RESPONSE OF CUCUMBER (*Cucumis melo* L.) TO DRIP IRRIGATION UNDER VARYING LEVELS OF NITROGEN AND POTASH

By

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DECLARATION

I hereby declare that this thesis entitled **"Response of cucumber (*Cucumis melo* L.) to drip irrigation under varying levels of nitrogen and potash"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University of Society.

Vellayani,
19 - 5 - 1997.

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CERTIFICATE

Certified that this thesis entitled **"Response of cucumber (*Cucumis melo* L.) to drip irrigation under varying levels of nitrogen and potash"** is a record of research work done independently by **Smt. S. Lakshmi** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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ABBREVIATIONS USED IN THIS THESIS

t – Tonnes

kg – kilogram

g – gram

cm – centimetre

mm – millimetre

ha^{-1} – per hectare

°C – degree celsius

% – per cent

DAS Days after sowing

LAI – Leaf Area Index

FH – Final Harvest stage

N – Nitrogen

I – Drip irrigation

K – Potassium

@ – at the rate of

CD – Critical Difference at 5%

WUE – Water use efficiency

INTRODUCTION

1. INTRODUCTION

The availability of adequate, timely and assured supply of water is one of the important determinants of agricultural productivity. Irrigation is thus very critical to the agricultural development of the country. Irrigation raises cropping intensity and crop yields besides facilitating shifts in cropping patterns (Rangarajan, 1992). Growing demand for water for various purposes including industries and domestic use has made water more scarce and expensive especially for agricultural purposes. In India, agriculture takes major share of water accounting to 85-90 per cent of the total water use. The problem is further aggravated by the recurring droughts in the country. Hence, it has become extremely important that the available water is efficiently managed so that the growth in agricultural production is sustained.

India's crop production suffers not only from water scarcity but also from unsound and non-scientific water management practices. Vast developments have taken place in improving irrigation systems from wild flooding to more efficient surface methods such as border strip, ring and basin and furrow methods to suit different types of land and crops. The drawback of these systems is that they cannot be applied efficiently with high frequency to maintain optimum moisture level in the root zone. Further, this involves application of high volume of water which may cause deep percolation especially in light textured soils. On the other hand, higher frequency with less quantity of water results in non-uniform and shallow wetting leading to greater evaporation. Further large time fluctuations arise in soil water potential between two irrigation cycles.

Irrigation, water management and water harvesting practices using plastic materials offer a range of relevant technologies which dramatically improve the efficiency of water usage. Drip irrigation is one such technology which can help increase the irrigation potential by optimising the use of available water.

In India, though drip irrigation was introduced in the early seventies, significant development has taken place only in the eighties. Presently the area under drip irrigation is 25,000 ha. These developments have taken place in areas where there has been acute water scarcity and among commercial / horticultural crops.

The growth of drip irrigation in India has gained momentum in the last ten years. The major crops under drip irrigation include coconut, grapes, sugarcane, citrus and other horticultural crops, vegetables and plantation crops.

Drip or trickle irrigation system is a low pressure system, where in water is applied in small quantities to wet limited area, very frequently so as to maintain low constant soil water suction. Several potential advantages have made drip system unique over other methods. Its capacity to save water to meet the daily water needs is the foremost among them (Rawlins, 1973). Drip irrigation is found advantageous in soils with high infiltration and land with high slopes without causing run off or deep percolation. Among vegetables where trickle irrigation is followed in the order of importance are tomatoes, green pepper, egg plant, cucurbits, lettuce, green peas, asparagus and artichoke (Halevy *et al.*, 1973).

Kerala, is at present trying to increase the vegetable production to meet the states demand. Most of the vegetables are raised in summer, where water availability become a problem. Moreover, it is observed that 30-35 per cent of the total expenditure for vegetable cultivation is accounted for irrigation. By adopting drip irrigation, considerable savings in the labour charges is also possible. The Government of Kerala is at present encouraging the layout of drip irrigation units among farmers by providing them 50 per cent of the total cost as subsidy. Under these circumstances appropriate technology development for the cultivation of vegetables under drip irrigation becomes essential.

In India cucumber is grown in an area of 16,288 ha and the production is 105690 tons. The productivity is 6.48 t ha^{-1}. Cucumber occupies a prominent position among the vegetables cultivated in Kerala. The total area under vegetables in Kerala is 15,250 ha and about 30 per cent of the area occupied by vegetables come under cucumber. only culinary type cucumber is cultivated in Kerala. The importance of this vegetable emanates not only from its nutritive and medicinal properties but also due to its succulent nature which increases its demand during summer. It ranks high among the group of cucurbitaceous vegetables with regard to nutritive value of fruits particularly proteins, ascorbic acid, phosphorus, potassium and digestible sugars (Choudhary, 1979). The fruit is considered to be a good remedy for indigestion, constipation, dehydration, jaundice and several stomach ailments. It is also reported to possess cooling, appetising, carminative, antipyretic, laxative and vermifuge properties (Blatter *et al.*, 1935, Nadkarni, 1954). The fruit is consumed raw, pickled or in cooked form. It forms a major component of salads, sauces and mixed vegetable preparations. In North India, during summer, sliced tender cucumber fruits are of high demand for raw eating with powdered spices sprinkled over it. The high moisture content of fruit help of quench the thirst during the summer season. On account of these unique qualities this vegetable has become very popular not only in Kerala but all over the country also.

Water and fertilizer are the two vital and costly inputs in crop production. The full potential of any crop can be exploited only with the judicious application of water and fertilizer. Therefore when studies to work out the optimum irrigation schedule for any crop is being conducted, the standardisation of optimum fertilizer schedule should also go side by side with that. More so under drip irrigation, where the nutrient distribution in the soil and in the root zone follows a different trend compared to the surface methods of irrigation. Among the three major nutrients, nitrogen and potassium are more important because cucumber is reported to have a low capacity for utilising phosphorus (Jaszczolt, 1975). In view of the above, an experiment was undertaken to study the response of cucumber to drip irrigation and NK nutrition during the summer season of 1992-93 at College of Agriculture, Vellayani with the following objectives.

1. To study the effect of drip irrigation and application of N and K fertilizers on the growth and yield of cucumber.

2. To determine the content and uptake of major nutrients at different stages

3. To study the interaction between drip irrigation and fertilizers

4. To conduct soil moisture studies

5. To work out the economics for evolving suitable drip irrigation recommendations.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Research work done earlier on drip irrigation with special reference to its adaptability to vegetables and other row crops are briefly presented here. Besides this, effect of nitrogen and potassium on growth characters, yield attributes and yield, nutrient composition and uptake of cucurbits are also reviewed.

2.1. History and development of drip irrigation

Irrigation system comparable with drip method were practiced as early as 1869 in West Germany, where porous pipes were used to irrigate as well as to drain off the excess water through suction (Davis 1974 and Finkel, 1982). Later in 1930's orchards were being irrigated in Australia and then in 1940's British farmers used it in glass house crops with fairly high discharge rates (Black 1976). Initial results were not encouraging and inherent problems such as clogging, non uniform application and mechanical failures were not solved. However, later developments advocated the use of surface running of pipes with proper design and discharge rates to over come earlier problems.

At present drip is being used successfully in many countries for orchards, vegetables and ornamental crops under glass house as well as field conditions. (Halevy *et al.*, 1973 and Gustafson *et al.*, 1974). Its use gained momentum in a few years from 1970 and two international Congresses, (1971 and 1974) were held on the prospects of its use. In the first International Congress, Israel reported that it was possible to produce double the yield of fruits, vegetables and other crops under drip as compared to other types of irrigation, while using 30 per cent less water. (Deshmukh, 1974).

The development of low flow rate emitter proved to be the key to high frequency irrigation in terms of minimum equipment, minimum power (low pressure) and most important by realistic application rates for the short intervals and small areas per emitter. (Jensen, 1981). Several types of adjustable and non adjustable compact emitters are being used today and improvement in designs are brought about for pressure compensation, self flushing and turbulent flow so as to maintain uniform discharge (Howell *et al.*, 1981).

In India drip irrigation is still in an experimental stage, although research works carried out in certain regions were quite encouraging (Shivanappan *et al.*, 1974, 1978 and Singh and Punjab Singh, 1978).

2.2. Drip versus other methods of irrigation

Out of several contributing characters for adoption of drip, foremost are the economical use of water and potential to maintain low soil moisture tension in a portion of root zone, (Aljibury *et al.*, 1974, Farrel, 1974 and

Davis, 1975) are its ability to maximise crop response and yield, decreased tillage, improvement of quality of produce, reduced weed growth (Bester *et al.*, 1974) and plant diseases (Palt and Shaham, 1983) improved fertilizer use efficiency (Phene and Beale, 1976), low labour requirement and relatively lower energy consumption as compared to sprinkler (Rolston *et al.*, 1979). Besides, it is also successfully used in lands with difficult terrain, high slopes (>50%), soils having wide range of permeability and poor water holding capacity (Kenworthy, 1972, Goldberg *et al.*, 1976, Bresler, 1977). The system is claimed to enable satisfactory use of saline water (Bernstein and Francois, 1973 and 1975) and sewage effluent (Rawlins, 1975).

In a study in California, drip irrigation, yielded 13-15 per cent higher tomatoes than furrow irrigation using 56 cm of water (Elmstorm *et al.*, 1982). An experiment conducted to test the feasibility of trickle irrigation for processing tomatoes recorded an yield of 90-128 t ha^{-1} for drip irrigation as against 87 t ha^{-1} for furrow irrigated treatment (Rose *et al.*, 1982). Paunel *et al.* (1984) reported that energy saving was upto 62 per cent greater with drip irrigation than with surface irrigation, weed and disease incidence were also lower and an increase in yield of 4 t ha^{-1} was also recorded.

In a trial conducted to study the influence of different methods of irrigation in crops by Khasson *et al.* (1986) it was observed that the greatest crop yields and water savings were obtained with trickle irrigation. When overhead sprinkler irrigation was compared with drip irrigation, drip irrigation treatments produced higher yields for onion (Alspach *et al.*, 1988). In a case study conducted by Or (1988), flood irrigation gave significantly poorer results than drip irrigation. Foster *et al.* (1989) evaluated the moisture regime and plant growth of four vegetables under drip irrigation and compared them with conventional furrow irrigation. The results showed greater water savings and higher yields under drip. Trials conducted by Rubeiz *et al.* (1989) in vegetables revealed that drip irrigation used only half of the water required under furrow irrigations. Highest marketable yields of *Cucumis melo* was obtained under drip when compared to sprinkler irrigation. Chartzoulakis and Michelakis (1990) reported that water use efficiency for cucumber was highest with drip compared to furrow, microtube drip, porous clay tube and porous plastic tube. An experiment conducted by Constable *et al.* (1990) to compare drip and furrow irrigated cotton on a cracking clay soil revealed that the drip is highly efficient over furrow irrigation in nitrogen use. Hodgson *et al.* (1990) reported that in cotton high water use efficiency similar to that of drip can be obtained under furrow system by reducing transmission losses in the pumping and in the field. When compared with the surface irrigation methods, drip irrigation resulted in 40 to 65 per cent saving in water and 35 to 48 per cent increase in yields for tomato and cauliflower respectively. The field water use and consumptive use efficiencies were found to be higher with drip (Reddy *et al.*, 1990). A study of different irrigation practices used for *Mentha piperita* by Nedkov and Georgiev (1991) revealed that surface and subsurface drip irrigation methods resulted in higher yields compared to sprinkler and subsurface irrigation at 35 cm depth.

Bosu and Duraisamy (1992) reported that for banana in Tamil Nadu, highest production per unit quantity of water was achieved under drip irrigation, which gave 35 per cent water saving over surface method without significant difference in yield. Moynihan and Haman (1992) described micro irrigation system for small scale farms in which they found that water requirement for cucumber was 3-4 times more, produced less yield and required more labour in furrow system compared to drip system. When drip irrigation was compared with surface irrigation in six different vegetables, the water saving and yield were very much higher in all the cases under drip irrigation. (Acharya, 1993). Jhadhav *et al.* (1993) compared drip and furrow methods of irrigation in tomato to work out the cost economics. The benefit cost ratios were 5.15 and 2.96 respectively for drip and furrow.

With regard to quality of fruits, Lester *et al.* (1994) reported significantly lower sweetness and overall preference ratings for fruits from plots drip irrigated four days prior to harvest compared with those that received no water after eight days.

However, certain disadvantages, both agricultural and technical have restricted its application. Agricultural problems under drip irrigation are that the localized water application causes development of limited root mass, resulting in reduced effectivity of rainfall. There may be poor tree anchorage to withstand strong winds (Finkel, 1982). Technical limitations include clogging of emitters by physical impediments, chemical precipitates, growth of biological organisms (Algae and fungi), emitter non uniformity, damage by rodents, high initial cost, need for managerial skill and faulty designs (Black, 1976, Bucks *et al.*, 1981, Jensen, 1981, Howell *et al.*, 1981 and Finkel, 1982).

2.3. Crop response to drip irrigation

The yields of many crops is increased by maintaining high soil water potential in the effective root zone as in drip irrigation (Rawitz, 1970, Childs and Hanks, 1975, Bresler, 1977). Several workers have reported the superiority of drip over other conventional methods in maximising yield (Goldberg and Shmueli, 1970, Hiler and Howel, 1973, Halevy *et al.*, 1973 and Bucks *et al.*, 1981). Vegetables which have produced favourable response under drip are, tomatoes (Oliveira *et al.*, 1981, Robins (1978) and Puglin and Casico (1978) muskmelon (Borelli and Zerbi, 1977) melons (Abrew *et al.*, 1978 and Olitta *et al.*, 1978) and green pepper (Alexander and Csizinsky, 1980).

Ootegen *et al.* (1982) in Tunsinia observed highest yields of tomato (113 t ha^{-1}) when irrigation was applied at the rate of 100 per cent PET whereas yields were economical at irrigation rate of 90 per cent PET. In another study marketable yield of tomatoes were 13 to 15 per cent higher with drip than with furrow irrigation in both lysimeter as well as field plots. (Tarantino *et al.*, 1982). Bar-Yosef and Sagiv (1982) found highest fruit yields of tomatoes when irrigation rates up to 80 per cent of the pan evaporation were given through trickle irrigation. Studies on marketable yields of tomato at Taiwan indicated that it will be higher by 20-40 per cent under drip compared to furrow irrigation (Lin *et al.*, 1983). Besides total yields were also higher by weekly drip to maintain 25-100 per cent of available moisture compared to monthly furrow irrigation.

In sandy loam soils with contribution from rainfall, drier regimes (-60 KPA) produced higher yields and greater WUE in potato under trickle and subsurface irrigation (Sammis, 1980) compared to furrow and sprinkler.

Even in India, several studies conducted on vegetables, indicated higher crop yields under trickle compared to conventional surface irrigation. Work done in Tamil Nadu Agricultural university, Coimbatore on vegetables showed that crops produced higher yields by consuming only one-third to one-fourth of water requirement of other surface methods (Shivanappan, 1978). Singh and Punjab Singh (1978) reported that drip irrigation showed the way to increases the yield of most vegetables and water use efficiency under drip irrigation was nearly twice as high as with other methods. Drip irrigation increased yields of long gourd by 48-49 per cent, round gourd by 21-38 per cent and water melon by 10-22 per cent, compared to sprinkler and furrow irrigation. Padmakumari and Shivanappan (1978) observed higher yields of brinjal under trickle using 30 per cent of the total water consumption in other methods. Similar results in Bhendi and cotton were reported by Shivanappan (1979).

Further studies by Earl and Jury (1977) indicated that crop yield of squash in sandy loam soils was higher in the periphery of the wetted area under weekly trickle irrigations compared to daily drip. Their studies support the idea that weekly trickle or furrow irrigation would be prefrable to daily trickle irrigation when oxygen may be sensitive. In a study on tomato, daily drip did not cause any increase in yield compared to other two methods (Meek *et al.*, 1983). Reports also indicate that drip irrigation is not economical in agricultural crops especially if row spacings are narrow. (Chapman *et al.*, 1978 Saurel *et al.*, 1981).

Thus it is evident from the above review that crop response varies under drip depending upon crop type and agroclimatic as well as edaphic conditions. As opined by Howell *et al.* (1981) benefits of drip is greater in widely spaced than narrow spaced, coares textured than fine textured, high value crop than low value crops, arid belts than in humid belts, lands with marginal utility than high utility lands.

2.4. Soil moisture regime and water requirement under drip

From agro technical point of view it is extremely difficult to irrigate conventionally at short intervals because of large amount of water and considerable labour involved in it. Thus soil moisture tension under conventional irrigation ranges from almost values 0 to 100-200 Cbr and even higher, depending upon frequency level of irrigation and soil type. While under trickle irrigation it remained around 33 cbr and the favourable mositure regime resulted in high yields of various crops (Goldberg *et al.*, 1976, 1976a). Further work by the Bernstein and Francois, 1975, revealed that maintaining similar potential of 15 to 60 Cbr at 15 cm depth in different methods of irrigation did not result in significant yield differences. However this required double the water under sprinkler during the first week and 20-50 per cent more during the rest of the period.

There are reports indicating that drip irrigation does not necessarily produce favourable soil moisture tension specially in fine textured soils. In a lysimetric study on sandy loam soils, sprinkler irrigation every three days produced similar regime as that of drip every three days and yielded slightly higher (10 vs 9 t ha^{-1}) of grain sorghum. Trickle irrigation thrice weekly failed to produce better soil moisture regime than that produced under weekly drip. (Ravelo *et al.*, 1977). Studies conducted on loamy sand by Singh *et al.* (1978) showed that soil moisture near the emitter was above field capacity and it was 60 per cent of available moisture at a point 20 cm away from dripper and moisture level was below wilting point at a distance of 40cm from the emitter.

Studies in Arid zone Research Institute, Jodhpur by Singh *et al.* (1978) indicated that drip irrigation required 50 per cent less water (18.9cm) than furrow irrigation to obtain identical yields of potatoes. Drip at 0.5 Ep produced 20.5 t ha^{-1} as aganist 20.2 t ha^{-1} under furrow irrigation at the rate of 1 Ep. Under drip irrigation, soil moisture level was above field capacity near the emitter and it remained above 60 per cent of the available water (at 15cm) on a loamy sandy soil. However, best yield was produced by irrigation at the rate of 1 Ep (36.6cm) under drip. In another study tomatoes responded linearly to soil moisture potential and a decrease in potential from -50 to -150 centibars markedly suppressed the yields (Bar-Yosef and Sagev, 1982).

Trickle irrigation aims at maximum crop response using low volume of water and there are specific references where work has been done to optimise crop response to limited supply of water (Shivanappan *et al.*, 1978, Singh, 1978). Bernstein and Francois (1975) observed that although pepper yields were similar in drip and sprinkler when good quality water was used drip consumed only 683 mm water as against 1,054 mm in the sprinkler. Shivanappan (1978) observed that drip irrigation requires one-third to one fifth of water compared to the other surface methods to equal or for slightly higher yields. Doss *et al.* (1980) reported that in tomatoes amount of irrigation water applied was 16 cm ha^{-1} in drip compared to 34.7 cm ha^{-1} used in furrows and 37.4 cm ha^{-1} in sprinkler. Phene and Sanders (1976) and Singh and Punjab Singh (1978) observed higher water savings in twin row spacing even though yields did not increase.

Wendt *et al.* (1977) and Ravelo *et al.* (1977) also found no significant difference in seasonal CU of sweet corn and grain sorghum respectively under sprinkler furrow and subsurface irrigation.

Summer drip irrigation requirements of cucumber showed that drip irrigation on based on tensiometer readings at 30 cm depth gave significant increases in crop yields compared with 15 cm and 45 cm depths. (Goyal and Allison, 1983). Safadi (1987) reported that results on the studies conducted for irrigation scheduling for squash under drip irrigation, the water use was 12.79, 12.75 and 12.44 cm respectively for irrigation schedules at 30, 50 and 80 KPa. Results of the experiment conducted by Safadi and Battikhi (1988) on squash indicated that irrigation water application at 30 cm maximum depth is ideal. Capsicum plants yield was highest when irrigation was applied at 15 KPa (Dysko and Kaniszewski, 1989). Irrigation for tomato at a rate of 80 per cent Ep was required to avoid yield loss and the soil water potential at 15 cm depth should be -10 to -20 KPa. (El-Shafei 1989) No significant difference in the total fruit yield of tomato was observed by Lindsay *et al.* (1989) when drip irrigation was applied by evaluating soil moisture status based on tensiometers, neutron probe, ET model and crop co-efficient x Epan methods.

From the fore going review it is evident that drip irrigation keeps soil moisture at a constant, optimal level by renewing the water supply to the root zone at the same rates as it is used up. This results in low soil suction facilitating better water and nutrient uptake by the plant. Water saving is also facilitated as losses due to deep percolation, evaporation and run off are minimised. Because of longer interval between irrigations in surface methods, large time fluctuations in soil-water potential will be caused, which is partly removed by high frequency trickle irrigation (Rawlins *et al.*, 1975).

2.5. Hydraulics of water flow under drip

The distribution of water in drip irrigated soil is very important since it determines the boundaries of the root zone and the concentration of water and salts. Hence it is necessary to adjust the wetting region to the root system that is characteristic of each crop. Under drip, in addition to a generally higher frequency of application, water enters the soil from a point source and the flow is one dimensional or two dimensional. Accordingly, the root system was observed to be concentrated in the volume of the wetted zone from the dripper (Gold berg *et al.*, 1976a).

Three factors found to be responsible for determining the area wetted by the dripper were soil properties, dripper discharge rate and the amount of water applied per irrigation. Bresler and Russo (1975) compared computed wetting front with experimental data and opined that there was a good agreement between calculated and observed wetting front. Goldberg *et al.* (1976a) in their conclusive statements remarked that despite discrepancies between experimental and theoretical results, the theory gave a good qualitative and in cases even quantitative picture of the soil conditions during infiltration from a drip source. The discrepancies were attributed to inadequency of the assumptions used in the general unsaturated soil water flow theory, lack of precision in estimating soil water parameters and soil water measurements, inaccurate definition of soil surface conditions and hysteresis during infiltration process.

2.5.1. Soil type and wetting front

Soils differing in their hydraulic characters were found to differ in their wetting fronts. In general, higher the discharge rate and lower the infiltrability of the soil, larger was the wetted area (Bresler 1977, Bucks *et al.*, 1981 and Jensen, 1981). Hence, sandy soils had a deeper and narrower wetting pattern compared to loamy soils which had wider and narrower wetting front (Bresler, 1977). The ponded zone became larger as the soil became less permeable and as the trickle rate increased. Hence, the possibility of controlling the wetting front using trickle discharge rate depending upon hydraulic property of soil is of practical interest in adjusting the drippers and designing the system.

A radial area of ponded water might develop in the viscinity of trickle source due to saturation if discharge rate was higher than infiltration capacity of soil. Two forces were considered responsible for penetration of water into the soil, tension gradient and force of gravitation (Goldberg *et al.*, 1976a). Soil texture, structure and heterogeneity of the profile are identified to play an important role in determining the wetting pattern (Jensen, 1981). Tension gradient reduced as the distance of wetting front increased from point source and thus infiltration decreased. The author was also of opinion that high discharge rate of 18.45 l per h caused surface run off even in sandy soils. However discharge rate of even 4 l per h caused run off in fine textured soils (Tsipori and Shimshi, 1979). Further, surface run off was affected by dripper discharge, slope, soil texture and composition of soil surface. This was supported by the studies of Shivanappan and Padmakumari (1980) where in they observed that horizontal movement (1.2 m to 1.7 m) was greater than vertical movement (1 to 1.2 m) for discharge rates ranging from 5 to 30 l per h. They advocated lower discharge rate for longer duration for better crop response.

Singh *et al.* (1978) in their studies on loamy sand observed saturated zone below the emitter and moisture above 60 per cent of available range upto 20 cm radius from the point source. The water content was below or near the wilting point (3-4%) near the wetting front which was 40 cm from the lateral when discharge rate was 2 l per h and volume of water given was at the rate of 0.6 of pan evaporation. Others who have contributed to this aspect of study are Earl and Jury (1977), Jury and Earl (1977), Obbink and Alexander (1977) and Levin *et al.* (1979).

Experiments on soil water distribution for a tensiometer controlled trickle irrigation system by Martin and Chesness (1984) showed that soil water distribution beneath the emitter was not affected by soil layering. Experiments conducted by Mc Auliffe (1986) showed that shape and size of the wetted profile vary greatly under point source watering. Soil water distribution and storage characteristics had a major bearing on the spread of the wetted profile. Application rate did not significantly affect the wetted profile. Goyal (1987) reported that soil moisture distribution under an emitter is onion shaped with a radius of wetted hemisphere of 40 cm and a dripper spacing of 50 cm will allow enough wetted surface to keep the soil near field capacity. Based on field experience Reddy (1988) reported the optimal fraction of the wetted area under drip irrigation for given environmental condition ranges from 30 to 50 per cent, which depends on emitter spacing, discharge rate and soil conditions. Shein *et al.* (1988) reported that the location and shape of the wetting profile produced by trickle irrigation is governed by the pre-irrigation moisture tension distribution in the horizontal and vertical directions and the wetted zone is displaced towards the region of lower moisture tension which is due to the higher rate of water flow towards this region and specifically to the higher soil water permeability. The wetted patterns of sandy loam soil under trickle irrigation conditions showed that the horizontal distance of the wetted zone, the wetted distance in vertical direction and infiltration capacity is a function of time 't' (Kim and Lee, 1989). Amir and Dag (1993) reported that high Instantaneous Application Rates (IAR) increase the uniformity of the wetting pattern and its width and decrease the depth through an emitter.

Contrary to the general inferance there are a few reviews indicating that on heavy textured soils, increase in discharge rate resulted in increase in vertical component and a decrease in horizontal component probably due to higher gravitational potential under greater discharge (Mostoghami *et al.*, 1982). These findings are in conformity with the findings of Bar-Yosef and Sheikholslami (1976) on clay as well as sandy soils.

2.5.2. Wetting pattern in cropped soil

Crops can alter the wetting pattern depending upon the mode of absorption, rooting pattern and reduction in evaporation.

