm. Fertigation of half N recorded significantly higher NH_4OAc-K followed by full N and soil application while fertigation of NPK recorded the least.

In the interaction of soils and fertigation, in loamy sand, soil application of fertilisers recorded significantly higher NH_4OAc-K while fertigation of half N which was on par with NPK, recorded the least. In sandy clay loam, fertigation of half N recorded significantly higher NH_4OAc-K followed by fertigation of full N, soil application of fertilisers, fertigation of N & K and NPK, the latter two being on a par.

In surface soil of loamy sand, soil application of fertilisers recorded significantly higher NH_4OAc-K while fertigation of either NPK or N & K recorded the least. In subsurface soil, fertigation of half N was on par with soil application of fertilisers and fertigation of full N recorded significantly higher NH_4OAc-K than fertigation of either N & K or NPK, the latter two were on par and recorded the least. In sandy clay loam surface soil, fertigation of either half N or full N recorded significantly higher NH_4OAc-K while fertigation of N & K recorded the least. In subsurface soil, fertigation of half N recorded significantly higher NH_4OAc-K while fertigation of NPK recorded the least.

Post-harvest soil (Table 20)

Of the two soils, sandy clay loam recorded significantly higher NH_4OAc-K (330 ppm) than loamy sand (234 ppm). Surface soil with 349 ppm recorded significantly higher NH_4OAc-K than subsurface soil (215 ppm). Among the fertigation combinations, NH_4OAc-K varied from 229 to 326 ppm. Soil application of fertilisers recorded significantly higher NH_4OAc-K while fertigation of half N recorded the least. The rest of the three fertigation treatments were on a par.

In the interaction effect of soils and fertigation, in loamy sand, fertigation of full N was on par with soil application of fertilisers and recorded significantly higher NH_4OAc-K than rest of the treatments which were on par among themselves. In sandy clay loam, soil application of fertilisers was on par with fertigation of NPK and recorded significantly higher NH_4OAc-K while fertigation of half N recorded the least.

In surface soil of loamy sand, soil application of fertilisers was on par with fertigation of full N and in subsurface soil, fertigation of either full N or N & K recorded higher NH_4OAc-K. In sandy clay loam, in both depths, fertigation of NPK was on par with soil application of fertilisers and recorded significantly higher NH_4OAc-K.

Table 20. Mean effect of fertigation on **NH_4OAc-K content of post-harvest soil**

(ppm)

Fertigation	Loamy sand		Sandy clay loam		Mean
	Depth (cm)				
	0-10	10-20	0-10	10-20	
Half N	288	146	323	160	**229**
Full N	311	250	368	252	**295**
Full N & K	230	205	416	245	**274**
Full NPK	235	135	496	270	**284**
Soil appln.	353	181	465	305	**326**
Mean	**284**	**183**	**414**	**246**	-

Fertigation	Soils		Depth (cm)	
	ls	scl	0-10	10-20
Half N	217	242	306	153
Full N	281	310	340	251
Full N & K	218	331	323	225
Full NPK	185	383	366	203
Soil appln.	267	385	409	243
Mean	**234**	**330**	**349**	**215**

	SEd	CD (0.05)		SEd	CD (0.05)
Soils (S)	8.8	17.6	S x D	12.5	24.9
Depth (D)	8.8	17.6	D x F	19.7	39.4
Fertig. (F)	13.9	27.9	S x F	19.7	39.4
			S x D x F	27.9	55.8

Table 21. Mean effect of fertigation on **shoot weight at stages, fruit yield and total biomass production** of tomato at harvest

(g bag^{-1})

Fertigation	Shoot Weight					
	45th day			75th day		
	ls	scl	Mean	ls	scl	Mean
Half N	81	65	**73**	304	183	**244**
Full N	65	84	**74**	238	306	**272**
Full N & K	56	60	**58**	194	175	**184**
Full NPK	55	65	**60**	214	270	**243**
Soil appln.	60	60	**60**	234	260	**247**
Mean	**63**	**67**	-	**237**	**239**	-

	SEd	CD (0.05)	SEd	CD (0.05)
Soil (S)	1.1	2.4	4.9	NS
Fertig. (F)	1.8	3.8	7.9	16.5
S x F	2.6	5.4	11.1	23.4

	At Harvest					
	Fresh Fruit Yield			Total biomass		
	ls	scl	Mean	ls	scl	Mean
Half N	835	674	**754**	1137	881	1009
Full N	882	758	**820**	1138	1067	1103
Full N & K	560	504	**532**	761	709	735
Full NPK	765	637	**701**	1044	970	1007
Soil appln.	619	556	**588**	889	859	874
Mean	**732**	**625**	-	**994**	**897**	-

	SEd	CD (0.05)	SE_d	CD (0.05)
Soil (S)	22.5	45.6	36.0	NS
Fertig.(F)	35.6	72.2	56.0	114.0
[illegible]			[illegible]	[illegible]

The shoot weight varied from 194 to 304 and 175 to 306 g bag^{-1} in loamy sand and sandy clay loam respectively. Fertigation with half N in loamy sand and full N in sandy clay loam recorded significantly higher shoot weight. In both soils, fertigation with N & K recorded significantly lower shoot weight.

4.1.2.2. Fresh Fruit Yield (Table 21 and Fig. 6)

Comparing the two soils, loamy sand recorded significantly higher fruit yield (732 g bag^{-1}) than sandy clay loam (625 g bag^{-1}). Among the fertigation combinations, the fruit yield of tomato varied from 532 to 820 g bag^{-1}. Fertigation of either full N or half N or NPK which were on par among themselves recorded significantly higher fruit yield than soil application of fertilisers which was on par with fertigation of N & K.

The interaction effect of fertigation with soils on fruit yield of tomato was not significant.

4.1.2.3 Total biomass production at harvest (Table 21)

Among the fertigation combinations, the total dry matter production at harvest varied from 735 to 1103 g bag^{-1}. Fertigation of either full N or NPK or half N which were on par among themselves, recorded significantly higher total biomass production at harvest than fertigation of N & K which recorded the least. The individual effect of soil was not significant.

The interaction effect of fertigation on soils on total biomass production at harvest was not significant.

4.1.3. Effect of Fertigation on Nutrient Uptake by Tomato

4.1.3.1. Nitrogen uptake (Table 22)

45th day

Among the fertigation combinations, fertigation with full N recorded significantly higher N uptake (189 mg bag^{-1}) followed by half N (174 mg bag^{-1}) than rest of the treatments. Fertigation of N & K registered lower N uptake (116 mg bag^{-1}), which was on par with soil application of fertilisers. Between the two soils there was no significant difference with respect to N uptake.

The N uptake varied from 92 to 185 and 99 to 214 mg bag^{-1} in loamy sand and sandy clay loam respectively. In loamy sand, fertigation of half N followed by full N and in sandy clay loam, fertigation of full N followed by half N recorded significantly higher N uptake. Fertigation of N & K and soil application of fertilisers recorded significantly lower N uptake in loamy sand and sandy clay loam respectively.

Table 22. Mean effect of fertigation on **N uptake at stages and at harvest** by tomato

(mg bag^{-1})

Fertigation	N uptake by shoot					
	45th day			75th day		
	ls	scl	Mean	ls	scl	Mean
Half N	185	162	**174**	696	320	**508**
Full N	165	214	**189**	534	792	**663**
Full N & K	92	140	**116**	509	415	**462**
Full NPK	140	115	**127**	631	646	**639**
Soil appln.	149	99	**124**	548	676	**612**
Mean	**146**	**146**	-	**583**	**570**	-
	SEd	CD (0.05)		SEd	CD (0.05)	
Soil (S)	3.01	NS		13.9	NS	
Fertig. (F)	4.86	10.0		22.0	46.3	
S x F	6.7	14.1		31.2	65.4	

	At Harvest					
	N uptake by fruits			Total N uptake		
	ls	scl	Mean	ls	scl	Mean
Half N	2029	1623	**1826**	3292	2718	**3005**
Full N	2464	1854	**2157**	3641	3223	**3432**
Full N & K	1637	1198	**1418**	2408	2326	**2367**
Full NPK	1881	1557	**1719**	3365	3078	**3222**
Soil appln.	1505	1151	**1328**	2754	2335	**2544**
Mean	**1902**	**1477**	-	**3092**	**2736**	-
	SEd	CD (0.05)		SEd	CD (0.05)	
Soil (S)	69.4	140.8		119.6	242.5	
Fertig.(F)	109.8	222.6		189.1	383.5	
S x F	155.2	NS		267.4	NS	

75th day

In the fertigation combinations, N uptake varied from 462 to 663 mg bag^{-1}. Fertigation of full N was on par with NPK and recorded significantly higher N uptake than soil application of fertilisers. Fertigation with either half N or N & K, were on par and recorded the least. The individual effect of soil on N uptake was not significant.

The N uptake varied from 509 to 696 and 320 to 792 mg bag^{-1} in loamy sand and sandy clay loam respectively. In loamy sand, fertigation of half N recorded significantly higher N uptake than fertigation of NPK followed by rest of the treatments which were on par among themselves. In sandy clay loam, fertigation of full N recorded significantly higher N uptake while fertigation of half N recorded the least.

Nitrogen uptake by fruits

Loamy sand recorded significantly higher N uptake by fruits (1902 mg bag^{-1}) than sandy clay loam (1477 mg bag^{-1}). Among the fertigation combinations, N uptake by fruits varied from 1328 to 2157 mg bag^{-1}. Fertigation of full N recorded significantly higher N uptake by fruits while soil application of fertilisers was on par with fertigation of N & K and recorded the least.

The interaction effect of fertigation with soils was not significant.

Total nitrogen uptake at harvest

Loamy sand recorded significantly higher total N uptake (3092 mg bag^{-1}) than sandy clay loam (2736 mg bag^{-1}). Among the fertigation combinations, total N uptake varied from 2367 to 3432 mg bag^{-1}. Fertigation with full N which was on par with NPK, recorded significantly higher N uptake than soil application of fertilisers and fertigation of N & K, the latter two being on a par.

The interaction effect of fertigation with soils was not significant.

4.1.3.2. Phosphorus uptake (Table 23)

45th day

In loamy sand, the P uptake was significantly higher (25 mg bag^{-1}) than sandy clay loam (15 mg bag^{-1}). Among the fertigation combinations, P uptake varied from 16 to 26 mg bag^{-1}. Fertigation with half N recorded significantly higher P uptake than other treatments. Fertigation of N & K which was on par with NPK, recorded significantly the least.

Phosphorus uptake varied from 19 to 36 and 13 to 20 mg bag^{-1} in loamy sand and sandy clay loam respectively. In

Table 23. Mean effect of fertigation on **P uptake at stages and at harvest** by tomato

(mg bag^{-1})

Fertigation	P uptake by shoot					
	45th day			75th day		
	ls	scl	Mean	ls	scl	Mean
Half N	36	16	**26**	68	34	**51**
Full N	22	20	**21**	42	102	**72**
Full N & K	19	13	**16**	71	38	**54**
Full NPK	20	14	**17**	71	65	**68**
Soil appln.	27	14	**20**	87	77	**82**
Mean	**25**	**15**	-	**68**	**63**	-
	SEd	CD (0.05)		SEd	CD (0.05)	
Soil (S)	0.91	1.9		1.8	3.8	
Fertig. (F)	1.5	3.0		2.9	6.0	
S x F	2.1	4.3		4.0	8.5	

	At Harvest					
	P uptake by fruits			Total P uptake		
	ls	scl	Mean	ls	scl	Mean
Half N	452	305	**378**	631	406	**519**
Full N	554	396	**475**	717	581	**649**
Full N & K	290	260	**275**	372	392	**382**
Full NPK	401	362	**381**	560	529	**544**
Soil appln.	335	337	**336**	440	476	**458**
Mean	**406**	**332**	-	**544**	**479**	-
	SEd	CD (0.05)		SEd	CD (0.05)	
Soil (S)	20.6	41.7		25.5	51.8	
Fertig.(F)	32.5	65.9		40.4	81.9	
	[illegible]	NS		57.1	115.8	

loamy sand, fertigation with half N recorded significantly higher P uptake than soil application of fertilisers followed by rest of the fertigation combinations, which were on a par. In sandy clay loam, fertigation of full N recorded the highest P uptake followed by other treatments which were on par among themselves.

75th day

Of the two soils, loamy sand recorded significantly higher P uptake (68 mg bag^{-1}) than sandy clay loam (63 mg bag^{-1}). Among the fertigation combinations, P uptake varied from 51 to 82 mg bag^{-1}. Soil application of fertilisers recorded significantly higher P uptake while fertigation of N & K which was on par with half N recorded the least.

The P uptake varied from 42 to 87 and 34 to 102 mg bag^{-1} in loamy sand and sandy clay loam respectively. In loamy sand, soil application of fertilisers recorded the highest P uptake while fertigation of full N recorded the least. In sandy clay loam, fertigation of full N recorded significantly higher P uptake followed by soil application of fertilisers, fertigation of NPK while fertigation of N & K was on par with half N and recorded the least.

Phosphorus uptake by fruits

Comparing the soils, loamy sand recorded significantly higher P uptake (406 mg bag^{-1}) than sandy clay loam (332 mg bag^{-1}). Fertigation of full N recorded significantly higher P uptake (475 mg bag^{-1}) than other treatments. Fertigation of N & K was on par with soil application of fertilisers and recorded the least (275 mg bag^{-1}).

The interaction effect of fertigation with soil was not significant.

Total phosphorus uptake at harvest

Loamy sand recorded significantly higher total P uptake (544 mg bag^{-1}) than sandy clay loam (479 mg bag^{-1}). Fertigation with full N recorded significantly higher total P uptake (649 mg bag^{-1}) followed by fertigation with NPK (544 mg bag^{-1}) and half N (519 mg bag^{-1}) while N & K recorded the least (382 mg bag^{-1}).

The total P uptake at harvest varied from 372 to 717 and 392 to 581 mg bag^{-1} in loamy sand and sandy clay loam respectively. In both soils, fertigation of full N recorded the highest total P uptake while fertigation of N & K the least.

4.1.3.3. Potassium uptake (Table 24)

45th day

Of the two soils, sandy clay loam recorded significantly higher K uptake (272 mg bag^{-1}) than loamy

Table 24. Mean effect of fertigation on **K uptake at stages and at harvest** by tomato

(mg bag^{-1})

Fertigation	K uptake by shoot					
	45th day			75th day		
	ls	scl	Mean	ls	scl	Mean
Half N	319	246	**283**	662	427	**544**
Full N	237	305	**271**	495	857	**676**
Full N & K	248	261	**254**	655	378	**517**
Full NPK	187	274	**231**	592	928	**760**
Soil appln.	234	273	**253**	677	685	**681**
Mean	**245**	**272**	-	**616**	**655**	-
	SEd	CD (0.05)		SEd	CD (0.05)	
Soil (S)	6.9	14.4		18.4	38.6	
Fertig. (F)	10.8	22.8		29.1	61.1	
S x F	15.3	32.2		41.1	86.5	

	At Harvest					
	K uptake by fruits			Total K uptake		
	ls	scl	Mean	ls	scl	Mean
Half N	2118	1575	**1846**	4028	2931	**3479**
Full N	2796	1995	**2395**	4665	3939	**4302**
Full N & K	1569	1277	**1423**	2722	2730	**2726**
Full NPK	1878	1501	**1689**	3507	3239	**3373**
Soil appln.	1541	1192	**1366**	2958	2839	**2899**
Mean	**1980**	**1508**	-	**3576**	**3135**	-
	SEd	CD (0.05)		SEd	CD (0.05)	
Soil (S)	77.1	156.3		134.3	272.4	
Fertig.(F)	121.9	247.2		212.4	430.7	
S x F	172.3	NS		300.4	NS	

sand (245 mg bag^{-1}). Among the fertigation combinations, K uptake ranged from 231 to 283 mg bag^{-1}. Fertigation with half N was on par with full N and recorded the highest K uptake while soil application of fertilisers and fertigation with NPK, the latter two being on par recorded the lowest K uptake.

The K uptake ranged from 187 to 319 and 246 to 305 mg bag^{-1} in loamy sand and sandy clay loam respectively. Fertigation with half N and full N recorded significantly higher K uptake in loamy sand and sandy clay loam respectively while other treatments were on par among themselves except fertigation of NPK in loamy sand which recorded significantly lower K uptake than others.

75th day

Sandy clay loam recorded significantly higher K uptake (655 mg bag^{-1}) than loamy sand (616 mg bag^{-1}). Fertigation of NPK recorded significantly higher K uptake (760 mg bag^{-1}) while fertigation of N & K which was on par with half N, recorded the least (517 mg bag^{-1}).

The K uptake ranged from 495 to 677 and 378 to 928 mg bag^{-1} in loamy sand and sandy clay loam respectively. In loamy sand, fertigation with full N recorded significantly lower K uptake than others which were on par among themselves. But in sandy clay loam, fertigation of NPK was on par with full N and recorded the highest K uptake followed by soil application of fertilisers and fertigation of half N and N & K, the latter two being on a par.

Potassium uptake by fruits

The potassium uptake by fruits was significantly higher in loamy sand (1980 mg bag^{-1}) compared to sandy clay loam (1508 mg bag^{-1}). Among the fertigation combinations, the K uptake by fruits ranged from 1366 to 2395 mg bag^{-1}. Fertigation of full N recorded the highest K uptake by fruits while soil application of fertilisers which was on par with fertigation of N & K, recorded the least. The interaction effect of fertigation with soil was not significant.

Total K uptake at harvest

The total K uptake was 3576 and 3135 mg bag^{-1} in loamy sand and sandy clay loam respectively, both being significantly different. Among the fertigation combinations, total K uptake ranged from 2726 to 4302 mg bag^{-1}, with fertigation of full N recording the highest and fertigation of N & K on par with soil application of fertilisers recording the least.

The interaction effect of fertigation with soils was not significant.

4.1.3.4. Calcium uptake (Table 25)

45th day

Among the fertigation combinations, Ca uptake ranged from 106 to 182 mg bag^{-1}. Fertigation of half N recorded significantly higher Ca uptake while soil application of fertilisers, on par with fertigation of N & K recorded the least. The individual effect of soil was not significant.

The Ca uptake ranged from 93 to 207 and 112 to 181 mg bag^{-1} in loamy sand and sandy clay loam respectively. In loamy sand, fertigation of half N, followed by full N and in sandy clay loam, fertigation of full N followed by half N recorded the highest Ca uptake. In both soils, lowest Ca uptake was recorded in soil application of fertilisers.

75th day

Sandy clay loam recorded statistically higher Ca uptake (515 mg bag^{-1}) than loamy sand (433 mg bag^{-1}). Among the fertigation combinations, the Ca uptake ranged from 328 to 601 mg bag^{-1}. Fertigation of full N recorded significantly higher Ca uptake followed by soil application of fertilisers while fertigation of N & K recorded the least.

Table 25. Mean effect of fertigation on **Ca uptake at stages and at harvest** by tomato

(mg bag^{-1})

Fertigation	Ca uptake by shoot					
	45th day			75th day		
	ls	scl	Mean	ls	scl	Mean
Half N	207	157	**182**	472	427	**450**
Full N	156	181	**169**	441	761	**601**
Full N & K	111	112	**112**	313	343	**328**
Full NPK	119	137	**128**	432	502	**466**
Soil appln.	93	118	**106**	508	544	**526**
Mean	**137**	**141**	-	**433**	**515**	-
	SEd	CD (0.05)		SEd	CD (0.05)	
Soil (S)	3.3	NS		11.0	23.2	
Fertig. (F)	5.2	11.0		17.4	36.7	
S x F	7.4	15.6		24.7	51.8	

	At Harvest					
	Ca uptake by fruits			Total Ca uptake		
	ls	scl	Mean	ls	scl	Mean
Half N	309	220	**265**	1280	924	**1102**
Full N	438	204	**321**	1290	944	**1117**
Full N & K	230	186	**208**	862	992	**927**
Full NPK	291	214	**252**	1109	1609	**1359**
Soil appln.	237	252	**245**	1015	1525	**1270**
Mean	**301**	**215**	-	**1111**	**1199**	-
	SEd	CD (0.05)		SEd	CD (0.05)	
Soil (S)	23.2	47.0		63.2	NS	
Fertig.(F)	36.7	NS		100.0	202.7	
S x F	51.8	105.1		141.4	286.8	

The Ca uptake ranged from 313 to 508 and 343 to 761 mg bag^{-1} in loamy sand and sandy clay loam respectively. In both soils, fertigation of N & K recorded significantly lower Ca uptake while in loamy sand, soil application of fertilisers was on par with fertigation of half N. In sandy clay loam, fertigation of full N recorded the higher Ca uptake.

Calcium uptake by fruits

Of the two soils, loamy sand recorded significantly higher Ca uptake (301 mg bag^{-1}) than sandy clay loam (215 mg bag^{-1}). The individual effect of fertigation treatments was not significant.

The Ca uptake by fruits ranged from 230 to 438 and 186 to 252 mg bag^{-1} in loamy sand and sandy clay loam respectively. In loamy sand, fertigation of full N recorded significantly higher Ca uptake than all other treatments which were on par among themselves. In sandy clay loam, all the fertigation combinations were on a par.

Total calcium uptake at harvest

Among the fertigation combinations, the Ca uptake ranged from 927 to 1359 mg bag^{-1}. Fertigation of NPK recorded the highest Ca uptake which was on par with soil application of fertilisers. Fertigation of N & K was on par with half N and recorded the lowest. The individual effect of soils was not significant.

The total Ca uptake ranged from 862 to 1290 and 924 to 1609 mg bag^{-1} in loamy sand and sandy clay loam respectively. In loamy sand, the fertigation with full N, half N and NPK, were on par with soil application of fertilisers. In sandy clay loam, fertigation of NPK was on par with soil application of fertilisers and recorded the highest Ca uptake.

4.1.3.5. Magnesium uptake (Table 26)

45th day

Among the fertigation combinations, the Mg uptake ranged from 54 to 97 mg bag^{-1}, the higher uptake being in fertigation of N & K followed by soil application of fertilisers (85 mg bag^{-1}), fertigation of full N (74 mg bag^{-1}), half N (59 mg bag^{-1}) and NPK, the latter two being on par. The individual effect of soil was not significant.

The Mg uptake ranged from 51 to 106, and 49 to 87 mg bag^{-1} in loamy sand and sandy clay loam respectively. In both soils, fertigation of N & K recorded the highest Mg uptake while fertigation of NPK recorded the lowest.

Table 26. Mean effect of fertigation on **Mg uptake at stages and at harvest** by tomato

($mg\ bag^{-1}$)

Fertigation	Mg uptake by shoot					
	45th day			75th day		
	ls	scl	Mean	ls	scl	Mean
Half N	69	49	**59**	283	122	**203**
Full N	66	82	**74**	238	206	**222**
Full N & K	106	87	**97**	223	163	**193**
Full NPK	51	58	**54**	183	250	**216**
Soil appln.	84	86	**85**	181	201	**191**
Mean	**75**	**72**	-	**222**	**188**	-
	SEd	CD (0.05)		SEd	CD (0.05)	
Soil (S)	2.6	NS		4.6	9.8	
Fertig. (F)	4.1	8.5		7.4	15.5	
S x F	5.7	12.1		10.4	21.9	

	At Harvest					
	Mg uptake by fruits			Total Mg uptake		
	ls	scl	Mean	ls	scl	Mean
Half N	111	63	**87**	626	619	**622**
Full N	127	140	**134**	801	933	**867**
Full N & K	67	36	**51**	687	635	**661**
Full NPK	80	139	**109**	765	1145	**955**
Soil appln.	48	48	**48**	780	597	**689**
Mean	**87**	**85**	-	**732**	**786**	-
	SEd	CD (0.05)		SEd	CD (0.05)	
Soil (S)	11.2	NS		31.3	NS	
Fertig.(F)	17.7	36.0		49.5	100.5	
S x F	25.1	NS		70.1	142.1	

75th day

Of the two soils, loamy sand with 222 mg bag^{-1} recorded statistically higher Mg uptake than 188 mg bag^{-1} in sandy clay loam. Among the fertigation combinations, Mg uptake ranged from 191 to 222 mg bag^{-1}, the highest being in fertigation of full N which was on par with NPK. All other treatments which were on par among themselves recorded the lowest.