Mostaghimi *et al.* (1983) studied soil moisture distributions in cropped soil at different depths and distances from the water source in trickle irrigated tomato plant. In the presence of crops, results indicated non uniform water distribution pattern at different sections of the soil profile. Drip irrigation resulted in higher time average soil moisture content in contrast to other surface methods (Kumar, 1984).

Carmi and Plant (1988) reported that most of the available water supplied by drip irrigation was found at 0-30 cm depth but infiltration depth increased as evaporation rate decreased. Studies conducted by Randall and Locascio (1988) in trickle irrigated cucumber and tomato showed that discharge rate of 8 litres per hour resulted in higher water content in top 20 cm of soil than lower application rate.

Localised irrigation of stone fruit crops by Yastreb (1988) showed that highest yields were produced by wetting 10 per cent of the nutrient area to maintains an optimum soil moisture content not below 70 per cent of field capacity. Soing (1989) reported that in chery orchards irrigated through drip at the rate of 4.5 mm hour at least 5 per cent at the soil zone penetrated by roots was moistened by the high rate of drip irrigation. Water content at a lateral distance of 40 cm was significantly lower in the root zone of corn at any depth (Hernandez *et al.*, 1991).

2.5.3. Redistribution of moisture in trickle irrigation

When drip irrigation is not operated continuously redistribution of moisture takes place once the emitter is shut off. The movement of water in response to hydraulic gradient will result in change in moisture levels in soil. It is observed that while water was being added, the wetted region was adjacent to the emitter and after redistribution, it was some where below the emitter at a depth depending upon the time that had passed since irrigation was cut off (Jensen, 1981). The cyclic pattern of moisture change within a profile was proportional to the application frequency. The variations in moisture depended upon the frequency of irrigation, rate of discharge and also the location relative to the source. The time at which the increase occured was also different within the profile and tended to lag more at points farther away from the source (Ben Asher *et al.*, 1978, and Merril *et al.*, 1978). The other studies which considered redistribution of moisture in the considered redistribution of moisture in the wetted perimeter are that of Bar-Yosef and Sheikholslami, 1976 and Mostoghami *et al.*, 1982).

Mc Auliffe (1986) reported that drainage loss of water applied was high with 50 per cent or more of applied 16-24 litre pulse. Initial water content, volume of water applied, soil water storage and distribution characteristics and the time from application to sampling influenced drainage losses.

Thus, it is evident from the review that soil moisture distribution pattern for trickle irrigation is different from other methods as water is applied at discrete points and renewed frequently. This limited wetting creates a highly active plant - soil - water relation within the wetted zone and is of great importance in eliciting plant response in terms of water and nutrients utilization and in turn in yield.

2.6. Air water relations under trickle

Studies conducted on sandy soils indicated no aeration problems and entire wetted zone was found congenial for root development under normal quality water. In general, oxygen supply near plant roots under drip may not be a problem as there is neither wettings of the entire profile, nor mechanical disturbance to soil aggregates (Goldberg *et al.*, 1976a). Water spreading in drip irrigation is mainly due to cappillary movement, from a saturated central region to a dry prephery. Thus a water potential gradient is created in between the dripper and wetting front and a gradient of air in the opposite direction. Studies of Lin *et al.* (1983) in loamy soils showed no reduction in aeration under trickle.

However, trickle irrigation of clay soil at frequent intervals was found to cause near saturation and result in low oxygen concentrations (Silberbush *et al.*, 1979 and Meek *et al.*, 1983).

Root development was proportional to oxygen concentrations and root concentrations occured above the oxygen diffusion rate of 20 x 10^{-8} g/cm^2/ min which was considered as critical (Goldberg *et al.*, 1976a and Silberbush *et al.*, 1979). This concentration was observed at 15-20cm radial distance and above. Meek *et al.* (1983) observed low oxygen concentration (3.6 per cent) upto 40cm depth under daily trickle irrigation at the rate of 100 per cent and 120 per cent of Epan. But yields of tomato were not affected by this. However, it was opined that proper water application rate under drip may not pose much problem of aeration and roots can adapt and develop in favourable air water zone (Goldberg *et al.*, 1976a, Silberbush *et al.*, 1979, Willoughby and Cockroft, 1974).

2.7. Nutrient management under trickle

2.7.1. Nitrogen

Operational techniques of drip irrigation and fertilizer management in highly weathered, leached, relatively low fertility acid oxisol by Keng *et al.* (1981) in sweet pepper revealed no significant yield difference when nitrogen was injected into the drip system and when banded but both these treatments were superior in yield to that of broadcast. Interaction studies between water amounts and nitrogen applied through a drip irrigation system on oranges revealed that best yields and fruit size were obtained with irrigation based on 0.65 class A pan evaporation and 750 g N per tree annually (Legaz *et al.*, 1983).

Studies conducted by Bhella and Wilcox (1985) on nitrogen fertilization and muskmelon growth, yield and nutrition showed that the highest vegetative growth and total yield were obtained with 150 g per litre of N applied through trickle. Figliolia *et al.* (1985) reported No_3 N in soil layers of maize to be markedly higher under drip irrigation even a few days after application, which is due to the higher soil moisture and temperature under drip irrigation.

Fitter and Manger (1985) reported that increasing irrigation efficiency reduced No_3N leaching amounts. Fresh market tomato production was significantly increased by N rates of 130 -200 kg/ha by increasing the yield of extra large and large fruits which was due to the reduced leaching of nutrients and soft fruit storage syndrome under trickle irrigation (Karlen *et al.*, 1985). Studies conducted by Santiago and Goyal (1985) on solute movement in drip irrigated summer peppers revealed that N movements in relation to dripper location did not vary at 15 cm depth and 15 cm horizontal distance from the dripper at 6, 64 and 118 DAT. Nitrogen effects at two drip irrigation levels on almonds reported by Schulbach and Meyer (1985) ranged from 0 to 32 oz N per tree at both the levels.

Singh *et al.* (1984) reported that in dry sandy loam urea applied to the soil surface was leached by irrigation water and peaks of urea coincided with the water front, but in sandy soil the wetting front moved faster than the urea peak and urea leached down to only 30 cm with 5 and 7.5 cm of irrigation water.

Halevy and Cramer (1986) reported the maximum yield of seed cotton at 25 ppm N grown under drip irrigation. Concentrations of 50 ppm N and above did not increase the yield and sometimes even decreased them due to excessive vegetative growth. N feeding of rockmelons under trickle irrigation by Pryor and Kelly (1987) resulted in higher yields with 1:1 NK ratios than 2:1 ratios at 240:240 NK.

Goyal *et al.* (1988) reported that nitrogen fertilization of drip irrigated pepper did not influence the root distribution. Increase in nitrogen fertilization increased significantly the yield, No_3-N content and N uptake of water melon under irrigation (Hegde, 1988). Tomato responded upto trickle irrigations based on 80 per cent of Pan evaporation at the level of 300 kg N ha^{-1}. (El-Shafei, 1989) Madramootoo and Rigby (1989)reported that trickle irrigated capsicum plants did not show significant response to varying rates of N applied. Petiole No_3 concentration was higher in drip irrigated *Cucurbita pepo* than furrow irrigated ones. (Rubeiz *et al.*, 1989). Singh *et al.* (1989) reported that for tomato drip irrigation equal to 0.5 ET required 25 per cent less N than irrigation equal to ET. N at 38 g per m^2 was found sufficient for drip irrigated cucumber and higher rates did not increase yield or have a significant effect on differences in fruit and leaf nutrient contents (Castilla *et al.*, 1990). A comparison study conducted by Constable *et al.* (1990) on growth and nitrogen uptake of drip and furrow irrigated cotton revealed that total nitrogen uptake was less in furrow than in drip irrigated treatments and N was often taken up later under drip irrigation than furrow and 40 per cent less N was taken up by drip irrigated plants than furrow irrigated plants. Csermi *et al.* (1990) reported that irrigation and nitrogen application at 120 kg ha^{-1} had greater beneficial effect on fruit and seed yield of cucumber.

The ammonium fertilizer applied at the emitter discharge rate of 2 litres per hour was concentrated in the 10 cm of soil immediately below the emitter and little lateral movement occured. Urea and nitrate because of their greater mobility in the soil were evenly distributed in the soil profile below the emitter and had moved laterally in the profile upto 15 cm radius from the emitter. Following conversion to No_3 N, urea caused acidification in the wetted soil volume upto a depth of 40 cm. Increasing trickle discharge rate from 2 litres per hour to 4 litres per hour reduced the downward movement of urea and encouraged its lateral spread in the surface soil (Haynes, 1990).

Titulaer and Slangen (1990) reported that N removed from the field determined by analysing the N content of fruits picked was used to calculate the N required by trickle irrigated lettuce and gherkin and by applying N in tune with crop growth minimised leaching losses and reduced fertilizer costs. Efficient use of water and N under trickle is achieved through fertilization corresponding to a defined energy level of soil moisture (Christov *et al.*, 1991). Antil *et al.* (1992) from the results of their experiments concluded that at all the water application rates tried, moisture content and amount of urea and NH_4-N decreased with depth and time. Moisture management had a significant effect on the distribution of N species in the soil columns. Increasing the frequency of water addition increased the amount of urea derived NH_4 in the surface layers of the soil and initial soil moisture had a considerable effect on movement of urea. The movement of urea and urea derived N into soil increased with increasing initial soil mositure content but was restricted to upper 7 cm of soil columns. At all soil moisture contents, 60-65% of the urea derived N was recovered from the top 2 cm of the soil column. In general, the recovery of urea derived N from the soil ranged from 78 to 85 per cent. Mullins *et al.* (1992) evaluated the effect of drip irrigation and different rates of N on drip irrigation and different rates of N on fruit yield and quality of tomato in which broadcast application of 1000 lb of 10:10:10 NPK mixture before planting in combination with drip irrigation produced yields equal to those with higher rates of fertilizer partly applied before planting and partly via the irrigation system. Lysimeter studies conducted by Szaloki (1992) showed that NO_3 was leached out by seepage and anions in seepage water originated from the fertilizers added. Torre and Victoria (1992) studied the distribution of NO_3 in soil with drip irrigation and reported that broadcast application slightly increased the soil NO_3 content near the dripper and at the end of two months treatments NO_3 recovery was 56 per cent.

Buzetti *et al.* (1994) reported that the three rates of N applied to muskmelon grown under drip irrigation did not influence fruit yield size, average weight and nutritional status.

2.7.2 Potassium

Keng *et al.* (1981) gave initial broadcast application of K fertilizer and later injection into the drip system and band application both of which were superior to broadcast application in sweet pepper. Mandarins gave best yields and fruit size when irrigated based on 0.65 class A pan evaporation through a drip system and fertilized with 600 g K_2o per tree annually (Legaz *et al.*, 1983). Karlen *et al.* (1985) reported that fresh market tomato yield production under trickle irrigation was not affected by the different levels of K tried. Evaluation of solute movement at different positions in the rootzone of drip irrigated summer peppers by Santiago and Goyal (1985) revealed that the K movement at different position were not statistically different.

Rock melons grown under trickle irrigation and applied with different levels of N and K by Pryor and Kelly (1987) showed that yields were higher with 1:1 NK ratios than 2:1 and highest yield was obtained at 240 kg K ha^{-1}. Response of tomato plants to drip application of fertilizers on the basis of total versus wetted surface area was studied as conventional broadcast and drip applications of fertilizer by Singh *et al.* (1989). Drip irrigation at 0.5 ET required 25 per cent less fertilizer than irrigation equal to ET and K at the rate of 168 kg ha^{-1} gave the highest yield.

Csermi *et al.* (1990) reported that K application had no effect on the seed yield of cucumber. Rao and Srinivas (1990) confirmed that K application to muskmelon markedly increased fruit yield and TSS content.

The effect of energy levels of soil moisture on K evaluated by Christov *et al.* (1991) revealed that a reduction in soil moisture lead to a slight increase in K in soil under field conditions and efficient use of K is achieved through fertilization corresponding to a defined energy level of soil moisture. Studies conducted by Christensen *et al.* (1991) on K fertilization of grapes under drip irrigation revealed that increasing the levels of K increased petiole K and reduced visual K deficiency symptoms. Greatest concentration of K was observed directly below the emitter for all levels except the highest level for which the K concentration was high at 0.5 m distance and depth from the emitter.

Hernandez *et al.* (1991) reported that in sweet corn soluble K concentration was maximal near the emitters and K moved in a hemisphere in the soil. This resulted in a soluble K concentration of 214 mg kg^{-1} in the 30-40 cm soil layer. K movement outside a radius of 30 cm from the trickler was negligible. Studies on the response of tomato to potassium fertilization conducted by Valez-Ramos *et al.* (1991) revealed that response to K application was nil when K was applied either banded or fertigated as the soil had an exchangeable K concentration of 370 ppm.

Trails conducted to evaluate the effect of drip irrigation and different rates of K fertilizer on fruit yield and quality of tomato by Mullins et al. (1992) revealed that broadcast application of 1000 lb of 10:10:10 NPK fertilizer before planting produced yields equal to those with higher rates of fertilizer partly applied before planting and partly via the irrigation system.

Singh and Singh (1992) reported that available and fixed K in the soil at field capacity showed a steady increase upto two weeks, then a sharp increase at the end of third week, after fourth week there was a sudden decrease which stabilized after the fifth week.

Lysimetric studies conducted by Szaloki (1992) showed that under increased seepage, K was washed out. Torre and Victoria (1992) reported that downward distribution of exchangeable K in the soil with drip irrigation was very small, the nutrient being absorbed in the upper soil horizons.

2.8. Crop characters as influenced by trickle irrigation

2.8.1. Growth and yield

Many studies have reported linear response in plant growth to increase in water application rate Goldberg *et al.*, 1976, Aleksicor, 1977 and Beese *et al.*, 1982). While some studies indicated that only yield parameters are significantly affected by reduced irrigation levels rather than growth parameters (Bar-Yosef *et al.*, 1980, Bar-Yosef and Sagev, 1982).

With regard to response of plants Padmakumari and Shivanappan (1978) found that brinjal plants had higher number of branches under trickle which contributed for yield. Further studies by Locascio et al. (1981) indicated that the stem diameter of tomato plants irrigated at 1.0 Ep was higher than at 0.5 Ep; however single drip line per bed (2 rows) and double drip line per bed did not cause significant difference. Beese *et al.* (1982) in their study on chilli pepper under trickle irrigation found linear response to water application rates at 0.8, 1.0, 1.2 and 1.4 times of the control (applied at -25 cbr) in leaf area and drymatter production, resulting in higher yields at higher regime. Limiting the water applied to chilli during the period of rapid vegetative growth reduced yield.

However, many studies indicate no relation between growth, dry matter production and fresh weight of final produce. Bar-Yosef and Sagev (1982) observed that though fresh yield of tomato was reduced by decreasing soil water potential from -50 to -150 cbr dry matter yield of fruit was higher between -90 to -150 cbr indicating that carbohydrate production was not retarded by drop in soil water potential within the prescribed range. Similarly in their earlier studies, Bar-Yosef *et al.* (1980) found that although dry fruit yield of tomato and vegetative growth were higher under lower regime (93 per cent of Epan) with higher frequency (thrice daily), fresh fruit yield was highest under higher regime (118 per cent Ep) and this points out that lower regime was sufficient to support the plants' dry matter, but insufficient to fill up the fruit and maintain water content necessary to increase the fresh yield.

Meek *et al.* (1983) opined that under high frequency irrigation in fine textured soils top growth was more sensitive to soil aeration than fruit yield.

Commenting on the growth rate of tomatoes in different stages, Bar-Yosef *et al.* (1980) observed that vegetative dry weight production was highest between 55 and 84 days after seeding and fruit production rate (dry weight) reached its maximum between 70 and 84 days after seeding. Maximum dry matter production rate (8-10 g day^{-1}) coincided with decrease in root weight in daily irrigations compared to bi-daily irrigations. Earlier fruit production as well as vegetative growth occured under higher level of irrigation. Lower temperature decreased dry matter production in plant as well as fruit. Most critical stage for water requirement of tomato was found between flowering to fruit setting (Ruggiero, 1977).

Many researchers have observed no differences in plant height in tomatoes under drip and other methods, although yield differences were significant (Lin *et al.*, 1983). Some have felt that plant height is not an indication of good yield (Doss *et al.*, 1977, Renquist *et al.*, 1982).

Summer drip irrigation requirements of cucumber conducted by Goyal and Allison (1983) showed that drip irrigated cucumbers gave significant increases in crop yields at 5 per cent level. Lin *et al.* (1983) reported 20-40 per cent more marketable yield for tomato under drip irrigation compared to furrow irrigation. Highest total yields of tomato were reported by Osorio *et al.* (1983) in drip irrigation compared to furrow irrigation. More over drip irrigation resulted in highest percentage of extra and first and second class fruits, highest number of fruits per hectare and per plant and greatest fruit weight and marketable yields. The amount of water needed to produce one quintal of apricot fruits under furrow irrigation was 133.83 m^3 and under drip irrigation was 46.6-116 m^3 (Leoni and Cabitza, 1984). Comparing drip and sprinkler methods of irrigation in melons Paunel *et al.* (1984) reported that the average yield under drip was 21.4 t ha^{-1} while under sprinkler it was 17.6 t ha^{-1}. Kumar (1984) reported drip of tomato resulted in higher leaf area index, leaf area duration, dry matter content and yield compared to other surface methods. Bhella and Wilcox (1985) also reported that total yield and vegetative growth of muskmelon is highest under trickle irrigation. Bhella (1985) opined that trickle irrigation increased stem length, diameter, leaf area, mean fruit weight and yield of muskmelon. Bui and Kinoshita (1985) reported 20 per cent higher yields in drip irrigated sugarcane fields than in fields irrigated by other means. Similar results were also obtained by Godoy *et al.* (1985) in sugarcane. Hanna *et al.* (1985) also confirmed that drip irrigation doubled the early and marketable yields of fresh market tomatoes. Trials conducted by Osorio (1987) pointed out that trickle irrigation increased the yields of tomatoes, cucumbers, melons and marrows.

Oweis *et al.* (1988) reported that maximum yield could be produced by trickle irrigation in tomatoes with 600 mm of net irrigation. Response of bell pepper to trickle irrigation showed increased early and total yields and fruit weight (Call and Courter, 1989). Marketable yields of capsicum increased with irrigation rate and highest yield was obtained at 90 per cent Fractional Soil Volume (Madramootoo and Rigby, 1989). Rubeiz *et al.* (1989)

opined that for *Cucurbita pepo* highest yields were obtained with drip irrigation which used only half the quantity of water used by furrow treatment. Yields of tomato increased with increase in trickle irrigation rate (Sanders *et al.*, 1989). Vigour of cherry plants was reported to be greater with drip irrigation which supplied 50 per cent of water supplied by sprinkler irrigation by Soing (1989).

In contrast to the above findings Warriner and Henderson (1989) reported that in rockmelons total yield was not affected by the irrigation treatments viz drip and sprinkler.

In cucumber Chartzoulakis and Michelakis (1990) obtained an average yield of 4.33 kg plant^{-1} by applying 363 mm of water through drip. LAI during boll filling stage and dry matter production of cotton were greater in drip than in furrow (Constable *et al.*, 1990). The total marketable yield of fruits in tomato increased by 50 and 100 per cent due to drip irrigation (Smajstrla and Locascio 1990). Highest yields in tomato, strawberry, citrus and banana were achieved by drip irrigation (Tekinel *et al.*, 1990) Marketable and total ear yields of sweet corn were higher for tricklers placed 30 cm below the soil surface than on the surface (Hernandez *et al.*, 1991). Oguzer *et al.* (1991) obtained the highest yields in capsicum with daily trickle irrigation. When yields of tomato were compared by Jhadhav *et al.* (1993) under drip and furrow irrigation methods, an additional yield of 16 t ha^{-1} was obtained under drip irrigation.

Thus it is evident that crop response to change in water levels vary and this may depend upon crop type and degree of stress created and environmental changes.

2.8.2. Physiological aspects

It is well known that plant growth is closely related to the internal water status of the plants (Boyer 1976, Begg and Turner 1976 and Hsiao *et al.*, 1976).

Direct studies on physiological aspects of plant growth under drip are few. However, conditions governing water relations under drip which are responsible for the physiological changes are discussed by some authors to reason out the growth and yield differences. The constant water regime that is established under trickle in the root zone is the pre condition to study the plant growth and plant water status under drip. Lower water availability in the root zone reduces the plant water status.

The observation of several authors revealed that longer the soil moisture is maintained at field capacity the more vigorous is plant growth and greater the yield (Goblberg *et al.*, 1976 and Goldberget *et al.*, 1976a). From a practical point of view drip irrigation is considered useful method because it maintains low matric forces in the soil for a long time (Bucks *et al.*, 1981).

Results of the experiments on several crops (tomato, cucumber and pepper) do show wide difference in turgidity, diffusible ions in the stem, ash content etc under drip compared to sprinkler. Sprinkling caused increase in levels of reducing sugars, aminoacids, free ammonia and soluble ions. On the other hand it reduced starch, protein, pigments and relative turgidity especially when saline water was used. However, Horton *et al.* (1982) based on their study in chile pepper, opined that considerable differences in transpiration occured when volume of water was reduced under trickle, but differences in plant water potentials and stomatal resistance was small. Begg and Turner (1976) stated that the reduction in leaf area is an important adaptive response to water limitation, since leaf growth is very sensitive to reduced leaf turgor even if the changes are only in the range of a few bars. They have also reported that stress may hasten senescence of old tissues and thus result in early maturity. Similarly Kamgar *et al.* (1978) also found that deficit daily drip irrigation of tomatoes strongly influenced plant growth whereas leaf water potential and stomatal resistances were only slightly influenced.

Figliolia *et al.* (1985) reported in drip irrigated plants of maize leaf amino acid content decreased at the early stages of growth and then increased. A similar pattern was observed for leaf glucose and fructose contents. This was not noticed in the other systems of irrigation. A quardatic relationship between total yield and transpiration rate in tomato was established by Oweis *et al.* (1988) and relative yield responded linearly to relative transpiration.

Experiments on physiological aspects of drip irrigation conducted by Santos (1988) in tomato revealed that adaptive mechanism to conserve water like reduced shoot production was not exhibited by the plant and leaf water potential was maintained even with a decrease in root volume exposed to water supply. The content of nutrients in the leaves of tomatoes was not found to be affected by drip irrigation by Grimstad and Baevre (1989). Constable *et al.* (1990) reported higher LAI in drip irrigated cotton than furrow irrigated ones.

The fore going discussion on plant water status and its influence on various physiological process had brought out the need for maintenance of high water potential in the root zone. This has been made possible even when a small amount of water is applied by adapting drip irrigation.

2.8.3. Root distribution

Generally plant root systems grown under trickle irrigation, where other sources of moisture supply is negligible are observed to have highly active and concentrated root system limited to the wetted zone (Goldberg *et al.*, 1976a, Bar-Yosef *et al.*, 1980, Bucks *et al.*, 1981 and Howell *et al.*, 1981 a).

Goldberg *et al.* (1976a) found that root weight at about 30 cm depth and 30 cm away from the drippers was only two per cent of the total weight and 80 per cent of the roots were within first 20 cm. This was in line with the observations of King *et al.* (1979) where capsicum roots were near porous drip tube.

On the other hand, in non arid regions where plants received some moisture from the external source, had more extensive root system throughout the soil volume (Black 1976). Similarly Silberbush *et al.* (1979) found concentration of roots in the periphery of the wetted zone (20-35 cm).

However, information on effect of partial wetting of soil root volume of vegetable crops is limited and there are contradictory reports. In one study it is indicated that wetting 50 per cent of the soil produced similar yield as full wetting (Singh, 1978) whereas, other reports indicated reduction in yield when area of wetting was reduced (Phene and Sanders, 1976, Locascio *et al.*, 1981). Even Singh (1978) observed reduced yields when 75 per cent of the area remained dry. Wetting of suboptimal soil volume might be detrimental even if the active root surface area were sufficient for uptake (Vaadia and Itai 1968). A level of drought sensitivity is induced in trickle irrigated plant and hence even smaller stress created in the root zone can affect markedly the crop performance (Black 1976, Bar -Yosef *et al.*, 1980). Hence emitter spacing, discharge rate and irrigation scheduling should differ according to planting pattern, crop and soil characteristics. In shallow and distinctly layered soil, root system will be limited and hence needs larger wetting volume (Phene and Beale, 1976) compared to uniform profile.

Bhella (1985) observed that in muskmelon under trickle irrigation the depth of root penetration decreased compared with no irrigation. In citrus

Siderius and Elbersen (1986) reported trickle irrigation produced shallow rooting with the result that roots become entirely dependent on the system for their supply of water and nutrients. Vertical root length, horizontal root length and oven dry root weight recorded no significant difference between three different drip irrigation schedules for squash (Safadi, 1987). Investigations conducted by Shatanawi (1987) on root development of squash as affected by emitter discharges and locations relative to the plant showed that roots were concentrated mainly in the upper 100 cm soil layer. Root mass was highest when emitter per four plants were used and roots penetrated upto a depth of 320 mm. Emitter discharges had no effect on root mass. In double cropping system based on frequent drip irrigation, Carmi and Plant (1988) observed that cotton roots grew towards the nearest drip irrigation line.

Studies on root growth and water status of trickle irrigated cucumber and tomato conducted by Randall and Locascio (1988) showed water application rates of two or eight litres per hour did not influence root density distributions. Goyal *et al.* (1988) reported that root distribution at 11-22, 22-33 and 33-44 cm soil depths showed no significant difference in fresh root weight and percentage distribution values. More than 80 per cent of the roots were in the 0-22 cm soil depth which corresponds to the wetting zone under the dripper. Fresh root weight and percentage distribution were significantly higher for 0-11 cm soil depth.