The Mg uptake ranged from 181 to 283 and 122 to 250 mg bag^{-1} in loamy sand and sandy clay loam respectively. In loamy sand, fertigation of half N recorded significantly higher Mg uptake while soil application of fertilisers which was on par with fertigation of NPK, recorded the least. In sandy clay loam, fertigation of NPK recorded significantly higher Mg uptake while fertigation of half N recorded the least.

Magnesium uptake by fruits

Among the fertigation combinations, Mg uptake by fruits ranged from 48 to 134 mg bag^{-1} while fertigation of full N which was on par with NPK, recorded the highest Mg uptake. Soil application of fertilisers which was on par with fertigation of N & K recorded the lowest Mg uptake by fruits. The individual effect of soils was not significant.

The interaction effect of fertigation with soils was also not significant.

Total Mg uptake at harvest

The highest total Mg uptake was recorded in fertigation of NPK (955 mg bag $^{-1}$) which was on par with full N (867 mg bag^{-1}), both being significantly different from other treatments which were on par among themselves. The individual effect of soil was not significant.

The total Mg uptake ranged from 626 to 801 and 597 to 1145 mg bag^{-1} in loamy sand and sandy clay loam respectively. In loamy sand, fertigation of full N recorded the highest Mg uptake which was on par with soil application of fertilisers and fertigation of NPK. In sandy clay loam, fertigation of NPK recorded significantly higher Mg uptake followed by full N and rest of the treatments which were on par among themselves.

4.2. FIELD EXPERIMENTS

Two field experiments were conducted during June - September 1988 and January - April 1989 to study the effect of different levels of trickle irrigation and methods of N application (Soil application vs. fertigation) on changes in soil chemical properties, yield and nutrient uptake by tomato. The results obtained in the study are summarised below.

4.2.1. Effect of Irrigation Levels and Methods of N Application on Soil Chemical Properties

4.2.1.1. Soil reaction (pH) (Tables 27 and 28)

Among the irrigation levels, soil pH varied from 8.15 to 8.28 and 8.10 to 8.16 in post-harvest soils of experiment I and II respectively. In experiment I, trickle irrigation at the rate of 4 L $d^{-1}e^{-1}$ (denoted as 4 L) recorded significantly higher pH followed by 2 L $d^{-1}e^{-1}$ (2 L) while 4 L (alt.) $d^{-1}e^{-1}$ (4 L alt.) recorded, significantly lower soil pH. In experiment II, trickle irrigation at 4 L recorded significantly higher soil pH than 4 L (alt.).

In experiment I, the soil reaction of post-harvest soil from CO 3 grown plots was significantly higher than that of Rupali grown plots. In experiment II, no significant difference was observed between varieties.

In both experiments, soil application of N recorded higher pH than fertigation of N.

Among the different distances from the emitter, soil pH varied from 8.19 to 8.27 and 8.06 to 8.16 in experiments I and II (Fig. 9) respectively. In experiment I, just below the emitter soil pH was significantly higher than 15 and 30 cm away perpendicularly from the emitter and

Table 27. Mean effect of irrigation levels and methods of N application on **soil reaction (pH)** of post-harvest soil (Experiment I)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	8.30	8.29	8.26	**8.28**	8.31	8.26
2 L	8.23	8.23	8.23	**8.23**	8.29	8.16
4 L (alt.)	8.18	8.15	8.12	**8.15**	8.16	8.14
Mean	**8.24**	**8.22**	**8.20**	-	**8.25**	**8.19**

	Distance from emitter (cm)				Depth (cm)	
	0	15.0	22.5	30.0	0-15	15-30
4 L	8.33	8.28	8.26	8.26	8.28	8.28
2 L	8.27	8.18	8.24	8.21	8.21	8.24
4 L (alt.)	8.20	8.10	8.13	8.16	8.14	8.16
Mean	**8.27**	**8.19**	**8.21**	**8.21**	**8.21**	**8.23**

Distance(cm)	Depth (cm) 0-15	Depth (cm) 15-30		SEd	CD(0.05)
0	8.29	8.26	Irrigation (I)	0.014	0.027
15.0	8.17	8.21	N appln. (N)	0.014	0.027
22.5	8.23	8.20	Varieties (V)	0.011	0.022
30.0	8.17	8.25	Distance (D)	0.016	0.031
			Depth (d)	0.011	NS
			I x N	0.024	NS
			D x d	0.022	0.044

Table 28. Mean effect of irrigation levels and methods of N application on **soil reaction (pH)** of post-harvest soil (Experiment II)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	8.18	8.11	8.19	**8.16**	8.16	8.16
2 L	8.16	8.13	8.09	**8.13**	8.15	8.10
4 L (alt.)	8.13	8.08	8.08	**8.10**	8.11	8.10
Mean	**8.16**	**8.11**	**8.12**	-	**8.14**	**8.12**

($d^{-1}e^{-1}$)	Distance from emitter (cm)				Depth (cm)	
	0	15.0	22.5	30.0	0-15	15-30
4 L	8.17	8.14	8.18	8.16	8.13	8.19
2 L	8.13	8.07	8.15	8.15	8.10	8.15
4 L (alt.)	8.11	7.98	8.15	8.14	8.06	8.14
Mean	**8.14**	**8.06**	**8.16**	**8.15**	**8.10**	**8.16**

Distance(cm)	Depth (cm)			SEd	CD(0.05)
	0-15	15-30			
0	8.10	8.18	Irrigation (I)	0.019	0.038
15.0	8.00	8.12	N appln. (N)	0.019	0.038
22.5	8.16	8.16	Varieties (V)	0.016	NS
30.0	8.12	8.18	Distance (D)	0.022	0.044
			Depth (d)	0.016	0.031
			I x N	0.033	NS
			D x d	0.031	NS

22.5 cm away along the lateral, the latter three being on a par. In experiment II, soil pH was significantly lower at 15 cm perpendicularly away from the emitter than other treatments which were on a par.

Between the two depths of sampling, in experiment II, subsurface soil recorded significantly higher pH (8.16) than surface soil (8.10). In experiment I, the effect was not significant.

The interaction effect of irrigation levels and methods of N application was not significant in both experiments.

In experiment I, in the surface soil, at just below the emitter, the soil pH was significantly higher while it was lowest at 15 or 30 cm away perpendicularly from the emitter. In subsurface soil, the soil pH at just below the emitter was on par with 30 cm away from the emitter and recorded significantly higher pH than 15 cm away perpendicularly or 22.5 cm away along the lateral, the latter two were on par and recorded the lower pH. In experiment II, the interaction effect of depth of sampling and distance from the emitter was not significant.

4.2.1.2. Soluble salt concentration

4.2.1.2.1. Electrical conductivity (EC) of soil (Tables 29 and 30)

In experiment I, among the irrigation levels, EC of soil varied from 0.68 to 0.85 dS m^{-1}. Trickle irrigation at 4 L (alt.) recorded significantly higher EC than other two daily irrigation levels which were on a par. In experiment II, the effect of irrigation levels on EC was not significant.

In experiment I, the EC of the post-harvest soils of Rupali grown plots was significantly higher than CO 3 grown plots. The effect of varieties in experiment II on EC of soil was not significant.

In both experiments, the effect of methods of N application on soil EC was not significant.

Among the distances from emitter, EC varied from 0.65 to 0.81 and 0.60 to 0.82 dS m^{-1} (Fig. 9) in experiments I and II respectively. In experiment I, at 30 cm perpendicularly away from the emitter, EC was significantly higher while the lowest EC was recorded at just below the emitter. In experiment II, at 15 cm perpendicularly away from the emitter, EC was significantly higher. The EC at 30 cm away perpendicularly was on par

Table 29. Mean effect of irrigation levels and methods of N application on **soluble salt concentration (EC)** of post harvest soil (Experiment I)

(dS m^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application N_1	N_2	N_3	Mean	Varieties CO 3	Rupali
4 L	0.68	0.68	0.70	**0.68**	0.64	0.73
2 L	0.79	0.68	0.71	**0.73**	0.68	0.77
4 L (alt.)	0.76	0.90	0.88	**0.85**	0.80	0.89
Mean	**0.74**	**0.75**	**0.76**	-	**0.71**	**0.80**

	Distance from emitter (cm) 0	15.0	22.5	30.0	Depth (cm) 0-15	15-30
4 L	0.61	0.69	0.72	0.73	0.70	0.67
2 L	0.66	0.70	0.71	0.84	0.75	0.70
4 L (alt.)	0.67	0.91	0.95	0.86	0.90	0.79
Mean	**0.65**	**0.77**	**0.79**	**0.81**	**0.79**	**0.72**

Distance(cm)	Depth (cm) 0-15	15-30		SEd	CD(0.05)
0	0.61	0.69	Irrigation (I)	0.031	0.062
15.0	0.81	0.72	N appln. (N)	0.032	NS
22.5	0.78	0.81	Varieties (V)	0.026	0.051
30.0	0.95	0.66	Distance (D)	0.036	0.072
			Depth (d)	0.026	0.051
			I x N	0.055	0.109
			D x d	0.052	0.102

Table 30. Mean effect of irrigation levels and methods of N application on **soluble salt concentration (EC)** of post harvest soil (Experiment II)

($dS\ m^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	0.68	0.71	0.59	**0.66**	0.62	0.70
2 L	0.71	0.63	0.69	**0.68**	0.72	0.63
4 L (alt.)	0.74	0.68	0.70	**0.71**	0.70	0.72
Mean	**0.71**	**0.67**	**0.66**	-	**0.68**	**0.68**

	Distance from emitter (cm)				Depth (cm)	
	0	15.0	22.5	30.0	0-15	15-30
4 L	0.58	0.75	0.69	0.63	0.72	0.60
2 L	0.60	0.77	0.72	0.62	0.73	0.62
4 L (alt.)	0.62	0.94	0.68	0.59	0.75	0.67
Mean	**0.60**	**0.82**	**0.70**	**0.61**	**0.74**	**0.63**

Distance(cm)	Depth (cm)			SEd	CD(0.05)
	0-15	15-30			
0	0.62	0.57	Irrigation (I)	0.033	NS
15.0	0.95	0.69	N appln. (N)	0.033	NS
22.5	0.71	0.69	Varieties (V)	0.027	NS
30.0	0.67	0.56	Distance (D)	0.038	0.076
			Depth (d)	0.027	0.054
			I x N	0.058	NS
			D x d	0.054	0.107

with that just below the emitter and recorded the lowest EC of soil.

In both experiments, surface soil recorded significantly higher EC than subsurface soil.

Due to the interaction effect of irrigation levels and methods of N application, in experiment I trickle irrigation at 4 L (alt.) with N_2 (30 kg N ha^{-1} through soil + 120 kg N ha^{-1} through fertigation) and N_3 (100 kg N ha^{-1} through soil + 120 kg N ha^{-1} through fertigation), both being on par recorded higher EC than other treatment combinations. In experiment II, the above effect was not significant.

The interaction between distances from the emitter and depths of sampling followed the same trend as that of EC recorded at different distances from the emitter.

4.2.1.2.2. Water soluble cations (Tables 31 and 32)

Water soluble Ca content of soil at different distances from the emitter varied from 0.44 to 0.53 and 0.37 to 0.49 c. mol (P^{+}) kg^{-1} in experiments I and II respectively. In experiment I, at 22.5 cm away along the lateral and in experiment II, at 15 cm perpendicularly away from the emitter, water soluble Ca content was

Table 31. Mean effect of irrigation levels and methods of N application on **Water soluble Ca, Mg, K and Na** content of post-harvest soil (Experiment I)

(c. mol. (p^+) kg^{-1})

Distance from emitter (cm)	Depth (cm) 0-15	Depth (cm) 15-30	Mean	Depth (cm) 0-15	Depth (cm) 15-30	Mean
	Water soluble Ca			**Water soluble Mg**		
0	0.44	0.44	**0.44**	0.26	0.22	**0.24**
15.0	0.52	0.43	**0.47**	0.25	0.25	**0.25**
22.5	0.53	0.53	**0.53**	0.27	0.22	**0.25**
30.0	0.57	0.35	**0.46**	0.29	0.22	**0.26**
Mean	**0.52**	**0.44**	-	**0.27**	**0.23**	-
	Water soluble K			**Water soluble Na**		
0	0.06	0.08	**0.07**	0.60	0.69	**0.64**
15.0	0.11	0.09	**0.10**	0.74	0.73	**0.73**
22.5	0.11	0.10	**0.11**	0.85	0.90	**0.87**
30.0	0.12	0.08	**0.10**	0.84	0.66	**0.75**
Mean	**0.10**	**0.09**	-	**0.75**	**0.74**	

	W.S. Ca SEd	**W.S. Ca** CD	**W.S. Mg** SEd	**W.S. Mg** CD	**W.S. K** SEd	**W.S. K** CD	**W.S. Na** SEd	**W.S. Na** CD
Dist -ance(D)	0.024	0.048	0.026	NS	0.006	0.013	0.024	0.048
Depth(d)	0.017	0.034	0.019	NS	0.005	0.009	0.017	NS
D x d	0.034	0.067	0.037	NS	0.009	0.018	0.034	0.068

CD at P(0.05)

Table 32. Mean effect of irrigation levels and methods of N application on **Water soluble Ca, Mg, K and Na** content of post-harvest soil (Experiment II)

(c. mol. (p^+) kg^{-1})

Distance from emitter(cm)	Depth (cm) 0-15	Depth (cm) 15-30	Mean	Depth (cm) 0-15	Depth (cm) 15-30	Mean
	Water soluble Ca			**Water soluble Mg**		
0	0.39	0.34	**0.37**	0.33	0.21	**0.27**
15.0	0.59	0.40	**0.49**	0.76	0.26	**0.51**
22.5	0.40	0.36	**0.38**	0.28	0.25	**0.26**
30.0	0.43	0.31	**0.37**	0.29	0.25	**0.27**
Mean	**0.46**	**0.35**	-	**0.41**	**0.24**	-
	Water soluble K			**Water soluble Na**		
0	0.14	0.10	**0.12**	0.77	0.70	**0.73**
15.0	0.16	0.12	**0.14**	0.70	0.67	**0.69**
22.5	0.13	0.12	**0.13**	0.83	0.79	**0.81**
30.0	0.13	0.10	**0.12**	0.65	0.68	**0.66**
Mean	**0.14**	**0.11**	-	**0.74**	**0.71**	

	W.S.Ca SEd	**W.S.Ca** CD	**W.S.Mg** SEd	**W.S.Mg** CD	**W.S.K** SEd	**W.S.K** CD	**W.S.Na** SEd	**W.S.Na** CD
Distance(D)	0.035	0.069	0.062	0.12	0.015	NS	0.044	.087
Depth (d)	0.025	0.049	0.044	0.09	0.011	0.02	0.031	NS
D x d	0.049	0.098	0.087	0.17	0.021	0.04	0.062	NS

CD at P(0.05)

4.2.1.2.3. Water soluble anions (Table 33)

The water soluble HCO_3 content of soil varied from 1.27 to 1.53 and 1.31 to 1.50 c.mol(P^-)kg^{-1} in experiments I and II respectively. In both experiments, at 30 cm perpendicularly away from the emitter, the water soluble HCO_3 content was higher than other distances from the emitter. In experiment I, the water soluble HCO_3 content was significantly higher at subsurface soil than surface soil while in experiment II, it was not significant.

The water soluble Cl content varied from 0.39 to 0.54 and 0.51 to 0.66 c.mol(P^-)kg^{-1} in experiments I and II respectively. In both experiments, the higher water soluble Cl content was recorded at 22.5 cm away along the lateral while it was lower at just below the emitter.

4.2.1.3. Ammoniacal-nitrogen (NH_4-N) content of soil (Tables 34 and 35)

In experiment II, among the irrigation levels NH_4-N content varied from 38 to 46 ppm while trickle irrigation at 4 L recorded significantly higher NH_4-N content than other two irrigation levels which were on a par. In experiment I the above effect was not significant.

In experiment II, among different methods of N application NH_4-N content varied from 36 to 44 ppm. Soil

Table 33. Mean effect of irrigation levels and methods of N application on **Water soluble HCO_3 and Cl** content of post-harvest soils of Experiments I and II

(c. mol. (p^-) kg^{-1})

Distance from emitter(cm)	Depth (cm) 0-15	Depth (cm) 15-30	Mean	Depth (cm) 0-15	Depth (cm) 15-30	Mean
	Water soluble HCO_3			**Water soluble Cl**		
			Experiment I			
0	1.44	1.26	**1.35**	0.37	0.41	**0.39**
15.0	1.19	1.36	**1.27**	0.48	0.47	**0.47**
22.5	1.34	1.30	**1.32**	0.52	0.55	**0.54**
30.0	1.22	1.86	**1.53**	**0.54**	**0.46**	**0.50**
Mean	**1.30**	**1.44**	-	**0.48**	**0.47**	-
			Experiment II			
0	1.28	1.34	**1.31**	0.53	0.55	**0.54**
15.0	1.46	1.39	**1.42**	0.60	0.60	**0.60**
22.5	1.58	1.40	**1.49**	0.66	0.65	**0.66**
30.0	1.28	1.72	1.50	0.53	0.49	**0.51**
Mean	**1.40**	**1.46**	-	**0.58**	**0.57**	

	Experiment I				**Experiment II**			
	W.S.HCO_3		**W.S.Cl**		**W.S.HCO_3**		**W.S.Cl**	
	SEd	CD	SEd	CD	SEd	CD	SEd	CD
Distance(D)	0.050	0.095	0.020	0.040	0.070	0.132	0.030	0.06
Depth (d)	0.034	0.067	0.015	NS	0.050	NS	0.020	NS
D x d	0.068	0.135	0.029	0.058	0.090	0.190	0.040	NS

CD at P(0.05)

Table 34. Mean effect of irrigation levels and methods of N application on NH_4-N content of post-harvest soil (Experiment I)

(ppm)

Irrigation ($d^{-1}e^{-1}$)	N application N_1	N_2	N_3	Mean	Varieties CO 3	Rupali
4 L	92	43	49	**61**	62	60
2 L	59	44	47	**50**	42	58
4 L (alt.)	71	50	47	**56**	60	53
Mean	**74**	**46**	**48**	**-**	**55**	**57**

	Distance from emitter (cm) 0	15.0	22.5	30.0	Depth (cm) 0-15	15-30
4 L	56	64	70	55	64	58
2 L	46	54	57	42	54	45
4 L (alt.)	62	61	52	50	56	57
Mean	**55**	**60**	**60**	**49**	**58**	**54**

Distance(cm)	Depth (cm) 0-15	15-30		SEd	CD(0.05)
0	57	52	Irrigation (I)	5.4	NS
15.0	56	63	N appln. (N)	5.4	10.7
22.5	67	53	Varieties (V)	4.4	NS
30.0	52	46	Distance (D)	6.2	NS
			Depth (d)	4.4	NS
			I x N	9.4	NS
			D x d	8.8	NS

Table 35. Mean effect of irrigation levels and methods of N application on **NH_4-N content** of post-harvest soil (Experiment II)

(ppm)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		*CO 1*	*CO 3*
4 L	58	47	34	**46**	35	57
2 L	35	41	37	**38**	33	42
4 L (alt.)	40	41	38	**40**	41	38
Mean	**44**	**43**	**36**	**-**	**36**	**46**

	Distance from emitter (cm)				Depth (cm)	
	0	15.0	22.5	30.0	0-15	15-30
4 L	46	54	46	39	49	43
2 L	39	37	38	36	39	36
4 L (alt.)	40	41	39	39	39	40
Mean	**42**	**44**	**41**	**38**	**43**	**40**

Distance(cm)	Depth (cm) 0-15	Depth (cm) 15-30
0	43	40
15.0	46	42
22.5	41	40
30.0	40	36

	SEd	CD(0.05)
Irrigation (I)	1.86	3.70
N appln. (N)	1.86	3.70
Varieties (V)	1.52	3.01
Distance (D)	2.15	NS
Depth (d)	1.52	3.01
I x N	3.22	6.40
D x d	*3.04*	*NS*

application of N(N_1) recorded significantly higher NH_4-N content than fertigation of N(N_3). In experiment I the effect was not significant.

Between the two varieties, CO 3 grown plots had significantly higher NH_4-N content than CO 1 grown plots. There was no significant difference between CO_3 and Rupali grown plots.

The main effect of distances of sampling from emitter was not significant in both experiments.

Of the two depths, surface soil recorded higher NH_4-N content than subsurface soil in experiment I. The above effect was not significant in experiment II.

Comparing the interaction effect of irrigation levels with methods of N application, in experiment II, trickle irrigation at 4 L with N_1 (soil application of N) recorded higher NH_4-N content followed by combination of N_2 (30 kg N ha^{-1} through soil + 120 kg N ha^{-1} through fertigation) with all the three levels of trickle irrigation, the latter three being on a par. In experiment I, the above effect was not significant.

The interaction effect of distances from emitter and depths of sampling was not significant in both experiments.

4.2.1.4. Nitrate-nitrogen (NO_3-N) content of soil (Tables 36 and 37)

In both experiments, the effect of irrigation levels and varieties on NO_3-N content of soil were not significant.

Among the different methods of N application, NO_3-N content varied from 3.8 to 6.0 and 3.2 to 7.3 ppm in experiments I and II respectively. In both the experiments, fertigation of N recorded higher NO_3-N content than soil application of N.

Comparing the distances from emitter, NO_3-N content varied from 3.9 to 6.5 and 4.3 to 7.5 ppm in experiments I and II respectively. Highest NO_3-N content was recorded in experiment I, at 22.5 cm away along the lateral and this was on par with 30 cm perpendicularly away from the emitter. In experiment II, highest NO_3-N content was recorded at just below the emitter.

Between the depths, in experiment II, surface soil recorded significantly higher NO_3-N content than subsurface soil. In experiment I, the effect of depths of sampling on NO_3-N content was not significant.