A study conducted by Safadi and Battikhi (1988) in squash to find out the effect of drip irrigation on root growth and distribution revealed no significant difference between the irrigations at different soil moisture tensions with regard to vertical and horizontal root growth and oven dry root weights. Root length densities of tomato determined at three depths for trickle irrigation treatments by Sanders *et al.* (1989) showed a decrease with soil depth. Greater root length density was found in irrigation at 35 per cent ET than at 70 or 105 per cent ET. Seventy four per cent of the total root weight of tomato grown under drip irrigation was confined to the top 15 cm soil layer (Singh *et al.*, 1989). The root system of cucumber under drip irrigation was noticed to be located mainly in the 0-30 cm soil layer by Chartzoulakis and Michaelakis (1990) and the root density was highest at 15 cm depth. Root distribution studies on cotton under trickle conducted by Hodgson *et al.* (1990) revealed that upto 80 per cent of all roots were found in the top 0.45 m soil and significantly more length was noticed under furrow irrigation than drip irrigation. The general concentration of roots in the top 0.3 m of soil follows the supply of water and fertilizer.

Studies conducted by Hernandez *et al.* (1991) in sweet corn revealed that root density decreased with increasing vertical or lateral distance from the emitter. High frequency drip irrigation of sweet corn studied by Phene *et al.* (1991) resulted in root extension to depths of 20 and higher root length density at surface 30 cm.

From the above it could be noted that root growth and concentration depend upon moisture and aeration as indicated by change in root concentration in the periphery of the wetted zone under clayey soil, contrary to sandy soils, where roots are near the emitter. One should be cautious of over irrigating or underirrigating in the limited active root zone of trickle as it can pose more problem due to highly active environment in that area.

2.9. Water use efficiency under trickle irrigation

Trickle is recommended to be used to maximise response to a limited water supply. Padmakumari and Shivanappan (1978) reported that adoption of drip irrigation is okra crop resulted in a saving of 84.7 per cent of water used in conventional furrow irrigation. Studies on vegetables have revealed that drip irrigation requires one third to one fifth of water use by surface irrigation, at the same time yields can be increased 10 to 40 per cent. Studies on tomatoes in Bulgaria (Aleksicor, 1977) suggested that water requirement under drip is 60 per cent of that used by furrow irrigation. Locascio (1975) found optimum soil moisture tension by providing one third as much water as applied by overhead. Bryon *et al.* (1976) supported this and found that drip plots required 50-60 per cent less water than overhead irrigation in tomatoes. Drip plots consumed 8.2" as against 20" by overhead irrigation. In a study in California, drip irrigation yielded 13-15 per cent higher tomatoes than furrow irrigation using 56cm of water. Elmstrom *et al.* (1982) observed 40 per cent less water consumption by water melon plants under drip compared to overhead irrigation in sandy soils.

Osorio *et al.* (1983) reported that drip irrigation in tomato used only 20 per cent of the water used by furrow irrigation. Kumar (1984) reported higher WUE in drip irrigation relative to other methods for tomato. The amount of water needed to produce to one quintal of apricot fruits under farrow irrigation was 133.8m^3 and that under drip irrigation was 46.6 - 116m^3 (Vakhidov, 1985). Bogle and Hartz (1986) found out that drip irrigation required 25 to 42 per cent of irrigation water volume needed by furrow irrigation for muskmelon. Using pouring method compared to drip, tomato showed a decrease in water use efficiency as a result of partial wetting with varying water regime (Santos, 1988). Trickle irrigation rates at 35, 60 and 105 per cent of ET did not differ in water use efficiency of tomato (Sanders *et al.*, 1989). Water use efficiency of cucumber was reported to be highest under drip irrigation (27.7) compared with furrow irrigation (16.8 kg per m^3) by Chartzoulakis and Michelakis (1990). Water use efficiency of cotton grown under trickle irrigation was 16 per cent higher than that under furrow irrigation (Hodgson *et al.*, 1990). When compared to other surface irrigation methods, drip irrigation resulted in 40 to 65 per cent saving in water and 35 to 48 per cent increased yields. The field water use and consumptive use efficiencies were found to be higher with drip irrigation method (Reddy *et al.*, 1990).

The effects of drip and other conventional methods of irrigation studies by Tekinel *et al.* (1990) revealed that the water use efficiency was highest under drip irrigation in tomato, strawberry, citrus and banana. Oguzer et al. (1991) opined that water use efficiency of capsicum was highest with daily trickle irrigation.

2.10. Effect of nitrogen on cucurbits

Attempts are made to review the important works conducted in India and abroad on cucurbits, a group of vegetables to which cucumber belongs.

2.10.1. Growth and yield

Bradley *et al.* (1975) compared the effect of plant population and nitrogen levels in cucumber and concluded that optimum N level was 60 lb acre^{-1} (68 kg ha^{-1}).

Ivanov and Surlekov (1975) showed that cucumber crop receiving a basic dose of 30 t FYM per hectare, application of N at 100 and 70 kg ha^{-1} raised yield by 28.1 and 25.6 per cent respectively compared with untreated controls. Jagoda and Kanisweski (1975) observed that when cucumbers receiving N at 300, 600 and 900 kg ha^{-1} were irrigated when soil water content fell to 58 per cent of field capacity, the optimum fertilizer rate was 600 kg ha^{-1} in both irrigated and unirrigated crops. Krynska (1975) reported that in cucumber N at 600 kg ha^{-1} gave a seven per cent increase compared with 300 kg ha^{-1} but 900 kg ha^{-1} gave only marginally higher yields than 600 kg ha^{-1}. Varma (1975) during a study with a monoecious cucumber line in which effects of N at 50 lb acre^{-1} (57 kg ha^{-1}) were compared either alone or with various growth hormones reported that yield was enhanced by all fertilizer levels significantly.

Borna (1976) studies the response of cucumber to fertilizer rates ranging from 200 to 2000 kg ha^{-1} and furrow irrigation at 2 or 3 levels. He concluded that irrigation generally increased the effectiveness of mineral fertilizers even at high rates. Fertilization, irrigation and their interactions had greater effect on marketable yield than on total yield. Kmiecik (1976) studied the response of cucumber to 40 kg ha^{-1} of nitrogen applied once or 80 to 200 kg ha^{-1} of N applied in splits and after sowing. A significant yield increase was observed in plots receiving N upto 120 kg ha^{-1} but yield increases at rates above that were not significant. Kretschmer and Zengerle (1976) reported that high cucumber yields were obtained from plants to which N liquid fertilizer was added through sprinkle irrigation water.

Krynska et al. (1976) conducted studies with N at 80, 160 and 240 kg ha^{-1} and irrigation rates at zero to 120mm to cucumber. It was observed that Vitamin C content of fruit increased with increasing N rates along with the increase in yield of fruits but high rates had adverse effect on the fruit quality. Cantliffe (1977) based on petiole analysis for N reported that optimum yields occured when leaves contained 4 to 5 per cent total nitrogen. Doss *et al.* (1977) conducted studies to determine the response of cucumber to low, intermediate and high irrigation and 56 or 112 kg ha^{-1} of N and concluded that N increased yields proportionately with the rate of application.

Katyal (1977) recommended a manurial schedule of 35-45 t ha^{-1} of FYM before sowing and 50 kg ha^{-1} of Ammonium sulphate at the time of final land preparation and 40-60 kg ha^{-1} of ammonium sulphate as top dressing in two separate doses-the first when the plants start to 'run' and later when fruiting has started for successful cucumber crop. Katyal (1977) also recommended the application of 50 t ha^{-1} FYM as a basal dose and a top dressing of ammonium sulphate at the rate of 100 kg ha^{-1} soon after flowering in bitter gourd.

Mahakal *et al.* (1977) reported optimum dose of N as 75 kg ha^{-1} for tinda (*Citrullus vulgaris* var. *fistulosus*) from trials on a medium heavy soil. Highest nitrogen dose of 75 kg ha^{-1} gave only slight increase in yield. Ottoson (1977) concluded from his trials that cucumber gives highest yields with N at 150 or 210 ppm. On Chernozem soils, the highest cucumber yields were obtained by Talmach (1977) by applying compost at 25 t ha^{-1} and N at 19 kg ha^{-1}. From trials with field grown cucumber, top grade fruits were obtained by Yakubitskaya *et al.* (1977) from plots receiving FYM at 90 t ha^{-1}, and N 90 kg ha^{-1}, or FYM at 60 t ha^{-1} and N at 135 kg ha^{-1}. Based on laboratory experiments on cucumber, Adams (1978) concluded that there is yield increase as the N content of the nutrient solution increased from 50 to 300 ppm, provided that other nutrients are not limiting. Under conditions of N deficiency over 50 per cent of potential yield was found to be reduced. Good quality fruits and yields were associated with 4.5 to 5.0 per cent N in the leaf.

From an evaluation of yield performance of water melon cv. sugar baby Bhosale *et al.* (1978) obtained highest yield with 75 or iso kg ha^{-1} N. El-Aidy and Moustafa (1978) reported that the best vegetative growth and fruit yield of cucumber was obtained at 1:1:2 ratio of NPK in the applied fertilizer. Hartmann and Waldhor (1978) proved that in cucumber top dressing with 5g N m^{2-1} per week starting from four weeks after planting until three weeks before harvest gave higher yield than 2.5 or 7.5g. It was also noted that increasing the water supply from 300mm m^{2-1} to 670mm m^{2-1} increased N utilization by 30 per cent. Within a plant 70 per cent of nitrogen was in the fruit and 30 per cent in the foliage and stem.

Oguremi (1978) studied the response of watermelon to N at zero to 72 kg ha^{-1} in several trials. Increased levels of nitrogen application increased the leaf number and was the highest in plots receiving 72 kg ha^{-1} N. Flowering was found to be delayed by a week, with high nitrogen application. Fruit number per unit area and fruit size were highest with N at 48 kg ha^{-1}. Williams (1978) based on a trial with chinese cucumbers reported that the total fruit yield rose markedly with N at 280 kg ha^{-1} and K at 78 kg ha^{-1}. Bradley *et al.* (1979) after comparing the effect of spacing and fertilizer treatments in cucumber observed that highest returns per hectare was obtained at 300 kg ha^{-1} of N.

Feigin *et al.* (1979) compared the effect of N from zero to 180 kg ha^{-1} in combination with FYM. Unfertilized controls gave very low yields

(2.5 t ha^{-1}). Good yields (8.7 to 12.0 t ha^{-1}) were obtained from all plots supplied with 60 to 120 kg ha^{-1} N with or without organic manure. Further addition of N didnot increase the yield significantly in cucumber. Will (1979) based on a study in cucumber with slow release nitrogen fertilizers reported an increase of 8 to 10 per cent in fruit yield and improved fruit quality. he also opined that for optimum utilization of slow release N fertilizers, adequate irrigation should also be provided.

A single application of N was reported to have a more beneficial effect on fruit yield of cucumber than top dressing by Ishkaev and Ibragimov (1980). Based on a three year trial with pickling cucumbers, O' Sullivan (1980) concluded that even though irrigation and N had no significant effect on yield, decreased rates of both had deleterious effects on quality of fruits. Fruit colour was affected by irrigation and N. Tissue N decreased with increasing irrigation indicating an increased demand for N when cucumbers are provided with irrigation. Randawa *et al.* (1981) in trials with two cultivars of muskmelon reported best results with regard to plant growth, number of fruits per vine, fruit weight per vine and fruit quality from plots receiving N at 50 kg ha^{-1}. Rajendran (1981) studied the effect of different doses of N on pumpkin. He found that N alone produced a significant difference in the number of days required for female flower production, percentage of fruit set, equitorial parameters of fruit and fruit weight. The effects of N was found to be significant in the case of LAI at 30 and 60 DAS. Total dry matter content at 60th day and at harvest increased with increased levels of N. He further noted that the response to N was quadratic and the economic level worked out to be 71 kg ha^{-1}.

From a multi locational trial in Kerala to study the effect of graded doses of N in cucumber with three levels of N (0, 25 and 50 kg ha^{-1}) it was observed that response to nitrogen was linear even upto 50 kg ha^{-1} (KAU, 1982). Smittle and Thread gill (1982) based on a comparative study with four levels of N in cucumber and squash reported that the highest marketable fruit yield resulted from application of 22.5 kg ha^{-1} N through irrigation system at 2, 3, 4, 5 and 6 weeks after planting cucumber. An experiment conducted in Kerala to find the response of different doses of N showed that N at 50 kg ha^{-1} gave maximum yield of bitter gourd (KAU, 1981).

Alan (1984) reported that fruit yield, N content of stem, leaves and roots increased with increasing N in the solution culture for cucumber. But yield decreased with applied N concentration above 300ppm.

Based on a study on water management and nutritional requirement of bitter gourd at Chalakudy, Kerala, Thomas (1984) reported that the crop responded to 60 kg ha^{-1} N. Biometric characters like leaf production, leaf area index and dry matter production were significantly influenced by N. Yield components like number of fruits per plant, mean length of fruit and mean weight of fruit were also favourably affected by N levels at 60 kg ha^{-1}. Effect of N on fruit yield at this level was also significant which produced maximum fruit yield of 9.35 t ha^{-1}. Maurya (1987) reported the highest number of female flowers, the best yield and best fruit quality at 80 kg ha^{-1} N applied to cucumber. The yields of pickling cucumbers increased as N was increased from 100 to 450 kg ha^{-1}. This also increased the fruit size and proportion of fruit that was picked in the first four harvests and a dose of 225 kg ha^{-1} N was found to be optimum. (Weichmann 1987). Valenzuela *et al.* (1987) reported that application of 100 kg N ha^{-1} was adequate for high yield of cucumber. Leaf N content increased with increasing rate of N application.

An experiment conducted by Subba Rao (1989) showed that N at 100 kg ha^{-1} in cucumber showed marked increase in the length of vine, number of leaves per plant, LAI total dry matter production, number of fruits harvested per plant, mean length of fruits, mean girth of fruits, mean weight of fruits, fruit setting percentage, sex ratio and fruit yield.

Standardisation of fertilizers for cucumber cv. *Mudikode Local* for Onattukara showed that 70 kg ha^{-1} N gave significantly higher yield (18.6 t ha^{-1}) (KAU, 1990). Csermi *et al.* (1990) reported that irrigation and nitrogen application had greater beneficial effects on fruit and seed yield of cucumber. Urea alone at 150 kg ha^{-1} was reported to give higher yields of cucumber by Kadyrkhodzhaev (1990).

In a study of muskmelon conducted by Kim *et al.* (1991) showed that top growth was best at the lowest rate of N.. Fruit yield and sugar content were normal but fruit quality tended to be higher at lowest rate. The highest rate reduced fruit size and weight. Zhang *et al.* (1991) noted an improvement in cucumber yield by increasing proportion of NH_4 upto 50 per cent and the rate of photosynthesis decreased with NH_4 or $Co(NH_2)_2$ at more than 50 per cent. Adams *et al.* (1992) observed that the main effect of N on cucumber yield was not significant. But the highest yield was obtained with 175-300 mg N litre^{-1} in the liquid feed. Good crops of high quality cucumbers can be grown using liquid feeds containing 200mg N litre^{-1} on peat substrates.

Trials on irrigation and fertilizer levels for cucumber conducted by Yingjajaval and Markmoon (1993) revealed that for optimum yields N level of 10 kg rai^{-1} (1 rai = 1600 m^2) was adequate. Pumpkin fruit set decreased at the low N rate of 56 kg ha^{-1} under sprinkler fertigation. Vine dry weight and stem elongation increased with N fertigation rate. Highest yields of early set marketable fruits and total marketable yields were obtained with fertigation of 112 kg ha^{-1}. Usable green and culled fruit production increased with increasing N fertigation rates (Swiader *et al.*, 1994).

The above literature show that mineral nutrition of N has a significant role to play in growth and yield of cucumber and cucurbits in general.

2.10.2. Chemical composition and nutrient uptake

Based on experiment with varying rates of N from zero to 268 kg ha^{-1}, Cantliffe (1977) observed that optimum yield was obtained when leaves contained 4 to 5 per cent total N. Moreover, N had a direct influence on mineral nutrient composition of the leaf tissue at harvest.

Solntseva (1978) reported that cucumber plants grown in fertile soils utilized 75 to 81 per cent of N from the soil and only 19 to 25 per cent from the applied fertilizers. The addition of N fertilizers increased plant N uptake from the soil by 53 to 63 per cent compared to the control plant which received no nitrogen. Combined application of N fertilizers and FYM increased plant utilization of N fertilizers. The co-efficient of utilization of N fertilizers by cucumber was 24 to 32 per cent. From trials with domestic cucumber, Laske (1979) showed that cucumber planted at the rate of 1.2 plants m^{2-1} removed equivalent of 500 kg ha^{-1} N during the growing season. Tserling *et al.* (1979) observed that about 15 kg m^{2-1} yields were produced in cucumber when the soil contained 20 to 30 mg N per kg of soil at flowering. At that time, the leaf blade contained about 5 per cent N.

Dorofeyuk (1980) based on field trials with ridge cucumbers concluded that both early and late sown plants showed a high requirement of N. The role of N in fruit formation was found to be significant. Tesi *et al.* (1981) reported that when adequate N is applied, the uptake of N in *Cucurbita pepo* amounted to 170.5 kg ha^{-1}. He also observed that the N requirement was greatest during the 15 days preceeding the first harvest and during the subsequent 15 days. Based on field experiments at Chalakudy in bittergourd, Thomas (1984) reported that all the N levels tried had significant influence on the content and uptake of nitrogen during the early stages and later stages. The interaction between N and irrigation also had significant influence on the uptake of N at final harvest. Subba Rao (1989) reported that in cucumber, the different nitrogen levels significant increased the percentage of nitrogen in plants at all the stages. Nitrogen uptake was significant increased by higher levels of nitrogen. Uptake of phosphorous and potassium also showed marked increase under higher levels of nitrogen.

2.11. Effect of potassium on cucurbits

2.11.1. Growth and yield

Ivanov and Surlekov (1975) showed that cucumber crop receiving a basal dose of 30 t ha^{-1} FYM and 200 kg ha^{-1} K raised the yields considerably. Jagoda and Kaniszewski (1975) observed that when cucumbers receiving K at 300 to 900 kg ha^{-1} were irrigated when soil water content fell to 58 per cent of field capacity, the optimum rate was 600 kg ha^{-1} in both irrigated and unirrigated crops. Krynska (1975) reported that in cucumber K at 600 kg ha^{-1} gave a seven per cent increase compared to 300 kg ha^{-1}, but 900 kg ha^{-1} gave only marginally higher yields than 600 kg ha^{-1}. Varma (1975) during a study with a monoecious cucumber line in which effects of K at 50, 75 and 100 lb $acre^{-1}$ (57, 85 and 114 kg ha^{-1}) reported that yield was enhanced at all levels significantly.

Borna (1976) studied the response of cucumber to K rates ranging from 200 to 2000 kg ha^{-1} which had greater effect on marketable yield and total yield. Kmiecik (1976) observed a significant yield increase in cucumber when applied 150 kg ha^{-1} K as basal dressing. Kretschmer and Zengerle (1976) reported that high cucumber yields were obtained from plants to which K liquid fertilizer was added through sprinkler irrigation water.

Krynska *et al.* (1976) conducted studies with K at 120, 240 and 360 kg ha^{-1} to cucumber. It was observed that Vitamin C content of fruits rose with increasing K rates along with increase in yield of fruits, but high rates had an adverse effect as fruit quality. Penny *et al.* (1976a) reported a markedly poor growth of cucumber in K deficient than in full nutrient solution. This was attributed to the reduced CO_2 fixation by cotyledons, which form bulk of the photosynthetic surface at this stage of growth, and to a much lower level of export of photosynthetic products from the cotyledons. Penny *et al.* (1976b) concluded from another study that cucumber seedlings with leaf like photosynthetic cotyledons, had higher growth rates and requirements for external K supply. They also opined that cucumber seedlings with expanding photosynthetic cotyledon utilized their reserve K during cotyledon development and it was not transported to epicotyl and hence, an external K supply was essential for development of photosynthetic system and the roots.

Katyal (1977) recommended a manuring schedule of 33-45 t ha^{-1} of FYM before sowing and 55 kg of potassium sulphate per hectare at the time of final land preparation for successful cucumber crop. Mahakal *et al.* (1977) reported the optimum dose of K as 100 kg ha^{-1} for tinda (*Citrullus* *vulgaris* var *fistulosa*) from trials on a medium heavy soil. Highest dose of 150 kg ha^{-1} gave only a slight increase in yield. Ottoson (1977) concluded from his trials that cucumber gives the highest yield with K at 180 ppm. On chernozem soils, highest cucumber yield was obtained by Talmach (1977) by applying compost at the rate of 25 t ha^{-1} and K at 60 kg ha^{-1}.

From trials with field grown cucumber, Adams (1978) concluded that there is a reduction of over 50 per cent of potential yield under conditions of K deficiency. With high K levels Mg deficiency could occur and reduce the yield upto 20 per cent. Good yield and fruit quality were associated with the following leaf nutrient levels of 2.5 to 3.5 per cent K. From an evaluation of field performance of water melon cv sugarbaby Bhosale *et al.* (1978) obtained highest yield with 75 or 100 kg ha^{-1} K_2O. El-Aidy and Moustafa (1978) reported that the best vegetative growth and fruit yield of cucumber was obtained at 1:1:2 ratio of NPK in the applied fertilizer.

Williams (1978) based on a trial with chinese cucumbers reported that the total fruit yield rose markedly with K at 78 kg ha^{-1}. Sugiyama and Iwata (1979) observed from a pot culture experiment that K application at 1g per pot increased the fresh weight of cucumber seedlings and the total fruit yield. A single application of K was reported to have a more beneficial effect on fruit yield of cucumber than top dressing by Ishkaev and Ibragimov (1980). Randawa *et al.* (1981) in his trials with two cultivars of muskmelon reported that best results with regard to plant growth, number of fruits per vine, fruit weight per vine and fruit quality from plots receiving a K level of 37.5 kg ha^{-1}.

Rajendran (1981) studied the effect of different doses of K as pumpkin. He found that K produced significant difference in the number of days required for female flower production, percentage of fruit set, equitorial parameters of fruit and fruit weight. The effect of K was found to be significant in the case of LAI at 30 and 60 DAS. The response to K_2O was not significant in respect of yield as the soil was good in the content of that nutrient. From a multilocational trial in Kerala to study the effect of graded doses of K in cucumber with three levels of K_2O (0, 50, 100 kg ha^{-1}) a linear response to K was observed upto 50 kg ha^{-1} which tended to be quadratic at 100 kg ha^{-1}. (KAU, 1982).

An experiment conducted in Kerala to find the response of different doses of K revealed that 50 kg ha^{-1} gave maximum yield of bittergourd (KAU 1981). Based on a study on water management and nutritional requirement of bittergourd at Chalakudy, Kerala. Thomas (1984) reported that the crop responded well to higher levels of K upto 60 kg ha^{-1}. Biometric characters like leaf production, leaf area index and dry matter production were significantly influenced by high fertility levels. Yield components like mean number of fruits per plant, mean length of fruit and mean weight of fruit were also favourably affected by high levels of K. Effect of fertilizers on fruit yield was also significant wherein the highest fertilizer level of

18 t FYM + K at 60 kg ha^{-1} produced the maximum fruit yield at 9.35 t ha^{-1}.

Singh and Chhonkar (1986) reported that application of K increased the length of main shoot, the number of leaves on the main shoot, the number of sub-shoots and fruit weight and yield of muskmelon. Application of 50 kg ha^{-1} K gave the best vegetative growth and fruit weight and yield. A pot experiment conducted by Guo and Lu (1988) to investigate K depletion in three calcareous soils of high, medium and low fertility showed that dry weight of cucumber was significantly correlated with the amount of K absorbed by the plant. Of the total K absorbed, only 0 to 7.21 per cent was from exchangeable K and more than 80 per cent from non exchangeable forms of soil K.

An experiment conducted in the loamy sand soil of the Agronomic Research Station, Chalakudy on water management and NK nutrition of cucumber in summer rice fallows by Subba Rao (1989) showed that K at 100 kg ha^{-1} increased the length of vine, number of leaves per plant, LAI, total dry matter production, number of fruits harvested per plot, mean length of fruits, fruit girth, fruit setting percentage and fruit yield. When the efficiency of K under different levels of irrigation was evaluated in the summer vegetable ashgourd (KAU, 1990) significant effect of K was observed in leaf area. K fertilization reduced chlorophyll content and increased proline content depending on the increase in dose.

Standardisation studies of fertilizers for cucumber cv. *Mudicode Local* for Onattukara revealed that 25 kg ha^{-1} of K gave significantly higher yield of 18.6 t ha^{-1} compared to 20 kg ha^{-1} which yielded 16.14 t ha^{-1} (KAU, 1990).

Csermi *et al.* (1990) obtained best results with cucumber seed crop with 180 kg ha^{-1} of K. Rao and Srinivas (1990) analysed the effect of different levels of K (0, 60 kg ha^{-1}) on petiole and leaf nutrients and their relationship to fruit yield and quality in muskmelon cv. Haramadhu. They found that K markedly increased the fruit yield and TSS content. Rajput *et al.* (1993) reported that the application of 75 kg and 100 kg K_2O ha^{-1} gave significantly more yield over 50 kg K_2O ha^{-1} in watermelon. But the yield differences between 75 kg and 100 kg K_2O ha^{-1} were statistically non significant. Percentage of total soluble solids in watermelon increased with the increase in levels of applied potash.

Experiments on fertilizer levels of K for cucumber showed that K at the rate of 5 kg rai^{-1} (1 rai = 1600 m^{-2}) was adequate for increased total yield which was due to increase in fruit number rather than fruit size (Yingjajaval and Markmoon 1993). Response of pumpkin to potash fertigation showed that fruit set decreased at low K fertigation rate of 112 kg ha^{-1}. K application rate had little effect on vine dry weight and stem elongation. Highest yields of early set marketable fruits and total marketable yields were obtained with fertigation of either 112 or 224 kg ha^{-1} of K. Usable green and culled fruit production increased with increasing K fertigation rates (Swaider *et al.*, 1994).

2.11.2. Chemical composition and uptake of nutrients

Tesi *et al.* (1981) reported that when adequate fertilizers were applied the uptake of K_2O in *Cucurbita pepo* amounted to 394.4 kg ha^{-1}. He also observed that nutrient requirements were greatest during the 15 days preceeding the first harvest and during the subsequent 15 days. In watermelon Sundstrom and Carter (1983) also reported negative correlation between K and Ca contents. Green house experiments conducted by Koukoukkis (1984) with cucumber revealed that K decreased leaf Mg content. Based on a field experiment at Chalakudy in bittergourd Thomas (1984) reported that all the K levels tried ad significant influence on the content and uptake of potassium during the early stages and during the later stages also.