In the interaction effect of irrigation levels with methods of N application, in both experiments, trickle

Table 36. Mean effect of irrigation levels and methods of N application on **NO_3-N content** of post-harvest soil (Experiments I)

(ppm)

Irrigation ($d^{-1}e^{-1}$)	N application N_1	N_2	N_3	Mean	Varieties CO 3	Rupali
4 L	3.7	3.7	5.2	**4.2**	4.2	4.2
2 L	3.9	5.1	5.3	**4.8**	5.3	4.2
4 L (alt.)	3.8	9.1	4.4	**5.8**	4.3	7.2
Mean	**3.8**	**6.0**	**5.0**	-	**4.6**	**5.2**

	Distance from emitter (cm) 0	15.0	22.5	30.0	Depth (cm) 0-15	15-30
4 L	3.2	2.6	5.6	5.4	4.2	4.2
2 L	4.1	4.0	5.0	6.0	5.5	4.0
4 L (alt.)	4.9	5.0	9.1	4.1	5.9	5.7
Mean	**4.1**	**3.9**	**6.5**	**5.2**	**5.2**	**4.6**

Distance(cm)	Depth (cm) 0-15	15-30		SEd	CD(0.05)
0	4.1	4.0	Irrigation (I)	0.76	NS
15.0	4.3	3.5	N appln. (N)	0.76	1.51
22.5	4.8	8.3	Varieties (V)	0.62	NS
30.0	7.6	2.7	Distance (D)	0.88	1.74
			Depth (d)	0.62	NS
			I x N	1.32	2.62
			D x d	1.24	2.47

Table 37. Mean effect of irrigation levels and methods of N application on NO_3-N of post-harvest soil (Experiment II)

(ppm)

Irrigation ($d^{-1}e^{-1}$)	N application N_1	N_2	N_3	Mean	Varieties CO 1	CO 3
4 L	3.2	6.7	5.4	**5.1**	4.2	6.0
2 L	3.9	4.6	7.8	**5.4**	6.6	4.3
4 L (alt.)	2.4	7.3	8.7	**6.1**	5.9	6.3
Mean	**3.2**	**6.2**	**7.3**	-	**5.6**	**5.5**

	Distance from emitter (cm) 0	15.0	22.5	30.0	Depth (cm) 0-15	15-30
4 L	6.0	4.9	4.5	4.9	7.0	3.2
2 L	7.7	4.9	5.2	4.1	7.0	3.9
4 L (alt.)	8.6	7.1	4.9	3.8	7.2	5.1
Mean	**7.5**	**5.6**	**4.9**	**4.3**	**7.1**	**4.0**

Distance (cm)	Depth (cm) 0-15	15-30		SEd	CD(0.05)
0	9.8	5.1	Irrigation (I)	0.80	NS
15.0	6.2	5.1	N appln. (N)	0.80	1.58
22.5	6.1	3.6	Varieties (V)	0.65	NS
30.0	6.1	2.4	Distance (D)	0.92	1.83
			Depth (d)	0.65	1.39
			I x N	1.38	NS
			D x d	1.30	NS

irrigation at 4 L (alt.) with N_2 (30 kg N ha^{-1} through soil + 120 kg N ha^{-1} through fertigation) recorded higher NO_3-N content. In general, the treatment combinations where N was applied both through soil + fertigation with different trickle irrigation rates recorded higher NO_3-N content than combinations of trickle irrigation with soil application of N.

In the interaction effect of distance from emitter and depth of sampling, in surface soil, at 30 cm perpendicularly away from the emitter and in subsurface soil at 22.5 cm away along the lateral, the NO_3-N content was higher than other treatments which were on par among themselves.

4.2.1.5.Sodium bicarbonate extractable phosphorus($NaHCO_3$-P) (Tables 38 and 39)

In experiment I, the effect of irrigation levels, and methods of N application on $NaHCO_3$-P content of soil was not significant. In experiment II, the $NaHCO_3$-P content varied from 4.9 to 5.6 and 5.1 to 5.8 ppm in different trickle irrigation levels and different methods of N application respectively. Among the irrigation levels, trickle irrigation at 2 L or 4 L (alt.) which were on par themselves, recorded significantly higher $NaHCO_3$-P than 4 L. Among different methods of N application, fertigation of

Table 38. Mean effect of irrigation levels and methods of N application on $NaHCO_3$-P of post-harvest soil (Experiment I)

(ppm)

Irrigation ($d^{-1}e^{-1}$)	N application N_1	N_2	N_3	Mean	Varieties CO 3	Rupali
4 L	9.3	9.6	8.1	**9.0**	9.2	8.9
2 L	9.8	8.7	9.0	**9.2**	8.6	9.7
4 L (alt.)	9.2	9.5	10.3	**9.7**	8.4	11.0
Mean	**9.5**	**9.3**	**9.1**	-	**8.7**	**9.9**

	Distance from emitter (cm) 0	15.0	22.5	30.0	Depth (cm) 0-15	15-30
4 L	8.9	9.4	9.7	8.1	10.0	8.0
2 L	9.3	9.3	10.0	8.0	10.2	8.1
4 L (alt.)	9.1	11.1	9.9	8.6	11.1	8.2
Mean	**9.1**	**9.9**	**9.9**	**8.2**	**10.5**	**8.1**

Distance(cm)	Depth (cm) 0-15	15-30		SEd	CD(0.05)
0	9.8	8.5	Irrigation (I)	0.37	NS
15.0	11.2	8.7	N appln. (N)	0.37	NS
22.5	10.7	9.0	Varieties (V)	0.31	0.61
30.0	10.1	6.3	Distance (D)	0.43	0.86
			Depth (d)	0.30	0.61
			I x N	0.65	1.39
			D x d	0.61	1.21

Table 39. Mean effect of irrigation levels and methods of N application on $NaHCO_3$- P content of post-harvest soil (Experiment II)

(ppm)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	4.5	4.8	5.3	**4.9**	4.7	5.1
2 L	5.4	5.7	5.8	**5.6**	6.6	4.7
4 L (alt.)	5.3	5.3	6.1	**5.5**	5.0	6.1
Mean	**5.1**	**5.3**	**5.8**	-	**5.4**	**5.3**

	Distance from emitter (cm)				Depth (cm)	
	0	15.0	22.5	30.0	0-15	15-30
4 L	4.5	4.9	5.1	5.0	5.2	4.6
2 L	4.9	6.9	5.8	5.0	6.3	5.0
4 L (alt.)	4.9	6.6	5.8	4.9	6.2	4.9
Mean	**4.8**	**6.1**	**5.6**	**4.9**	**5.9**	**4.8**

Distance(cm)	Depth (cm) 0-15	15-30		SEd	CD(0.05)
0	4.9	4.7	Irrigation (I)	0.27	0.53
15.0	7.4	4.9	N appln. (N)	0.27	0.53
22.5	6.1	5.0	Varieties (V)	0.22	NS
30.0	5.1	4.7	Distance (D)	0.31	0.61
			Depth (d)	0.22	0.43
			I x N	0.46	NS
			D x d	0.44	0.87

N at 120 kg ha^{-1} (N_3) recorded higher $NaHCO_3$-P than soil application of N at 150 kg ha^{-1} (N_1).

The $NaHCO_3$-P content of Rupali grown plot was significantly higher (9.9 ppm) than CO 3 (8.7 ppm) grown plots while there was no significant difference between CO 1 and CO 3 grown plots.

In experiment I, $NaHCO_3$-P at the distances, 15 cm perpendicularly away (9.9 ppm), 22.5 cm away along the lateral (9.9 ppm) and just below the emitter (9.1 ppm) were on par among themselves and recorded significantly higher $NaHCO_3$-P than 30 cm perpendicularly away (8.2 ppm) from the emitter. In experiment II, both distances 15 cm perpendicularly away (6.1 ppm) and 22.5 cm away along the lateral were on par among themselves, and recorded significantly higher $NaHCO_3$-P than both 30 cm perpendicularly away and just below the emitter (4.8 ppm), the latter two being on a par.

In both experiments, surface soil recorded significantly higher $NaHCO_3$-P than subsurface soil.

In the interaction effect of irrigation levels and methods of N application, $NaHCO_3$-P varied from 8.1 to 10.3 ppm in experiment I. The trend was inconsistent. The above effect was not significant in experiment II.

In the interaction effect of distance from emitter and depth of sampling, in both experiments, surface soil, at 15 cm perpendicularly away from emitter higher $NaHCO_3$-P was recorded followed by 22.5 cm away along the lateral and at 30 cm perpendicularly away from the emitter. At just below the emitter lower $NaHCO_3$-P was observed. In subsurface soil, in both experiments, lower $NaHCO_3$-P was observed at 30 cm perpendicularly away from the emitter than other distances which were on par among themselves.

4.2.1.6. Ammonium acetate extractable potassium (NH_4OAc-K) (Tables 40 and 41)

In experiment I, the NH_4OAc-K content varied from 378 to 421 ppm. Trickle irrigation at 4 L (alt.) or 2 L which were on par recorded significantly higher NH_4OAc-K than daily trickle irrigation at 4 L while in experiment II the effect was not significant.

Among the methods of N application , NH_4OAc-K varied from 387 to 444 and 398 to 442 ppm in experiments I and II respectively. In both experiments, soil application of N (N_1) recorded significantly higher NH_4OAc-K than both levels of fertigation of N which were on par among themselves.

Table 40. Mean effect of irrigation levels and methods of N application on NH_4OAc-K content of post-harvest soil (Experiment I)

(ppm)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	404	389	340	**378**	364	392
2 L	483	361	420	**421**	463	379
4 L (alt.)	447	411	406	421	404	439
Mean	**444**	**387**	**388**	-	**410**	**403**

	Distance from emitter (cm)				Depth (cm)	
	0	15.0	22.5	30.0	0-15	15-30
4 L	314	411	395	391	396	359
2 L	342	440	491	412	441	401
4 L (alt.)	345	445	463	431	437	405
Mean	**333**	**431**	**449**	411	**425**	**388**

Distance(cm)	Depth (cm) 0-15	15-30
0	302	365
15.0	444	420
22.5	471	428
30.0	482	340

	SEd	CD(0.05)
Irrigation (I)	14.7	29.3
N appln. (N)	14.7	29.3
Varieties (V)	12.1	NS
Distance (D)	17.1	33.8
Depth (d)	12.1	23.9
I x N	25.6	50.8
D x d	24.1	47.9

Table 41. Mean effect of irrigation levels and methods of N application on NH_4OAc- K content ofpost-harvest soil (Experiment II)

(ppm)

Irrigation ($d^{-1}e^{-1}$)	N application N_1	N_2	N_3	Mean	Varieties CO 1	CO 3
4 L	448	392	382	**407**	376	439
2 L	456	433	388	**425**	444	407
4 L (alt.)	424	370	454	**416**	428	404
Mean	**442**	**398**	**408**	-	**416**	**416**

	Distance from emitter (cm) 0	15.0	22.5	30.0	Depth (cm) 0-15	15-30
4 L	308	455	429	437	418	396
2 L	331	493	422	455	442	409
4 L (alt.)	342	438	448	438	441	391
Mean	**327**	**462**	**433**	**443**	**434**	**399**

Distance(cm)	Depth (cm) 0-15	15-30		SEd	CD(0.05)
0	272	381	Irrigation (I)	16.7	NS
15.0	509	415	N appln. (N)	16.7	33.1
22.5	443	421	Varieties (V)	13.6	NS
30.0	510	376	Distance (D)	19.3	38.2
			Depth (d)	13.6	27.0
			I x N	28.9	57.3
			D x d	27.3	54.0

In both experiments, growing different varieties of tomato had no significant influence on NH_4OAc-K.

Comparing the distances from the emitter, NH_4OAc-K varied from 333 to 449 and 327 to 462 ppm in experiments I (Fig.10) and II (Fig.11) respectively. In both experiments, the NH_4OAc-K was significantly lower at just below the emitter than other distances which were on par among themselves.

Between the two depths, surface soil recorded significantly higher NH_4OAc-K than subsurface soil in both experiments.

In the interaction effect of irrigation levels with methods of N application, NH_4OAc-K varied from 340 to 483 and 370 to 456 ppm in experiments I and II respectively. In general, trickle irrigation at 2 L or 4 L (alt.) in combination with all methods of N application recorded higher NH_4OAc-K than other combinations in both experiments.

In both experiments, in surface soil higher NH_4OAc-K was observed at 30 and 15 cm perpendicularly away from the emitter. At just below the emitter, NH_4OAc-K content was significantly lower than other distances. In subsurface soil, at 22.5 cm away along the lateral and 15 cm away perpendicularly from the emitter which were on par among themselves recorded higher NH_4OAc-K than either at just below the emitter or 30 cm perpendicularly away, the latter two being on a par.

4.2.2. Effect of Irrigation levels and Methods of N Application an Shoot, Fruit yield and Total dry matter Production of Tomato

4.2.2.1. Shoot yield (Tables 42 and 43)

Among the different trickle irrigation levels, the shoot yields of tomato varied from 10.9 to 13.6 and 6.6 to 7.3 t ha^{-1} in experiments I and II respectively. In experiment I, trickle irrigation at 4 L (13.6 t ha^{-1}) or 2 L (13.0 t ha^{-1}) which were on par recorded significantly higher shoot yield than trickle irrigation at 4L (alt.) (10.9 t ha^{-1}). In experiment II, trickle irrigation at 2 L (7.2 t ha^{-1}) or 4 L (alt.) (7.3 t ha^{-1}) which were on par recorded significantly higher shoot yield than 4 L (6.6 t ha^{-1}).

Among the methods of N application, in experiment II, the shoot yield varied from 6.6 to 7.6 t ha^{-1}. The

Table 42. Mean effect of irrigation levels and methods of N application on **Shoot Yield** of tomato (Experiment I)

($t\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	14.0	14.8	11.9	**13.6**	11.2	15.9
2 L	13.7	11.6	13.7	**13.0**	10.2	15.8
4 L (alt.)	10.7	10.5	11.5	**10.9**	10.1	11.7
Mean	**12.8**	**12.3**	**12.4**	-	**10.5**	**14.5**

Varieties	N_1	N_2	N_3
CO 3	10.7	10.3	10.4
Rupali	14.9	14.3	14.3

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.42	1.0	V at I	0.44	1.0
N appln. (N)	0.42	NS	V at N	0.44	NS
I x N	0.72	1.7	I at V	0.52	1.2
Varieties (V)	0.26	0.6	N at V	0.52	NS

Table 43. Mean effect of irrigation levels and methods of N application on **Shoot Yield** of tomato (Experiment II)

($t\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	6.4	6.8	6.6	**6.6**	5.4	7.8
2 L	5.6	8.7	7.3	**7.2**	6.9	7.5
4 L (alt.)	7.8	7.2	6.9	**7.3**	6.8	7.9
Mean	**6.6**	**7.6**	**6.9**	-	**6.4**	**7.7**

Varieties	N_1	N_2	N_3
CO 1	5.8	6.9	6.5
CO 3	7.5	8.3	7.4

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.20	0.5	V at I	0.28	0.6
N appln. (N)	0.20	0.5	V at N	0.28	NS
I x N	0.36	0.8	I at V	0.29	0.7
Varieties (V)	0.16	0.4	N at V	0.29	NS

treatment (N_2) (30 kg N ha^{-1} through soil + 120 kg N ha^{-1} through fertigation) recorded higher shoot yield than application of full dose of N through soil (N_1). In experiment I, the effect of different methods of N application was not significant.

Comparing the different varieties of tomato, in experiment I, Rupali recorded significantly higher shoot yield (14.5 t ha^{-1}) than CO 3 (10.5 t ha^{-1}) and in experiment II CO 3 recorded significantly higher shoot yield (7.7 t ha^{-1}) than CO 1 (6.4 t ha^{-1}).

In the interaction effect of trickle irrigation levels and methods of N application, in experiment I, the four combinations viz., daily trickle irrigation at 4 L with N_1 or N_2 and daily trickle irrigation at 2 L with N_1 or N_3 (100 kg N ha^{-1} through soil + 120 kg N ha^{-1} through fertigation) were on par and recorded significantly higher shoot yield of tomato. All the three combinations of trickle irrigation at 4 L (alt.) with different methods of N application were on par among themselves and recorded lower shoot yield of tomato. In experiment II, daily trickle irrigation at 2 L with N_2 recorded significantly higher shoot yield than rest of the treatments.

In both experiments the interaction effect of irrigation levels with CO 3 was not significant. For Rupali, daily trickle irrigation either at 4L or 2 L, both being on par, recorded significantly higher shoot yield than trickle irrigation at 4 L (alt.). For CO 1, trickle irrigation at 2 L or 4 L (alt.), were on par, and recorded higher shoot yield than 4 L. In both experiments, the interaction effect of methods of N application with varieties was not significant.

4.2.2.2. Fruit yield of tomato (Tables 44 and 45)

In experiment I, daily trickle irrigation at 4 L recorded significantly higher fruit yield (40.5 t ha^{-1}) than 4 L (alt.) which was on par (33.5 t ha^{-1}) with 2 L rate of trickle irrigation (32.5 t ha^{-1}). In experiment II, daily trickle irrigation at 2 L was on par with 4 L and recorded higher fruit yield (20.1 t ha^{-1}). Trickle irrigation at 4 L (alt.) which was on par with daily trickle irrigation at 4 L recorded the lowest fruit yield (18.3 t ha^{-1}).

Among the methods of N application, the fruit yield varied from 33.1 to 37.8 and 16.5 to 22.1 t ha^{-1} in

Table 44. Mean effect of irrigation levels and methods of N application on **Fruit Yield** of tomato (Experiment I)

(t ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application N_1	N_2	N_3	Mean	Varieties CO 3	Rupali
4 L	45.6	36.0	40.0	**40.5**	48.0	33.0
2 L	35.6	30.4	31.5	**32.5**	38.3	26.6
4 L (alt.)	32.3	32.9	35.2	**33.5**	40.4	26.6
Mean	**37.8**	**33.1**	**35.6**	-	**42.2**	**28.7**

Varieties	N_1	N_2	N_3
CO 3	46.5	38.4	41.9
Rupali	29.2	27.8	29.3

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	1.7	3.9	V at I	1.9	NS
N appln. (N)	1.7	3.9	V at N	1.9	NS
I x N	3.0	NS	I at V	2.2	NS
Varieties (V)	1.1	2.4	N at V	2.2	NS

Table 45. Mean effect of irrigation levels and methods of N application on **Fruit Yield** of tomato (Experiment II)

($t\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	16.5	22.7	19.3	**19.5**	21.5	17.5
2 L	16.0	22.2	22.1	**20.1**	22.2	18.0
4 L (alt.)	16.9	21.4	16.5	**18.3**	19.2	17.3
Mean	**16.5**	**22.1**	**19.3**	-	**21.0**	**17.6**

Varieties	N_1	N_2	N_3
CO 1	18.3	23.7	21.0
CO 3	14.6	20.4	17.7

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.54	1.3	V at I	0.44	1.0
N appln. (N)	0.54	1.3	V at N	0.44	NS
I x N	0.94	2.2	I at V	0.62	1.4
Varieties (V)	0.25	0.6	N at V	0.62	NS

Table 45. Mean effect of irrigation levels and methods of N application on **Fruit Yield** of tomato (Experiment II)

($t\ ha^{-1}$)

Irrigation ($d^{-1} e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	16.5	22.7	19.3	**19.5**	21.5	17.5
2 L	16.0	22.2	22.1	**20.1**	22.2	18.0
4 L (alt.)	16.9	21.4	16.5	**18.3**	19.2	17.3
Mean	**16.5**	**22.1**	**19.3**	-	**21.0**	**17.6**

Varieties	N_1	N_2	N_3
CO 1	18.3	23.7	21.0
CO 3	14.6	20.4	17.7

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.54	1.3	V at I	0.44	1.0
N appln. (N)	0.54	1.3	V at N	0.44	NS
I x N	0.94	2.2	I at V	0.62	1.4
Varieties (V)	0.25	0.6	N at V	0.62	NS

levels of trickle irrigation, being on par with each other, recorded significantly lower tomato fruit yield (Fig.12).

In experiment II, for CO 1, daily trickle irrigation either at 2 L or 4 L, were on par and recorded significantly higher tomato fruit yield than trickle irrigation at 4 L(alt.). For CO 3, the effect of different levels of trickle irrigation tried were not significant. In experiment I, the above effect was not significant.

In both experiments, the interaction effect of methods of N application with varieties were not significant.

4.2.2.3. Total biomass production at harvest (Tables 46 and 47)

In experiment I, the total biomass production of tomato at harvest varied from 44.4 to 54.1 t ha^{-1} among the different trickle irrigation levels. Daily trickle irrigation at 4 L recorded significantly higher total biomass production than other two levels of trickle irrigation which were on a par. In experiment II, the above effect was not significant.

Table 46. Mean effect of irrigation levels and methods of N application on **Total biomass production** of tomato (Experiment I)

(t ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	56.9	50.8	51.9	**54.1**	59.2	48.9
2 L	49.3	42.0	45.2	**45.5**	48.5	42.4
4 L (alt.)	43.0	43.4	46.7	**44.4**	50.5	38.3
Mean	**50.6**	**45.4**	**48.0**	-	**52.7**	**43.2**

Varieties	N_1	N_2	N_3
CO 3	57.2	48.7	52.3
Rupali	44.1	42.1	43.6

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	1.73	4.0	V at I	1.50	3.3
N appln. (N)	1.73	NS	V at N	1.50	NS
I x N	3.10	NS	I at V	2.07	4.7
Varieties (V)	0.81	2.0	N at V	2.07	NS

Table 47. Mean effect of irrigation levels and methods of N application on **Total biomass production** of tomato (Experiment II)

($t\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	22.9	29.5	25.9	**26.1**	26.9	25.3
2 L	21.6	30.9	29.4	**27.3**	29.1	25.5
4 L (alt.)	24.7	28.6	23.4	**25.6**	26.0	25.2
Mean	**23.1**	**29.7**	**26.2**	-	**27.3**	**25.3**

Varieties	N_1	N_2	N_3
CO 1	24.1	30.6	27.5
CO 3	22.1	28.7	25.1

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.58	NS	V at I	0.58	1.2
N appln. (N)	0.58	1.2	V at N	0.58	NS
I x N	0.92	2.3	I at V	0.69	1.30
Varieties (V)	0.35	NS	N at V	0.69	NS

Comparing the different methods of N application, in experiment II, the total biomass production varied from 23.1 to 29.7 t ha^{-1}. The treatment N_2 recorded significantly higher total biomass production followed by N_3 and N_1. *In experiment I, the effect of methods of* N application was not significant.

Inexperiment I, CO 3 recorded significantly higher total biomass production (52.7 t ha^{-1}) than Rupali (43.2 t ha^{-1}). In experiment II, there was no significant difference between CO 1 and CO 3.

In the interaction effect of irrigation levels with methods of N application, the total biomass production at harvest varied from 42.0 to 59.6 and 21.6 to 36.9 t ha^{-1} in experiments I and II respectively. In experiment II, daily trickle irrigation at 2 L with N_2 recorded significantly higher total biomass production followed by other combinations. In experiment I, the above interaction effect was not significant.

In experiment I, for CO 3, daily trickle irrigation at 4 L recorded significantly higher total biomass production than other two levels of trickle irrigation which were on par among themselves. In experiment II, for CO 3 the interaction effect with irrigation levels was not significant. For Rupali, daily trickle irrigation at 4 L recorded significantly higher total biomass production followed by 2 L and 4 L(alt.) in that order. For CO 1, daily trickle irrigation at 2 L gave significantly higher total biomass production than 4 L or 4 L(alt.), the latter two were on par with each other.

In both experiments, the interaction effect of methods of N application with varieties were not significant.

4.2.3. Effect of Irrigation Levels and Methods of N Application on Nutrient Uptake by Tomato at Harvest

4.2.3.1. Nitrogen

Nitrogen uptake by tomato fruits (Tables 48 and 49)

Among the different trickle irrigation levels, the N uptake by tomato fruits varied from 58 to 73 and 37 to 43 kg ha^{-1} in experiment I and II respectively. In experiment I, daily trickle irrigation at 4 L recorded significantly higher N uptake by fruits (73 kg ha^{-1}) than the other two rates of trickle irrigation [61 and 58 kg ha^{-1} for 4 L (alt.) and 2 L respectively] which were on a par. In experiment II, daily trickle irrigation at 2 L (43 kg ha^{-1})

Table 48. Mean effect of irrigation levels and methods of N application on **N uptake by fruits** of tomato (Experiment I)

($kg\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	80	67	72	**73**	81	66
2 L	57	56	62	**58**	65	51
4 L (alt.)	58	61	65	**61**	67	55
Mean	**65**	**61**	**66**	**-**	**71**	**57**

Varieties	N_1	N_2	N_3
CO 3	73	66	73
Rupali	57	56	59

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	2.6	6.0	V at I	3.7	NS
N appln. (N)	2.6	NS	V at N	3.7	NS
I x N	4.5	NS	I at V	3.7	NS
Varieties (V)	2.1	5.0	N at V	3.7	NS

Table 49. Mean effect of irrigation levels and methods of N application on **N uptake by fruits** of tomato (Experiment II)

($kg\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	31	47	43	**40**	43	37
2 L	31	49	49	**43**	44	42
4 L (alt.)	33	45	32	**37**	38	36
Mean	**31**	**47**	**41**	**-**	**42**	**38**

Varieties	N_1	N_2	N_3
CO 1	31	51	43
CO 3	32	43	38

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	1.63	4.0	V at I	1.44	NS
N appln. (N)	1.63	4.0	V at N	1.44	3.0
I x N	2.82	7.0	I at V	1.92	NS
Varieties (V)	0.83	2.0	N at V	1.92	4.0

which was on par with 4 L (40 kg ha^{-1}) recorded higher N uptake by fruits than 4 L (alt.) (37 kg ha^{-1}). The latter two treatments were also on a par.

Comparing the methods of N application, in experiment II, the treatment N_2 recorded significantly higher N uptake by fruits (47 kg ha^{-1}) than N_3 (41 kg ha^{-1}). While N_1 recorded significantly lower N uptake by fruits (31 kg ha^{-1}) but in experiment I, the effect of methods of N application was not significant.

Between the two varieties of tomato, in experiment I, CO 3 recorded significantly higher N uptake by fruits (71 kg ha^{-1}) than Rupali (57 kg ha^{-1}) and in experiment II, CO 1 recorded significantly higher N uptake by fruits (42 kg ha^{-1}) than CO 3 (38 kg ha^{-1}).

In experiment II, in the interaction effect of irrigation levels and methods of N application, N uptake by fruits varied from 31 to 49 kg ha^{-1}. But the trend was inconsistent. The above effect was not significant in experiment I.

Between CO 1 and CO 3, N_2 recorded significantly higher N uptake by fruits than N_3 while N_1 recorded significantly lower N uptake by fruits but this difference was not marked between CO 3 and Rupali in experiment I.

The interaction effect of irrigation levels with varieties was not significant in both experiments.

Total nitrogen uptake at harvest (Tables 50 and 51)

Comparing the different trickle irrigation levels, in experiment I, total N uptake by tomato varied from 96 to 111 kg ha^{-1}. Daily trickle irrigation at 4 L recorded significantly higher total N uptake (111 kg ha^{-1}) than other two levels of trickle irrigation (100 and 96 kg ha^{-1} at 2 L and 4 L (alt.) respectively which were on a par. In experiment II, the different trickle irrigation levels were not significantly different.

The treatment N_2 recorded significantly higher total N uptake (68 kg ha^{-1}) than N_3. However N_1 recorded significantly lower total N uptake (49 kg ha^{-1}) in experiment II, but this effect could not be observed in experiment I.

There was no significant difference in total N uptake by different varieties of tomato tested in both experiments.

Table 50. Mean effect of irrigation levels and methods of N application on **Total N uptake** by tomato at harvest (Experiment I)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	119	108	106	**111**	113	109
2 L	101	94	104	**100**	102	97
4 L (alt.)	93	92	104	**96**	99	93
Mean	**104**	**98**	**105**	-	**105**	**100**

Varieties	N_1	N_2	N_3
CO 3	110	100	105
Rupali	99	96	105

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	3.8	9.0	V at I	4.5	NS
N appln. (N)	3.8	NS	V at N	4.5	NS
I x N	6.6	NS	I at V	5.0	NS
Varieties (V)	2.6	NS	N at V	5.0	NS

Table 51. Mean effect of irrigation levels and methods of N application on **Total N uptake** by tomato at harvest (Experiment II)

($kg\ ha^{-1}$)

Irrigation	N application			Mean	Varieties	
($d^{-1}e^{-1}$)	N_1	N_2	N_3		CO 1	CO 3
4 L	48	66	62	**59**	59	59
2 L	46	73	68	**62**	62	62
4 L (alt.)	54	65	53	**57**	57	58
Mean	**49**	**68**	**61**	-	59	60

Varieties	N_1	N_2	N_3
CO 1	46	70	61
CO 3	52	67	61

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	2.27	NS	V at I	1.56	NS
N appln. (N)	2.27	5.0	V at N	1.56	4.0
I x N	3.93	9.0	I at V	2.52	NS
Varieties (V)	0.90	NS	N at V	2.52	6.0

In experiment II, in the interaction effect of irrigation levels with methods of N application, trickle irrigation at 2 L with N_2 recorded higher total N uptake while the above levels of N with trickle irrigation at 4 L recorded the lower total N uptake. But in experiment I, this interaction was not significant.

In experiment II, the interaction effect of methods of N application with varieties was significant. In both varieties similar trend was observed as N_2 recorded higher total N uptake followed by N_3 and N_1 which recorded the lower N uptake. In CO 1, all the treatments were significantly different while in CO 3, N_2 was on par with N_3 and both were significantly higher than N_1. The above effect was not significant in experiment I.

In both experiments, the interaction effect of different irrigation levels with varieties were not significant.

4.2.3.2. Phosphorus

Phosphorus uptake by tomato fruits (Tables 52 and 53)

In both experiments, the effects of different levels of trickle irrigation on P uptake by tomato fruits were not significant.

Table 52. Mean effect of irrigation levels and methods of N application on P **uptake by fruits** of tomato (Experiment I)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	19.2	17.7	19.0	**18.6**	20.8	16.5
2 L	18.0	15.9	14.4	**16.1**	17.6	14.6
4 L (alt.)	14.2	17.5	16.6	**16.1**	16.6	15.5
Mean	**17.1**	**17.0**	**16.6**	-	**18.3**	**15.5**

Varieties	N_1	N_2	N_3
CO 3	19.3	18.7	17.0
Rupali	15.0	15.4	16.3

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	1.06	NS	V at I	1.28	NS
N appln. (N)	1.06	NS	V at N	1.28	NS
I x N	1.84	NS	I at V	1.39	NS
Varieties (V)	0.74	1.7	N at V	1.39	NS

Table 53. Mean effect of irrigation levels and methods of N application on **P uptake by fruits** of tomato (Experiment II)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	6.3	11.2	9.5	**9.0**	9.2	8.9
2 L	7.7	9.8	8.9	**8.8**	8.7	8.9
4 L (alt.)	7.6	11.5	7.4	**8.8**	9.2	8.5
Mean	**7.2**	**10.8**	8.6	-	**9.0**	**8.7**

Varieties	N_1	N_2	N_3
CO 1	7.1	10.9	9.1
CO 3	7.3	10.8	8.1

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.38	NS	V at I	0.66	NS
N appln. (N)	0.38	0.9	V at N	0.66	NS
I x N	0.65	1.5	I at V	0.60	NS
Varieties (V)	0.38	NS	N at V	0.60	NS

In experiment II, among the methods of N application, the treatment N_2 recorded significantly higher P uptake by fruits (10.8 kg ha^{-1}) than N_3 (8.6 kg ha^{-1}) while N_1 recorded significantly lower P uptake by fruits (7.2 kg ha^{-1}) . In experiment I, the effect was not significant.

The variety CO 3 recorded significantly higher P uptake by fruits (18.3 kg ha^{-1}) than Rupali (15.5 kg ha^{-1}). Between CO 1 and CO 3, there was no significant difference in P uptake by fruits in experiment II.

In the interaction effect of irrigation levels and methods of N application the P uptake by fruits varied from 6.3 to 11.5 kg ha^{-1} and this showed an inconsistent trend in experiment II while it was not significant in experiment I.

In both experiments the interaction effects of irrigation levels and methods of N application with varieties were not significant.

Total phosphorus uptake at harvest (Tables 54 and 55)

In both experiments, the effects of different levels of trickle irrigation on total P uptake were not significant.

Table 54. Mean effect of irrigation levels and methods of N application on **Total P uptake** by tomato at harvest (Experiment I)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	22.6	22.3	22.6	**22.5**	25.7	19.3
2 L	21.6	19.3	17.8	**19.6**	21.0	18.1
4 L (alt.)	17.4	21.0	19.9	**19.4**	19.6	19.2
Mean	20.5	**20.9**	**20.1**	-	**22.1**	**18.9**

Varieties	N_1	N_2	N_3
CO 3	23.1	22.7	20.6
Rupali	18.0	19.0	19.6

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	1.19	NS	V at I	1.47	NS
N appln. (N)	1.19	NS	V at N	1.47	NS
I x N	2.06	NS	I at V	1.58	NS
Varieties (V)	0.85	1.9	N at V	1.58	NS

Table 55. Mean effect of irrigation levels and methods of N application on **Total P uptake** by tomato at harvest (Experiment II)

($kg\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	7.5	12.8	11.3	**10.5**	11.0	10.1
2 L	8.9	11.8	10.3	**10.3**	10.3	10.3
4 L (alt.)	8.8	12.8	8.5	**10.0**	10.3	9.8
Mean	**8.4**	**12.5**	10.0	-	**10.5**	**10.1**

Varieties	N_1	N_2	N_3
CO 1	8.3	12.7	10.6
CO 3	8.5	12.2	9.5

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.38	NS	V at I	0.65	NS
N appln. (N)	0.38	0.9	V at N	0.65	NS
I x N	0.66	1.5	I at V	0.59	NS
Varieties (V)	0.37	NS	N at V	0.59	NS

In experiment II, among the different methods of N application, the total P uptake varied from 8.4 to 12.5 kg ha^{-1}. The treatment N_2 recorded significantly higher P uptake (12.5 kg ha^{-1}) than N_3 (10.0 kg ha^{-1}) while N_1 (8.4 kg ha^{-1}) recorded significantly lower total P uptake but this effect was not significant in experiment I.

Between varieties, CO 3 recorded significantly higher total P uptake (22.1 kg ha^{-1}) than Rupali (18.9 kg ha^{-1}) while it was not significantly different between CO 1 and CO 3 in experiment II.

As in the case of P uptake by fruits, though total P uptake was significant in experiment II due to the interaction of irrigations levels and methods of N application the trend was inconsistent. The above effect was not significant in experiment I.

In both experiments, the interaction effects of irrigation levels and methods of N application with varieties were not significant.

4.2.3.3. Potassium

Potassium uptake by fruits (Tables 56 and 57)

Among the different levels of trickle irrigation, K uptake by tomato fruits varied from 69 to 84 and 40 to 52

Table 56. Mean effect of irrigation levels and methods of N application on K **uptake by fruits** of tomato (Experiment I)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	87	78	78	**81**	91	71
2 L	95	78	81	**84**	90	79
4 L (alt.)	71	64	72	**69**	72	66
Mean	**84**	**73**	**77**	-	**85**	**72**

Varieties	N_1	N_2	N_3
CO 3	95	77	82
Rupali	73	70	72

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	4.26	10.0	V at I	4.33	NS
N appln. (N)	4.26	NS	V at N	4.33	NS
I x N	7.38	NS	I at V	5.25	NS
Varieties (V)	2.50	6.0	N at V	5.25	NS

Table 57. Mean effect of irrigation levels and methods of N application on **K uptake by fruits** of tomato (Experiment II)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	41	66	49	**52**	65	39
2 L	42	58	57	**52**	60	45
4 L (alt.)	37	48	34	**40**	46	33
Mean	**40**	**57**	**47**	-	**57**	**39**

Varieties	N_1	N_2	N_3
CO 1	46	70	55
CO 3	34	44	38

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	1.64	4.0	V at I	1.99	5.0
N appln. (N)	1.64	4.0	V at N	1.99	5.0
I x N	2.84	7.0	I at V	2.16	5.0
Varieties (V)	1.15	3.0	N at V	2.16	5.0

kg ha^{-1} in experiment I and II respectively. In both the experiments, daily trickle irrigation either at 4 L or 2 L which were on par among themselves, recorded significantly higher K uptake by fruits than trickle irrigation at 4 L (alt.).

The influence of different methods of N application on K uptake by fruits could not be observed in experiment I while in experiment II, N_2 recorded significantly higher K uptake by fruits (57 kg ha^{-1}) than N_3 (47 kg ha^{-1}) while N_1 recorded significantly lower K uptake by fruits (40 kg ha^{-1}).

In experiment I, CO 3 recorded significantly higher K uptake by fruits (85 kg ha^{-1}) than Rupali (72 kg ha^{-1}) while in experiment II, CO 1 recorded significantly higher K uptake by fruits (57 kg ha^{-1}) than CO 3 (39 kg ha^{-1}).

In the interaction effect of irrigation levels and methods of N application, in experiment II trickle irrigation at 4 L with N_2 recorded significantly higher K uptake by fruits followed by trickle irrigation at 2 L with N_2 or N_3, the latter two being on a par. In experiment I, the above effect was not significant.

In experiment II, in the interaction effect of irrigation levels with varieties, in CO 1, trickle irrigation at 4 L or 2 L, both being on par recorded significantly higher K uptake by fruits than trickle irrigation at 4 L(alt.). In CO 3, all the irrigation levels were significantly different, the order of higher K uptake by fruits being 2 L followed by 4 L and 4 L(alt.). The above interaction was not significant in experiment I.

In the interaction effect of methods of N application with varieties, in both varieties, N_2 recorded significantly higher total K uptake by fruits followed by N_3 and N_1 The above interaction was not significant in experiment I.

Total potassium uptake at harvest (Tables 58 and 59)

The total K uptake among the different trickle irrigation levels varied from 101 to 127 and 51 to 64 kg ha^{-1} in experiments I and II respectively. In both experiments, as in the case of K uptake by tomato fruits, daily trickle irrigation at either 4 L or 2 L were on par with each other and recorded significantly higher total K uptake than trickle irrigation at 4 L (alt.).

Table 58. Mean effect of irrigation levels and methods of N application on **Total K uptake** by tomato at harvest (Experiment I)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	124	125	104	**118**	127	109
2 L	142	114	124	**127**	122	131
4 L (alt.)	103	96	105	**101**	108	94
Mean	**123**	**112**	**111**	-	**119**	**112**

Varieties	N_1	N_2	N_3
CO 3	130	114	114
Rupali	116	110	108

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	5.9	14.0	V at I	6.2	14.0
N appln. (N)	5.9	NS	V at N	6.2	NS
I x N	10.2	NS	I at V	7.3	17.0
Varieties (V)	3.6	NS	N at V	7.3	NS

Table 59. Effect of irrigation levels and methods of N application on **Total K uptake** by tomato at harvest (Experiment II)

($kg\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	51	78	62	**64**	75	53
2 L	52	71	69	**64**	73	55
4 L (alt.)	50	59	45	**51**	59	44
Mean	**51**	**70**	**59**	**-**	**69**	**51**

Varieties	N_1	N_2	N_3
CO 1	56	83	70
CO 3	46	57	50

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	1.98	5.0	V at I	1.80	4.0
N appln. (N)	1.98	5.0	V at N	1.80	4.0
I x N	3.44	8.0	I at V	2.35	5.0
Varieties (V)	1.04	2.0	N at V	2.35	5.0

In experiment II, the total K uptake among the different methods of N application varied from 51 to 70 kg ha^{-1}. The treatment (N_2) recorded significantly higher total K uptake (70 kg ha^{-1}) than N_3 (59 kg ha^{-1}) and N_1 recorded significantly lower total K uptake (51 kg ha^{-1}. In experiment I, the effect was not significant.

Between varieties, CO 1 recorded significantly higher total K uptake (69 kg ha^{-1}) than CO 3 (51 kg ha^{-1}) while the total K uptake was not significantly different between CO 3 and Rupali in experiment I.

In the interaction effect of irrigation levels with methods of N application in experiment II, trickle irrigation at 2 L with N_2 was on par with N_3 and trickle irrigation at 4 L with N_2, and recorded significantly higher total K uptake. In experiment I, the effect was not significant.

The interaction effect of irrigation levels with varieties was significant in both the experiments. In both experiments for CO 3, daily trickle irrigation at 2 L was on par with 4 L and recorded significantly higher total K uptake than trickle irrigation at 4 L(alt.). In case of CO 1, the same trend as that of CO 3 was observed. For Rupali, daily trickle irrigation at 2 L recorded significantly higher total K uptake than 4 L or 4 L(alt.), the latter two being on a par.

In experiment II, the interaction effect of methods of N application with varieties indicated that in both varieties, N_2 recorded significantly higher total K uptake followed by N_3 and N_1. In experiment I, the above effect was not significant.

4.2.3.4. Calcium

Calcium uptake by tomato fruits (Tables 60 and 61)

Among the different trickle irrigation levels, in experiment I, Ca uptake by fruits varied from 11.0 to 14.6 kg ha^{-1}. Daily trickle irrigation at 4 L recorded significantly higher Ca uptake by fruits (14.6 kg ha^{-1}) than trickle irrigation at 4 L (alt.) (13.0 kg ha^{-1}) while daily trickle irrigation at 2 L recorded significantly lower Ca uptake by fruits (11.0 kg ha^{-1}) and the effect was not significant in experiment II.

Comparing the different methods of N application, the Ca uptake by fruits varied from 11.3 to 13.9 and 5.8 to 8.6 kg ha^{-1} in experiments I and II

Table 60. Mean effect of irrigation levels and methods of N application on **Ca uptake by fruits** of tomato (Experiment I)

($kg\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	12.8	15.2	15.7	**14.6**	14.5	14.6
2 L	10.1	11.5	11.4	**11.0**	11.2	10.6
4 L (alt.)	10.8	13.5	14.6	**13.0**	14.3	11.7
Mean	**11.3**	**13.4**	**13.9**	-	**13.4**	**12.3**

Varieties	N_1	N_2	N_3
CO 3	12.6	13.4	14.2
Rupali	9.8	13.4	13.6

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.53	1.2	V at I	0.79	NS
N appln. (N)	0.53	1.2	V at N	0.79	NS
I x N	0.92	2.1	I at V	0.77	NS
Varieties (V)	0.46	1.0	N at V	0.77	NS

Table 61. Mean effect of irrigation levels and methods of N application on **Ca uptake by fruits** of tomato (Experiment II)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	5.8	9.5	7.2	**7.5**	8.9	6.1
2 L	5.4	7.2	7.6	**6.7**	7.6	5.9
4 L (alt.)	6.3	9.1	6.8	**7.4**	8.6	6.2
Mean	**5.8**	**8.6**	**7.2**	-	**8.4**	**6.0**

Varieties	N_1	N_2	N_3
CO 1	7.1	10.5	7.6
CO 3	4.6	6.7	6.8

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.51	NS	V at I	1.1	NS
N appln. (N)	0.51	1.2	V at N	1.1	NS
I x N	0.88	NS	I at V	0.9	NS
Varieties (V)	0.64	1.4	N at V	0.9	NS

respectively. In experiment I, N_3 (13.9 kg ha^{-1}) was on par with N_2 (13.4 kg ha^{-1}) and recorded significantly higher Ca uptake by fruits than N_1 (11.3 kg ha^{-1}). In experiment II, the treatment N_2 recorded significantly higher Ca uptake by fruits (8.6 kg ha^{-1}) than N_3 (7.2 kg ha^{-1}) while N_1 recorded significantly lowest Ca uptake by fruits (5.8 kg ha^{-1}).

In experiment I, CO 3 recorded significantly higher Ca uptake by fruit (13.4 kg ha^{-1}) than Rupali (12.3 kg ha^{-1}) and in experiment II, CO 1 recorded significantly higher Ca uptake by fruits (8.4 kg ha^{-1}) than CO 3 (6.0 kg ha^{-1}).

In experiment I, in the interaction effect of irrigation levels and methods of N application, Ca uptake by fruits varied from 10.1 to 15.7 kg ha^{-1}. But the trend was inconsistent. In experiment II, the above effect was not significant.

In both experiments, the individual interaction effect of irrigation levels and methods of N application with varieties were not significant.

Total calcium uptake at harvest (Tables 62 and 63)

Among the different trickle irrigation levels, total Ca uptake varied from 74.1 to 93.7 and 27.7 to 31.2

Table 62. Mean effect of irrigation levels and methods of N application on **Total Ca uptake** by tomato at harvest (Experiment I)

($kg\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	91.6	101.1	88.5	**93.7**	73.2	114.3
2 L	74.6	82.8	90.3	**82.6**	67.5	97.7
4 L (alt.)	66.1	70.6	85.6	**74.1**	72.6	75.6
Mean	**77.4**	**84.8**	**88.1**	-	**71.1**	**95.9**

Varieties	N_1	N_2	N_3
CO 3	70.8	68.3	74.1
Rupali	84.0	101.4	102.2

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	4.71	10.9	V at I	4.93	11.2
N appln. (N)	4.71	NS	V at N	4.93	11.2
I x N	8.16	NS	I at V	5.86	13.4
Varieties (V)	2.84	6.4	N at V	5.86	13.4

Table 63. Mean effect of irrigation levels and methods of N application on **Total Ca uptake** by tomato at harvest (Experiment II)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application N_1	N_2	N_3	Mean	Varieties CO 1	CO 3
4 L	27.0	32.2	28.8	**29.3**	27.0	31.6
2 L	21.0	42.2	30.5	**31.2**	31.5	31.0
4 L (alt.)	28.1	28.2	26.9	**27.7**	28.1	27.3
Mean	**25.3**	**34.2**	**28.7**	-	**28.8**	**30.0**

Varieties	N_1	N_2	N_3
CO 1	25.5	33.2	27.8
CO 3	25.2	35.2	29.6

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.79	1.8	V at I	2.54	NS
N appln. (N)	0.79	1.8	V at N	2.54	NS
I x N	1.37	3.2	I at V	1.97	NS
Varieties (V)	1.47	NS	N at V	1.97	NS

kg ha^{-1} in experiments I and II respectively. In experiment I, daily trickle irrigation at 4 L recorded significantly higher total Ca uptake (93.7 kg ha^{-1}) than other two levels of trickle irrigation which were on a par [82.6 and 74.1 kg ha^{-1} in 2 L and 4 L (alt.) respectively]. In experiment II, daily trickle irrigation at 2 L recorded significantly higher total Ca uptake (31.2 kg ha^{-1}) than daily trickle irrigation at 4 L (29.3 kg ha^{-1}). Trickle irrigation at 4 L(alt.) recorded significantly lower total Ca uptake (27.7 kg ha^{-1}).

In experiment II, the treatment N_2 recorded significantly higher total Ca uptake (34.2 kg ha^{-1}) than N_3 (28.7 kg ha^{-1}) while N_1 recorded significantly lower total Ca uptake (25.3 kg ha^{-1}). The effect was not significant in experiment I.

In experiment I, Rupali recorded significantly higher total Ca uptake (95.9 kg ha^{-1}) than CO 3 (71.0 kg ha^{-1}) but in experiment II the difference between CO 1 and CO 3 was not statistically different.

In experiment II, comparing the interaction effect of irrigation levels with methods of N application, trickle irrigation at 2 L with N_2 recorded significantly higher total Ca uptake. But trickle irrigation at same level with N_1 recorded the lowest total Ca uptake. The effect was not significant in experiment I.

In case of Rupali variety trickle irrigation at 4 L recorded significantly higher total Ca uptake followed by 2 L and 4 L (alt.), in that order, while in CO 3, the effect was not significant. In experiment II also the effect was not significant.

Due to the interaction effect of methods of N application, in case of Rupali, N_3 on par with N_2 and recorded significantly higher total Ca uptake than N_1. This effect was not significant for CO 3 in experiment I and for both varieties in experiment II.