Subba Rao (1989) reported that in cucumber K had no effect on the nitrogen and phosphorous content of plant but increased the plant content of K during all the stages of growth. Uptake of N, P and K by the crop was significantly increased by higher levels of K. Guo and Lu (1991) reported an intermediate K uptake ability for cucumber among the various vegetables tried. But cucumber recorded a lower resistance to K starvation.

The studies conducted in this aspect reveals that a higher level of plant content of K during early stages and adequate quantities during the later stages is important in higher uptake of K which will lead to better fruit yield.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation was undertaken at College of Agriculture, Vellayani, Kerala Agricultural University to study the effect of drip irrigation and application of nitrogen and potassium on the growth and yield of cucumber. Details of techniques adopted, procedures followed, schedule of operations and materials used are presented in this chapter.

3.1. General

3.1.1. Location

The experiments were conducted in the uplands of Instructional Farm, attached to College of Agriculture, Vellayani, situated at 8.5°N latitude 76.9°E longitude and at an altitude of 29m above mean sea level.

3.1.2. Soil characters

Composite samples were drawn from the experimental site from the upper 90cm layer and analysed for physical and chemical characters. Soil physical constants were determined at four depths separately (0-15cm, 15-30cm, 30-60cm, and 60-90cm). Mechanical analysis was done for the surface layer (0-30cm). Chemical analysis was also done for 0-30cm depth. The results are presented in Table 1.

Table 1. Soil characteristics of the experimental area

Properties	Mean value	Rating	Method used
A. Physical Properties			
1. Particle size distribution	%		International Pipette Method (Piper, 1966)
Coarse Sand	36.35		
Fine Sand	15.00		
Silt	17.50		
Clay	30.00		
Textural class	Sandy clay loam		
2. Infiltration Rate	6 cm/hr		Gupta and Dakshinamoorthy (1980)
3. Soil physical constants			

Constant	Depth of soil layer (cm)				
	0-15	15-30	30-60	60-90	
Field capacity (%)	13	14.3	14.5	14.5	Colman (1944)
Bulk density (g/cm^3)	1.20	1.22	1.20	1.20	Gupta and Dakshinamoorthy (1980)

Contd...

Table 1. (Contd...)

Properties	Mean value	Rating	Method used
B. Electro-chemical properties			
Soil reaction (p^H) (1:2.5 soil water suspension)	5.28	Acidic	Elico p^H meter with glass electrode (Jackson, 1973)
C. Chemical properties			
Organic carbon (%)	0.64	Medium	Walkley and Black Rapid Tiration Method (Jackson, 1973)
Available nitrogen kg ha^{-1}	250.88	Medium	Alkaline Potassium Permanganate Method (Subbiah and Asija 1956)
Available P_2O_5 kg ha^{-1}	38.91	High	Bray colorimetric method (Jackson, 1973)
Available K_2O kg ha^{-1}	77.25	Low	Ammonium acetate method (Jackson, 1973)

The soils are classified as oxisols having a pH of 5.28, medium in available nitrogen, high in available phosphorous and low in available potassium. The soil of the experimental site was medium in organic matter.

The field capacity of the surface soil was low (13 per cent) and it gradually increased to 14.5 per cent in the 60-90cm layer.

3.1.3. Cropping history of the field

The experiments were conducted in Block IV of the Instructional Farm Vellayani, which is the vegetable growing area of the farm. The area was grown with cowpea during the previous seasons.

3.1.4. Season

The observational trial (Experiment 1a and 1b) was conducted during the period from 9th April 1992 to 29th April 1992. The main experiment was repeated twice. The first one (Experiment 2) during the period from 16th December 1992 to 22nd February 1993 and again the same was repeated (Experiment 3) during 5th March 1993 to 12th May 1993. These seasons coincide with the summer season, which is the regular vegetable growing season of the state.

3.1.5. Weather conditions

The area of the experimental site enjoys a humid tropical climate. The meteorological data for the period April 1992 and December 1992 to May 1993 and mean values for this period of the last fifteen years (1977-1991) as observed at the meteorological observatory at College of Agriculture, Vellayani are presented in Appendix - Ia and Ib. The mean values of the weather parameters for the season, average values for the last fifteen years and deviations from the average values are presented in Table 2.

Generally November end to May are the driest months of the year. The comparison of meteorological data for the crop period in 1992-93 with the mean indicates that maximum temperature was below normal by 0.1°C, 0.7°C and 0.5°C during the course of Experiments 1, 2 and 3 respectively. But minimum temperature recorded an increase of 0.7°C over the normal in Experiment 1, whereas during the Experiments 2 and 3 it recorded decrease of 0.8°C and 0.5°C respectively. The relative humidity in the forenoon also followed the same trend as that of minimum temperature which recorded a decrease of 1 per cent in the case of Experiment 1 and increase of 8 per cent and 4 per cent respectively for Experiments 2 and 3. In the after noon, the relative humidity was less by 10 and 5 per cent respectively in Experiments 1 and 2 and more by 5 per cent in Experiment 3.

The rainfall, which is the most important weather parameter in this study recorded lower values for all the Experiments (6mm, 6.3mm and 93.6mm respectively for Experiment 1, 2 and 3) compared to the average values of 50.9mm, 41.7mm and 118mm respectively for Experiments 1, 2 and 3. Evaporation per day recorded no difference from the average during Experiment 1 where as it was less by 0.8mm and 0.7mm in Experiments 2 and 3 respectively.

Table 2. Mean values of weather parameters during the experiment season, average values for the last fifteen years and deviation from the average values

Standard weeks	Maximum temperature (°C)			Minimum temperature (°C)			Relative Humidity (%)						Rainfall (mm)			Evaporation (mm day^{-1})		
							Forenoon			Afternoon								
	C	A	D	C	A	D	C	A	D	C	A	D	C	A	D	C	A	D
Experiment 1																		
15-17	33.2	33.3	-0.1	25.8	25.1	+0.7	86	87	-1	66	76	-10	6	50.9	-44.9	5.5	5.5	—
Experiment 2																		
51-8	30.7	31.4	-0.7	20.9	21.7	-0.8	92	84	+8	63	68	-5	6.3	41.7	-35.4	3.7	4.5	-0.8
Experiment 3																		
9-19	32.5	33.0	-0.5	24.2	24.7	-0.5	89	85	+4	71	66	+5	93.6	118	-24.4	4.7	5.4	-0.7

C	-	Current Season
A	-	Average for last five years
D	-	Deviation of current season from the average
+	-	Increase
-	-	Decrease

3.2. Materials

3.2.1. Seeds used

The seeds of the local cv. Vellarikka obtained from Instructional Farm, College of Agriculture, Vellayani was used for the experiment.

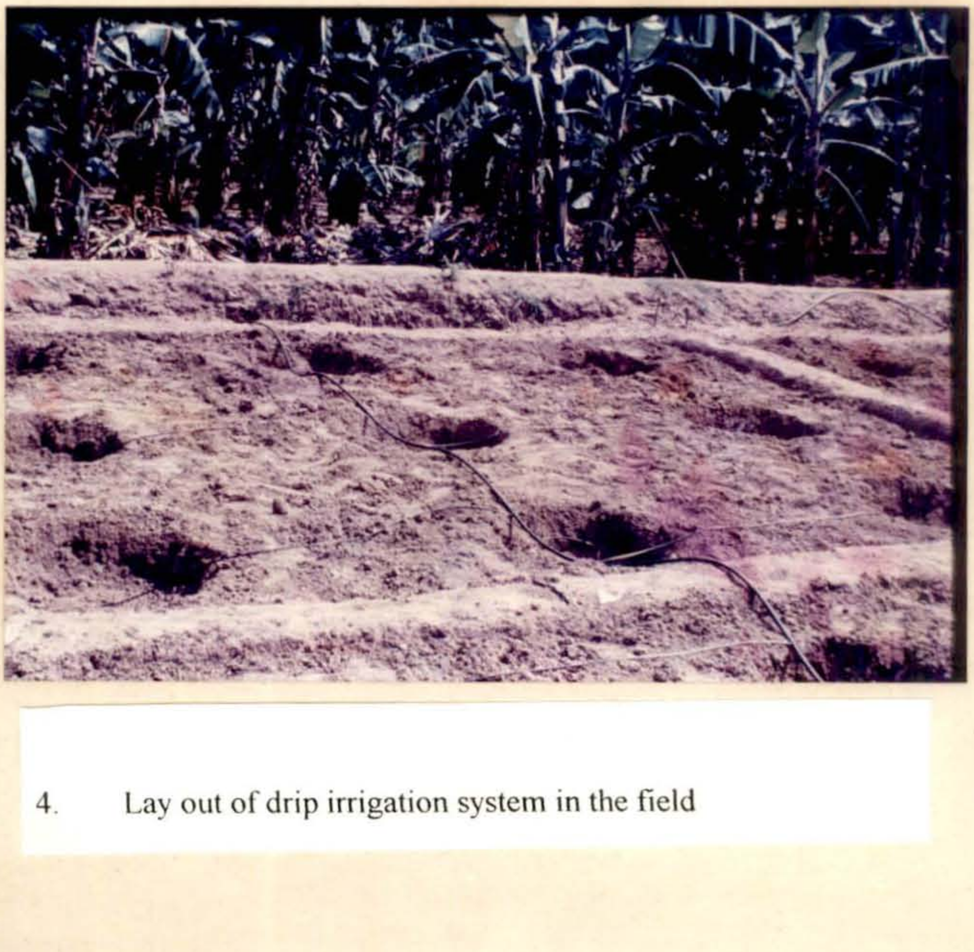
3.2.2. Manures and Fertilizers used

Farm yard manure analysing 42 per cent moisture, 0.4 per cent N, 0.3 per cent P_2O_5 and 0.2 per cent K_2O, urea (46 per cent N), mussoriephos (22 per cent P_2O_5) and muriate of potash (60 per cent K_2O) were used as sources of organic manure nitrogen, phosphorous and potassium respectively.

3.2.3. Drip unit and lay out

The drip unit was installed in the experimental site of 5000 sq.m.

The unit had a tank of capacity five lakh litres which is one of the main storage tanks of the irrigation unit of Instructional Farm, Vellayani. The outlet of the tank is provided with mesh filter of size 75mm. The water is again filtered at the entry of the plot by using another mesh filter of size 63mm. The drip unit had control values, 63mm main lines, 16mm submains and 3mm laterals. Tap type adjustable drippers were fixed to the laterals which were placed at the base of each plant. The pipelines and laterals were of low density polyethylene (LDPE) material.



4. Lay out of drip irrigation system in the field

3.2.4. Source of irrigation water

Kayal water from the Vellayani Lake pumped in for irrigating the farm area of Instructional Farm, Vellayani was used for irrigation.

3.3. Methods

3.3.1. Experiment 1. Preliminary observation trials

3.3.1.1. Experiment 1a

An observation trial was conducted to assess the flow rate from the drippers to standardise the number of drippers per plant and duration of irrigation. This trial of one week duration was repeated thrice at 3 different places within the main plot.

This trial was conducted in the drip irrigation unit existing in the Instructional Farm, College of Agriculture, Vellayani. Separate small ancillary drip unit was fitted with a single stage filter to which 16mm LDPE pipe was fitted. Tap type adjustable drippers were fitted on the 3mm LDPE pipe laterals at 24 points at a spacing of 1.5m. In 12 points one dripper per point was fitted and in the remaining 12 points 2 drippers point^{-1} were fitted at a spacing 20cm between the two drippers. The drippers were adjusted to give the discharge rates as mentioned in the treatments.

Treatments

(a) Levels of drip irrigation (3) : 4 l plant^{-1} day^{-1}
3 l plant^{-1} day^{-1}
2 l plant^{-1} day^{-1}

(b) Timings of irrigation (4) : 1 hour duration
2 hours duration
3 hours duration
4 hours duration

(c) Number of drippers plant^{-1} (2) : 1 number
2 numbers

(d) Discharge rates : Based on treatments a, b and c the combinations of a, b and c were fixed with suitable discharge rates. Thus each level of irrigation had 8 discharge rates as detailed in Table 3.

Table 3. Discharge rates of different drip irrigation levels

No. of drippers	Level of irrigation	Timing (hrs)	Discharge rate per dripper (l hr^{-1})
1	4 l $plant^{-1}$ day^{-1}	1	4
2	4 l $plant^{-1}$ day^{-1}	1	2
1	4 l $plant^{-1}$ day^{-1}	2	2
2	4 l $plant^{-1}$ day^{-1}	2	1
1	4 l $plant^{-1}$ day^{-1}	3	1.33
2	4 l $plant^{-1}$ day^{-1}	3	0.67
1	4 l $plant^{-1}$ day^{-1}	4	1
2	4 l $plant^{-1}$ day^{-1}	4	0.5
1	3 l $plant^{-1}$ day^{-1}	1	3
2	3 l $plant^{-1}$ day^{-1}	1	1.5
1	3 l $plant^{-1}$ day^{-1}	2	1.5
2	3 l $plant^{-1}$ day^{-1}	2	0.75
1	3 l $plant^{-1}$ day^{-1}	3	1
2	3 l $plant^{-1}$ day^{-1}	3	0.5
1	3 l $plant^{-1}$ day^{-1}	4	0.75
2	3 l $plant^{-1}$ day^{-1}	4	0.38
1	2 l $plant^{-1}$ day^{-1}	1	2
2	2 l $plant^{-1}$ day^{-1}	1	1
1	2 l $plant^{-1}$ day^{-1}	2	1
2	2 l $plant^{-1}$ day^{-1}	2	0.5
1	2 l $plant^{-1}$ day^{-1}	3	0.67
2	2 l $plant^{-1}$ day^{-1}	3	0.34
1	2 l $plant^{-1}$ day^{-1}	4	0.5
2	2 l $plant^{-1}$ day^{-1}	4	0.25

Observations recorded

a. Discharge rate

The discharge rate of each dripper was recorded daily by collecting the water discharged through the drippers for a period of 15 minutes and converted to l hr^{-1}.

b. Wetting front

Wetting was carried out for a week as per the treatment and the profile was dug out leaving 15cm in front of the dripper. The maximum width (cm) upto which the soil was moistened from the point of dripper was noted. Similarly the maximum depth (cm) upto which the soil was moistened was also noted for each dripper. Depth and width of wetted boundary was averaged for three places to draw the wetted boundary diagrammatically (Fig. 2).

c. Depth of irrigation

Based on the width of wetting, the area of wetting one plant was calculated based on the formula

$$\text{Area of irrigation} = \pi r^2$$

where r is the radius of wetting which was half of the width of wetting.

$$\text{Depth of irrigation} = \frac{\text{Volume of irrigation for one plant } (m^3)}{\text{Wetting area of one plant } (m^2)}$$

3.3.1.2. Experiment 1b

Another observational trial was conducted to find out the depth and spread of root system of cucumber. For this eighteen cucumber plants were raised during the period from 15.04.1992 to 24.05.1992 (40 days) with cultural practices as per KAU (1989). Irrigation was given through drip system at the rate of 4 l plant^{-1} day^{-1}, 3 l plant^{-1} day^{-1} and 2 l plant^{-1} day^{-1}. Each level of irrigation was applied for 6 plants. After 40 days of sowing, the roots of these plants were excavated and recorded the depth and spread of roots of each plant (Weaver, 1926).

Method of application of fertilizers

Based on the observational trial conducted to find out the depth and spread of roots of cucumber, the method of application of fertilizers was also standardised.

3.3.2. Experiment 2 and Experiment 3

3.3.2.1. Design

The design used was a $3^3 + 1 + 3$ confounded factorial experiment, confounding INK in Replication I and IN^2K^2 in Replication II. In all there were 27 treatment combinations, farmers practice and 3 control plots with irrigation alone as the treatment. The details of the treatments are as follows.

(a) Level of drip irrigation : i_1 - 2 l plant^{-1} day^{-1}
i_2 - 3 l plant^{-1} day^{-1}
i_3 - 4 l plant^{-1} day^{-1}

(b) Levels of nitrogen : n_1 - 35 kg ha^{-1}
n_2 - 70 kg ha^{-1}
n_3 - 105 kg ha^{-1}

(c) Levels of potash : k_1 - 25 kg ha^{-1}
k_2 - 50 kg ha^{-1}
k_3 - 75 kg ha^{-1}

(d) Farmers practice recommendation : f_1 - Pot watering @
4 l $plant^{-1}$ day^{-1}
nitrogen @ 35 kg ha^{-1}
and potash @ 25 kg ha^{-1}

(c) Control : c_1 - Drip irrigation @
2 l $plant^{-1}$ day^{-1}
without nitrogen and potash

c_2 - Drip irrigation @
3l $plant^{-1}$ day^{-1}
without nitrogen and potash

c_3 - Drip irrigation @
4 l $plant^{-1}$ day^{-1}
without nitrogen and potash

Phosphorous @ 25 kg ha^{-1} was supplied uniformly to all plots. Full phosphorous, full potash and half nitrogen was applied as basal, one fourth nitrogen at vining stage and one fourth at full blooming stage.

Number of treatments : 27 + 4 = 31

Treatment combinations : 27

Farmer's practice : 1

Control : 3

1. $i_1n_1k_1$ 2. $i_1n_1k_2$ 3. $i_1n_1k_3$ 4. $i_1n_2k_1$

5. $i_1n_2k_2$ 6. $i_1n_2k_3$ 7. $i_1n_3k_1$ 8. $i_1n_3k_2$

9. $i_1n_3k_3$ 10. $i_2n_1k_1$ 11. $i_2n_1k_2$ 12. $i_2n_1k_3$

13. $i_2n_2k_1$ 14. $i_2n_2k_2$ 15. $i_2n_2k_3$ 16. $i_2n_3k_1$

17. $i_2n_3k_2$ 18. $i_2n_3k_3$ 19. $i_3n_1k_1$ 20. $i_3n_1k_2$

21. $i_3n_1k_3$ 22. $i_3n_2k_1$ 23. $i_3k_2k_2$ 24. $i_3n_2k_3$

25. $i_3n_3k_1$ 26. $i_3n_3k_2$ 27. $i_3n_3k_3$ 28. f_1

29. c_1 30. c_2 31. c_3.

Number of replications : 2

Number of blocks per replication : 3

Number of plots per block : 13

Gross plot size : 8m x 7.5m.

Net plot size : 4m x 4.5m.

Spacing : 2m x 1.5m.

At the above spacing as per the Package of Practices Recommendation, Kerala Agricultural University (KAU, 1989), two plants can be maintained per pit. In these experiments, the number of plants per pit was limited to one. Hence the spacing given for the plants were 1m x 0.75m and the gross plot size and net plot size worked out to 6m x 5.25m and 2m x 2.25m respectively.

Out of the total 20 plants per plot, one row on all the sides was left as border. The remaining six plants were taken as observation plants from which biometric observations were recorded. Details of the lay out are given in Fig 3.

The allocation of various treatment combinations to different plots was as per the method advocated by Cochran and Cox (1965).

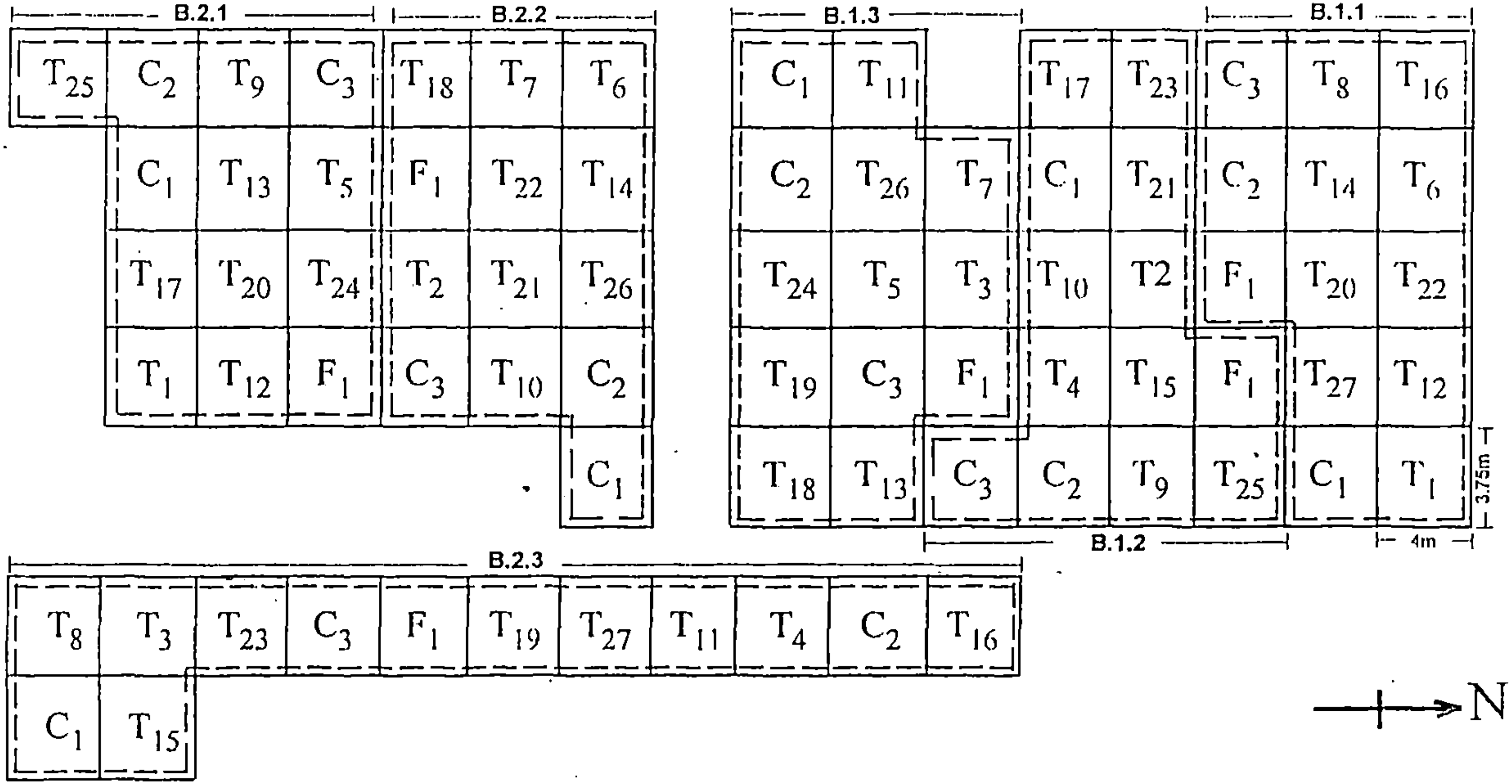
3.3.2.2. Land preparation

The land was ploughed twice with a power tiller, levelled and plots were laid out as per the layout plan given (Fig. 3). Farmyard manure @ 20 t ha^{-1} was applied to all the plots. The bund width of 1m between blocks and 0.75m between plots was maintained. Each pit was half filled with a mixture of top soil and dried and powdered cowdung before sowing of seeds.

3.3.2.3. Sowing of seeds

Seeds were sown in pits of diameter 60cm and depth 30cm. Three seeds were sown per pit.. After two weeks, it was thinned to one plant per pit.

Fig. 3. Lay out plan of Experiment 2 and 3



Design - Partially confounded factorial in Randomised Block Design. No. of blocks = 6 No. of plots / block = 13

Confounded effects - INK in RI and IN^2K^2 in RII.

3.3.2.4. Post planting operations

The seeds sown were given uniform irrigation immediately after planting and thereafter daily at the rate of half litre of water per pit for one week after sowing and at the rate of one litre per pit upto 2 weeks after sowing. From 15 days after sowing the irrigation as per the treatments started. The crop was weeded on 23 days after sowing at vining stage and the first top dressing was given. The second top dressing and earthing up was done on 38 days after sowing. At vine elongation stage banana leaves were spread on the ground for vines to spread (KAU, 1989). The vines were individually trained on the spreading area.

3.3.2.5. Plant protection

Stringent plant protection schedule was followed to prevent the incidence of yellow vein mosaic (vector control), aphids, fruit borers and diseases like powdery mildew.

3.3.2.6. Harvesting

The crop was harvested periodically almost at the rate of twice in a week. Harvesting commenced 45 days after sowing. Picking was continued for about four weeks, till most of the bearing ceased. Maturity of fruits for harvest was judged by visual observation.

3.3.2.7. Scheduling irrigation

The irrigation treatments were imposed once the seedlings were established from 15 days after sowing onwards. The method of irrigation was drip system except for the cultivators practice which received pot watering. The frequency of irrigation was daily through drippers which were adjusted to give the required discharge. Details of discharge rates are given in Table 4a.

Table 4a. Discharge rates for different levels of drip irrigation

Level of drip irrigation	Discharge rate (l hr^{-1})
2 l $plant^{-1}$ day^{-1} (i_1)	0.67
3 l $plant^{-1}$ day^{-1} (i_2)	1.00
4 l $plant^{-1}$ day^{-1} (i_3)	1.33

From the day of sowing upto 7 days of sowing, irrigation by pot watering at the rate of half litre of water per pit was given. From 8 days after sowing to 15 days after sowing (7 days) the crop was irrigated uniformly with one litre of water per pit. In terms of depth of irrigation it works out to 0.33mm and 0.67mm respectively for half litre and one litre.

On the 15th day of sowing the differential irrigations as per the treatments were started. Based on the wetted area of the basins of each plant, the depth of irrigation was worked out. The details of irrigation are given in Table 4b. Irrigation was withheld on the succeeding day of receiving more than 8mm rainfall.

Table 4b. Details of irrigation given

	Experiment 2				Experiment 3			
	i_2	i_3	i_4	f_1	i_2	i_3	i_4	f_1
Total number of irrigations (as per treatment)	55	55	55	55	50	50	50	50
Depth of irrigation (mm)	5	8	8	5.3	5	8	8	5.3
Quantity of irrigation water applied (mm)	275	440	440	292	250	400	400	265
Pre-treatment irrigation (mm)	7	7	7	7	7	7	7	7
Total quantity of water applied (mm)	282	447	447	299	257	407	407	272
Rainfall contribution (mm)	3.5	3.5	3.5	3.5	93.6	93.6	93.6	93.6

3.4. Observations

3.4.1. Biometric observations

In Experiments 2 and 3, 6 plants in the centre of the plot were selected as observation plants and the following observations were recorded at 30 DAS, 60 DAS and at final harvest stages.