4.2.3.5. Magnesium

Magnesium uptake by tomato fruits (Tables 64 and 65)

The effect of different levels of trickle irrigation on Mg uptake by tomato fruits was significant in both the experiments. In experiment I, daily trickle irrigation at 4 L on par with 2 L recorded significantly higher Mg uptake by fruits (4.8 kg ha^{-1}) than trickle irrigation at 4 L (alt.) (2.7 kg ha^{-1}). In experiment II,

Table 64. Mean effect of irrigation levels and methods of N application on **Mg uptake by fruits** of tomato (Experiment I)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	5.3	5.4	3.8	**4.8**	4.5	5.2
2 L	4.5	5.1	4.8	**4.8**	5.1	4.5
4 L (alt.)	2.7	2.3	3.1	**2.7**	2.6	2.8
Mean	**4.2**	**4.3**	**3.9**	-	**4.0**	**4.2**

Varieties	N_1	N_2	N_3
CO 3	5.1	3.6	3.4
Rupali	3.3	4.9	4.4

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.29	0.7	V at I	0.29	0.7
N appln. (N)	0.29	NS	V at N	0.29	0.7
I x N	0.50	NS	I at V	0.36	0.8
Varieties (V)	0.16	NS	N at V	0.36	0.8

Table 65. Effect of irrigation levels and methods of N application on **Mg uptake by fruits** of tomato (Experiment II)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	1.5	2.3	1.4	**1.7**	1.7	1.7
2 L	2.1	2.1	2.1	**2.1**	1.9	2.3
4 L (alt.)	1.1	1.4	1.2	**1.2**	1.3	1.2
Mean	**1.6**	**1.9**	**1.6**	-	**1.6**	**1.7**

Varieties	N_1	N_2	N_3
CO 1	1.2	1.6	2.1
CO 3	1.8	2.2	1.1

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.13	0.3	V at I	0.16	NS
N appln. (N)	0.13	NS	V at N	0.16	0.4
I x N	0.23	NS	I at V	0.18	NS
Varieties (V)	0.09	NS	N at V	0.18	0.4

daily trickle irrigation at 2 L recorded significantly higher Mg uptake by fruits (2.1 kg ha^{-1}) than at 4 L (1.7 kg ha^{-1}) while at 4 L (alt.) recorded significantly lower Mg uptake by fruits (1.2 kg ha^{-1}).

In both experiments, the main effect of different methods of N application and different varieties on Mg uptake by fruits were not significant.

In both experiments, the interaction effect of irrigation levels and methods of N application were not significant.

In experiment I, for CO 3, trickle irrigation at 2 L followed by 4 L and for Rupali, 4 L followed by 2 L, recorded significantly higher Mg uptake by fruits. In both varieties, trickle irrigation at 4 L (alt.) recorded the lowest. The above effect was not significant in experiment II.

In the interaction effect of methods of N application with varieties, in both experiments, and in case of CO 3, N_1 recorded significantly higher Mg uptake by fruits. For Rupali, N_3 which was on par with N_2 recorded higher Mg uptake by fruits. In CO 1, N_3 recorded higher Mg uptake by fruits than other treatments which were on par among themselves. The above effect was not significant in experiment II.

Total Magnesium uptake at harvest (Tables 66 and 67)

In experiment I, both levels of daily trickle irrigation either at 2 L or 4 L were on par and recorded significantly higher total Mg uptake (35.3 kg ha^{-1}) than trickle irrigation at 4 L (alt.) (23.8 kg ha^{-1}). In experiment II, daily trickle irrigation at 2 L recorded significantly higher total Mg uptake (21.6 kg ha^{-1}) than trickle irrigation at 4 L (alt.)(20.7 kg ha^{-1}). Daily trickle irrigation at 4 L recorded significantly lower total Mg uptake (17.7 kg ha^{-1}).

Comparing the methods of N application, total Mg uptake varied from 28.8 to 33.3 and 19.0 to 21.8 kg ha^{-1} in experiment I and II respectively. In both experiments, N_2 recorded significantly higher total Mg uptake than other two methods of N application which were on a par.

Between the two varieties, in experiment I, Rupali recorded significantly higher total Mg uptake (34.3 kg ha^{-1}) than CO 3 (26.4 kg ha^{-1}) while in experiment II, CO 3

Table 66. Mean effect of irrigation levels and methods of N application on **Total Mg uptake** by tomato at harvest (Experiment I)

($kg\ ha^{-1}$)

Irrigation ($d^{-1} e^{-1}$)	N application N_1	N_2	N_3	Mean	Varieties CO 3	Rupali
4 L	32.8	37.9	25.0	**31.9**	27.7	36.2
2 L	31.5	38.4	36.0	**35.3**	32.0	38.6
4 L (alt.)	22.1	23.8	25.7	**23.8**	19.5	28.2
Mean	**28.8**	**33.3**	**28.9**	-	**26.4**	**34.3**

Varieties	N_1	N_2	N_3
CO 3	28.7	26.5	24.0
Rupali	28.9	40.2	33.8

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	1.72	4.0	V at I	3.51	NS
N appln. (N)	1.72	4.0	V at N	3.51	NS
I x N	2.98	6.9	I at V	3.02	NS
Varieties (V)	2.03	4.6	N at V	3.02	NS

Table 67. Effect of irrigation levels and methods of N application on **Total Mg uptake** by tomato at harvest (Experiment II)

($kg\ ha^{-1}$)

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	17.7	18.8	16.8	**17.7**	15.4	20.2
2 L	17.8	26.3	20.6	**21.6**	20.7	22.5
4 L (alt.)	21.6	20.2	20.2	**20.7**	18.3	23.0
Mean	**19.0**	**21.8**	**19.2**	-	**18.1**	**21.9**

Varieties	N_1	N_2	N_3
CO 1	17.1	19.7	17.6
CO 3	21.0	23.9	20.9

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.70	1.6	V at I	1.78	NS
N appln. (N)	0.70	1.6	V at N	1.78	NS
I x N	1.20	2.8	I at V	1.43	NS
Varieties (V)	1.03	2.3	N at V	1.43	NS

recorded significantly higher total Mg uptake (21.9 kg ha^{-1}) than CO.1 (18.1 kg ha^{-1}).

In both experiments, trickle irrigation at 2 L with N_2 recorded higher total Mg uptake than the other combinations.

The interaction effect of irrigation and methods of N application on varieties were not significant in both the experiments.

4.2.3.6. Sodium

Sodium uptake by tomato fruits (Tables 68 and 69)

Among the different levels of trickle irrigation, in experiment II, Na uptake by tomato fruits varied from 3.6 to 4.2 kg ha^{-1}. Trickle irrigation at 2 L recorded significantly higher Na uptake by fruits than other two levels of trickle irrigation which were on a par. In experiment I, the effect was not significant.

Comparing the different methods of N application, in experiment I, N_1 was on par with N_2 and recorded higher Na uptake by fruits (6.1 kg ha^{-1}). The latter treatment was on par with N_3 which recorded the lower Na uptake by fruits (5.4 kg ha^{-1}). In experiment II, N_2 was on par with

Table 68. Mean effect of irrigation levels and methods of N application on **Na uptake by fruits** of tomato (Experiment I)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	6.9	5.4	5.4	**5.9**	8.1	3.7
2 L	6.0	5.3	4.7	**5.3**	7.5	3.2
4 L (alt.)	5.4	6.0	6.0	**5.8**	8.3	3.3
Mean	**6.1**	**5.6**	**5.4**	-	**8.0**	**3.4**

Varieties	N_1	N_2	N_3
CO 3	8.7	7.6	7.6
Rupali	3.5	3.6	3.2

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.22	NS	V at I	0.35	NS
N appln. (N)	0.22	0.50	V at N	0.35	NS
I x N	0.38	0.90	I at V	0.33	NS
Varieties (V)	0.20	0.50	N at V	0.33	NS

Table 69. Mean effect of irrigation levels and methods of N application on **Na uptake by fruits** of tomato (Experiment II)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application N_1	N_2	N_3	Mean	Varieties CO 1	CO 3
4 L	3.3	4.2	3.9	**3.8**	4.4	3.2
2 L	3.6	4.4	4.7	**4.2**	4.6	3.9
4 L (alt.)	3.2	4.5	3.2	**3.6**	3.3	3.9
Mean	**3.3**	**4.3**	**3.9**	-	**4.1**	**3.6**

Varieties	N_1	N_2	N_3
CO 1	3.8	4.5	4.0
CO 3	2.9	4.2	3.8

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.19	0.4	V at I	0.36	0.8
N appln. (N)	0.19	0.4	V at N	0.36	NS
I x N	0.33	NS	I at V	0.32	0.7
Varieties (V)	0.21	NS	N at V	0.32	NS

N_3 and recorded significantly higher Na uptake by fruits (4.3 kg ha^{-1}) than N_1 (3.3 kg ha^{-1}).

Between varieties, CO 3 recorded significantly higher Na uptake by fruits (8.0 kg ha^{-1}) than Rupali, (3.4 kg ha^{-1}) while in experiment II, Na uptake by fruits was not significantly different between CO1 and CO3.

In experiment I, in the interaction effect of irrigation levels with methods of N application, Na uptake by fruits varied from 4.7 to 6.9 kg ha^{-1} but the trend was inconsistent while the above effect was not significant in experiment II.

Comparing the interaction effect of irrigation with varieties, in experiment II, for CO1, daily trickle irrigation at 2 L was on par with 4 L and recorded higher Na uptake by fruits than 4 L (alt.) while for CO 3, the effect was not significant. In experiment I, the interaction between irrigation levels and varieties was not significant.

In both experiments, the interaction effects of methods of N application with varieties were not significant.

Total sodium uptake at harvest (Tables 70 and 71)

Among the different levels of trickle irrigation, in experiment I, total Na uptake varied from 11.6 to 13.5 kg ha^{-1}. Daily trickle irrigation at 4 L was on par with 2 L and recorded higher total Na uptake. The latter level of trickle irrigation was on par with 4 L (alt.) and recorded the lower level of total Na uptake. In experiment II, the effect was not significant.

The effect of different methods of N application on total Na uptake was not significant in both experiments.

In experiment I, CO 3 recorded significantly higher total Na uptake (13.0 kg ha^{-1}) than Rupali (12.0 kg ha^{-1}) while in experiment II, the difference in total Na uptake by CO 1 and CO 3 was not statistically significant.

In both experiments, the interaction effects of irrigation levels with methods of N application and irrigation levels with varieties were not significant.

In experiment II, the interaction effect of methods of N application with varieties, in CO 1, N_3 recorded significantly higher total Na uptake than N_2 and N_1 which were on a par. The above effect was not significant in case of both varieties in experiment I and only in case of CO 3 in experiment II.

Table 70. Mean effect of irrigation levels and methods of N application on **Total Na uptake** by tomato at harvest (Experiment I)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 3	Rupali
4 L	14.7	13.5	12.2	**13.5**	14.0	12.9
2 L	13.1	12.0	11.8	**12.3**	12.2	12.4
4 L (alt.)	10.9	12.1	12.0	**11.6**	12.7	10.6
Mean	**12.9**	**12.5**	**12.0**	-	**13.0**	**12.0**

Varieties	N_1	N_2	N_3
CO 3	13.7	12.4	12.9
Rupali	12.1	12.6	11.1

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.56	1.30	V at I	0.56	NS
N appln. (N)	0.56	NS	V at N	0.56	NS
I x N	0.98	NS	I at V	0.69	NS
Varieties (V)	0.32	0.70	N at V	0.69	NS

Table 71. Mean effect of irrigation levels and methods of N application on **Total Na uptake** by tomato at harvest (Experiment II)

(kg ha^{-1})

Irrigation ($d^{-1}e^{-1}$)	N application			Mean	Varieties	
	N_1	N_2	N_3		CO 1	CO 3
4 L	8.0	9.2	9.7	**9.0**	8.9	9.0
2 L	8.9	10.0	11.8	**10.2**	10.8	9.6
4 L (alt.)	8.7	9.6	7.7	**8.7**	8.8	8.6
Mean	**8.5**	**9.6**	**9.7**	-	**9.5**	**9.1**

Varieties	N_1	N_2	N_3
CO 1	8.3	9.4	10.7
CO 3	8.8	9.8	8.8

	SEd	CD(0.05)		SEd	CD(0.05)
Irrigation (I)	0.65	NS	V at I	0.67	NS
N appln. (N)	0.65	NS	V at N	0.67	1.5
I x N	1.13	NS	I at V	0.80	NS
Varieties (V)	0.38	NS	N at V	0.80	1.8

DISCUSSION

CHAPTER 5

DISCUSSION

To have a sustainable effect on crop growth, many workers have pointed out that trickle irrigation should not be viewed as an irrigation system alone and it should be viewed as total nutritional as well as irrigation support system (Townsend, 1978; and Menzel and Obe, 1990). In trickle irrigation, by irrigating smaller volume of soil, the foraging area of the roots of crops is widely reduced. To replenish the water and nutrients exhausted from the root zone, a clear understanding about the soil, crop and nutrient requirement of crops at different growth stages is necessary. For that fertigation of nutrients through trickle irrigation comes in handy. Fertiliser savings to the tune of 25 to 50 per cent were reported under trickle fertigation.

In this chapter, the results obtained in the glasshouse and two field experiments are discussed.

5.1. GLASSHOUSE EXPERIMENT

The main objective of the experiment was to study the effect of fertigation of single or combinations of major nutrients versus soil application of the same on changes in soil properties, yield and nutrient uptake by tomato (Rupali-F_1 hybrid) in two texturally different soils viz., loamy sand (Typic Ustifluvent) and sandy clay loam (Typic Haplustalf). The results obtained in the above study are discussed below.

5.1.1. Effect of Fertigation on Soil Chemical Properties

5.1.1.1. Soil reaction (pH)

Soil reaction (pH) plays an important role in deciding the availability of most of the essential nutrients to plants.

From the soil pH recorded in this study at two growth stages of tomato viz., 45 DAT (Fig.3) and 75 DAT (Table 72), it was observed that fertigation with either half N or full N or N & K lowered the pH than soil application of fertilisers. Though N was applied as urea in all the above treatments, frequent application of N at weekly intervals in the fertigation of N alone or in combinations lowered the soil pH than soil application of fertilisers where N was applied in two splits viz., basal and 45 DAT. The possible reason for this could be that fertigation of N as urea led to uniform distribution of the same in the wetted volume which on further hydrolysis and volatilisation had lowered the pH. The decrease in soil pH due to fertigation of N as urea was also reported by

Haynes (1988 and 1990). At post-harvest stage (Fig.4) the effect of fertigation of N on lowering the pH was not observed, and this might be due to the reason that the fertigation of N was stopped at 77 DAT, which was more than one month prior to final harvest.

Table 72. Summary of results on the effect of fertigation on soil pH and its relationship with soil EC at different growth stages of tomato

Fertigation	Soil pH			Correlation coefficient		
	45DAT	75DAT	Post-harvest	45DAT	75DAT	Post-harvest
Half N	7.65	7.55	7.76	-0.72*	NS	-0.58**
Full N	7.64	7.67	7.78	NS	-0.60*	-0.94**
Full N & K	7.69	7.60	7.74	-0.73*	NS	-0.57**
Full NPK	**7.93**	**7.87**	**7.88**	NS	NS	-0.79**
Soil appln.	7.79	7.75	7.66	-0.76**	-0.98**	-0.67**
CD(0.05)	0.06	0.06	0.06			

But in all the stages, fertigation with NPK increased the soil pH than soil application of fertilisers and also other fertigation treatments. In fertigation of NPK treatment, P was applied as phosphoric acid (H_3PO_4) while in other treatments it was applied as single superphosphate. The absence of single super phosphate

FIG.3 EFFECT OF FERTIGATION ON SOIL pH AND EC AT 45 DAT

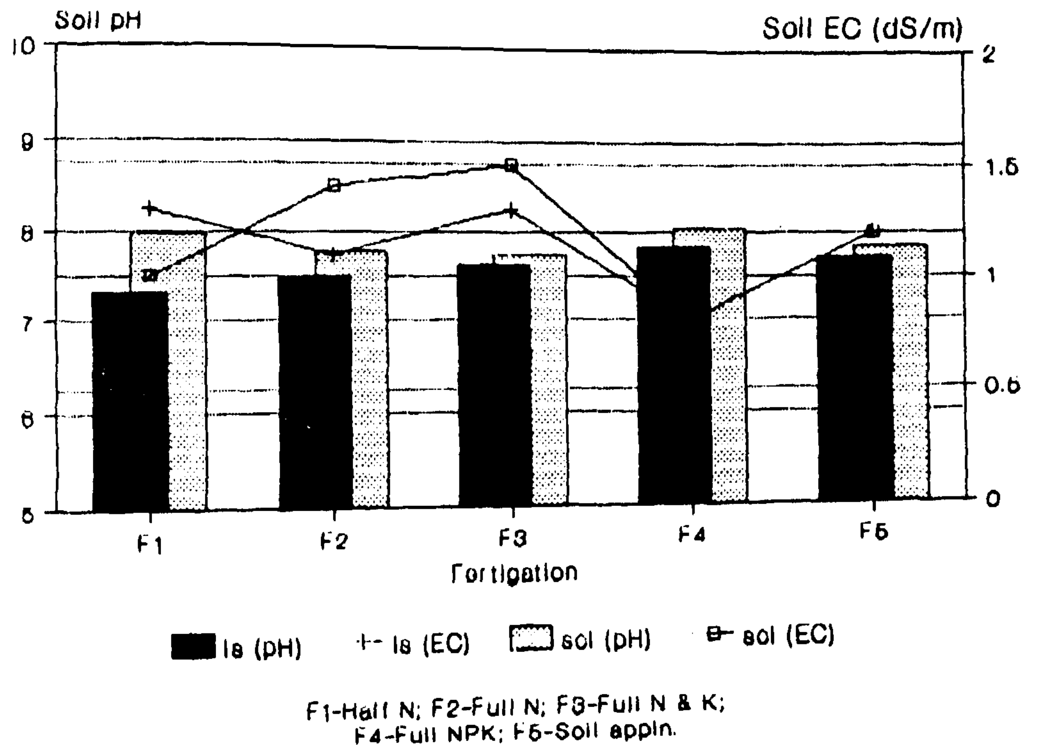
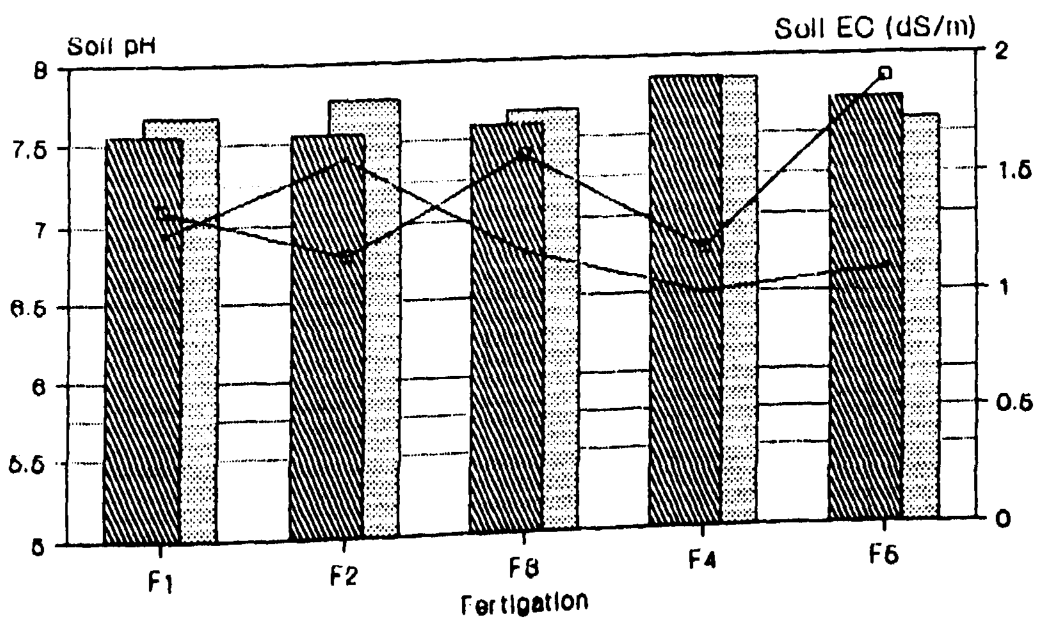


FIG.4 EFFECT OF FERTIGATION ON SOIL pH AND EC AT POST-HARVEST



increased soil EC under fertigation of N. This influence on soil EC was not marked at post-harvest, possibly due to stopping of fertigation on 77 DAT itself (Fig.4).

Table 73. Summary of results on the effect of fertigation on soluble salt concentration of soil at different growth stages of tomato

($dS\ m^{-1}$)

Fertigation	45 DAT	75 DAT	Post-harvest
Half N	1.14	1.80	1.37
Full N	1.23	1.69	1.38
Full N & K	1.38	1.41	1.39
Full NPK	0.78	1.00	1.09
Soil appln.	1.18	1.24	1.50
CD(0.05)	0.10	0.23	0.12

Contrary to the above, fertigation with full NPK lowered the soil EC in all the stages of sampling compared to soil application of fertilisers. The possible reason for this, as pointed out in the earlier discussion on soil pH, could be the use of H_3PO_4 as the source of P through irrigation water. This would have combined with Ca and Mg salts present either in the irrigation water or in the soil and would have got precipitated as Ca and Mg phosphates (Bucks *et al.*, 1982).

5.1.1.3. Ammoniacal-nitrogen content of soil (NH_4-N)

In soil, applied urea will be hydrolysed to NH_4 and subsequently will undergo nitrification under aerobic condition. In the present study, in all the three stages, fertigation with half N or full N or full NPK, recorded higher or comparable NH_4-N content with soil application of fertilisers (Table 74). Frequent applications of N alone or in combination with P & K in 10 equal splits at weekly intervals would have helped to retain more NH_4 on the soil exchange complex as compared to two split applications of N done in soil application of fertilisers.

Table 74. Summary of results on the effect of fertigation on NH_4-N and NO_3-N content of soil at different growth stages of tomato

(ppm)

Fertigation	NH_4-N			NO_3-N		
	45 DAT	75 DAT	Post-harvest	45 DAT	75 DAT	Post-harvest
Half N	53.8	46.4	59.6	16.5	19.1	12.7
Full N	48.5	47.6	57.9	17.2	20.4	21.3
Full N & K	53.2	37.7	52.8	19.8	20.2	17.7
Full NPK	53.2	44.1	56.8	13.7	20.1	17.5
Soil appln.	50.9	45.2	53.4	19.0	19.3	21.4
CD(0.05)	2.6	4.9	4.1	1.2	NS	1.3

But on both 75 DAT and post-harvest, fertigation with N & K recorded either lower or comparable NH_4-N content with soil application of fertilisers. When both N & K were fertigated, both being cations, in their competition to get adsorbed on soil exchange complex some amount of NH_4 would have been leached away compared to fertigation of N alone.

5.1.1.4. Nitrate nitrogen content of soil (NO_3-N)

The bulk of any form of N applied to the soil is likely to be transformed to NO_3-N. In the present study at both 45 DAT and post-harvest, soil NO_3-N content (Table 74) followed just the reverse trend of NH_4-N content. In general, those treatments like soil application of fertilisers which had lower NH_4-N content recorded higher NO_3-N. The possible reason might be that the soil application of fertilisers with 50 per cent of N as basal application would have resulted in higher initial concentration of N and it would have been transformed to NO_3-N. But in fertigation combination of N, frequent application of N but in small quantities would have just met the crop requirements. Rolston et al. (1979) also reported lesser nitrification under trickle irrigation as the soil was always kept relatively wet below the emitter, thus removing the oxygen which is a prerogative for nitrification.

5.1.1.5. Sodium bicarbonate extractable phosphorus ($NaHCO_3$-P)

Generally P fertilisation through trickle irrigation is not recommended due to its clogging problem and also due to its lesser mobility in the soil. But O'Neill et al. (1976) using H_3PO_4 as a source of P demonstrated distribution of P in greater soil volume than that with triple superphosphate.

In the current investigation at all stages of observation, fertigation with either half N, or full N or N & K recorded higher $NaHCO_3$-P than soil application of fertilisers. In all the above four treatments, P was applied basally as single superphosphate. But the increased availability of P in the former three fertigation treatments might be due to decrease in pH but within neutral range as compared to soil application of fertilisers or might be due to positive interaction of fertigation of N, on P availability.

In contrast to the above, at 45 and 75 DAT, fertigation with NPK recorded lower $NaHCO_3$-P than soil application of fertilisers and other fertigation

Table 75. Summary of results on the effect of fertigation on $NaHCO_3$-P content of soil at different growth stages of tomato

(ppm)

Fertigation	45 DAT	75 DAT	Post-harvest
Half N	18.2	17.5	6.7
Full N	18.1	16.0	11.3
Full N & K	16.3	12.7	10.7
Full NPK	10.5	7.1	9.5
Soil appln.	13.6	10.5	7.5
CD (0.05)	1.0	3.1	0.8

treatments. As pointed out earlier, this might be due to the change in the source of P and frequent application of the same. Thus at 45 and 75 DAT, only 50 and 90 per cent of P would have been added compared to full basal application in other treatments. This split application of P would have led to lower $NaHCO_3$-P at both 45 and 75 DAT. This reason was found to be correct as $NaHCO_3$-P at post-harvest soil in fertigation of NPK treatment was found to be higher than soil application of fertilisers.

For most of the crops as P is needed in the early phase of growth for root proliferation, fertigation of P in still higher frequency at the early stage of crop growth can be considered.

5.1.1.6. Ammonium acetate extractable potassium (NH_4OAc-K)

Most of the workers have detected considerable lateral and downward movement of trickle applied K. But the extent of movement of K was found to depend on the cation exchange capacity of the soil and the rate at which K was applied (Uriu et al., 1977).

From the summary of results given in Table 76, it can be observed that NH_4OAc-K content of soil increased upto 75 DAT and again decreased at post-harvest stage. This might be due to crop removal.

Table 76. Summary of results on the effect of fertigation on NH_4OAc-K content of soil at different growth stages of tomato

(ppm)

Fertigation	45 DAT	75 DAT	Post-harvest
Half N	565	571	229
Full N	468	529	295
Full N & K	473	346	274
Full NPK	423	333	284
Soil appln.	514	534	326
CD (0.05)	18	27	28

In both 45 and 75 DAT, NH_4OAc-K was higher in fertigation of N alone treatments and soil application of fertilisers than fertigation with N & K and NPK which might be due to application of K through soil in two splits compared to 10 split applications at weekly intervals in fertigation with N & K and NPK combinations.

Though in all the treatments, total quantity of K applied either through soil or fertigation was same, the disparity on availability of K can be attributed to the competition between NH_4 and K to get adsorbed on the exchange complex when both were fertigated simultaneously. Similar competitive effect was also observed and discussed under NH_4-N content of soil.

At post-harvest stage, availability of K was reduced in all the fertigation combinations compared to soil application of fertilisers. This might be due to higher K uptake by tomato in all the fertigation treatments. Goyal et al. (1989) also observed higher K uptake by plants under fertigation.

5.1.2. Effect of Texture on the Changes in Soil Chemical Properties due to Fertigation

Numerous studies have shown that general response of trickle irrigation either through reduction in crop water requirements or increased fertiliser use efficiency can be felt significantly in coarse textured soils than fine textured ones (Bucks et al., 1982). Of the two texturally different soils used in the present study, in all the stages of sampling, sandy clay loam recorded higher pH, EC, NH_4-N, NO_3-N and NH_4OAc-K while loamy sand recorded higher $NaHCO_3$-P. This difference in the content or values of above parameters could be attributed to the inherent or higher initial content in the respective soils.

Table 77. Summary on the effect of fertigation in two texturally different soils on soil pH at 45 DAT

Fertigation/ Soil	Half N	Full N	Full N & K	Full NPK	Soil appln.	CD (0.05)
Loamy sand	7.33	7.51	7.63	7.83	7.73	0.08
Sandy Clay loam	7.98	7.78	7.75	8.03	7.85	0.08

But difference in texture had different influence on soil pH and EC due to fertigation (Fig.3 & 4). On 45 DAT itself, in loamy sand, fertigation treatments had an influence on soil pH (Table 77) while in sandy clay loam the reduction in soil pH due to fertigation with N alone or N & K could not be clearly felt but the increase in soil pH due to fertigation with NPK was clearly established in both soils. The reason being, loamy sand, a coarse textured soil with CEC of 10.8 c. mol (p^{+}) kg^{-1} could not significantly buffer the changes in pH due to fertigation. But sandy clay loam, with higher clay content and CEC could buffer the changes in pH especially due to fertigation of N alone or N & K.

But changes in soil EC (Table 78), followed just a reverse trend. In loamy sand at post-harvest stage only fertigation with full N or half N increased the soil EC while the above treatments were on par with soil application of fertilisers at both 45 and 75 DAT. This could be attributed to the rapid water movement in a coarse

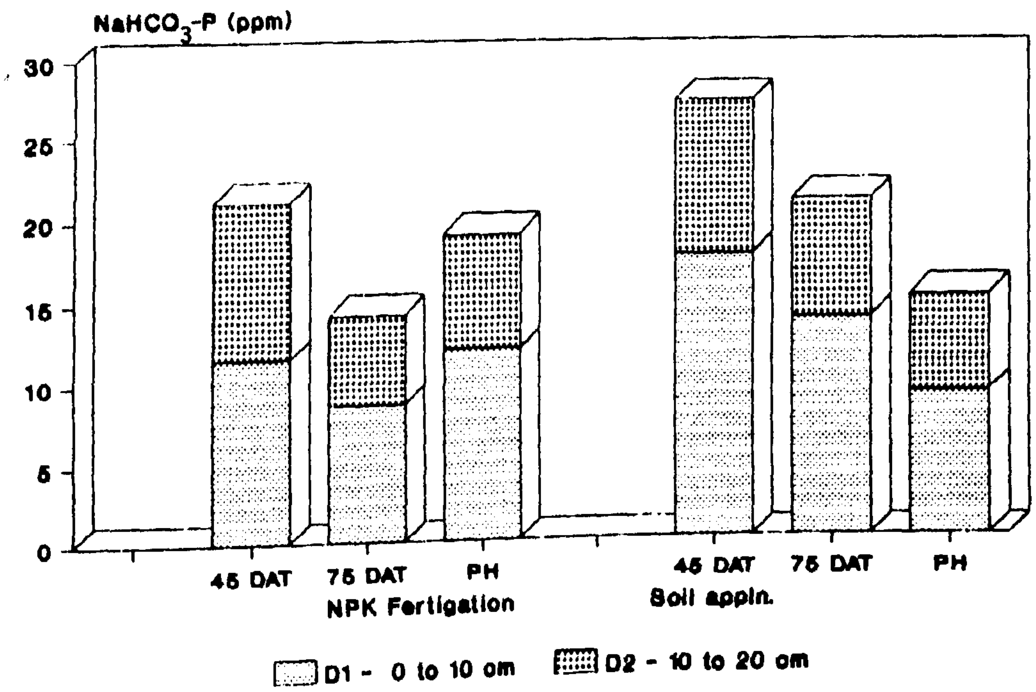
Table 78. Summary of results on the effect fertigation in two texturally different soils on soil EC at different growth stages of tomato

Fertigation	Loamy sand			Sandy clay loam		
	45 DAT	75 DAT	post-harvest	45 DAT	75 DAT	post-harvest
Half F	1.3	1.5	1.3	1.0	2.1	1.4
Full N	1.1	1.5	1.6	1.4	1.9	1.2
Full N & K	1.3	1.3	1.2	1.5	1.6	1.6
Full NPK	0.8	0.9	1.0	0.8	1.1	1.2
Soil appln.	1.2	1.3	1.1	1.2	1.2	1.9
CD (0.05)	0.14	0.33	0.17	0.14	0.33	0.17

the present study, at different stages of sampling, NH_4-N and NO_3-N contents were varying inconsistently between the two depths studied.

Phosphorus, in general is relatively immobile element in the soil. But considerable vertical and horizontal movement of P in a clay loam soil was reported when it was applied as orthophosphate through trickle irrigation (Rauschkolb et al.,1976). In the present study, the higher $NaHCO_3$-P in surface soil can be attributed to the lesser mobility of P when applied as single super phosphate. But under fertigation of NPK, where P was

FIG.5 DISTRIBUTION OF PHOSPHORUS IN SOIL



PH-Post-harvest

applied as H_3PO_4, the distribution of P in wetted soil volume was found to be comparatively uniform as difference between two depths was 2.1 ppm compared to 7.9 ppm in soil application of fertilisers (Fig.5). This finding falls in line with that of O'Neill et al. (1979).

The higher NH_4OAc-K observed in the surface soil could be attributed to adsorption of applied K on the exchange sites of surface soil itself (Haynes, 1985).

5.1.4. Effect of Fertigation on Fruit and Shoot Yield of Tomato

Most of the workers have reported increased yields of most of the crops with lower level of nutrient requirement under trickle fertigation compared to conventional methods (Goyal et al., 1985). Under trickle fertigation, application of nutrients directly at the site of active root zone, in frequencies and quantities as needed by the crop in its different growth stages results in improved nutrient use efficiency.

In the present study, the fresh fruit yield of tomato was significantly higher under fertigation of full N or half N. Fertigation with full NPK also recorded comparable yield with the latter one (Table 79 and Fig.6).

Nitrogen, when applied in small quantities (1/10th of total requirement) at weekly intervals directly to the active root zone through trickle fertigation would have been utilised by the test crop tomato better than soil application of fertilisers where the full quantity of N was applied in two splits viz., basal and at 45 DAT. Miller et al. (1981) also reported more efficient use of N by tomato when applied through trickle system. Hence from the results of the present study, the superiority of fertigation of N alone or NPK was established compared to soil application of nutrients with trickle irrigation.

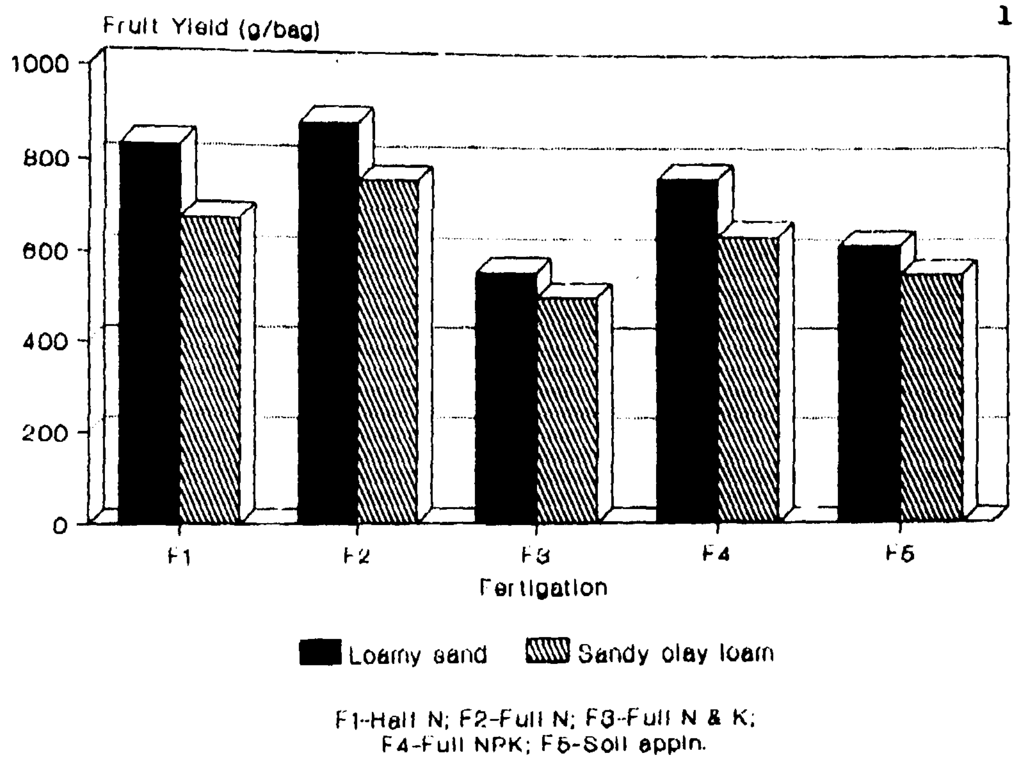
Table 79. Summary of results on the effect of fertigation on fruit yield and total biomass production at harvest by tomato

($g\ bag^{-1}$)

Fertigation/ Parameter	Half N	Full N	Full N & K	Full NPK	Soil appln.	CD (0.05)
Fruit yield	754	820	532	701	588	72
Total biomass production	1009	1103	735	1007	874	114

But fertigation with N & K recorded comparable fruit yield of tomato with soil application of fertilisers. Compared to fertigation of N alone, lower yields in

FIG.6 EFFECT OF FERTIGATION ON FRUIT YIELD OF TOMATO



fertigation of N & K could be explained due to competition between NH_4 and K which ultimately would reduce their availability particularly leading to lower fruit yield. The NH_4-N and NH_4OAc-K contents of soil during fruit formation stage given in tables 74 and 76 also lend support to this reasoning. Another possible reason might be as explained by Rubeiz (1990) who attributed the lower yields of cucumber in N & K and NPK fertigation compared to fertigation of N alone to the initial high P and K status of soil.

The lower fruit yield of tomato with fertigation of NPK than fertigation of full N could be attributed to the delayed application of P. Phosphorus, being a nutrient required at initial phase of the crop especially for root proliferation, application of it from 15 to 77 DAT in 10 equal splits at weekly intervals would not have met the tomato crop requirements. Hence more detailed studies on fertigation of P under trickle irrigation are needed.

The loamy sand, being a coarse textured soil, low in water holding capacity and CEC, frequent applications of water and nutrients through trickle irrigation would have created more favourable environment for optimum growth of tomato and higher fruit yield as compared to sandy clay loam Bucks et al. (1982) also reported better performance of trickle irrigation in a sandy soil than fine textured one.

The effect of fertigation of nutrients on total biomass production of tomato at harvest almost followed the same trend as that of fresh fruit yield as discussed above.

From the summary of results given in table 80, in sandy clay loam, the superiority of fertigation with full N was clearly established. In loamy sand, at both 45 and 75 DAT, shoot yield was higher under fertigation of half N (Fig.7) indicating that in coarse textured soil, initial nutrient build up was necessary either through soil application or through frequent fertigation of N.

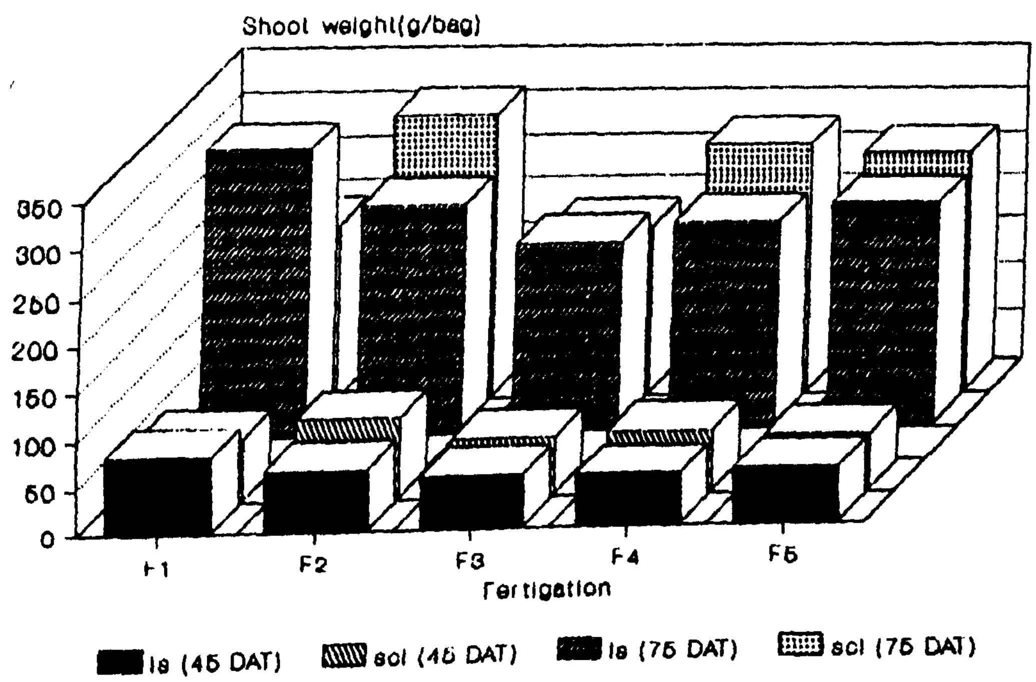
Table 80. Summary of results on the effect of fertigation on fruit yield and shoot weight (45 and 75 DAT) of tomato

($g\ bag^{-1}$)

Fertigation	Fruit yield		Shoot weight (45 DAT)		Shoot weight (75 DAT)	
	ls	scl	ls	scl	ls	scl
Half N	835	674	81	65	304	183
Full N	882	758	65	84	238	306
Soil appln.	619	556	60	60	234	260

ls - loamy sand ; scl - sandy clay loam

FIG.7 EFFECT OF FERTIGATION ON SHOOT WEIGHT OF TOMATO



F1-Half N; F2-Full N; F3-Full N & K; F4-Full NPK; F5-Soil appln.

Hence studies on fertigation of nutrients especially N, with graded levels of N have to be taken up to find out the exact amount of fertiliser savings possible under trickle fertigation.

5.1.5 Effect of Fertigation on Nutrient uptake by Tomato

The uptake of any nutrient is a product of total dry matter produced with that of respective nutrient concentration. The computation of uptake of any nutrient, roughly gives an idea about the use efficiency of the applied nutrient though some amount of uptake would have come from soil.

The higher total N uptake observed in the present study (Table 81) with fertigation of full N or NPK or half N was again a reflection of higher total dry matter production in the respective treatments. For the same level of nutrients applied, higher total N uptake in the above fertigation treatments indirectly reflected the better nitrogen use efficiency under fertigation of N compared to soil application of the same. Haynes (1988) also observed higher N uptake by pepper under fertigation of N.

Similarly, total P and total K uptake by tomato at harvest were also higher under fertigation of full N compared to other treatments.

Table 81. Summary of results on the effect of fertigation on total nutrient uptake by tomato at harvest (mg bag^{-1})

Fertigation	Total uptake at harvest				
	N	P	K	Ca	Mg
Half N	3005	519	3479	1102	622
Full N	3432	649	4302	1117	867
Full N & K	2367	382	2726	927	661
Full NPK	3222	544	3373	1359	955
Soil appln.	2544	458	2899	1270	689
CD (0.05)	384	82	431	203	101

The higher total Ca and total Mg uptake by tomato under fertigation of NPK was significant as the above treatment recorded higher uptake values inspite of indirect addition of Ca and Mg in the other treatments.

5.1.6. Relative Nutrient Use Efficiency under Fertigation

For the same level of nutrient application, fertigation of half N or full N or full NPK recorded higher relative nutrient use efficiency to the tune of 6 to 12 per cent for N, 0.8 to 2.3 per cent for P and 5 to 15 per cent for K compared to soil application of fertilisers (Table 82 and Fig.8). Increased fertiliser use efficiency more than two fold, has been reported under trickle fertigation compared to soil application (Rolston *et al.*, 1979). In the present study, as there was no graded levels of nutrients, exact level of fertiliser savings or higher level of nutrient use efficiency that can be obtained under trickle fertigation could not be established. Further studies on these aspects will be useful.

Table 82. Relative nutrient use efficiency under trickle fertigation compared to soil application of fertilisers

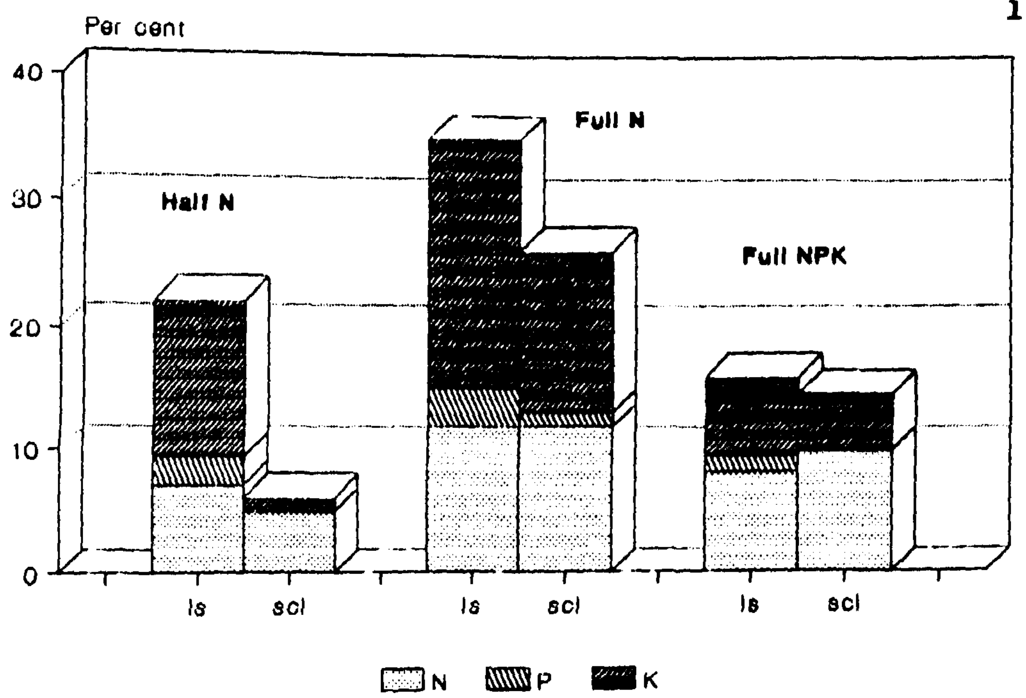
(per cent)

Fertigation	N	P	K
Half N	40.5 (+6.2)	6.2 (+0.8)	41.2 (+6.8)
Full N	46.2 (+11.9)	7.7 (+2.3)	51.0 (+16.6)
Full N & K	31.9 (-2.4)	4.5 (-0.9)	32.3 (-2.1)
Full NPK	43.4 (+9.1)	6.4 (+1.0)	40.0 (+5.6)
Soil appln.	34.3	5.4	34.4

(Values in parenthesis indicate relative increase or decrease over soil application)

To sum up, fertigation of full N at 10 equal splits at weekly intervals from 15 to 77 DAT, and application of P and K through soil recorded higher total fresh fruit yield

FIG.8 RELATIVE NUTRIENT USE EFFICIENCY UNDER FERTIGATION



ls-Loamy sand; scl-Sandy clay loam

of tomato and increased relative nutrient use efficiency of N, P and K. Fertigation of full N decreased the soil pH, increased the EC, NH_4-N and $NaHCO_5$-P content of soil in most of the stages of sampling compared to soil application of fertilisers. The absence of response to simultaneous fertigation of full N & K for increasing the fresh fruit yield of tomato and decreasing the relative nutrient use efficiency with lower NH_4-N and NH_4OAc-K content of soil compared to soil application of fertilisers needs further study.

5.2. FIELD EXPERIMENTS

In most of the studies, water savings under trickle irrigation due to improved on-farm efficiency or limited area of wetting or efficient water use by plants and fertiliser savings ranged from 25 to 50 per cent (Haynes, 1985) have been reported. To study the effect of different levels of trickle irrigation and fertigation of N to tomato, two field experiments were conducted during June-October 1988 and January-April 1989. The results obtained in the field experiments are discussed hereunder.