3.4.1.1. Growth characters

3.4.1.1.1. Length of vine

The length of vine was recorded on the six observation plants at three growth stages viz. 30 DAS, 60 DAS and at final harvest. The length of the longest vine was measured from the base to the growing tip of the vine and the mean length per vine worked out.

3.4.1.1.2. Number of leaves per plant

The total number of leaves from the six observation plants was recorded on 30 DAS, 60 DAS and at final harvest stages and the mean number of leaves per plant worked out.

3.4.1.1.3. Leaf Area Index (LAI)

Leaf Area Index (LAI) was worked out in the sample plant used for the estimation of dry matter production on 30 DAS, 60 DAS and final harvest stages. Area of all leaves produced by the plant were recorded using LI - 3100 leaf area meter and LAI was worked out using the formula suggested by William (1946).

3.4.1.1.4. Dry matter production per hectare

Dry matter production was recorded during three growth stages viz. 30 DAS, 60 DAS and at final harvest. One plant per row was randomly selected from the border for that purpose at each stage, cut close to ground and oven dried at 80 ± 5°C to a constant weight. The dry weight of fruits and vines recorded separately were added together to obtain the total dry matter production and then converted into per hectare value.

3.4.1.2. Yield components and yield

3.4.1.2.1. Number of fruits harvested per plant

The number of fruits harvested from all the plants in the net plot was counted and average worked out for a plant.

3.4.1.2.2. Length of fruits

The length of all the fruits harvested from each observational plant was recorded in centimetres and the mean length worked out.

3.4.1.2.3. Girth of fruit

The girth at the centre of each fruit harvested from the observational plant was recorded and the mean girth of the fruit calculated.

3.4.1.2.4. Weight of fruit

The weight of all the fruits harvested from the observational plants were recorded in kilograms and the mean weight worked out.

3.4.1.2.5. Fruit setting percentage

The total number of female flowers produced by the observational plants and the total number of fruits harvested from these observational plants were recorded and the fruit setting percentage worked out.

3.4.1.2.6. Sex ratio

The total number of male flowers produced by each observational plant in each plot was related to the total number of female flowers produced by that plant and the sex ratio calculated and expressed as number of female flowers per hundred male flowers.

3.4.1.2.7. Fruit yield per hectare

Weight of individual fruits from the various harvests of each plot was totalled at the end of the cropping period and the average yield in tons per hectare worked out.

3.4.1.2.8. Vine yield per hectare

Weight of the vines of all the observational plants in each plot was recorded after the final harvest of fruits and converted into vine yield per hectare.

3.4.1.1.3. Shelf life of fruits

a. Selection of fruits for noting shelf life

Composite samples were made treatment wise separately in each replication by selecting ten fruits. This was done at two stages of harvesting 60 DAS and at final harvest by visual observations on firmness of fruits and colour of fruits.

b. Firmness of fruits

The fruit samples were kept on a wooden table and the firmness of flesh was noted daily physically. The days upto which firmness was maintained was recorded.

c. Colour of fruits

The days from harvest upto which the green colour of fruits were maintained was also recorded.

3.4.2. Root studies at harvest

Root studies such as rooting pattern, depth of penetration and root dry matter produced as influenced by levels of irrigation and nutrients were studied in both the experiments. Root studies were undertaken immediately after the final harvest of the crop.

3.4.2.1. Rooting pattern

Two plants were selected in each treatment from the middle of the plot. After wetting the soil around the plant thoroughly, trenches were dug on one side of the plant in a semicircular way leaving a radius of 75cm from the base of the plant and also taking care to see that no major roots are cut. Then the soil around the semicircular hemisphere of plant was slowly exposed using jets of water spray. This was done till the net work of roots were clearly visible. However, it was difficult to maintain profile position of roots because of sagging caused by soil removal. Care was taken as far as possible to maintain the position of roots intact, by use of small nails. Spread of the main roots was measured ignoring small rootlets as they were damaged during excavation (Weaver, 1926).

3.4.2.2. Root dry matter

After the profile study, trenches were dug all around the plant and soil was removed by using water spray. The root system was carefully uprooted, washed and oven dry weight was recorded and expressed as gram per plant.

3.4.2.3. Root depth

The depth upto which the main root has penetrated was measured from the base of the plant to the tip of the root and expressed in centimetres.

3.4.3. Moisture studies

Moisture studies included soil sampling to know soil moisture status, computation of water use, water use per day, field water use efficiency, consumptive use, and evaporation studies.

3.4.3.1. Soil moisture status

The soil moisture status was found out by taking soil samples before planting, just before the treatment imposition and after the final harvest from the root zone of the plant. Samples were taken at 0-15, 15-30, 30-60 and 60-90cm depths and percentage of moisture estimated gravimetrically. Moisture percentage was estimated on oven dry basis as outlined by Dasthane (1967).

3.4.3.2. Water use

Amount of irrigation water applied to various treatments was considered as total water used in crop production. In addition water consumed for the initial establishment and effective rainfall were also added.

Total water use was obtained by adding up all the daily depths of irrigation water applied plus effective rainfall and water given for the initial establishment. Irrigation water use per day was also calculated by dividing the total irrigation water applied by the number of days.

3.4.3.3. Field water use efficiency

Field water use efficiency was calculated by dividing the economic crop yield (Y) by the total amount of water used in the field (WR) and expressed as kilogram per hectare millimetre.

$$\text{Field water use efficiency } (E\ \ ) = \frac{Y}{WR}$$

3.4.3.4. Consumptive use

Consumptive use was worked out from the data on soil moisture depletion as suggested by Dasthane (1972). Soil moisture depletion from the layers at depths of 0-15, 15-30, 30-60 and 60-90cm were estimated, at the final harvest stage of the crop. Mean daily consumptive use was obtained by dividing total consumptive use by the total number of days.

3.4.3.5. Evaporation studies

Daily open pan evaporimeter readings were recorded and from that cumulative pan evaporation per week and average per day were worked out.

3.4.4. Plant analysis

The plant samples were analysed for nitrogen, phosphorus and potassium at 30 DAS, 60 DAS and at final harvest. The plant was seperated into root, stem, leaves and fruits. These were chopped and dried separately in air oven at 70 ± 5°C till constant weights were obtained. Samples were ground to pass through a 0.4mm mesh in a Willey mill. The required quantity of samples were then weighed out accurately in a physical balance and analysed.

3.4.4.1. Total nitrogen content

Total nitrogen content was estimated by modified microkjeldahl method as given by Jackson (1973) and the values were expressed as percentages.

3.4.4.4.2. Uptake of nitrogen

This was calculated by multiplying the nitrogen content of root, stem, leaves or the fruits as the case may be with the total dry weight of root, stem, leaves or fruits. The uptake values were expressed in kg ha^{-1}.

3.4.4.3. Total phosphorous content

Phosphorous content was analysed colorimetrically (Jackson 1973) after wet digestion of the sample using 2:1 mixture of nitric acid and perchloric acid and developing colour by Vanadomolybdo phosphoric yellow colour method and read in a Klett Summerson photo electric colorimeter.

3.4.4.4. Uptake of phosphorous

This was calculated by multiplying the phosphorus content and dry weight of the root, stem, leaves and fruits as the case may be. The values were expressed in kg ha^{-1}.

3.4.4.5. Total potash content

Total potash content in plants was estimated by the flame photometric method in a Systronics Flame photometer after wet digestion of the sample using diacid mixture.

3.4.4.6. Uptake of potash

This was calculated by multiplying the dry weights and potash content of the root, stem, leaves or fruits as the case may be. The uptake values were expressed in kg ha^{-1}.

3.4.5. Soil analysis

Soil samples were taken from the experiment area before and after each experiment for the estimation of available nitrogen, available phosphorous and available potash. The air dried samples were analysed for available nitrogen by the Alkaline potassium permanganate method (Subbiah and Asija 1956). The soil samples were analysed for available phosphorous by Bray colorimetric method (Jackson 1973) and available potash by the ammonium acetate method (Jackson 1973).

3.5. Economics of the study

Economics of drip irrigation, was worked out using discounted cash flow technique (Gittinger 1972). The parameters used were Benefit-cost ratio, Internal rate of returns and Net present worth. Details of assumptions made in working out the economics are given in Appendix II.

3.6. Statistical analysis

The experimental data was analysed statistically by applying the technique of analysis of variance as per the layout of experiments (Panse and Sukhatme, 1967) and pooled analysis was also conducted for important characters. The physical and economic optimum for drip irrigation level, nitrogen and potassium were worked out separately for each crop fitting quadratic response surface function for drip irrigation, nitrogen and potassium using the formula $y = b_0 + b_1I + b_2N + b_3K + b_{11}I^2 + b_{22}N^2 + b_{33}K^2 + b_1b_2IN + b_1b_3IK + b_2b_3NK$ (Das and Giri, 1979). Stepwise regression was performed to study the influence of available N and K content of the soil on the yield of cucumber (Draper and Smith, 1966).

RESULTS

4. RESULTS

The present investigation was undertaken to study the growth and yield of cucumber under drip irrigation and to standardise a suitable drip irrigation and fertilizer schedule. A preliminary observation trial was conducted during April 1992 in the experimental fields of Instructional Farm, College of Agriculture, Vellayani. The results are presented below.

4.1. Experiment 1

4.1.1. Experiment 1a

Observational trial to standardise the flow rate from the drippers, number of drippers per plant and duration of irrigation

The results obtained in the trial are presented in Table 5 and Fig. 1, 2 and 2a.

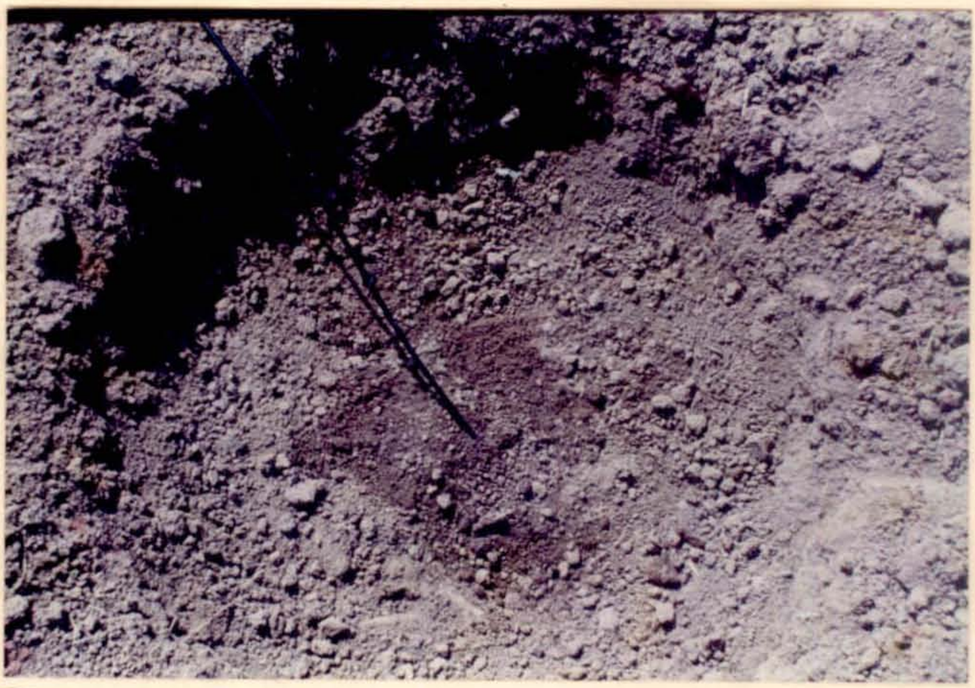
Based on the available results from literature, it can be seen that the effective root system of cucumber may spread up to a distance of 40 cm from the dripper under drip irrigation. The pattern of wetting observed in the trial is given in Table 5. In the present study the treatments which recorded a width of wetting upto 50cm were considered better as a first step. Accordingly the following treatments were selected.

Level of irrigation (l plant^{-1} day^{-1})	Serial number in table 5	Inferance drawn
4	5	Can be considered favourably
	6	Can be considered favourably
	7	Can be considered favourably
	8	Cannot be considered since there is tendency for air blocks.
3	13	Can be considered favourably
	14	Cannot be considered since there is tendency for air blocks.
	15	Cannot be considered since the depth of irrigation is less.
	16	Cannot be considered since there is tendency for air blocks.
2	19	Can be considered favourably
	21	Can be considered favourably
	22	Cannot be considered since there is tendency for air blocks.
	23	Cannot be considered since there is tendency for air blocks.
	24	Cannot be considered since there is tendency for air blocks.

Table 5. Pattern of wetting observed in the trial

Sl No.	Level of irrigation l plant^{-1} day^{-1}	No. of drippers plant^{-1}	Duration of irrigation (hrs.)	Discharge rate per dripper (l hr^{-1})	Width of wetting (cm)	Depth of wetting (cm)	Observations on dripper performance
1.	4	1	1	4.00	83.45	74.50	Uniform
2.	4	2	1	2.00	91.33	75.66	Uniform
3.	4	1	2	2.00	64.43	47.00	Uniform
4.	4	2	2	1.00	75.85	65.54	Uniform
5.	4	1	3	1.33	40.12	23.04	Uniform
6.	4	2	3	0.67	49.56	26.51	Uniform
7.	4	1	4	1.00	35.97	20.50	Uniform
8.	4	2	4	0.50	47.48	25.39	Tendency for air block
9.	3	1	1	3.00	84.59	75.10	Uniform
10.	3	2	1	1.50	92.20	76.29	Uniform
11.	3	1	2	1.50	52.31	36.11	Uniform
12.	3	2	2	0.75	64.32	46.35	Uniform
13.	3	1	3	1.00	35.37	19.68	Uniform
14.	3	2	3	0.50	43.68	24.14	Tendency for air block
15.	3	1	4	0.75	23.48	9.12	Uniform
16.	3	2	4	0.38	35.94	20.05	Tendency for air block
17.	2	1	1	2.00	70.56	44.68	Uniform
18.	2	2	1	1.00	86.17	70.86	Uniform
19.	2	1	2	1.00	42.87	23.95	Uniform
20.	2	2	2	0.50	59.83	41.51	Tendency for air block
21.	2	1	3	0.67	35.09	18.99	Uniform
22.	2	2	3	0.34	40.40	23.54	High tendency for air block
23.	2	1	4	0.50	21.51	8.64	Tendency for air block
24.	2	2	4	0.25	36.22	21.40	Dripping seriously hampered by air blocks

1. Width of wetting at the drip irrigation level of 2l plant^{-1} day^{-1}



2. Width of wetting at the drip irrigation level of 3l plant^{-1} day

3. Width of wetting at the drip irrigation level of 4l plant^{-1} day

From among the above, treatments 5, 13 and 21 were selected for levels of irrigation of 4,3 and 2 liters per plant per day since for all there three treatments the duration of irrigation and number of drippers were uniform being 3 hours per day and one dripper per plant respectively. The flow rates per dripper for the levels 4, 3 and 2 l plant^{-1} day^{-1} were 1.33, 1.00 and 0.67 l hr^{-1} respectively.

The results on the depth of irrigation in terms of mm plant^{-1} day^{-1} is given in Table 6.

4.1.1. Experiment Ib

The depth and spread of root system of cucumber were studied under different levels of drip irrigation. The results are presented in Table 7a.

Method of application of fertilizers

The observational plants raised under the Experiment 1b were further studied for their root distribution pattern. The roots of three observation plants raised under each level of irrigation were removed and separated at lateral distances of 0-30cm and 30-60cm. The dry weight at each distance was recorded and presented in Table 7b. Similary the roots of the other three observation plants receiving each level of irrigation were removed and separated at vertical distances of 0-25cm and 25-50cm and below 50cm. The dry weight of roots at each vertical distance were noted and given in Table 7b.

Table 6. Details of depth of irrigation

Level of irrigation	Width of wetting (cm)	Wetting area of one plant (sq.m)	Depth of irrigation mm/plant/day
A. Drip irrigation			
2 l plant^{-1} day^{-1}	35.09	0.3847	5
3 l plant^{-1} day^{-1}	35.37	0.3847	8
4 l plant^{-1} day^{-1}	40.12	0.5024	8
B. Farmer's practice			
Pot watering @ 4 l plant^{-1} day^{-1}	—	0.75	5.3

Table 7 a. Depth and spread of root system of cucumber under drip irrigation

Level of drip irrigation (l plant^{-1} day^{-1})	Depth of root system (cm)	Spread of root system (cm)
2	38.62	26.24
3	48.59	32.72
4	56.55	43.50

Table 7b. Dry weight of root of cucumber (g) in different depths and lateral distances under drip irrigation

Levels of irrigation (l plant^{-1} day^{-1})	Depth (cm)			Lateral distance (cm)	
	0-25	25-50	> 50	0-30	30-60
2	8.12	2.84	—	10.76	—
3	8.69	2.84	—	10.98	0.22
4	9.13	2.14	0.90	11.02	1.05

The results given in Table 7b showed that 75 per cent of the roots of drip irrigated cucumber at all the three levels of irrigation were located at a depth of 0-25cm and at a lateral distance of 0-30cm from the base of the plant. Based on this result, it was concluded that fertilizers can be applied as a ring at a distance of 20cm from the base of the plant.

4.2. Experiment 2 and Experiment 3

4.2.1. Growth characters

4.2.1.1. Length of vine

4.2.1.1.1. Effect of I, N and K on the length of vine (Table 8)

The data on mean length of vine recorded at 30 DAS, 60 DAS and at final harvest indicated that vine length was significantly influenced by levels of irrigation, nitrogen and potassium during all the three stages in both the experiments.

Among the levels of irrigation i_2 was significantly superior to others during all the three stages in both the experiments while the treatments i_1 and i_3 were on par at all the three stages in Experiment 2 and at 60 DAS and final harvest stages in Experiment 3 while at 30 DAS they varied significantly.

The increase in vine length due to each increment in the level of nitrogen application was positive and significant up to n_2 during all the three stages. Significantly lower vine length was recorded at n_3 than n_1 at all the three stages.

Table 8. Effect of I, N and K on the length of vine (cm)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1	151.23	218.40	277.89	168.71	254.90	321.38
i_2	170.37	263.68	336.85	196.44	303.97	389.47
i_3	156.81	235.39	298.02	176.32	265.25	336.32
$F_{2,22}$	21.96**	8.05**	11.98*	279.27**	37.87**	6.33**
n_1	140.23	222.93	267.36	149.30	237.32	284.08
n_2	176.58	252.95	338.02	211.57	317.56	420.92
n_3	161.60	241.59	307.38	180.60	269.23	342.18
$F_{2,22}$	75.64**	3.53*	16.74**	1318.04**	92.41**	23.33**
k_1	138.28	206.38	263.79	147.84	233.89	284.89
k_2	177.48	268.20	342.37	209.89	316.74	412.93
k_3	162.66	242.89	306.60	183.75	273.48	349.36
$F_{2,22}$	88.79**	14.85*	20.65**	1319.50**	97.23**	20.27**
SEd	2.971	11.404	12.246	1.213	5.943	20.109
CD	6.161	23.652	25.398	2.515	12.326	41.706

* Significant at 0.05 level ** Significant at 0.01 level

Successive increase in the level of potassium up to k_2 level also significantly increased the vine length during the three stages of observation in both experiments.

4.2.1.1.2. Interaction effect of I, N and K on the length of vine (Table 9)

The interaction effect of irrigation and nitrogen level was significant only at final harvest stages in Experiment 2 where as in Experiment 3, significance was observed at 30 DAS and 60 DAS. At all stages in both crops, the effect due to i_2n_2 was found to be the highest. At i_1 level no difference in vine length was observed due to the different nitrogen levels. At i_2 level of irrigation n_2 and n_3 were on par at the final harvest stage of Experiment 2. In Experiment 3, at 30 DAS, effect due to the levels of nitrogen were significant at i_2, where i_2n_2 recorded the highest vine length (233.06cm) followed by i_2n_3 (196.35 cm) and i_2n_1 (159.92 cm). At 60 DAS, i_2n_1 and i_2n_3 were on par while i_2n_2 recorded the highest vine length of 367.27cm. At i_3 level, in all the cases, the maximum response was observed at n_2 level.

The length of vine was significantly influenced by IK interactions at 30 DAS in Experiment 2 and at 30 DAS and 60 DAS in Experiment 3. At i_1 the vine length due to k_1 was significantly lower at all the stages. The levels i_2k_2 and i_2k_3 were on par at 30 DAS in Experiment 2 and at 60 DAS in Experiment 3. At i_2 and i_3, k_2 recorded the maximum vine length which was significantly higher than that at k_1 and k_3.

Table 9. Interaction effect of I, N and K on the length of vine(cm)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1n_1	136.34	214.96	263.56	142.82	225.32	274.08
i_1n_2	162.24	205.95	283.32	194.88	284.99	379.35
i_1n_3	155.13	234.30	286.80	168.42	254.40	310.71
i_2n_1	147.04	232.00	274.84	159.92	252.21	299.87
i_2n_2	190.06	298.84	389.05	233.06	367.27	476.57
i_2n_3	174.01	260.20	346.66	196.35	292.43	391.97
i_3n_1	137.31	221.83	263.68	145.16	234.44	278.29
i_3n_2	177.44	254.07	341.69	206.77	300.43	406.82
i_3n_3	155.67	230.28	288.68	177.03	260.88	323.87
$F_{4,22}$	NS	NS	2.91^{*}	12.71^{**}	4.78^{**}	NS
i_1k_1	123.49	160.00	234.68	137.22	213.21	261.11
i_1k_2	164.92	247.90	307.13	186.92	279.54	362.61
i_1k_3	165.30	247.31	291.88	181.98	271.96	340.42
i_2k_1	150.75	238.38	292.23	160.53	253.93	312.48
i_2k_2	191.24	300.90	379.39	232.13	366.94	468.41
i_2k_3	169.12	251.77	338.94	196.68	291.04	387.52
i_3k_1	140.60	220.77	264.46	145.77	234.53	281.09
i_3k_2	176.27	255.81	340.61	210.61	303.75	407.77
i_3k_3	153.56	229.59	288.98	172.57	257.47	320.12
$F_{4,22}$	5.27^{**}	NS	NS	41.20^{**}	6.86^{**}	NS
n_1k_1	125.29	195.43	240.10	136.28	212.35	261.68
n_1k_2	153.86	244.13	300.67	162.63	257.52	314.00
n_1k_3	141.55	229.22	261.33	148.99	242.10	276.56
n_2k_1	148.28	197.58	280.46	159.30	251.96	308.98
n_2k_2	198.85	306.00	387.21	253.14	390.48	520.23
n_2k_3	182.61	255.28	346.38	222.26	310.24	433.53
n_3k_1	141.28	226.13	270.80	147.93	237.36	284.02
n_3k_2	179.72	254.49	339.24	213.89	302.22	404.56
n_3k_3	163.82	244.16	312.09	179.99	268.13	337.97
$F_{4,22}$	NS	NS	NS	144.43^{**}	11.94^{**}	NS
SEd	5.155	—	21.252	2.105	10.314	—
CD	0.670	—	43.991	4.357	21.349	—

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

The interaction effect of NK was not found to be significant at any stages during Experiment 2. But in Experiment 3, this effect was significant at 30 DAS and 60 DAS. At n_1 the effect due to k_1, k_2 and k_3 significantly varied at 30 DAS where as at 60 DAS, k_2 and k_3 where on par. At n_2 and n_3 levels also k_2 recorded the highest vine length followed by k_3 and k_1.

4.2.1.2. Number of leaves per plant

4.2.1.2.1. Effect of I, N and K on the number of leaves per plant (Table 10)

The data recorded on 30 DAS, 60 DAs and at final harvest stage revealed that the number of leaves produced per plant was significantly influenced by the levels of irrigation, nitrogen and potassium at all the three stages in both experiments.

Among irrigation levels i_2 produced the highest number of leaves at all the three stages in both experiments which was significantly superior to the levels, i_1 and i_3.

The successive increase in the levels of nitrogen application showed significant increase in leaf number upto n_2 at all the three stages in both experiments.

The increase in leaf number at k_2 over k_3 and k_3 over k_1 was significant at all the three stages in both experiments.

Table 10. Effect of I, N and K on the number of leaves per plant

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1	30.08	57.54	27.87	43.05	94.18	73.25
i_2	39.46	87.14	45.05	54.59	126.77	111.49
i_3	33.27	64.51	36.21	46.66	109.94	91.05
$F_{2,22}$	18.43**	34.62**	18.98**	18.91**	29.82**	36.87**
n_1	25.32	45.33	19.64	35.60	76.87	56.74
n_2	43.68	96.13	55.49	61.34	153.44	132.19
n_3	33.82	67.73	33.99	47.36	100.57	86.86
$F_{2,22}$	68.38**	93.65**	83.73**	90.07**	172.47**	145.21**
k_1	24.85	43.24	17.24	34.91	80.53	50.95
k_2	43.72	98.03	55.99	61.31	141.61	132.94
k_3	34.25	67.92	35.90	48.07	108.74	91.98
$F_{2,22}$	72.16**	108.80**	96.59**	94.49**	104.94**	169.24**
SEd	1.571	3.721	2.788	1.920	4.221	4.457
CD	3.259	7.717	5.783	3.983	8.754	9.243

* Significant at 0.05 level ** Significant at 0.01 level

4.2.1.2.2. Interaction effect of I, N and K on the number of leaves per plant (Table 11)

Interactions due to irrigation and nitrogen on the number of leaves per plant was significant at 60 DAS and final harvest stage of both experiments. At all the levels of drip irrigation (i_1, i_2, i_3) the highest number of leaves was recorded at n_2 level followed by n_3 and then by n_1. All the interactions were significantly varying from one another.

The effects due to IK were significant at all the stages in both experiments. At i_1, k_2 and k_3 were on par at the three stages in both experiments. At i_2 and i_3, k_2 recorded the highest number of leaves at all stages in both experiments which was significantly superior to k_3 and k_1.