5.2.1. Effect of Irrigation levels and Methods of N application on Soil Chemical Properties

Under trickle fertigation, where water and nutrients are frequently applied to meet the crop requirements, efficiency of both these inputs is increased at times beyond the levels attainable under conventional methods. But wetting limited area around root zone and application of higher concentration of nutrients directly to the active root zone under trickle irrigation have their own limitations, at times, like changing the soil properties to such an extent as to affect crop growth.

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5.2.1.1. Soil reaction (pH) and soluble salt concentration (EC) of soil

Soil reaction is a single property of soil which has a greater say on the availability of most of the plant nutrients. Many workers have observed decrease in soil pH of the wetting zone under fertigation of N to an extent to increase the concentration of exchangeable Al and micronutrients to toxic levels (Haynes, 1988 and 1990).

In the present study, in both experiments, daily trickle irrigation at 4 L recorded higher soil pH than at 4 L(alt.). But the soil EC followed just a reverse trend (Table 83).

Table 83. Summary of results on the effect of trickle irrigation levels on soil pH and EC

Irrigation	Soil reaction (pH)		Soil EC	
($d^{-1}e^{-1}$)	Exp.I	Exp.II	Exp.I	Exp.II
			-- ($dS\ m^{-1}$) --	
4 L	8.28	8.16	0.68	0.66
2 L	8.23	8.13	0.73	0.68
4 L(alt.)	8.15	8.10	0.83	0.71
CD (0.05)	0.03	0.04	0.06	NS

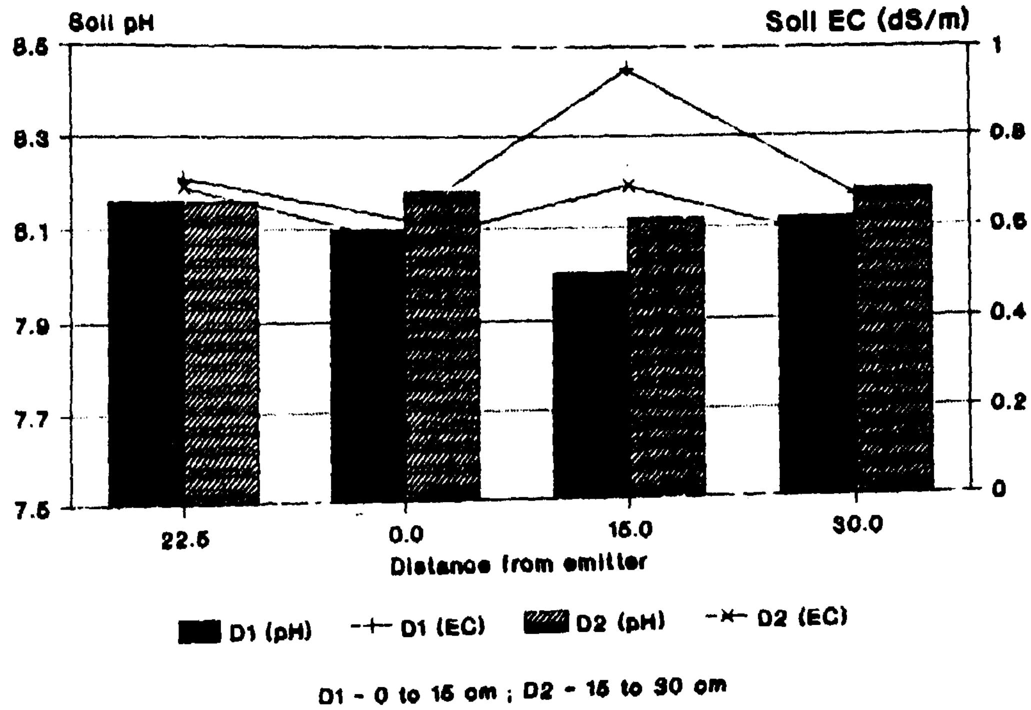
The higher soil EC in trickle irrigation at 4 L (alt.) could be attributed to the increased irrigation interval which would have led to greater evapotranspiration, thereby accumulating the salts in the wetted area. Thus the lower pH recorded at 4 L(alt.) than 4 L can be reasoned out using the significant but negative correlation (r = -0.50*, -0.73** in experiment I and II respectively).

The higher pH and lower EC (Table 84 and Fig.9) recorded at just below the emitter could be attributed to the movement of salts towards wetting front under trickle irrigation (Singh *et al.*, 1978)

Table 84. Summary of results on the effect of distance of sampling from emitter on soil pH and EC

Distance (cm)	Soil reaction		Soil EC	
	Exp.I	Exp.II	Exp.I	Exp.II
			-- ($dS\ m^{-1}$) --	
0	8.27	8.14	0.65	0.60
15.0	8.19	8.06	0.77	0.82
22.5	8.21	8.16	0.79	0.70
30.0	8.21	8.15	0.88	0.61
CD (0.05)	0.03	0.04	0.07	0.08

FIG.9 RELATIONSHIP BETWEEN SOIL pH AND EC IN THE WETTING ZONE (EXPERIMENT II)



Another important point to be observed in experiment II was, higher soil EC was recorded at 15 cm perpendicularly away from the emitter at both depths. This zone coincides with active crop root zones and in the present study the effect of salinity or higher EC could not be felt as the salt build up was below injurious levels.

5.2.1.2. Distribution of water soluble cations and anions in the wetting zone

The distribution of water soluble cations like Ca, Mg, K and Na and anions like HCO_3 and Cl in the wetting zone due to different levels of trickle irrigation is discussed below.

Comparing the total quantity of cations, water soluble Na content was higher followed by Ca and Mg with lower amount of K (Table 85). The higher amount of divalent cations at 15 cm perpendicularly away from the emitter and monovalent cations at 22.5 cm away along the lateral could be attributed to the difference in their ionic property. The lower contents of all the cations at just below the emitter was a clear evidence of movement of ions with water and also their getting adsorbed at different distances from the emitter depending upon their ionic nature.

Table 85. Summary of results on the distribution of water soluble cations in the wetting zone
(c. mol (p^{+}) kg^{-1})

Distance (cm)	Experiment I				Experiment II			
	Na	Ca	Mg	K	Na	Ca	Mg	K
0	0.64	0.44	0.24	0.07	0.73	0.37	0.27	0.12
15.0	0.73	0.47	0.25	0.10	0.69	0.49	0.51	0.14
22.5	0.87	0.53	0.25	0.11	0.81	0.38	0.26	0.13
30.0	0.75	0.46	0.26	0.10	0.66	0.37	0.27	0.12
CD(0.05)	0.05	0.05	NS	0.01	0.09	0.07	0.12	NS

Higher contents of Ca, Mg and K at surface soil also lend support to the above reasoning. Kranjac-Berisarljevic (1988) also reported similar type of salt accumulation in the surface soil under trickle irrigation.

The water soluble HCO_3 content in the wetting zone was more than two-fold than Cl content. The distribution of HCO_3 was higher at 30 cm perpendicularly away from the emitter while Cl was higher at 22.5 cm away along the lateral. In both cases, the content of HCO_3 and Cl was lower at just below the emitter. This showed the movement of Cl and HCO_3 with irrigation water to the wetting front or to the mid point between emitters. This was again established as HCO_3 content was higher in the subsurface than surface soil.

5.2.1.3. Distribution of NH_4-N and NO_3-N in the Wetting zone

When N was applied as urea through trickle irrigation, its distribution in soil around the emitter will be uniform, as urea is not adsorbed on soil colloids readily compared to ammoniacal form of N. But when on hydrolysis to NH_4 and NO_3 forms, its behaviour will be different.

Irrigation quantity and frequency had an influence on nitrification process under trickle irrigation. Higher NH_4-N at daily trickle irrigation with 4L observed in the experiment II of the present study is in agreement with Haynes (1985) who attributed this to retarded nitrification.

As expected higher amount of N addition either through soil or soil + fertigation enhanced the NH_4-N content of soil as could be evidenced from the treatments where N was applied at 150 kg ha^{-1}.

Moreover, higher NH_4-N content observed at the surface soil might be due to adsorption of applied N at the surface itself. Similar accumulation of NH_4 was earlier reported by Haynes (1990).

Urea being nonpolar in nature, due to its initial uniform distribution in the wetting zone (Haynes, 1985) would have resulted in even distribution of NH_4-N at different distances from the emitter.

Higher NO_3-N accumulation at wetting front or midpoint between emitters observed in experiment I, was a clear evidence of fast movement of NO_3-N under trickle fertigation of N as also reported by Bielorai (1985).

5.2.1.4. Distribution of $NaHCO_3$-P in the wetting zone

In both the experiments, P was applied basally as single superphosphate and banded in between the lateral line and plant row. The higher $NaHCO_3$-P content of soil recorded around the zone of banding (15 and 22.5 cm away from the emitter perpendicularly and along the lateral respectively) confirmed the immobile nature of P in soil. The higher $NaHCO_3$-P in the surface soil also lend support to this.

5.2.1.5. Distribution of NH_4OAc-K in the wetting zone

Most of the workers have observed considerable lateral and downward movement of trickle applied K in soil and this was again found to depend upon CEC of soil and rate of K application (Uriu et al., 1977). In both the experiments, K was applied as KCl and banded between the lateral line and plant row.

The higher NH_4OAc-K recorded in trickle irrigation at 4L (alt.) or 2 L might be due to the lesser quantum of water applied leading to retention of NH_4OAc-K in the site of sampling itself. The lower level of NH_4OAc-K observed under fertigation treatments over soil application (Table 86) might be attributed to frequent application of N, which on transformation to NH_4 would have replaced the K ions from the exchange sites owing to its similar ionic radii and leached down out of the root zone.

Table 86. Summary of results on the effect of methods of N application and distribution of NH_4OAc-K in the wetting zone

(ppm)

Experiment	Methods of N application			Distance from the emitter (cm)			
	N_1	N_2	N_3	0	15	22.5	30.0
I	444	388	381	333	431	449	411
II	442	398	408	327	462	433	443

The distribution of NH_4OAc-K was higher at the outer periphery of the wetting zone than at just below the emitter. Also surface soil recorded higher NH_4OAc-K content of soil than subsurface soil (Fig.10 and 11). This might be due to the lateral and downward movement of K under trickle irrigation as also reported by Goode *et al.* (1978); Keng *et al.* (1979) and Kafkafi and Bar-Yosef (1980).

5.2.2. Effect of Irrigation levels and Methods of N application on Fresh Fruit yield of Tomato

The superiority of trickle irrigation and

FIG.10 DISTRIBUTION OF NH_4OAc-K IN THE WETTING ZONE (EXPERIMENT I)

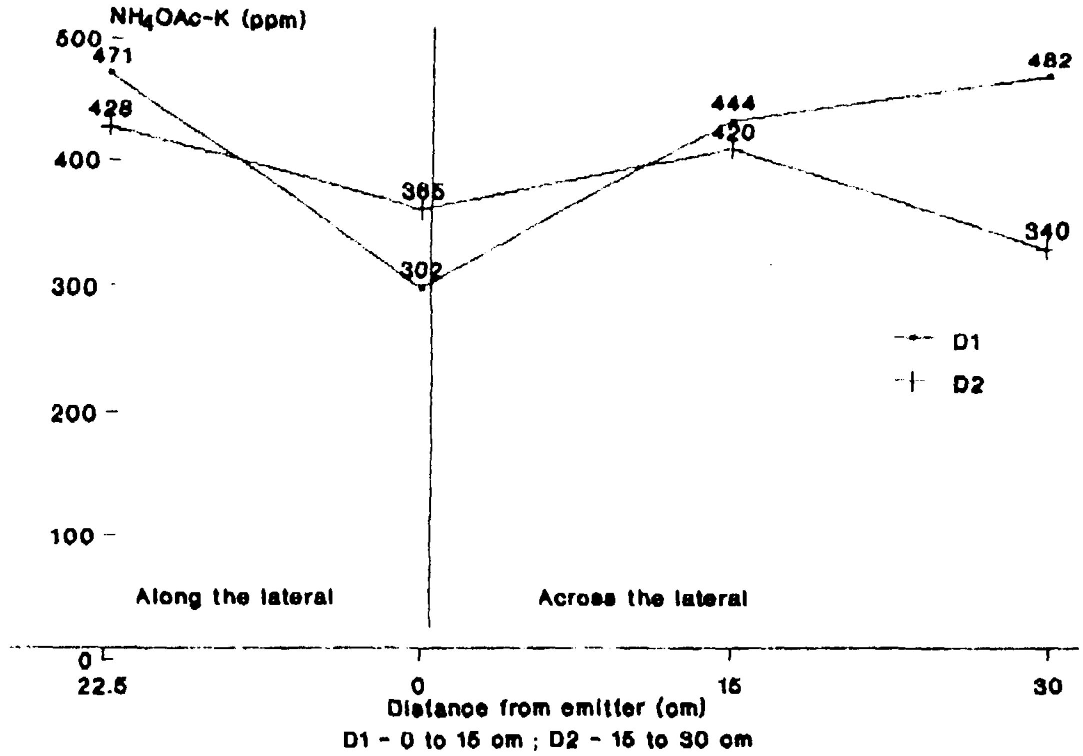
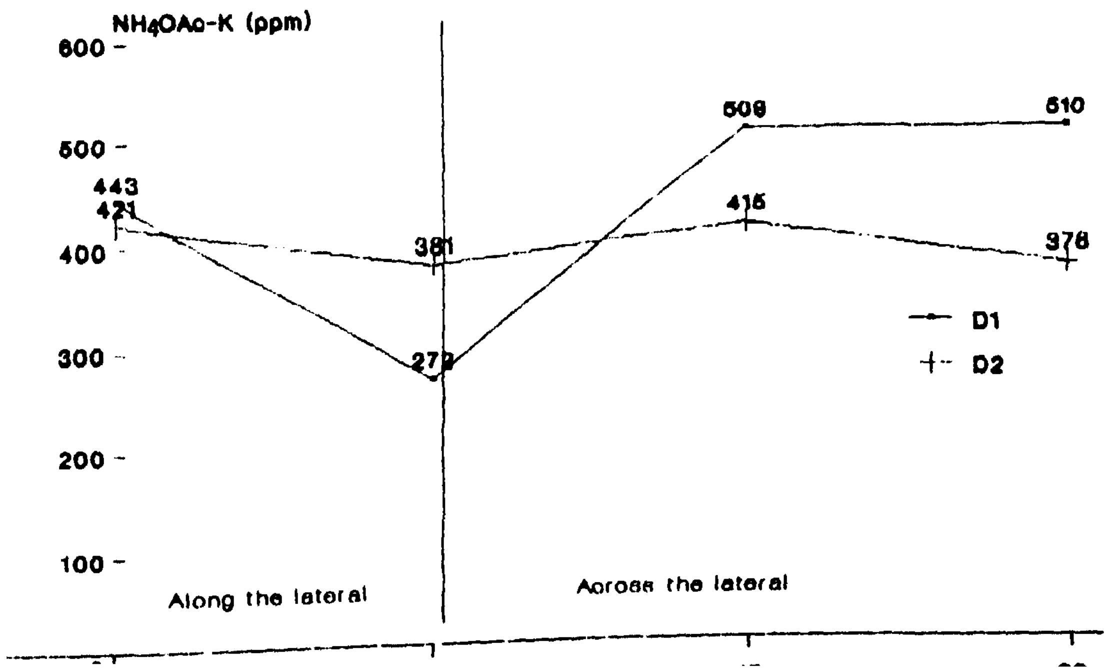


FIG.11 DISTRIBUTION OF NH_4OAc-K IN THE WETTING ZONE (EXPERIMENT II)



fertigation of nutrients in terms of water and nutrients savings with increased yields over conventional methods is mainly due to limited area of wetting and application of water and nutrients directly to the active root zone at frequent intervals and as needed by the crop. The effect of trickle irrigation with respect to different quantities of water applied in varying frequencies and its combined influence with fertigation of N on fresh fruit yield of tomato are discussed hereunder (Table 87).

Table 87. Summary of results on the effect of trickle irrigation on fruit yield of tomato

Trickle Irrigation	Total water applied		Fresh fruit yield		Water Use efficiency	
($d^{-1}e^{-1}$)	Exp.I	Exp.II	Exp.I	Exp.II	Exp.I	Exp.II
	(mm)		($t\ ha^{-1}$)		($kg\ m^{-3}$)	
4 L	510	712	40.5	19.5	7.9	2.7
2 L	394	438	32.5	20.1	8.2	4.6
4 L (alt.)	422	438	33.5	18.3	7.9	4.2
Furrow Irrigation	575	-	25.5	-	4.4	-

5.2.2.1. Comparing with furrow irrigation

In the present study, the increased fruit yield of tomato to the tune of 25 to 57 and 30 to 62 per cent for

CO 3 and Rupali respectively were obtained under trickle irrigation as compared to furrow irrigation besides savings in water to the tune of 11 to 37 per cent. The reason for water savings could be due to the limited area of wetting (45 per cent to the total area as observed in the study) and improved on-farm efficiency. The frequent water application under trickle irrigation which would have enabled the plant to extract water with less energy and with greater water use efficiency (86 per cent) compared to furrow irrigation as observed in this study, might have contributed to this higher fruit yield (Sivanappan *et al.* (1972). As high as 50 per cent water savings under trickle irrigation were also reported by Jaime *et al.* (1987); Padmakumari and Sivanappan (1989) and Rubeiz *et al.* (1989).

5.2.2.2. Irrigation quantity

When both irrigation amount and frequency were varied using trickle irrigation, the quantity of water applied had a large effect on yield than frequency (Bucks *et al.*, 1982).

In the present study, in experiment II, higher tomato fruit yield were obtained under daily trickle irrigation with 2 L which was comparable with 4 L (Fig.12).

FIG.12 EFFECT OF TRICKLE IRRIGATION LEVELS AND METHODS OF N APPLICATION ON FRUIT YIELD OF TOMATO (EXPERIMENT II)

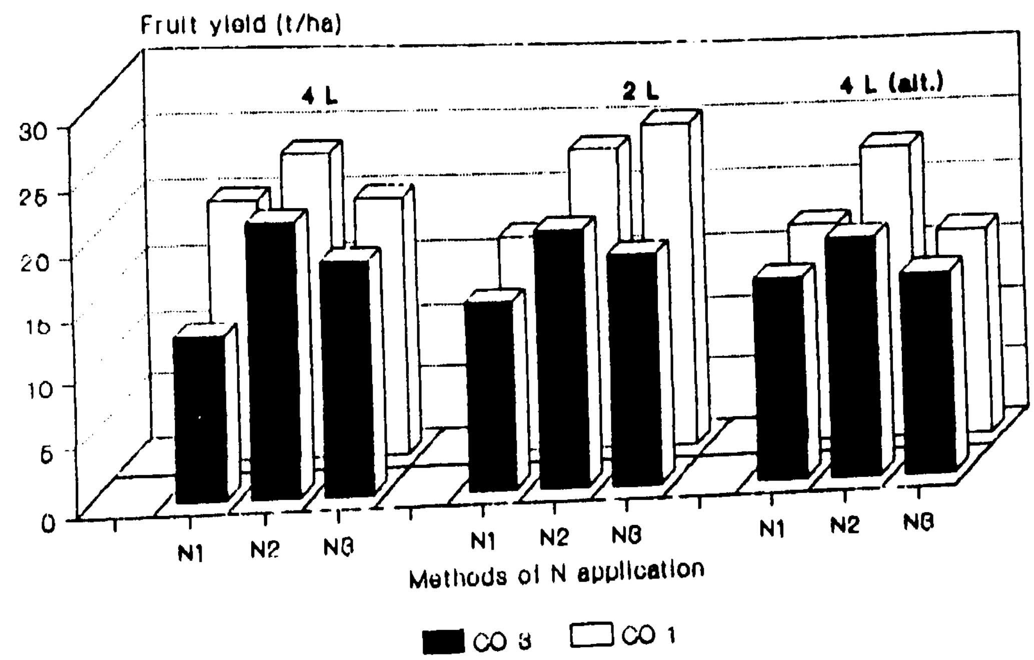
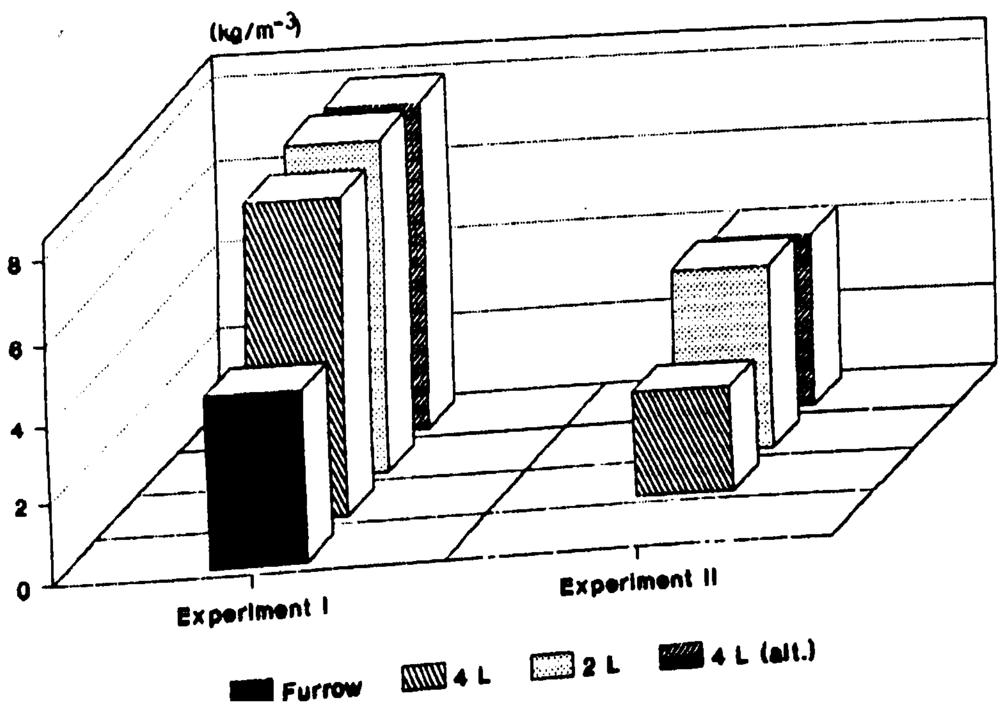


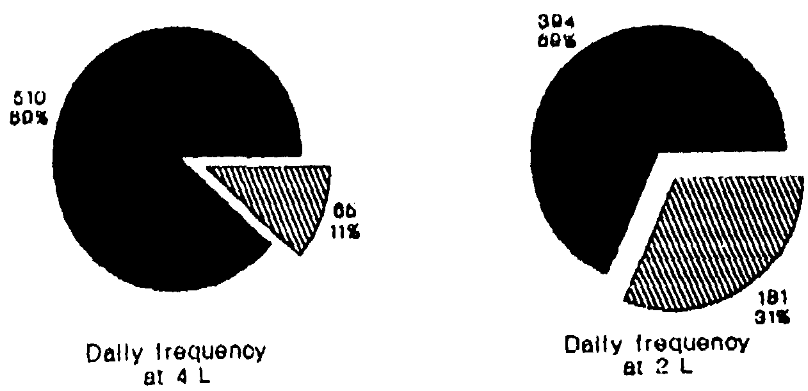
FIG.13 WATER USE EFFICIENCY UNDER DIFFERENT LEVELS OF TRICKLE IRRIGATION



From this, it can be concluded that the optimum water requirement of tomato under trickle irrigation was found to be 2 L per day per emitter to irrigate 3 tomato plants. The increased water-use efficiency recorded in the 2 L level (4.6 kg m^{-3}) compared to 4 L (2.7 kg m^{-3}) also lend support to this. In experiment I also, trickle irrigation at 2 L recorded higher water-use efficiency (8.2 kg m^{-3}) than 4 L (7.9 kg m^{-3}) (Fig.13). From the results of above two experiments, it could be concluded that of the trickle irrigation levels tried, 2 L applied at daily frequency per emitter was optimum. Based on this the per plant water requirement worked out to 1.0 L and 0.67 L per day in experiment I and II respectively. The increased fruit yield in the above treatment could be due to frequent application of water to the root zone as needed by the crop.