The NK interactions were also significant at all the three stages in both experiments. At n_1, n_2 and n_3 the highest number of leaves was recorded at k_2 level followed by k_3 and k_1 levels. At n_1, the levels k_3 and k_1 were on par at 30 DAS and 60 DAS in both experiments.

4.2.1.3. Leaf Area Index

4.2.1.3.1 Effect of I, N and K on Leaf Area Index (Table 12)

Significant influence on leaf area index due to the levels of irrigation, nitrogen and potassium was observed from the data recorded at 30 DAS, 60 DAS and at final harvest.

Table 11. Interaction effect of I, N and K on the number of leaves per plant

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1n_1	23.82	40.93	17.02	35.19	66.92	49.92
i_1n_2	36.94	72.80	39.82	53.30	130.68	100.13
i_1n_3	29.48	58.90	26.77	40.66	84.94	69.69
i_2n_1	28.15	53.50	25.05	38.81	89.11	68.00
i_2n_2	50.75	126.92	66.38	70.52	180.81	157.44
i_2n_3	39.49	81.03	43.71	54.45	110.38	109.03
i_3n_1	24.00	41.56	16.87	32.80	74.59	52.28
i_3n_2	43.35	88.68	60.27	60.20	148.82	138.98
i_3n_3	32.48	63.28	31.52	46.97	106.4	81.88
$F_{4,22}$	NS	5.84^{**}	3.02^{*}	NS	3.03^{*}	4.35^{**}
i_1k_1	20.88	34.80	9.85	30.71	66.66	30.59
i_1k_2	35.69	71.25	36.81	49.93	105.62	94.19
i_1k_3	33.67	66.59	36.95	48.51	110.26	94.97
i_2k_1	29.05	52.17	24.38	40.08	97.68	69.77
i_2k_2	51.97	134.82	72.16	71.93	162.87	166.79
i_2k_3	37.37	74.45	38.61	51.77	119.76	97.91
i_3k_1	24.61	42.75	17.50	33.95	77.25	52.50
i_3k_2	43.51	88.03	59.01	62.09	156.36	137.85
i_3k_3	31.72	62.73	32.16	43.94	96.21	82.79
$F_{4,22}$	3.11^{*}	11.51^{**}	6.94^{**}	4.97^{**}	10.75^{**}	11.53^{**}
n_1k_1	20.72	33.87	10.76	30.02	59.69	33.98
n_1k_2	30.11	59.72	28.66	41.91	91.53	78.00
n_1k_3	25.15	42.40	19.52	34.87	79.41	58.22
n_2k_1	29.73	55.47	25.12	41.41	100.89	69.30
n_2k_2	57.84	140.07	87.60	80.48	213.28	198.44
n_2k_3	43.48	92.87	53.76	62.13	146.14	128.82
n_3k_1	24.10	40.38	15.85	33.31	81.00	49.57
n_3k_2	43.22	94.31	51.71	61.55	120.04	122.38
n_3k_3	34.13	68.51	34.44	47.22	100.68	88.64
$F_{4,22}$	5.94^{**}	10.58^{**}	10.87^{**}	8.54^{**}	19.33^{**}	15.94^{**}
SEd	2.727	6.457	4.839	3.333	7.325	7.734
CD	5.645	13.365	10.017	6.899	15.162	16.010

* Significant at 0.05 level   ** Significant at 0.01 level   NS Not Significant

Table 12. Effect of I, N and K on the leaf area index

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1	0.30	0.53	0.28	0.45	0.79	0.36
i_2	0.36	0.74	0.41	0.53	1.01	0.58
i_3	0.33	0.57	0.33	0.49	0.79	0.48
$F_{2,22}$	6.5**	13.69**	8.44**	4.68*	33.33**	8.54**
n_1	0.28	0.41	0.22	0.41	0.59	0.30
n_2	0.37	0.86	0.49	0.54	1.15	0.69
n_3	0.34	0.57	0.31	0.51	0.84	0.43
$F_{2,22}$	13.17**	56.71**	35.49**	13.69**	161.00**	29.67**
k_1	0.26	0.39	0.19	0.42	0.56	0.28
k_2	0.35	0.85	0.50	0.55	1.15	0.71
k_3	0.33	0.60	0.33	0.50	0.87	0.43
$F_{2,22}$	11.92**	58.43**	42.99**	13.35**	168.91**	36.19**
SEd	0.017	0.043	0.033	0.026	0.032	0.051
CD	0.036	0.090	0.069	0.053	0.066	0.106

* Significant at 0.05 level ** Significant at 0.01 level

With i_2, the highest LAI was recorded at all the stages. The other two levels of i_1 and i_3 were on par at all the stages in both experiments.

Leaf Area Index was significantly influenced by nitrogen levels. Significantly higher leaf area index at all the stages in both the experiments was recorded by n_2, the highest being at 60 DAS (0.86 and 1.15 for Experiments 2 and 3 respectively).

Potash levels also influenced the leaf area index significantly. Higher values of leaf area index at all the three stages, was recorded at k_2 the highest being at 60 DAS (0.85 and 1.15 respectively for Experiments 2 and 3).

4.2.1.3.2. Interaction effect of I, N and K on the Leaf Area Index (Table 13)

The interaction effects of irrigation and nitrogen on LAI recorded significance at final harvest stage of Experiment 2 and at 60 DAs and final harvest stages of Experiment 3. The interaction effect due to i_1 was statistically on par for n_1, n_2 and n_3 at the final harvest stages of both experiments. At the levels i_2 and i_3 the highest leaf area was at n_2 level at final harvest stage, while n_1 and n_3 were found to be on par. With respect to IN interaction at 60 DAS in Experiment 3 at all the levels of drip irrigation the highest leaf area index was recorded at n_2 followed by n_3 and then at n_1.

Table 13. Interaction effect of I, N and K on leaf area index

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1n_1	0.27	0.38	0.23	0.41	0.55	0.29
i_1n_2	0.32	0.73	0.33	0.48	1.09	0.44
i_1n_3	0.31	0.48	0.27	0.46	0.71	0.37
i_2n_1	0.31	0.47	0.25	0.45	0.66	0.34
i_2n_2	0.40	1.05	0.63	0.59	1.35	0.87
i_2n_3	0.38	0.71	0.36	0.55	1.02	0.52
i_3n_1	0.27	0.38	0.18	0.38	0.55	0.27
i_3n_2	0.38	0.80	0.52	0.57	1.02	0.76
i_3n_3	0.34	0.53	0.29	0.51	0.49	0.42
$F_{4,22}$	NS	NS	3.69*	NS	2.91*	2.97*
i_1k_1	0.23	0.35	0.15	0.34	0.48	0.21
i_1k_2	0.33	0.64	0.34	0.50	0.97	0.46
i_1k_3	0.34	0.60	0.34	0.50	0.90	0.42
i_2k_1	0.33	0.43	0.25	0.48	0.64	0.35
i_2k_2	0.40	1.14	0.65	0.57	1.44	0.92
i_1k_3	0.36	0.66	0.34	0.53	0.95	0.46
i_3k_1	0.29	0.38	0.18	0.43	0.57	0.27
i_3k_2	0.38	0.79	0.51	0.57	1.03	0.75
i_3k_3	0.32	0.54	0.30	0.47	0.76	0.42
$F_{4,22}$	NS	5.96**	3.95*	NS	10.26**	3.14*
n_1k_1	0.24	0.35	0.14	0.35	0.46	0.21
n_1k_2	0.32	0.48	0.30	0.48	0.75	0.41
n_1k_3	0.28	0.39	0.21	0.42	0.55	0.28
n_2k_1	0.32	0.44	0.27	0.47	0.66	0.38
n_2k_2	0.41	1.24	0.79	0.61	1.52	1.15
n_2k_3	0.38	0.91	0.42	0.55	1.29	0.54
n_3k_1	0.30	0.38	0.17	0.43	0.57	0.25
n_3k_2	0.37	0.84	0.42	0.55	1.18	0.57
n_3k_3	0.36	0.50	0.35	0.54	0.78	0.49
$F_{4,22}$	NS	10.90**	6.55**	NS	18.84**	7.60**
SEd	—	0.075	0.058	—	0.055	0.089
CD	—	0.155	0.120	—	0.114	0.184

* Significant at 0.05 level ** Significant at 0.01 level NS *Not Significant*

The interactions due to IK were significant at 60 DAS and final harvest stages of both experiments. At the drip irrigation level of i_1, the highest LAI was at k_2 which was on par with k_3, at both the stages in both experiments. With respect to i_2 at 60 DAS, highest LAI was observed at k_2, followed by k_3 and by k_1. At the final harvest stage in both experiments, for i_2 and i_3, the highest leaf area index was recorded at k_2. The levels of k_3 and k_1 were on par, with respect to this character.

NK interactions with respect to LAI were significant at 60 DAS and final harvest stages of both experiments. In Experiment 2, at n_1, the levels of k_1, k_2 and k_3 were all on par at both stages. At n_2, the level of k_2 (1.24 and 0.79 at 60 DAS and FH respectively) recorded the highest LAI followed by n_3 and n_1. At 60 DAS k_2 recorded the highest LAI (0.84) followed by k_3 and k_1 which were on par. At final harvest stage, the highest LAI of 0.42 was at k_2 followed by k_3 (0.35) which were on par.

During Experiment 3, at n_1, the highest LAI was recorded at k_2 (0.75 and 0.41 respectively) at 60 DAS and FH. This was followed by k_3 and then by k_1 which were on par at both stages. At 60 DAS the highest LAI was at k_2 level with respect to n_2 and n_3 (1.52 and 1.18 respectively). This was followed by k_3 and k_1. At final harvest for n_2 and n_3 levels, the highest LAI was found to be at k_2 level (1.15 and 0.57 respectively). It was seen that k_3 and k_1 were on par at both n_2 and n_3 in this stage.

4.2.1.4. Dry matter production per hectare

4.2.1.4.1. Effect of I, N and K on dry matter production per hectare (Table 14) (Fig. 4)

The dry matter production was significantly influenced by irrigation, nitrogen and potash levels. At all the stages for both the experiments irrigation levels of i_2 recorded highest dry matter production. For both experiments the dry matter production recorded at final harvest was the highest being 2675.26 and 3957.14 kg ha^{-1} respectively in Experiment 2 and Experiment 3.

Different levels of nitrogen tried, recorded significant variation at all the three stages in both the experiments with respect to dry matter production. The highest dry matter at all stages, was produced by n_2 (3074.84 and 4288.03 kg ha^{-1} respectively).

Potash level of k_2 was found to be superior with respect to dry matter production. The other two levels recorded significantly lower values of dry matter. At k_2 level, the highest dry matter recorded was at final harvest stage of the experiment. (3020.68 and 4333.35 kg ha^{-1}).

4.2.1.4.2. Interaction effect of I, N and K on dry matter production per hectare (Table 15)

The dry matter production by plant was not influenced by the interaction due to IN, IK and NK at 30 DAS in both experiments.

Table 14. Effect of I, N and K on the dry matter production per hectare (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1	268.67	1281.27	2466.58	427.74	2187.17	3660.86
i_2	301.95	1722.88	2675.26	471.01	2359.44	3957.14
i_3	289.36	1470.59	2356.27	452.01	2099.47	3518.28
$F_{2,22}$	3.54*	48.24**	4.98*	3.48*	5.63*	5.97**
n_1	238.89	1174.62	1965.40	398.65	1866.34	3123.26
n_2	336.63	1832.96	3074.84	502.97	2557.49	4288.03
n_3	284.45	1467.16	2457.87	449.15	2222.25	3724.98
$F_{2,22}$	23.35**	109.93**	58.66**	15.19**	38.45**	40.45**
k_1	236.33	1145.48	1916.59	382.50	1777.45	2973.81
k_2	331.32	1801.31	3020.67	506.48	2584.82	4333.35
k_3	292.33	1527.95	2560.85	461.79	2224.11	3829.12
$F_{2,22}$	22.26**	106.65**	58.40**	22.01**	53.63**	56.31**
SEd	14.312	45.112	102.638	18.928	78.830	129.521
CD	29.684	93.562	212.872	39.256	163.493	268.627

* Significant at 0.05 level ** Significant at 0.01 level

Table 15. Interaction effect of I, N and K on the dry matter production per hectare (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1n_1	230.24	1019.24	1848.76	389.63	1797.63	3007.03
i_1n_2	357.70	1511.80	3080.39	514.82	2576.16	4310.78
i_1n_3	280.15	1312.76	2470.61	451.60	2187.73	3664.76
i_2n_1	257.84	1375.91	2219.06	423.09	2014.89	3373.43
i_2n_2	344.15	2182.70	3325.49	518.79	2689.12	4515.84
i_2n_3	303.85	1610.03	2481.24	471.16	2374.31	3982.14
i_3n_1	228.61	1128.71	1828.39	383.23	1786.49	2989.33
i_3n_2	308.05	1804.39	2818.63	475.30	2407.20	4037.47
i_3n_3	269.35	1478.68	2421.77	424.70	2104.71	3528.03
$F_{4,22}$	NS	3.51*	NS	NS	NS	NS
i_1k_1	243.95	986.40	1648.80	376.15	1697.47	2837.96
i_1k_2	308.50	1518.48	2839.25	482.16	2398.22	4009.75
i_1k_3	315.65	1338.92	2911.70	497.73	2465.83	4134.87
i_2k_1	242.71	1284.98	2135.26	398.27	1896.62	3176.19
i_2k_2	371.58	2144.09	3417.98	561.18	2903.40	4874.74
i_2k_3	291.54	1739.57	2472.56	453.58	2278.30	3820.49
i_3k_1	222.34	1165.06	1965.71	373.09	1737.37	2907.27
i_3k_2	339.79	1741.36	2804.79	476.09	2452.83	4115.57
i_3k_3	289.88	1505.36	2298.29	434.05	2108.20	3532.00
$F_{4,22}$	NS	NS	6.35**	NS	3.62*	3.88*
n_1k_1	208.61	975.90	1630.56	363.65	1629.23	2723.26
n_1k_2	259.76	1342.35	2248.14	417.73	2029.17	3399.27
n_1k_3	248.31	1205.61	2017.51	414.57	1940.61	3247.26
n_2k_1	276.70	1332.14	2231.48	407.42	1955.14	3274.83
n_2k_2	394.41	2299.01	3859.57	587.36	3070.73	5146.00
n_2k_3	338.80	1867.75	3133.46	514.13	2646.60	4443.26
n_3k_1	223.69	1128.41	1887.73	376.44	1747.09	2923.33
n_3k_2	339.79	1762.57	2954.31	514.34	2654.54	4454.79
n_3k_3	289.88	1510.50	2531.58	456.67	2265.12	3796.83
$F_{4,22}$	NS	7.42**	4.06*	NS	3.68*	3.82*
SEd	—	78.287	178.118	—	136.802	224.771
CD	—	162.054	368.705	—	283.18	465.276

* Significant at 0.05 level   ** Significant at 0.01 level   NS Not Significant

IN interaction was significant at 60 DAS in Experiment 2. At the levels of i_1, i_2, and i_3 the maximum dry matter production was recorded at the n_2 level followed by n_3 and then at n_1 levels.

IK interaction recorded significant difference at final harvest stage of Experiment 2 and at 60 DAS and final harvest stage of Experiment 3. At i_1 level of irrigation k_2 and k_3 were on par at all these stages. At i_2, during final harvest stage of Experiment 2, k_1 and k_3 were on par while in Experiment 3, during 60 DAS and final harvest stages the dry matter production varied significantly between k_1, k_2 and k_3. k_2 recorded the highest dry matter production at all the stages. When drip irrigated at i_3 level, k_2 produced the maximum dry matter production followed by k_3 and k_1.

Significant interaction effect for NK combinations were seen at 60 DAS and final harvest of both experiments for dry matter production. At n_1, k_2 recorded the highest dry matter production which was on par with k_3. The dry matter produced by k_2 was also the highest at n_2 and n_3 which was significantly superior to k_3 and k_1.

4.2.2. Yield components and yield

4.2.2.1. Number of fruits harvested per plant

4.2.2.1.1. Effect of I, N and K on the number of fruits harvested per plant (Table 16) (Fig. 5)

The different levels of irrigation nitrogen and potassium were found to have influence on the number of fruits harvested per plant.

Table 16. Effect of I, N and K on the number of fruits harvested plant,$^{-1}$ length of fruit (cm) and girth of fruit (cm)

	No. of fruits harvested plant^{-1}			Length of fruit (cm)			Girth of fruit (cm)		
	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3	Pooled data
i_1	2.75	3.10	2.93	25.62	28.27	26.94	22.95	23.99	23.47
i_2	3.21	3.51	3.36	29.82	33.40	31.61	26.25	26.71	26.48
i_3	2.86	3.24	3.05	26.33	29.62	27.98	22.39	24.27	23.48
$F_{2,22}$	108.10**	20.94**	75.04**	103.45**	9.43**	NS	75.98**	9.82**	45.16**
n_1	2.40	2.84	2.62	21.66	24.10	22.88	18.66	20.36	19.51
n_2	3.50	3.77	3.63	33.05	37.16	35.11	28.79	29.94	29.33
n_3	2.92	3.24	3.08	27.06	30.03	28.54	24.14	24.97	24.56
$F_{2,22}$	593.59**	102.29**	391.64**	666.71**	57.02**	NS	450.11**	109.79**	364.86**
k_1	2.34	2.75	2.54	21.07	22.99	22.03	18.44	20.22	19.33
k_2	3.49	3.78	3.64	32.84	37.06	34.95	28.23	29.19	28.71
k_3	2.99	3.32	3.16	27.87	31.24	29.55	24.92	25.85	25.39
$F_{2,22}$	660.68**	124.72**	455.00**	716.63**	66.63**	NS	433.84**	98.46**	339.98**
SEd	0.0321	0.065	0.034	0.312	1.225	—	0.338	0.647	0.357
CD	0.066	0.135	0.07	0.647	2.540	—	0.701	1.341	0.74

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

Irrigation at i_2 level produced highest number of fruits per plant (3.21 and 3.51) respectively in Experiments 2 and 3. At n_2, 3.5 and 3.77 fruits plant^{-1} were recorded in Experiment 2 and 3 while 3.49 and 3.78 fruits plant^{-1} were produced at k_2 level.

The pooled analysis revealed that there was significant difference between the seasons and the highest number of fruit of 3.36 cm was recorded at I3, 3.36 cm at n_2 and 3.64 cm at k_2 levels.

4.2.2.1.2. **Interaction effect of I, N and K on the number of fruits harvested per plant** (Table 17)

There was significant effect due to IN, NK and IK interaction in Experiment 2 on the number of fruits harvested per plant while in Experiment 3, IN interaction was not significant.

At all the irrigation levels of i_1, i_2 and i_3 the highest number of fruits per plant was recorded at k_2 (3.23, 3.87 and 3.41 respectively).

With respect to IK, k_2 produced the highest number of fruits per plant at all the irrigation levels in both experiments. At i_1, k_2 and k_3 were on par. At all the other levels, significant difference was observed among the K levels.

In both the experiments, the interaction effect of NK showed that k_2 recorded the highest number of fruits per plant at n_1, n_2 and n_3 which was significantly superior to k_3 and k_1 except at n_1 level in Experiment 3 where k_2 and k_3 were on par.

Table 17. Interaction effect of I, N and K on the number of fruits harvested plant,$^{-1}$ length of fruit (cm) and girth of fruit (cm)

	No. of fruits harvested plant^{-1}			Length of fruit (cm)			Girth of fruit (cm)		
	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3	Pooled data
i_1n_1	2.27	2.73	2.50	20.38	22.67	21.52	17.36	19.35	18.35
i_1n_2	3.23	3.49	3.36	30.41	33.78	32.10	28.70	29.11	28.90
i_1n_3	2.79	3.08	2.93	26.07	28.36	27.21	22.29	23.50	23.15
i_2n_1	2.62	2.96	2.79	23.87	26.17	25.02	20.89	21.73	21.31
i_2n_2	3.87	4.13	4.00	36.61	41.44	39.03	31.34	32.38	31.86
i_2n_3	3.14	3.46	3.30	28.96	32.58	30.77	26.52	26.02	26.27
i_3n_1	2.32	2.83	2.58	20.73	23.46	22.09	17.74	20.00	18.87
i_3n_2	3.41	3.69	3.55	32.13	36.25	34.19	26.34	28.34	27.34
i_3n_3	2.84	3.19	3.02	26.14	29.15	27.64	23.11	25.38	24.25
$F_{4,22}$	4.65**	NS	4.43**	5.32**	NS	NS	3.69*	NS	3.14*
i_1k_1	2.02	2.60	2.31	17.73	20.33	19.03	15.93	17.95	16.94
i_1k_2	3.15	3.40	3.27	29.79	32.83	31.31	26.81	26.61	26.71
i_1k_3	3.10	3.31	3.20	29.34	31.65	30.50	26.11	27.41	26.76
i_2k_1	2.60	2.91	2.76	23.83	25.57	24.70	20.86	21.41	21.41
i_2k_2	3.88	4.13	4.01	36.78	41.53	39.16	31.69	32.17	31.93
i_2k_3	3.14	3.50	3.31	28.83	33.10	30.97	26.19	26.55	26.37
i_3k_1	2.39	2.74	2.56	21.63	23.08	22.36	18.53	21.29	19.91
i_3k_2	3.45	3.81	3.63	31.93	36.82	34.38	26.19	28.81	27.50
i_3k_3	2.73	3.17	2.95	25.43	28.96	27.19	22.46	23.62	23.04
$F_{4,22}$	34.14**	4.32**	18.04**	40.28**	NS	NS	19.46**	7.57**	19.36**
n_1k_1	2.04	2.55	2.29	17.85	19.83	18.84	14.91	17.31	16.11
n_1k_2	2.75	3.10	2.93	25.49	28.16	26.82	22.50	23.26	22.88
n_1k_3	2.41	2.87	2.64	21.64	24.32	22.98	18.57	20.50	19.54
n_2k_1	2.64	3.01	2.82	24.29	26.89	25.59	22.39	22.92	22.65
n_2k_2	4.26	4.42	4.34	40.88	45.87	43.38	32.64	34.84	33.74
n_2k_3	3.61	3.88	3.75	33.99	38.72	36.35	31.35	32.05	31.70
n_3k_1	2.34	2.69	2.51	21.06	22.26	21.66	18.03	20.41	19.22
n_3k_2	3.47	3.82	3.65	32.14	37.15	34.64	29.55	29.47	29.51
n_3k_3	2.95	3.22	3.08	27.98	30.68	29.33	24.85	25.02	24.93
$F_{4,22}$	34.94**	8.08**	26.02**	36.46**	3.37*	NS	13.97**	5.17**	12.42**
SEd	0.056	0.113	0.063	0.542	2.125	—	0.586	1.122	0.618
CD	0.115	0.234	0.130	1.121	4.399	—	1.214	2.323	1.280

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

The interaction effects on the pooled data show that IN, IK and NK effects recorded significance. With regard to IN interaction, n_2 recorded significant values with respect to the highest number of fruits of i_1, i_2 and i_3.

IK interaction on pooled data show that at i_1, k_2 and k_3 were on par. At i_2 and i_3, k_2 recorded the highest number of fruits followed by k_3 and k_1.

At all the levels of N applied, k_2 recorded the maximum number of fruits followed by k_3 and k_1.

4.2.2.2. Length of fruit

4.2.2.2.1. Effect of I, N and K on the length of fruits (Table 16) (Fig. 5)

The mean length of fruit was significantly influenced by irrigation, nitrogen and potassium.

The irrigation treatment i_2 produced fruits with maximum length of 29.82 cm in Experiment 2. The mean length of fruits at i_1 and i_3 levels were found to be statistically lower than i_2 (25.62 cm and 26.33 cm respectively). The data of Experiment 3 also showed that irrigation at i_2 level produced fruits with maximum length (33.40 cm). The mean length of fruits at i_1 and i_3 levels were found to be on par during Experiment 3 (28.27 and 29.62cm respectively).

The highest fruit length was recorded at n_2 level (33.05 cm and 37.16 cm) in both the experiments. The fruit length recorded at n_1 and n_3 levels were statistically lower than this.

The fruits length due to k_2 (32.84 cm and 37.06 cm) was significantly superior to the fruit length at the other two levels in both experiments. There was no significant difference between the seasons with respect to the length fruit.

4.2.2.2.2. Interaction effect of I, N and K on the length of fruits (Table 17)

Length of fruit recorded significant variation due to IN, IK and NK interactions in Experiment 2 while in Experiment 3 only NK interaction was significant.

The interaction effect of IN showed that maximum length of fruit was recorded by n_2 at i_1 (30.41cm), i_2 (36.61cm) and i_3 (32.13cm), which was followed by n_3 and then by n_1.

IK interaction results revealed the superiority of k_2 over k_3 and k_1 at the drip irrigation levels i_1 (32.83cm), i_2 (41.53cm) and i_3 (36.82cm).

NK interactions were significant in both experiments, where in at all the levels of nitrogen, the maximum length of fruit was recorded at k_2 level. In Experiment 3, at n_1 level, k_2 and k_3 were on par.

Pooled data revealed that there was no significant interactions between the seasons.

4.2.2.3. Girth of fruits

4.2.2.3.1. Effect of I, N and K on the girth of fruits (Table 16)

Data on girth of fruits showed significant influence by the levels of irrigation, nitrogen and potassium.

The irrigation treatment i_2 (26.25 cm and 26.71 cm) was statistically comparable and significantly superior to i_1 (22.95 and 23.99) and i_3 (22.39 and 24.57) which were on par.

The fruits girth due to the level n_2 (28.79cm and 29.94cm) was superior to that at the other two levels, n_1 (18.66 and 20.36cm) and n_3 (24.14 and 24.97cm).

The effect due to k_2 (28.23cm and 29.19cm) on fruit girth was significant which was superior to k_1 and k_3 (18.44cm and 20.22cm and 24.92cm and 25.85cm respectively).

Season was found to effect a significant influence on the girth of fruit. The highest values were recorded by i_2 (26.48cm) n_2 (29.36cm and k_2 (28.71cm).