The total water requirements of tomato at 2 L level of trickle irrigation worked out to 394 and 438 mm with a saving of 116, 274 mm compared to 4 L level of trickle irrigation in experiment I (Fig.14) and II respectively. The increased water requirement under experiment II could be attributed to the closer spacing (60 x 30 cm) followed than in experiment I (75 x 45 cm). The lower level of water saving in experiment I might be due to the rains

FIG.14 IRRIGATION REQUIREMENTS AND WATER SAVINGS UNDER TRICKLE IRRIGATION (mm) (EXPERIMENT I)



received during the crop period which was included in working out the water requirements. Many workers have reported the water requirement of tomato under trickle irrigation as 218 mm (Bengal et al., 1986) to as high as 400 mm (Kafkafi and Bar-Yosef, 1980) depending upon the climate.

5.2.2.3. *Irrigation frequency*

For the same quantity of total water applied, changing frequency from daily to alternate day had an influence on tomato fruit yield. Daily trickle irrigation at 2 L recorded 10 per cent higher tomato fruit yield in experiment II and comparable yield in experiment I, compared to alternate day irrigation at 4 L. The reason could be for the same amount of total water applied, daily irrigation with half the quantity of water would have met the crop water requirements by wetting the root zone alone than full dose applied at alternate day. In the latter level of trickle irrigation (4 L alt.), applying double the quantity of water at one time would have increased the vertical and lateral movement of water beyond the root zone (Bresler, 1978). Bucks et al. (1982) also reported increased yields with increased frequency for the same quantity of water applied. The increased water use efficiency recorded at 2 L level of trickle irrigation also confirmed its superiority over 4 L (alt.) (Table 87).

5.2.2.4. Seasonal effect and plant spacing

In the present study, the fruit yield of tomato was almost two fold in experiment I than experiment II. This could be attributed to the seasonal effect as the experiment I was conducted during main season while the experiment II was conducted during summer.

Between the experiments, there was variation in the plant spacing also. The optimum plant spacing recommended for CO 1 and CO 3 was 60 x 30 cm which was followed in experiment II, while in experiment I, the spacing recommended for Rupali (75 x 45 cm) was followed for CO 3 also, in order to maintain uniform population. But when two rows of tomato plants were clubbed within a distance of 20 cm to facilitate the use of single lateral for two rows of plants, 30 cm in between plant spacing followed in experiment II would have created competition among plants leading to the reduced yields over and above the seasonal effect. Phene and Beale (1976) and Singh (1978) also proposed two row plant configuration per trickle lateral in order to reduce the trickle laterals cost but without reduction in yield. This indicates the need to standardise the optimum plant spacing under trickle irrigation for the row crops.

5.2.2.5. Methods of N application

Many workers have reported increased yields with reduced N levels when it was applied through trickle irrigation.

In experiment II, the higher fruit yield of tomato (34 per cent) under soil + fertigation of N over soil application alone was obtained. This might be due to the frequent application of N in 10 splits at weekly intervals enabling the tomato crop to utilise it efficiently.

Similar findings were reported by Miller et al. (1981). From the increased fruit yield of tomato (17 per cent) recorded under fertigation alone over soil application alone it could be concluded that a saving of 20 per cent N was possible due to fertigation. Similar increased yields with fertiliser savings to the tune of 50 per cent were reported under fertigation with tomato (Goyal et al., 1985), pepper (Haynes, 1985), peaches (Bussi et al., 1991).

Comparing soil + fertigation with that of fertigation alone, about 15 per cent higher tomato fruit yield was recorded in the former. From that, it could be concluded that, for the initial establishment of tomato some amount of N was needed initially. Hence fertigating N in still higher frequency at the initial stage of the crop may be necessary.

Almost a reverse trend was observed in the experiment I. Frequent rains received during the fertigation cycle (15-77 DAT) of experiment I would have leached N down from the active root zone and caused the reversal.

5.2.2.6. Multiple regression analysis

From the multiple regression equation given in table 88, only the different quantities of water applied through trickle irrigation was found to influence the total fresh fruit yield of tomato in both the varieties tried in experiment I. The influence of different levels of N application on the fruit yield of tomato was not significant.

Table 88. Results of multiple regression analysis (Experiment I)

Dependant variable (Y)	Multiple Regression equation	R^2 value
1. Total fresh fruit yield of tomato (CO 3)	$Y = 20.13 + 0.083\ I^{*} - 0.083\ N$ (0.031) (0.046)	0.4107*
2. Total fresh fruit yield of tomato (Rupali)	$Y = 7.91 + 0.060\ I^{**} - 0.012\ N$ (0.015) (0.022)	0.5221**

I - Total water applied in different trickle irrigation levels.
N - Total quantity of N applied to the crop

5.2.3. Effect of Irrigation levels and Methods of N application on Nutrient uptake by Tomato

5.2.3.1. Nitrogen uptake and use efficiency

In the present study, in experiment I higher total N uptake recorded with trickle irrigation at 4 L was due to the higher total dry matter production. In experiment II, higher total N uptake at soil + fertigation of N also was due to the above effect. Increased N uptake by tomato under fertigation was also reported by Stark *et al*. (1983).

Table 89. Relative N use efficiency under trickle fertigation

(per cent)

N application	Experiment I	Experiment II
N_1	59	33
N_2	66 (+7.0)	46 (+13.0)
N_3	48 (-11.0)	51 (+18.0)

(Values in parenthesis indicate relative increase or decrease over soil application of N)

Increased relative nitrogen use efficiency (NUE) under soil + fertigation of N was observed to the tune of 7.0 and 13.0 per cent in experiments I and II respectively (Table 89)than soil application alone. This increased NUE might be due to frequent application of N, in 10 splits at weekly intervals, directly to the active root zone of the crop as compared to soil application alone. In experiment II, still higher NUE to the tune of 18 per cent was observed under fertigation alone possibly due to the

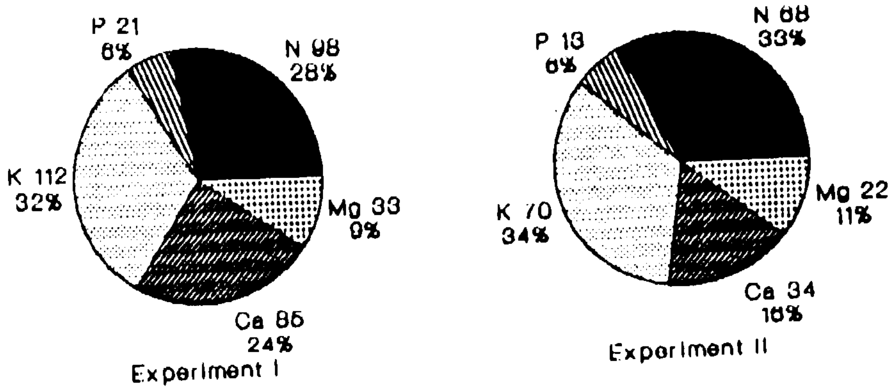
20 per cent less of N applied. The reduced NUE (-11.0 per cent) under soil + fertigation of N @ 220 kg ha^{-1} in experiment I, could be attributed to higher dose of N applied. Similar increased NUE under trickle fertigation were reported earlier with potato (Rolston *et al.*, 1979) and with tomato (Miller *et al.*, 1981).

5.2.3.2. Uptake of other nutrients

Increased total uptake of K, Ca, Mg and Na were observed under daily irrigation frequency either at 2 L or 4 L compared to alternate day irrigation at 4 L. This might be due to increased availability of nutrients under continuous wetting which led to higher dry matter production and ultimately reflected as increased nutrient uptake.

The N applied through soil + fertigation recorded invariably higher total P, K, Ca and Mg uptake (Fig.15) than other methods of N application, possibly because the initial soil application of N (30 kg ha^{-1}) would have enabled the initial vigorous growth which was maintained further by the frequent fertigation of N, leading to higher total dry matter production and finally higher nutrient uptake.

FIG.15 TOTAL NUTRIENT UPTAKE BY TOMATO IN SOIL + FERTIGATION OF N



(Values indicate actual uptake in kg/ha)

From the above discussion, it can be concluded that when a single lateral is used to irrigate two rows of tomato plants, trickle irrigation at 2 L per day per emitter with emitters placed 0.45 m apart would be optimum in terms of higher fresh fruit yield of tomato and increased water use efficiency. Nitrogen application @ 150 kg ha^{-1} through soil + fertigation would increase the fruit yield of tomato and relative N use efficiency than soil application alone.

SUMMARY AND CONCLUSIONS

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1. GLASSHOUSE EXPERIMENT

A glasshouse experiment was conducted during July - October 1988, to compare the effect of fertigation of single or combinations of major nutrients (N, P and K) with that of soil application of the same in two texturally different soils viz., loamy sand (Typic Ustifluvent) and sandy clay loam (Typic Haplustalf), with tomato (Rupali - F_1 hybrid) as test crop. The effect of fertigation on changes in soil chemical properties in both surface (0 to 10 cm) and subsurface (10 to 20 cm) soil in three stages viz., 45 DAT, 75 DAT and at post-harvest, were monitored. The effect of fertigation with respect to shoot weight at all the stages and fruit yield at harvest were recorded. They were analysed for their nutrient content and uptake values were computed. The relative nutrient efficiency was also worked out.

The salient findings from the above study are as follows:

Effect of Fertigation on Soil Chemical Properties

1. Fertigation with either half N or full N or N & K lowered the soil pH than soil application of fertilisers at both 45 and 75 DAT and this effect was found to be nullified at post-harvest.

2. Fertigation with NPK increased the soil pH than soil application of fertilisers, at all the stages of sampling.

3. Increased soil EC was observed under fertigation with N & K at 45 DAT while N alone and N & K fertigation treatments increased the soil EC at 75 DAT, compared to soil application of fertilisers. This effect was not observed at post-harvest.

4. Soil EC was lower at all the stages of sampling in fertigation with NPK than in soil application of fertilisers.

5. A significant negative correlation was observed between soil pH and soil EC in most of the treatments in all the stages of sampling.

6. In all the stages, fertigation with half N, full N or NPK recorded higher or comparable NH_4 - N content of soil than soil application of fertilisers, while fertigation with N & K decreased it at both 75 DAT and post-harvest stages.

7. Soil application of fertilisers recorded higher NO_3-N content at both 45 DAT and post-harvest than other fertigation treatments.

8. At all the three stages, fertigation with either half N, full N or N & K recorded higher $NaHCO_3$-P content of soil than soil application of fertilisers.

9. Fertigation with full NPK recorded lower $NaHCO_3$-P content of soil at both 45 and 75 DAT while it was higher at post-harvest than soil application of fertilisers.

10. At both 45 and 75 DAT, NH_4OAc-K content of soil was higher in fertigation of N alone treatments and soil application of fertilisers than fertigation with N & K and NPK .

11. At post-harvest, all the fertigation combinations recorded lower NH_4OAc-K content of soil than soil application of fertilisers.

12. Due to the effect of fertigation, sandy clay loam recorded higher pH, EC, NH_4-N, NO_3-N and NH_4OAc-K than loamy sand while the reverse was found in case of $NaHCO_3$-P content which was higher in loamy sand at all the stages of crop growth.

13. In loamy sand, decrease in pH due to fertigation of N alone or N & K was observed from 45 DAT onwards while in sandy clay loam no marked changes in soil pH were observed due to the fertigation of above combinations at that stage.

14. Changes in soil EC due to the fertigation of N alone or N & K were noted from 45 DAT itself in sandy clay loam while it was recorded only at post-harvest in loamy sand.

15. In both the soils studied, higher $NaHCO_3$-P and NH_4OAc-K contents of soil were observed in surface than subsurface soil.

Effect of Fertigation on Yield and Nutrient uptake by Tomato

1. Fertigation with full N or half N recorded significantly higher fresh fruit yield (28 to 40 per cent) of tomato in both the soils studied as compared to soil application of fertilisers.

2. Fertigation with NPK recorded fruit yield of tomato comparable to that of fertigation of half N but higher (19 per cent) than soil application of fertilisers.

3. Among the fertigation combinations studied, fertigation with N & K recorded lower fruit yield of tomato but was comparable with soil application of fertilisers.

4. In loamy sand, fertigation of nutrients recorded higher fresh fruit yield of tomato (732 g bag^{-1}) than sandy clay loam (625 g bag^{-1}).

5. At both 45 and 75 DAT, in loamy sand, fertigation with half N recorded higher shoot weight but in sandy clay loam fertigation with full N performed better.

6. Fertigation with full N, NPK or half N recorded higher total N uptake than soil application of fertilisers.

7. Fertigation with full N recorded higher total P and total K uptake than other treatment combinations.

8. As compared to soil application of fertilisers, fertigation with half N, or full N or NPK recorded higher relative nutrient use efficiency to the extent of 6.0 to 12.0, 0.8 to 2.3, 5.0 to 15.0 per cent for N, P and K respectively.

9. Total Ca and total Mg uptake by tomato were higher under fertigation of NPK than rest of the treatments.

6.2. FIELD EXPERIMENTS

Two field experiments were conducted during June-September, 1988 and January-April, 1989 to study the effect of different levels of trickle irrigation and methods of N application on changes in soil chemical properties, shoot and fruit yield of tomato apart from nutrient uptake. The experiments were conducted in Tamil Nadu Agricultural

University Orchard, Coimbatore, where the soil was sandy clay loam in texture and belonged to Typic Haplustalf. In experiment I, tomato varieties CO 3 and Rupali (F_1 hybrid) and in experiment II, CO 1 and CO 3 were grown as test crops.

In order to study the changes around the emitter samples were drawn at four distances from the emitter viz., 0, 15 and 30 cm away across the lateral and 22.5 cm away along the lateral (mid point between two emitters). At each distance soil samples were drawn at two depths viz., surface (0 to 15 cm) and subsurface (15-30 cm) and analysed for soil pH, EC, water soluble cations and anions, inorganic fractions of N, $NaHCO_3$-P and NH_4OAc-K content of soil. At harvest, shoot and fruit yields were recorded and analysed for their nutrients content. From that, total nutrient uptake and relative nitrogen use efficiency were computed.

The salient findings from the above two field experiments are summarised below:

Effect of Trickle Irrigation levels and Methods of N application on Soil Chemical Properties

1. In both experiments, trickle irrigation at 4L recorded higher soil pH than trickle irrigation at 4 L (alt.)

2. Soil EC was higher with trickle irrigation at 4 L(alt.) than daily trickle irrigation at 4 L, in both experiments.

3. Soil pH and soil EC were negatively correlated in both experiment I ($r = -0.50^{*}$) and experiment II ($r = -0.73^{**}$).

4. In both experiments, at just below the emitter, higher pH and lower EC were recorded as compared to other distances studied.

5. Higher soil EC was recorded at 30 cm and 15 cm perpendicularly away from the emitter in experiment I and II respectively.

6. In both experiments, water soluble cations content was lower just below the emitter and higher amounts of divalent cations were recorded at 15 cm perpendicularly away from the emitter and monovalent cations content at 22.5 cm away along the lateral.

7. Higher amount of water soluble Ca, Mg and K content were recorded at surface than in the subsurface soil.

8. The distribution of HCO_3 was higher at 30 cm perpendicularly away while Cl content was higher at 22.5 cm

away along the lateral from the emitter. But both the HCO_3 and Cl contents were lower at just below the emitter.

9. Higher amount of NH_4-N content of soil was found under trickle irrigation at 4 L and application of N at 150 kg ha^{-1} through soil + fertigation than other levels of trickle irrigation or methods of N application.

10. In experiment I, higher NO_3-N content was recorded either at 30 cm perpendicularly away from the emitter or 22.5 cm away along the lateral.

11. The $NaHCO_3$-P content of the soil was higher either at 15 cm perpendicularly away from the emitter or 22.5 cm away along the lateral.

12. In experiment I, higher NH_4OAc-K content was recorded in trickle irrigation either at 4 L(alt.) or 2 L than 4 L.

13. In both experiments, N application through soil alone recorded higher NH_4OAc-K than soil + fertigation or fertigation alone.

14. In both the experiments, NH_4OAc-K content of the soil was lower at just below the emitter than other distances.

15. The NH_4-N, $NaHCO_3$-P and NH_4OAc-K content of soil were higher at the surface than subsurface soil.

Effect of Trickle *Irrigation levels and Methods of N* application on Fruit yield of Tomato

1. In experiment I, compared to furrow irrigation, trickle irrigation increased the fresh fruit yield of tomato to the extent of 25 to 57 and 30 to 60 per cent in CO 3 and Rupali respectively besides saving water to the extent of 11 to 37 per cent.

2. In experiment I, increased water use efficiencies of 7.9, 8.2 and 7.9 kg m^{-3} were obtained at 4 L, 2 L and 4 L(alt.) rates of trickle irrigation respectively over furrow irrigation (4.4 kg m^{-3})

3. In experiment II, trickle irrigation at 2 L recorded tomato fruit yield comparable with 4 L while in experiment I, trickle irrigation at 4 L recorded higher tomato fruit yield than 2 L.

4. In both experiments, increased water use efficiency was obtained under trickle irrigation at 2 L. The water use efficiencies recorded were 8.2 and 7.9 kg m^{-3} in experiment I and 4.6 and 2.7 kg m^{-3} in experiment II in daily trickle irrigation at 2 L and 4 L respectively.

5. The total water requirements of tomato at 2 L level of trickle irrigation were 394 and 438 mm with a saving of 116 and 274 mm compared to 4 L level of trickle irrigation in experiment I and II respectively.

6. Daily trickle irrigation at 2 L recorded 10 per cent higher tomato fruit yield in experiment II and comparable fruit yield in experiment I to that of alternate day irrigation at 2 L.

7. In experiment II, application of N at 150 kg ha^{-1} through soil + fertigation recorded 34 per cent higher tomato fruit yield than soil application alone.

8. Application of N through fertigation alone increased the tomato fruit yield to the extent of 17 per cent with 20 per cent N saving in experiment II as compared to soil application alone at 150 kg ha^{-1}.

9. The 15 per cent increased fruit yield of tomato obtained in N application through soil + fertigation at 150 kg ha^{-1} than fertigation alone at 120 kg ha^{-1} in experiment II, indicated the need for N during the initial establishment of tomato.

10. In experiment I, soil application alone recorded higher tomato fruit yield (14 per cent) than soil + fertigation of N.

11. Higher total N uptake by tomato was recorded with trickle irrigation at 4 L than other levels of trickle irrigation in experiment I.

12. In experiment II, application of N through soil + fertigation recorded higher total N uptake by tomato followed by fertigation alone than soil application alone.

13. Increased relative nitrogen use efficiency (NUE) under soil + fertigation of N(N_2) to the extent of 7.0 and 13.0 per cent were observed in experiment I and II respectively over soil application alone (N_1).

14. In experiment II, higher NUE (18 per cent) was obtained under fertigation alone of N than soil application alone.

15. In both experiments, increased total uptake of K, Ca, Mg and Na were recorded under daily irrigation frequency either at 2 L or 4 L as compared to alternate day irrigation at 4 L.

16. In both the experiments, soil + fertigation of N recorded invariably higher total P,K, Ca and Mg uptake by tomato than other methods of N application.

To conclude, the superiority of fertigation of N alone or NPK on increasing fruit yield of tomato was established compared to soil application of fertilisers. Under field condition, in terms of higher water use efficiency, daily trickle irrigation at 2 L was found to be optimum when two rows of tomato plants were irrigated with single lateral in which emitters were placed at 0.45 m apart. Application of N through soil + fertigation performed better than soil application alone. When N was fertigated, N saving to the tune of 20 per cent was observed compared to soil application alone. But fertigation of N increased the soil EC and decreased the soil pH but still it was within noninjurious levels. The cause for the absence of response for simultaneous fertigation of N & K needs further study.

Further study on time of fertigation of nutrients, optimum nutrient requirements under trickle fertigation and optimum plant spacing for row crops under trickle irrigation apart from salt and nutrient distribution pattern under specific situations will make the trickle irrigation, more efficient one.

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* Originals not seen.

APPENDICES

APPENDIX I

Distribution efficiency and mean emitter flow rate of trickle irrigation system (Lateral wise)

Lateral No.	Distribution efficiency	Mean emitter flow rate
		L h^{-1}
I	88.5	5.10
II	88.5	4.92
III	88.0	5.09
IV	86.7	5.09
V	89.9	5.05
VI	86.8	5.05
VII	87.4	5.9
VIII	86.5	5.10
IX	85.7	5.11
	Grand mean	5.08

APPENDIX II

Correlation coefficents and regression equation between soil pH (Y) and EC (X) among different fertigation treatments

Fertigation	Correlation coefficient r	Regression equation
<u>45th day</u>		
Half N	- 0.724*	pH = 8.59 - 0.82 EC
Full N	- 0.158 NS	-
Full N & K	- 0.728*	pH = 8.12 - 0.32 EC
Full NPK	- 0.353 NS	-
Soil application	- 0.758**	pH = 8.22 - 0.36 EC
<u>75th day</u>		
Half N	- 0.197 NS	-
Full N	- 0.599*	pH = 8.18 - 0.30 EC
Full N & K	- 0.408 NS	-
Full N & K	0.181 NS	-
Soil application	- 0.983**	pH = 8.31 - 0.45 EC
<u>Post-harvest</u>		
Half N	- 0.581**	pH = 8.14 - 0.39 EC
Full N	- 0.940**	pH = 8.70 - 0.73 EC
Full N & K	- 0.567**	pH = 8.13 - 0.36 EC
Full NPK	- 0.792**	pH = 8.30 - 0.40 EC
Soil application	- 0.673**	pH = 8.02 - 0.24 EC

On 45th & 75th day n = 12; Post-harvest n = 20

* Significant at 5% level

** Significant at 1% level

NS Not significant

APPENDIX III

Yield and nutrient uptake by tomato under furrow irrigation

(Experiment I)

S.No.	Yield/uptake	CO 3	Rupali
1.	Shoot Yield (t ha^{-1})	7.2	10.0
2.	Fruit Yield (t ha^{-1})	30.6	20.4
3	Total Dry matter production at harvest (t ha^{-1})	2.8	3.0
4.	N uptake by fruits(kg ha^{-1})	50.17	33.6
5	Total N uptake at harvest (kg ha^{-1})	73.7	56.9
6.	P uptake by fruits(kg ha^{-1})	11.3	10.4
7.	Total P uptake at harvest (kg ha^{-1})	13.2	13.6
8.	K uptake by fruits(kg ha^{-1})	50.6	42.7
9.	Total K uptake at harvest (kg ha^{-1})	69.5	61.1
10.	Ca uptake by fruits(kg ha^{-1})	10.0	8.6
11.	Total Ca uptake at harvest (kg ha^{-1})	59.7	57.6
12.	Mg uptake by fruits(kg ha^{-1})	1.9	1.9
13.	Total Mg uptake at harvest (kg ha^{-1})	14.5	23.2
14.	Na uptake by fruits(kg ha^{-1})	5.3	2.9
15.	Total Na uptake at harvest (kg ha^{-1})	8.5	8.6

Plate 1. A view of soil bag arrangement in the glasshouse experiment