4.2.2.3.2. Interaction effect of I, N and K on the girth of fruits (Table 17)

The effect of IN, IK and NK were significant in Experiment 2 and those due to IK and NK were significant in Experiment 3. IN interactions result showed that at different irrigation levels of i_1 (28.70 cm), i_2 (31.34 cm) and i_3 (26.34 cm) the effect due to n_2 recorded the highest girth of fruit followed by n_3 and n_1. The same result was seen in Experiment 2 and in the pooled analysis.

When IK interactions are considered the girth of fruits were on par when fertilized at k_2 and k_3 levels, at the irrigation level of i_1, in both experiments and in pooled analysis also. But at i_2 and i_3 levels, the highest girth of fruit was at k_2 followed by k_3 and k_1.

In both Experiments and in pooled data, k_2 recorded the highest girth of fruit at all the nitrogen levels, followed by k_2 and k_1, with regard to NK interactions.

4.2.2.4. Weight of fruits

4.2.2.4.1. Effect of I, N and K on the weight of fruit (Table 18)

The levels of irrigation recorded significant influence on the weight of fruits. Irrigation at higher frequencies (i_2 and i_3 produced heavier fruits (1.83 kg and 1.81 kg and 1.83 kg and 1.83 kg respectively for Experiment 2 and 3, which were statistically at par. Nitrogen and potassium also influenced weight of fruits, with n_2 recording the highest weight of 1.78 kg and k_2 with 1.79 kg per fruit.

Table 18. Effect of I, N and K on the mean weight of fruit (kg), fruit setting percentage and sex ratio

	Mean weight of fruit (kg)		Fruit setting (%)			Sex Ratio		
	Expt. 2	Expt. 3	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3	Pooled data
i_1	1.68	1.68	48.56	53.86	51.21	16.56	19.09	17.82
i_2	1.83	1.83	54.00	64.29	59.14	17.70	20.59	19.15
i_3	1.81	1.82	49.54	60.46	55.00	15.77	18.47	17.12
$F_{2,22}$	9.35^{**}	4.70^{*}	38.74^{**}	27.54^{**}	51.31^{**}	21.28^{**}	3.52^{*}	10.95^{**}
n_1	1.69	1.68	43.70	55.91	49.80	14.61	18.02	16.32
n_2	1.78	1.78	58.00	63.89	60.95	18.92	20.83	19.88
n_3	1.76	1.77	50.40	58.80	54.60	16.50	19.29	17.89
$F_{2,22}$	7.09^{**}	3.53^{*}	236.40^{**}	16.15^{**}	101.86^{**}	104.72^{**}	5.83^{**}	32.78^{**}
k_1	1.70	1.67	42.71	53.53	48.12	14.44	17.67	16.06
k_2	1.79	1.79	58.03	63.92	60.98	18.77	20.68	19.72
k_3	1.77	1.77	51.36	61.15	56.26	16.82	19.80	18.31
$F_{2,22}$	5.19^{*}	3.48^{*}	272.64^{**}	28.66^{**}	137.98^{**}	105.06^{**}	7.08^{**}	35.27^{**}
SEd	0.038	0.054	0.658	1.421	0.762	0.299	0.823	0.429
CD	0.079	0.112	1.365	2.947	1.580	0.620	1.706	0.890

* Significant at 0.05 level ** Significant at 0.01 level

4.2.2.4.2. Interaction effect of I, N and K on the weight of fruits (Table 19)

There was no significant difference between treatment combinations with respect to IN, IK and NK interaction. Highest weight of fruit was recorded by i_3n_3 (1.84 kg), i_3k_3 (1.85 kg) and n_3k_3 (1.82 kg).

4.2.2.5. Fruit setting percentage

4.2.2.5.1. Effect of I, N and K on fruit setting percentage (Table 18)

The data on fruit setting percentage revealed significant influence of irrigation, nitrogen and potassium.

Fruit setting percentage due to the level of irrigation i_2 (54.00 and 64.29) was significantly superior to i_1 and i_3 which were on par in Experiment 2 (48.56 and 49.54) and statistically different in Experiment 3 (53.86 and 60.46).

The treatment n_2 (58.00 and 63.89) produced significantly higher setting percentage compared to the lower levels of n_1 (43.70 and 55.91) and higher level of n_3 (50.40 and 58.80) respectively.

Setting percentage increased significantly with increase in application of potassium up to k_2 level. (58.03 and 63.92).

Table 19. Interaction effect of I, N and K on the weight of fruit (kg), fruit percentage and sex ratio

	Weight of fruit (kg)		Fruit setting (%)			Sex Ratio		
	Expt. 2	Expt. 3	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3	Pooled data
i_1n_1	1.65	1.65	41.78	51.45	46.62	14.55	18.70	16.62
i_1n_2	1.71	1.71	54.69	56.05	55.37	18.34	19.53	18.94
i_1n_3	1.69	1.68	49.22	54.09	51.65	16.80	19.03	17.92
i_2n_1	1.80	1.81	46.59	59.85	53.22	15.60	18.27	16.93
i_2n_2	1.81	1.81	62.76	69.71	66.23	20.54	23.97	22.26
i_2n_3	1.82	1.81	52.63	63.31	57.97	16.98	19.53	18.25
i_3n_1	1.83	1.83	42.73	56.44	49.59	13.70	17.10	15.40
i_3n_2	1.82	1.82	56.55	65.91	61.23	17.89	18.98	18.44
i_3n_3	1.84	1.84	49.34	59.02	54.18	15.71	19.32	17.52
$F_{4,22}$	NS	NS	NS	NS	NS	NS	NS	3.30
i_1k_1	1.66	1.66	38.32	48.32	43.32	13.84	16.39	15.11
i_1k_2	1.68	1.68	53.91	57.67	55.79	18.02	20.30	19.61
i_1k_3	1.70	1.70	53.47	55.60	54.53	17.83	20.57	19.20
i_2k_1	1.81	1.81	46.13	57.77	51.95	15.52	18.77	17.14
i_2k_2	1.80	1.81	62.96	69.79	66.37	20.20	22.72	21.46
i_2k_3	1.82	1.82	52.90	65.29	59.10	17.40	20.28	18.84
i_3k_1	1.85	1.85	43.68	54.50	49.09	13.97	17.85	15.91
i_3k_2	1.79	1.79	57.23	64.30	60.79	18.07	19.01	18.54
i_3k_3	1.85	1.85	47.70	62.57	55.14	15.25	18.54	16.89
$F_{4,22}$	NS	NS	16.82^{**}	NS	3.46^{**}	5.49^{**}	NS	3.02^{*}
n_1k_1	1.74	1.74	38.60	53.86	46.23	13.35	17.35	15.35
n_1k_2	1.78	1.79	48.49	56.81	52.65	15.86	18.32	17.09
n_1k_3	1.77	1.77	44.02	57.07	50.55	14.63	18.39	16.51
n_2k_1	1.79	1.79	46.68	54.32	50.50	15.43	17.63	16.53
n_2k_2	1.77	1.77	68.02	70.67	69.35	21.90	23.02	22.46
n_2k_3	1.78	1.78	59.30	66.68	62.99	19.44	21.83	20.63
n_3k_1	1.79	1.79	42.85	52.42	47.63	14.54	18.02	16.28
n_3k_2	1.73	1.73	57.59	64.28	60.93	18.54	20.70	19.62
n_3k_3	1.82	1.82	50.75	59.71	55.23	16.41	19.16	17.78
$F_{4,22}$	NS	NS	13.07^{**}	4.10^{*}	11.04^{**}	8.08^{**}	NS	4.35^{**}
SEd	—	—	1.142	2.466	1.324	0.518	—	1.540
CD	—	—	2.364	5.104	2.74	1.073	—	1.540

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

Seasons recorded significant difference with respect to fruit setting percentage. Highest values of 59.14 per cent 60.95 per cent and 60.98 per cent seen at i_2, n_2 and k_2 levels.

4.2.2.5.2. Interaction effect of I, N and K on the fruit setting percentage (Table 19)

IN interaction on fruit setting percentage was not significant in both experiments.

The IK interaction as fruit setting percentage was significant in Experiment 2 and in pooled analysis. At all levels of irrigation, k_2 recorded the highest fruit setting percentage. At i_1, k_2 and n_3 were on par.

The interaction of N and K had significant effect on fruit setting percentage in both Experiment and in pooled data. At n_1, the highest fruit setting percentage of 48.49 was at k_2 in Experiment 2 while in Experiment 3,at n_1 the effects due to all levels of K were as par. In the pooled analysis, $k_2$and k_3 were as par at n_1. At n_2 and n_3 also k_2 recorded the maximum fruit setting percentage in both Experiments and in pooled analysis. In Experiment 3, k_2 and k_3 were as par at n_2 and n_3 levels.

4.2.2.6. Sex ratio

4.2.2.6.1. Effect of I,N and K on the sex ratio (Table 18)

The sex ratio, expressed as the number of female flowers per hundred male flowers was significantly influenced by irrigation, nitrogen and potassium.

Among the irrigation levels, i_2 (17.70 and 20.59) was significantly superior to the other two levels. The effect due to i_1 (16.56) was significant over i_3 (15.77) in Experiment 2 where as in Experiment 3 the effects of i_1 (19.09) and i_3 (18.47) were on par.

Increase in sex ratio due to n_2 (18.92,50.83) over n_1 (14.61,18.02) and n_3 (16.50,19.29) was also significant.

In the case of potassium, sex ratio due to k_2 (18.77) was significantly superior to k_1 (14.44) and k_3 (16.82) in Experiment 2 where as Experiment 3 the effects due to k_2 (20.68) and k_3 (19.80) were on par and significantly superior to k_1 (17.67)

Sex ratio was significantly influenced by the season. The levels of i_2, n_2 and k_2 recorded the highest sex ratio of 19.15, 19.88 and 19.72 respectively.

4.2.2.6.2. Interaction effect of I, N and K on the sex ratio (Table 19)

Significant difference was noticed due to IK and NK interactions in Experiment 2 and due to IN, IK and NK interactions in pooled analysis.

The IN interactions observed in pooled analysis showed that at i_1, the highest ratio of 18.94 recorded by n_2 was as par with n_3 (17.92) while n_3 was on par with n_1 (16.62). At i_2, the sex ratio was highest and significantly superior at n_2 (22.26)while n_3 and n_1 .were on par. The sex ratio of 18.44 recorded at i_3n_2 level was the highest while n_2 was on par with n_3 at i_3 level.

The interactions of IK on sex ratio revealed that at i_1, k_2 produced the highest sex ratio which was on par with k_3 in Experiment 2 and in pooled analysis. At i_2 and i_3 levels also k_2 recorded the highest sex ratio followed by k_3 and k_1.

NK interactions observed in Experiment 2 showed the highest sex ratio at k_2 at all the nitrogen levels which was significantly superior to k_3 and k_1. In the pooled analysis also k_2 record the highest sex ratio at all nitrogen levels, which was on par with k_3 at n_1. It was seen that at n_1 and n_3 levels, k_1 and k_3 were also on par.

4.2.2.7. Fruit yield per hectare

4.2.2.7.1. Effect of I, N and K on fruit yield per hectare (Table 20) (Fig. 6)

The fruit yield was markedly influenced by levels of irrigation, nitrogen and potassium.

Among the drip irrigation treatments, the level i_2 recorded significantly superior yield in both experiments (19.85 t ha^{-1} and 21.40 t ha^{-1}) over i_1 (17.43 t ha^{-1} and 19.58 t ha^{-1}) and i_3 (17.63 t ha^{-1} and 19.98 t ha^{-1}).

Table 20. Effect of I, N and K on the fruit yield, (t ha^{-1}), vine yield (t ha^{-1}) and shelf life (days) of fruits

	Fruit yield (t ha^{-1})			Vine yield (t ha^{-1})			Shelf life of fruits (days)	
	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3
i_1	17.43	19.58	18.50	7.72	12.39	10.07	6.99	6.90
i_2	19.85	21.40	20.63	8.39	13.52	10.95	6.09	6.00
i_3	17.63	19.98	18.81	7.37	11.88	9.62	6.05	6.00
$F_{2,22}$	20.09**	39.26**	46.66**	5.20*	6.07**	10.97**	NS	NS
n_1	15.18	17.94	16.56	6.17	10.35	8.26	7.13	6.95
n_2	21.31	22.96	22.14	9.67	14.75	12.21	6.98	6.92
n_3	18.41	20.06	19.23	7.67	12.68	10.18	6.02	6.04
$F_{2,22}$	104.92**	270.22**	274.85**	60.58**	41.76**	93.53**	NS	NS
k_1	14.85	17.46	16.15	6.01	9.77	7.89	5.14	4.90
k_2	21.53	22.92	22.22	9.48	15.02	12.25	6.01	5.99
k_3	18.53	20.58	19.55	8.02	12.99	10.51	5.97	6.01
$F_{2,22}$	124.93**	319.58**	327.40**	59.94**	60.33**	115.55**	NS	NS
SE	0.423	0.217	0.231	0.319	0.482	0.281	—	—
CD	0.878	0.450	0.480	0.662	1.000	0.583	—	—

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

The increase in fruit yield with each successive increase in the level of nitrogen was positive and significant upto n_2 level, which recorded fruit yields of 21.31 t ha^{-1} and 22.96 t ha^{-1} respectively in Experiment 2 and 3. At n_3 level, the fruit yield was 18.41 t ha^{-1} and 20.06 t ha^{-1} respectively for Experiment 2 and 3.

Among the potassium levels, fruit yield due to k_1 (14.85 t ha^{-1} and 17.46 t ha^{-1}) and k_3 (18.53 t ha^{-1} and 20.58 t ha^{-1}) were significantly lower when compared to the fruit yield at k_2 (21.53 t ha^{-1} and 22.92 t ha^{-1}) in both experiments.

The results of pooled analysis also show the same trend. There was significant difference between the treatments in both seasons. Seasons was found to influence the nitrogen and potash levels significantly. The highest yields of 20.63, 22.14 and 22.22 t ha^{-1} was recorded at i_2, n_2 and k_2 levels respectively. For the same level of n_2 and k_2, the yield was found to be higher in Experiment 3 compared to the Experiment 2.

4.2.2.7.2. Interaction effect of I, N and K on the fruit yield per hectare (Table 21)

The interaction effect due to IN were significant in Experiment 3 and in pooled analysis. While IK and NK interactions were significant in both experiments and in pooled analysis.

Table 21. Interaction effect of I, N and K on the fruit yield (t ha^{-1}), vine yield (t ha^{-1}) and shelf life of fruits (days)

	Fruit yield (tha^{-1})			Vine yield (tha^{-1})			Shelf life (days)	
	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3
i_1n_1	14.50	17.46	15.98	5.85	9.89	7.87	8.15	7.92
i_1n_2	20.02	21.68	20.85	9.72	14.89	12.31	5.91	5.88
i_1n_3	17.76	19.59	18.68	7.70	12.38	10.04	6.92	6.90
i_2n_1	16.40	18.55	17.47	6.95	11.29	9.12	6.11	5.83
i_2n_2	23.25	24.82	24.03	10.47	15.67	13.17	4.13	4.08
i_2n_3	19.90	20.84	20.37	7.74	13.60	10.67	5.04	5.08
i_3n_1	14.65	17.82	16.23	5.71	9.88	7.80	7.15	7.09
i_3n_2	20.68	22.38	21.53	8.81	13.70	11.25	4.89	4.79
i_3n_3	17.58	19.74	18.66	7.85	12.05	9.82	6.10	6.13
$F_{4,22}$	NS	5.16^{**}	2.72^{*}	NS	NS	NS	NS	NS
i_1k_1	12.97	16.63	14.80	5.19	9.28	7.23	6.08	5.84
i_1k_2	19.73	21.25	20.49	8.97	13.72	11.34	8.05	7.91
i_1k_3	19.58	20.86	20.22	9.11	14.17	11.64	6.85	6.94
i_2k_1	16.32	18.27	17.30	6.68	10.55	8.62	4.19	3.89
i_2k_2	24.33	24.85	24.59	10.72	17.05	13.88	6.04	6.04
i_2k_3	18.89	21.09	19.99	7.76	12.94	10.35	5.05	5.06
i_3k_1	15.26	17.47	16.37	6.14	9.49	7.82	5.16	4.96
i_3k_2	20.54	22.65	21.59	8.77	14.28	11.53	6.96	7.02
i_3k_3	17.10	19.81	18.46	7.19	11.86	9.53	6.02	6.04
$F_{4,22}$	9.71^{**}	11.85^{**}	18.06^{**}	6.23^{**}	4.13^{**}	9.02^{**}	NS	NS
n_1k_1	13.04	16.32	14.68	5.11	8.87	6.99	6.23	6.08
n_1k_2	17.32	19.47	18.40	7.05	11.38	9.22	8.17	7.89
n_1k_3	15.18	18.04	16.61	6.35	10.81	8.58	6.99	6.88
n_2k_1	16.36	18.95	17.79	7.02	10.82	8.92	4.21	3.79
n_2k_2	25.55	26.53	26.04	12.18	18.11	15.14	5.94	6.00
n_2k_3	21.77	23.40	22.58	9.80	15.32	12.56	4.79	4.97
n_3k_1	14.88	17.10	15.99	5.89	9.63	7.76	4.98	4.82
n_3k_2	21.73	22.76	22.24	9.22	15.56	12.39	6.93	7.09
n_3k_3	18.63	20.31	19.47	7.91	12.84	10.38	6.14	6.20
$F_{4,22}$	5.17^{**}	17.78^{**}	15.56^{**}	4.25^{**}	4.46^{**}	8.12^{**}	NS	NS
SEd	0.735	0.376	0.401	0.554	0.835	0.487	—	—
CD	1.521	0.779	0.830	1.146	1.729	1.009	—	—

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

The results of the interaction effect of irrigation and nitrogen showed that at all irrigation levels, n_2 produced the highest fruit yield followed by n_3 and n_1.

The interactions of IK revealed that at i_1, k_2 produced the highest fruit yield which was on par with k_3. At i_2 and i_2 levels also, k_2 produced the highest fruit yield followed by k_3 and k_1.

The NK interactions on fruit yield revealed that at all the three nitrogen levels, highest fruit yield was at k_2, followed by k_3 and k_1.

4.2.2.7.3. Physical and Economic optimum of I, N and K

The physical and economic optimum for drip irrigation, nitrogen and potassium were worked out separately for the two experimental crops fitting quadratic response surface for drip irrigation, nitrogen and potassium using the formula

$$Y = b_0 + b_1I + b_2N + b_3K + b_{11}I^2 + b_{22}N^2 + b_{33}K^2 + b_1b_2IN + b_1b_3IK + b_2b_3NK$$

The estimated equations are presented below

Experiment 2

$$Y = -18.61051 + 16.6022I + 0.1254N + 0.3701K - 2.7975I^2 + 0.0144IN - 0.0242IK - 0.0015N^2 + 0.0017NK - 0.0035K^2$$

(F for regression –54.18** R^2 -0.88 or 88 per cent. The fitted regression explains 88 per cent of the variation in yield of cucumber due to the influence of applied I, N and K treatments).

Experiment 3

$$Y = -6.134518 + 8.4948I + 0.1945N + 0.3327K - 1.4337I^2 + 0.0064IN - 0.0079IK - 0.0018N^2 + 0.0013NK - 0.0034K^2$$

(F for regression –120.12** $R^2 = 0.94$ or 94 per cent. The fitted regression explains 94 per cent of the variation in yield of cucumber due to the influence of applied I, N and K treatments)

The physical optimum for Experiment 2 was drip irrigation @ 3l plant^{-1} day^{-1}, 93 kg N ha^{-1} and 65 kg K ha^{-1}, while for Experiment 3, it worked out to drip irrigation @ 3l plant^{-1} day^{-1}, 75 kg N ha^{-1} and 60 kg K ha^{-1}.

The economic optimum dose of N and K is not determinable for the above fitted response surface with the existing market prices of N, K and cucumber.

The physical optimum for nitrogen and potassium were worked out separately for the two experimental crops and the three levels of drip irrigation fitting quadratic response surface for nitrogen and potassium.

The estimated equations are

Drip irrigation @ 2l plant^{-1} day^{-1}

Experiment 2

$$Y = 3.486506 + 0.1752N + 0.2427K - 0.0016N^2 + 0.0016NK - 0.0024K^2$$

(F for regression -61.86** R^2 = 0.95 or 95 per cent. The fitted regression explains 95 per cent of the variation in yield of cucumber due to the influence of applied N and K fertilizers).

Experiment 3

$$Y = 5.668892 + 0.2185N + 0.2438K - 0.0019N^2 + 0.0013NK - 0.0026K^2$$

(F for regression - 127.92** $R^2 = 0.97$ or 97 per cent. The fitted regression explains 97 per cent of the variation in yield of cucumber due to the influence of applied N and K fertilizers).

Drip irrigation @ 3l plant^{-1} day^{-1}

Experiment 2

$$Y = 5.889761 + 0.1459N + 0.4465K - 0.0018N^2 + 0.0027NK - 0.0061K^2$$

(F for regression - 26.58** $R^2 = 0.88$ or 88 per cent. The fitted regression explains 88 per cent of the variation in yield of cucumber due to the influence of applied N and K fertilizers).

Experiment 3

$$Y = 5.405455 + 0.2575N + 0.3782K - 0.0025N^2 + 0.0012NK - 0.0049K^2$$

(F for regression - 71.54** $R^2 = 0.95$ or 95 per cent. The fitted regression explains 95 per cent of the variation in yield due to the influence of applied N and K fertilizers).

Drip irrigation @ 4l plant^{-1} day^{-1}

Experiment 2

$$Y = 3.676022 + 0.2463N + 0.2894K - 0.0022N^2 + 0.0017NK - 0.0039K^2$$

(F for regression - 42.04** $R^2 = 0.92$ or 92 per cent. The fitted regression explains 92 per cent of the variation in yield due to the influence of applied N and K fertilizers).

Experiment 3

$$Y = 5.729342 + 0.1994N + 0.3531K - 0.0016N^2 + 0.0010NK - 0.0039K^2$$

(F for regression - 78.11** $R^2 = 0.96$ or 96 per cent. The fitted regression explains 96 per cent of the variation in yield due to the influence of applied N and K fertilizers).

The physical optimum worked out for N and K as per the above regression equation is given in Table 21a.

Table 21a. The physical optimum for N and K

Level of drip irrigation	Experiment 2		Experiment 3	
	optimum N (kg ha^{-1})	optimum K (kg ha^{-1})	optimum N (kg ha^{-1})	optimum K (kg ha^{-1})
2 l $plant^{-1}$ day^{-1}	96	83	80	67
2 l $plant^{-1}$ day^{-1}	74	53	74	55
2 l $plant^{-1}$ day^{-1}	77	54	80	55

4.2.2.8. Vine yield per hectare

4.2.2.8.1. Effect of I, N and K on vine yield per hectare (Table 20)

Among the irrigation treatments, i_3 and i_1 were on par while i_2 recorded significantly higher vine yields in both experiments (8.39 t ha^{-1} and 13.52 t ha^{-1}) respectively. The pooled data recorded an yield of 10.95 t ha^{-1}.

The vine yield due to the different levels of nitrogen revealed that n_2 produced significantly higher vine yield of 9.67 t ha^{-1} and 14.75 t ha^{-1} in Experiment 2 and 3 respectively with pooled yield of 12.21 t ha^{-1}.

With regard to the application of potassium k_2 produced 9.48 t ha^{-1} of vine yield in Experiment 2 where as Experiment 3 it was 15.02 t ha^{-1}. Pooled yield was 12.25 t ha^{-1}. The vine yield at this level was significantly superior to that at k_1 and k_3.

Season was found to influence the vine yield by its influence on potassium levels.

4.2.2.8.2. Interaction effect of I, N and K on vine yield N and K on vine yield per hectare (Table 21)

The interactions due to IK and NK were significant in both experiments and in pooled analysis.

The results of IK interactions revealed that at i_1 the highest vine yield was recorded at k_2 which was on par with k_3. In experiment 2, both at i_2 and i_3 the highest vine yield was at k_2 followed by k_3 and k_1 which were on par. In Experiment 3 and in pooled analysis, k_2 produced the the vine yield at i_2 and i_3 levels followed by k_3 and k_1.

With respect to NK interactions, at n_1, the highest vine yield was at k_2 followed by k_3 which were on par. At n_2 and n_3 levels also, k_2 recorded the highest vine yield followed by k_3 and k_1.

4.2.3. Shelf life of fruits

4.2.3.1. Effect of I, N and K on the shelf life of fruits (Table 20)

The shelf life was not influenced by irrigation, nitrogen and potassium levels.

Among the drip irrigation treatments, i_1 recorded significantly higher shelf life (6.99 days and 6.90 days) compared to i_3 (6.05 days and 6.00 days) and i_2 (6.09 days and 6.00 days) Experiment 2 and 3.

The lowest level of nitrogen (n_1) recorded higher shelf life of fruits (7.13 and 6.95 days respectively for Experiment 2 and 3. While higher levels of n_2 recorded the least shelf life of 6.98 and 6.92 days respectively for Experiment 2 and 3. At n_3 the shelf life recorded was 6.02 days and 6.04 days in the Experiment 2 and 3 respectively.

With regard to potassium, k_2 recorded higher shelf life of 6.01 days and 5.99 days in Experiment 2 and 3 respectively followed by k_3 with 5.97 and 6.01 days and k_1 with 5.14 and 4.90 days for Experiment 2 and 3 respectively.

4.2.3.2. Interaction effect of I, N and K on the shelf life of fruits (Table 21)

There was no significant difference between the combinations with respect to IN, IK and NK interactions.

4.2.4. Root studies

4.2.4.1. Root dry matter

4.2.4.1.1. Effect of I, N and K on the root dry matter (Table 22)

The effect of drip irrigation on root dry mater was not significant at any levels. However, highest dry matter of roots was recorded at i_3 level of irrigation (11.41g and 12.31g for Experiment 2 and 3 respectively). At i_2 level of irrigation, the dry matter recorded was 11.06g and 12.02g for Experiment 2 and 3 while the lowest root dry matter of 10.82g and 11.94g for both experiments was at i_2 level.

Nitrogen application was also found to have no significant influence on the accumulation of dry matter of roots. But at n_3 level the root dry matter was highest for Experiment 2 and 3 (11.22g and 12.18g respectively) closely followed by n_2 (11.19g and 12.04g in Experiment 2 and 3 respectively) and then by n_1 which recorded root dry matter production of 10.87g and 12.04g respectively in Experiment 2 and 3.

Potassium applied to the crop was found to have no significant influence on the dry weight of roots.

4.2.4.1.2. Interaction effect of I, N and K on the root dry matter (Table 23)

There was no significant influence due to IN, IK and NK interaction on root dry matter in both experiments.

Table 23. Interaction effect of I, N and K on root dry matter (g), root depth (cm) and root spread (cm)

	Root dry matter (g)		Root depth (cm)			Root spread (cm)	
	Expt. 2	Expt. 3	Expt. 2	Expt. 3	Pooled data	Expt. 2	Expt. 3
i_1n_1	10.93	11.75	38.53	38.52	38.52	24.41	24.22
i_1n_2	10.71	12.07	38.30	39.93	39.11	24.93	26.61
i_1n_3	10.80	12.01	39.98	39.59	39.79	26.44	27.60
i_2n_1	10.70	12.01	48.96	51.12	50.04	32.21	33.67
i_2n_2	11.30	11.87	49.43	49.34	49.38	36.95	37.94
i_2n_3	11.18	12.17	49.19	51.53	50.36	36.55	39.42
i_3n_1	10.82	12.37	51.89	58.65	55.27	41.47	40.57
i_3n_2	11.95	12.19	59.05	60.66	59.85	44.19	44.41
i_3n_3	11.47	12.36	60.50	61.66	61.08	45.00	45.15
$F_{4,22}$	NS	NS	NS	NS	NS	NS	NS
i_1k_1	10.96	11.97	40.39	38.98	39.69	24.47	23.08
i_1k_2	10.71	11.85	37.63	39.77	38.70	25.18	27.28
i_1k_3	10.80	12.01	38.79	39.29	39.04	26.13	28.08
i_2k_1	10.70	12.17	47.62	51.15	49.38	35.21	35.47
i_2k_2	11.30	11.95	50.67	51.48	51.08	35.36	38.49
i_2k_3	11.18	11.93	49.29	49.36	49.33	35.13	37.07
i_3k_1	10.82	12.28	56.54	58.92	57.73	42.18	42.55
i_3k_2	11.95	12.36	57.89	60.57	59.23	41.84	43.69
i_3k_3	11.47	12.28	57.00		59.24	46.64	43.88
$F_{4,22}$	NS	NS	NS	NS	NS	NS	NS
n_1k_1	10.97	12.06	46.32	48.20	47.26	33.76	30.99
n_1k_2	10.76	12.09	46.03	51.80	48.92	30.90	34.69
n_1k_3	10.89	11.97	47.03	48.27	47.65	33.42	32.78
n_2k_1	10.71	12.12	47.29	50.15	48.72	33.69	34.17
n_2k_2	11.75	12.05	49.55	49.01	49.28	34.53	35.47
n_2k_3	11.13	11.97	49.94	50.77	50.35	37.86	39.33
n_3k_1	10.80	12.24	50.95	50.70	50.82	34.41	35.95
n_3k_2	11.45	12.02	50.62	50.99	50.80	36.95	39.30
n_3k_3	11.44	12.28	48.11	51.09	49.60	36.63	36.92
$F_{4,22}$	NS	NS	NS	NS	NS	NS	NS

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

4.2.4.2. Root depth

4.2.4.2.1. Effect of I, N and K on root depth (Table 22)

The depth of roots was significantly influenced only by the irrigation treatments. There is a positive influence of the irrigation levels on root depth. The highest root depth of 57.14 cm and 60.32 cm were recorded respectively in Experiment 2 and 3 with i_3 irrigation closely followed by i_2 (49.19cm and 50.66cm) and i_1 (38.94cm and 39.35cm) respectively for Experiment 2 and 3.

Nitrogen was not found to influence the root depth significantly. But in both experiments highest level of n_3 recorded highest root depth (49.89 cm and and 50.93 cm respectively for Experiment 2 and 3). The root depths of 48.93 cm and 49.97 cm was recorded at n_2 and n_1 recorded 46.46 cm and 49.43 cm respectively in Experiment 2 and 3.

Potassium also had no significant influence on root depth. Highest root depth of 48.73 cm and 50.61 cm was at k_2 level respectively for Experiment 2 and 3 then at k_3 level (48.36 cm and 50.04 cm) and followed by k_1 (48.18 cm and 49.68 cm).

Root depth was significantly influenced by the season.

4.2.4.2.2. Interaction effect of I, N and K on root depth (Table 23)

Root depth of both the crops was not significantly influenced by the interaction due to I, N and K.

4.2.4.3. Root spread

4.2.4.3.1. Effect of I, N and K on root spread (Table 22)

Root spread was found to be influenced by drip irrigation levels and nitrogen levels.

The highest root spread (43.55 cm and 43.37 cm) recorded by i_3 was significantly higher compared to i_2 (35.23 cm and 37.01 cm) and i_1 (25.26 cm and 26.14 cm).

With respect to nitrogen levels also highest level of n_3 recorded 36.00 cm and 37.39 cm of root spread which was on par with n_2 (35.36 cm and 36.32 cm).

Potassium levels did not influence root spread significantly.

4.2.4.3.2. Interaction effect of I, N and K on root spread (Table 23)

There was no significant influence due to any of the interactions on root spread.

4.2.5. Moisture studies

4.2.5.1. Soil moisture status

Soil samples were taken from the base of the plant immediately below the emitter (5 cm radius) in drip irrigated plots and at a distance of 30 cm from the base of the plant in pot watered plots. Samples were taken before sowing, just before treatment imposition and immediately after the final harvest. The results of soil moisture data as influenced by different levels of irrigation are presented in Table 24 and Fig. 7.

Table 24. Soil moisture status (cm) in different layers as influenced by drip irrigation and surface irrigation

Treatment	Soil moisture status (cm)							
	Experiment 2				Experiment 3			
	0-15 cm	15-30 cm	30-60 cm	60-90 cm	0-15 cm	15-30 cm	30-60 cm	60-90 cm
Drip irrigation								
2 litre plant^{-1} day^{-1}	6.53	6.06	2.75	2.01	7.11	7.08	3.64	2.76
3 litre plant^{-1} day^{-1}	7.25	6.68	2.81	2.04	7.51	7.42	3.70	2.70
4 litre plant^{-1} day^{-1}	6.84	6.34	4.01	2.10	7.22	7.20	5.97	2.86
Surface irrigation	6.65	6.51	5.89	4.11	6.94	6.60	6.14	4.28

4.2.5.1.1. Moisture status in surface 15 cm depth

In both experiments the soil moisture status at 0-15 cm depth at all levels of drip irrigation had higher soil moisture. The soil moisture at this depth ranged from 6.53 cm (i_1) to 7.54 cm (i_3) in Experiment 2 and 7.11 cm (i_1) to 7.62 cm (i_3) in the Experiment 3. Fairly high amounts of soil moisture were observed even at i_1. In general the amount was high during Experiment 3 compared to Experiment 2. In pot watered plants, the soil moisture at 0-15 cm depth was found to be low (6.65 cm and 6.94 cm).

4.2.5.1.2. Moisture status in 15-30 cm depth

At all levels of irrigation the soil moisture status at 15-30 cm depth was lower than that at 0-15 cm depth. The highest soil moisture (7.02 cm and 7.55 cm) was recorded by i_3 followed by i_2 (6.68 cm and 7.51 cm) and then by i_1 (6.06 cm and 7.08 cm). The soil moisture status in pot watered plots were 6.51 cm and 6.60 cm respectively in Experiment 2 and 3.

4.2.5.1.3. Moisture status at 30-60 cm depth

The soil moisture recorded at this depth were highest for i_3 (4.01 cm and 5.97 cm) while those at i_1 and i_2 were very little and were below 4.00 cm. But in pot watered plots, higher moisture contents of 5.89 cm and 6.14 cm were recorded.

4.2.5.1.4. Moisture status at 60-90 cm depth

The drip irrigated treatments recorded almost same values of soil moisture ranging from 2.01 cm to 2.11 cm in Experiment 2 and 2.70 cm to 2.86 cm in Experiment 3. Comparatively higher soil moisture was recorded in pot watered plots (4.11 cm and 4.28 cm).

4.2.5.2. Water use

The data on total water use presented in Table 25 and 26 revealed that the irrigation water use in Experiment 3 was less compared to that of Experiment 2 as the drip irrigation was not operated during rainy days.

Table 25. Total water use (mm) under different levels of irrigation

Levels	Total water use		*Total water use	
	Expt. 2	Expt. 3	Expt. 2	Expt. 3
i_1	275	250	285.5	350.6
i_2	440	400	450.5	500.6
i_3	440	400	450.5	500.6
Surface irrigation	292	265	302.5	365.6

*Total water use includes
(1) irrigation water applied
(2) rainfall
(3) water consumed for initial establishment

Total water use amounted to 285.5 mm, 450.5 mm and 450.5mm for drip treatments of i_1, i_2, and i_3 respectively, in the Experiment 2 while in Experiment 3 it was 350.6mm 500.6mm and 500.6mm respectively for drip irrigated treatments of i_1, i_2 and i_3. In the surface irrigated plots the total water use were 302.5 mm and 365.6 mm respectively in Experiment 2 and 3.

Table 26. Irrigation water use per day and daily irrigation schedule for cucumber

Days after planting	Depth of irrigation (mm)						Daily schedule (mm)					
	Expt. 2			Expt. 3			Expt. 2			Expt. 3		
	i_1	i_2	i_3	i_1	i_2	i_3	i_1	i_2	i_3	i_1	i_2	i_3
1-14*	—	—	—	—	—	—	—	—	—	—	—	—
15-21	35	56	56	30	48	48	5	8	8	5	8	8
22-28	35	56	56	30	48	48	5	8	8	5	8	8
29-35	35	56	56	30	48	48	5	8	8	5	8	8
36-42	35	56	56	35	56	56	5	8	8	5	8	8
43-49	35	56	56	30	48	48	5	8	8	5	8	8
50-56	35	56	56	35	56	56	5	8	8	5	8	8
57-63	35	56	56	35	56	56	5	8	8	5	8	8
64-69	30	48	48	25	40	40	5	8	8	5	8	8
Total	275	440	440	250	400	400						

* Establishment period

4.2.5.3. Field water use efficiency

4.2.5.3.1. Effect of I, N and K on field water use efficiency (Table 27)

The data on field water use efficiency, calculated as kilograms fruits per hectare millimeter of water used, revealed significant influence of levels of irrigation nitrogen and potassium.

Among the drip irrigation treatments, the lowest level of i_1 recorded significantly highest water use efficiency of 61.79 kg and 76.18 kg in Experiments 2 and 3 respectively. This level was followed by i_2 (43.66 kg and 52.59 kg) and then by i_3 (39.45 kg and 49.07 kg)

Among nitrogen levels n_2 to recorded water use efficiency of 56.41 kg and 66.78 kg respectively in Experiments 2 and 3 followed by n_3 (48.20 kg and 58.64 kg) and n_1 (40.29 kg and 52.42 kg) respectively in Experiments 2 and 3.

Field water use efficiency was highest and significant at k_2 level (56.03 kg and 66.46 kg) followed by k_3 (49.99 kg and 60.54 kg) and k_1 (38.88 kg and 50.83 kg) respectively in Experiments 2 and 3.

4.2.5.3.2. Interaction effect of I, N and K on field water use efficiency (Table 28)

The data revealed that IN interactions significantly influenced field water use efficiency. The field water use efficiency was highest at n_2 for all the irrigations levels followed by n_3 and then by n_1.

Table 27. Effect of I, N and K on field water use efficiency (kg $ha^{-1}mm$)

	Expt. 2	Expt. 3
i_1	61.79	76.18
i_2	43.66	52.59
i_3	39.45	49.07
$F_{2,22}$	615.79**	1045.09**
n_1	40.29	52.42
n_2	56.41	66.78
n_3	48.20	58.64
$F_{2,22}$	283.98**	249.53**
k_1	38.88	50.83
k_2	56.03	66.46
k_3	49.99	60.54
$F_{2,22}$	330.67**	299.28**
SEd	1.172	0.645
CD	2.430	1.337

** Significant at 0.01 level

Table 28. Interaction effect of I, N and K on field water use efficiency (kg ha^{-1}mm)

	Field water use efficiency (kg ha^{-1}mm)	
	Expt. 2	Expt. 3
i_1n_1	51.41	67.93
i_1n_2	70.98	84.38
i_1n_3	62.99	76.22
i_2n_1	36.69	45.57
i_2n_2	52.01	60.98
i_2n_3	42.28	51.21
i_3n_1	32.77	43.75
i_3n_2	46.25	54.98
i_3n_3	39.32	48.49
$F_{4,22}$	5.38**	3.672*
i_1k_1	45.98	64.69
i_1k_2	69.95	82.69
i_1k_3	69.44	81.15
i_2k_1	36.51	44.89
i_2k_2	52.20	61.06
i_2k_3	42.26	51.82
i_3k_1	34.15	42.93
i_3k_2	45.94	55.62
i_3k_3	38.26	48.67
$F_{4,22}$	43.20**	15.35**
n_1k_1	34.11	47.86
n_1k_2	45.73	56.54
n_1k_3	41.03	52.85
n_2k_1	43.34	54.68
n_2k_2	67.15	76.74
n_2k_3	58.75	68.92
n_3k_1	39.20	49.97
n_3k_2	55.21	66.08
n_3k_3	50.18	59.87
$F_{4,22}$	14.65**	18.90**
SEd	1.174	1.119
CD	2.431	2.316

* Significant at 0.05 level ** Significant at 0.01 level

The IK interactions on field water use efficiency revealed that at i_1, the highest value was recorded by k_2 which was on par with k_3. At i_2 and i_3 also k_2 recorded the highest water use followed by k_3 and k_1.

The interaction effect between nitrogen and potassium on field water use efficiency was also significant. At different levels of nitrogen, k_2 recorded the highest field water use efficiency followed by k_3 and k_1.

4.2.5.4. Consumptive use

Seasonal Consumptive use and evaporation data are presented in Table 29 and 30.

Seasonal consumptive use was highest in i_2 during both experiments (428 mm and 489 mm in Experiment 2 and 3 respectively), followed by i_3 (299 mm and 341 mm respectively) and then by i_1 (288 mm and 332 mm).

The total open pan evaporation was 285.30 mm in Experiment 2 and 328.30 mm in Experiment 3. During Experiment 2 weekly cumulative evaporation values gradually rose from 17.5 mm per week at the time of sowing to 31.2 mm per week at the establishment period which continued upto the middle of the crop season and further rose to 33.6 mm during the end of the crop season. Mean evaporation values ranged from 2.5 mm per day to 4.8 mm per day during the crop period.

Table 29. Seasonal consumptive use (mm) and cummulative pan evaporation during the growth period of cucumber

Drip irrigation irrigation treatment	Total quantity of water applied (mm)	Seasonal consumptive use (mm)	Total CPE during the crop period (mm)
2 litres plant^{-1}day^{-1}			
Experiment 2	282	288	285.30
Experiment 3	257	332	328.30
3 litres plant^{-1}day^{-1}			
Experiment 2	447	428	285.30
Experiment 3	407	489	328.30
4 litres plant^{-1}day^{-1}			
Experiment 2	447	299	285.30
Experiment 3	407	341	328.30

In Experiment 3 at the time of establishment the cumulative weekly evaporation was 27.3 mm which rose to 31.5mm there after and a range upto 35 mm was maintained constantly during the growth period and till the end of the season. During the last week of the crop, a fall in weekly cumulative evaporation was observed (28.7 mm).

Table 30. Mean weekly evaporation (cm)

Days after sowing	Weekly evaporation (mm)	
	Experiment 2	Experiment 3
1-14	17.5	35.0
15-21	31.2	27.3
22-28	23.1	35.0
29-35	27.3	31.5
36-42	20.3	34.3
43-49	25.9	35.0
50-56	30.1	35.7
57-63	28.0	30.8
64-69	33.6	28.7

4.2.6. Content and uptake of major nutrients in plants parts

4.2.6.1. Nitrogen

4.2.6.1.1. Nitrogen content in plant parts

4.2.6.1.1.1. Effect of I, N and K on the nitrogen content of plant (Table 31)

The data on the percentage of nitrogen in plants recorded at 30 DAS 60 DAS and final harvest stages showed that nitrogen levels had significant influence while potassium and irrigation levels had no influence on the nitrogen content of plant parts in both experiments except on 30 DAS in Experiment 2 where nitrogen levels were on par. At all stages in both experiments n_2 recorded significantly higher content of nitrogen in plant parts.

4.2.6.1.1.2. Interaction effect of I,N and K on the nitrogen content of the plants (Table 32)

Interaction effect of IN, IK and NK could not effect any significant influence at any of the stages in both crops.

4.2.6.1.2. Uptake of nitrogen

4.2.6.1.2.1. Effect of I,N and K on the uptake of nitrogen by the plant (Table 33) (Fig. 8)

The data on uptake of nitrogen by plants recorded at 30 DAS, 60 DAS and at final harvest stages of Experiment 2 and 3 revealed significant influence of irrigation, nitrogen and potassium. Drip irrigation influenced nitrogen uptake at all the three stages of observation in Experiment 2 and 3.

The nitrogen uptake due to drip irrigation level of i_2 was significantly superior to the other two levels at all stages.

Table 32. Interaction effect of I, N and K on the nitrogen content of plant parts (%)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1n_1	2.16	1.57	1.59	2.23	1.61	1.63
i_1n_2	2.37	2.02	2.08	2.55	2.23	2.28
i_1n_3	2.22	1.75	1.78	2.41	1.91	1.94
i_2n_1	2.19	1.59	1.61	2.32	1.68	1.70
i_2n_2	2.42	2.11	2.15	2.61	2.26	2.31
i_2n_3	2.34	1.85	1.88	2.51	1.89	1.92
i_3n_1	2.20	1.59	1.61	2.27	1.65	1.69
i_3n_2	2.40	2.06	2.11	2.62	2.29	2.34
i_3n_3	2.31	1.81	1.84	2.50	1.95	1.99
$F_{4,22}$	NS	NS	NS	NS	NS	NS
i_1k_1	2.25	1.75	1.79	2.36	1.84	1.88
i_1k_2	2.26	1.79	1.83	2.42	1.93	1.96
i_1k_3	2.24	1.80	1.84	2.42	1.97	2.01
i_2k_1	2.30	1.80	1.83	2.47	1.93	1.96
i_2k_2	2.32	1.86	1.89	2.49	1.94	1.97
i_2k_3	2.32	1.89	1.92	2.48	1.96	2.00
i_3k_1	2.29	1.79	1.82	2.47	1.93	1.96
i_3k_2	2.29	1.83	1.86	2.50	1.99	2.02
i_3k_3	2.32	1.85	1.88	2.43	1.97	2.01
$F_{4,22}$	NS	NS	NS	NS	NS	NS
n_1k_1	2.17	1.53	1.55	2.27	1.60	1.62
n_1k_2	2.20	1.60	1.62	2.30	1.67	1.69
n_1k_3	2.18	1.62	1.64	2.25	1.67	1.69
n_2k_1	2.37	2.03	2.08	2.55	2.18	2.23
n_2k_2	2.40	2.08	2.14	2.61	2.27	2.32
n_2k_3	2.42	2.08	2.13	2.61	2.34	2.39
n_3k_1	2.30	1.78	1.81	2.48	1.92	1.95
n_3k_2	2.28	1.80	1.83	2.48	1.92	1.95
n_3k_3	2.28	1.84	1.87	2.46	1.90	1.94
$F_{4,22}$	NS	NS	NS	NS	NS	NS

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

Table 33. Effect of I, N and K on the uptake of nitrogen by plant (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1	6.05	23.21	45.89	10.93	42.96	73.21
i_2	6.98	32.63	51.39	11.71	46.46	79.31
i_3	6.66	27.41	44.59	10.59	41.92	71.57
$F_{2,22}$	4.18*	62.73**	6.62**	4.17*	5.36*	5.56*
n_1	5.21	18.65	31.59	9.07	30.77	52.13
n_2	8.06	38.05	65.15	13.06	58.04	99.45
n_3	6.50	26.56	45.12	11.11	42.53	72.51
$F_{2,22}$	40.69**	268.18**	145.08**	50.56**	177.08**	188.48**
k_1	5.41	20.71	35.28	9.33	34.12	58.12
k_2	7.64	33.75	57.62	12.58	51.47	87.86
k_3	6.73	28.79	48.96	11.33	45.76	78.11
$F_{2,22}$	25.11**	122.08**	64.56**	34.07**	74.05**	76.90**
SEd	0.316	0.842	1.983	0.397	1.453	2.445
CD	0.656	1.747	4.112	0.824	3.014	5.071

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

The levels of nitrogen recorded significant differences at all stages. The highest uptake at all stages was recorded at n_2 which was followed by n_3 and n_1.

Among the potassium levels, k_2 recorded highest uptake followed by k_3 and k_1.

4.2.6.1.2.2. Interaction effect of I, N and K on the uptake of nitrogen by the plant (Table 34)

Interactions due to IN were not significant at any stage in both experiments except at 60 DAS in Experiment 2. At all irrigation levels, n_2 recorded the highest uptake of nitrogen followed by n_3 and n_1.

IK interactions were significant at all stages in both experiments, except at 30 DAS in Experiment 2. At 60 DAS in Experiment 2, the highest nitrogen uptake was recorded at k_2 at all the irrigation levels followed by k_3 and k_1. During the final harvest stage,also the same result was obtained. At i_1, k_2 and k_3 were on par. In Experiment 3, on 30 DAS the uptake of nitrogen at k_2 and k_3 were on par at i_1 and i_3 levels. At i_2 and i_3 levels, the highest uptake was recorded by k_2, followed by k_3 and k_1. At i_2 and i_3, k_1 and k_3 were on par. During 60 DAS and final harvest stages, the highest uptake of nitrogen at i_1, was recorded by k_3 which was on par with k_2. At i_2 and i_3, k_2 recorded highest uptake followed by k_3 and k_1.

Table 34. Interaction effect of I, N and K on the uptake of nitrogen by plant parts (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60DAS	FH	30 DAS	60 DAS	FH
i_1n_1	4.97	16.02	29.50	8.69	28.88	48.91
i_1n_2	8.48	30.57	64.05	13.22	58.24	99.61
i_1n_3	6.21	23.05	44.12	10.89	41.76	71.11
i_2n_1	5.64	21.91	35.75	9.80	33.93	57.48
i_2n_2	8.32	46.19	71.75	13.51	60.68	104.16
i_2n_3	7.10	29.80	46.66	11.81	44.77	76.28
i_3n_1	5.03	18.01	29.51	8.71	29.52	49.99
i_3n_2	7.40	37.38	59.66	12.45	55.19	94.58
i_3n_3	6.20	26.84	44.59	10.62	41.06	70.13
$F_{4,22}$	NS	7.01^{**}	NS	NS	NS	NS
i_1k_1	5.52	17.49	29.80	8.89	31.32	53.32
i_1k_2	7.03	27.74	53.21	11.77	47.64	81.06
i_1k_3	7.11	24.41	54.66	12.13	49.94	85.25
i_2k_1	5.60	23.48	39.68	9.84	37.02	63.12
i_2k_2	8.66	40.77	66.31	14.02	57.18	97.72
i_2k_3	6.79	33.65	48.17	11.26	45.18	77.09
i_3k_1	5.12	21.17	36.37	9.25	34.00	57.91
i_3k_2	7.24	32.75	53.35	11.94	49.58	84.79
i_3k_3	6.28	28.31	44.05	10.58	42.17	72.01
$F_{4,22}$	NS	3.30^{*}	6.06^{**}	3.01^{*}	5.02^{**}	5.31^{**}
n_1k_1	4.53	14.95	25.30	8.24	26.05	44.78
n_1k_2	5.71	21.45	36.37	9.63	33.90	57.46
n_1k_3	5.41	19.54	33.09	9.32	32.28	54.84
n_2k_1	6.57	27.08	46.35	10.40	42.73	73.22
n_2k_2	9.45	48.04	82.53	15.37	69.57	119.15
n_2k_3	8.17	39.01	66.58	13.41	61.81	105.99
n_3k_1	5.14	20.11	34.20	9.34	33.57	57.05
n_3k_2	7.77	31.76	53.97	12.73	50.94	86.96
n_3k_3	6.61	27.82	47.20	11.25	43.08	73.52
$F_{4,22}$	NS	12.65^{**}	6.91^{**}	3.42^{*}	7.75^{**}	8.06^{**}
SEd	—	1.462	3.441	0.689	2.522	4.243
CD	—	3.026	7.122	1.427	5.220	8.784

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

IK interactions, at 30 DAS, were significant in Experiment 2. The highest nitrogen uptake of 9.63 kg ha^{-1} was at k_2 which was on par with k_1 and k_3. At n_2 and n_3 also, k_2 recorded the highest uptake followed by k_3 and k_1. At 60 DAS, in both experiments, k_2 recorded the highest uptake at n_1 which was on par with k_3. At n_2 and n_3 also k_2 recorded the highest uptake of nitrogen, followed by k_3 and k_1. During the final harvest stage at all the levels of nitrogen, k_2 recorded highest uptake which was on par with k_3 at n_1. At n_3 also, k_2 and k_3 were on par in Experiment 2.

4.2.6.1.2.3. Effect of I, N and K on the uptake of nitrogen by fruits
(Table 35)

The uptake of nitrogen by fruits was found to be significantly influenced by irrigation nitrogen and potash levels.

The highest uptake of nitrogen was observed at i_2 level (14.58 kg ha^{-1} and 16.75 kg ha^{-1}).

The highest uptake of nitrogen by fruits (16.86 kg ha^{-1} and 17.31 kg ha^{-1}) was recorded at n_2 followed by n_3 (14.26 kg ha^{-1} and 16.64 kg ha^{-1}) which was significantly superior to n_1 level (11.20 kg ha^{-1} and 12.66 kg ha^{-1}).

Potassium at 50 kg ha^{-1} k_2 recorded significantly higher uptake of nitrogen by fruits (16.38 kg ha^{-1} and 17.37 kg ha^{-1}) which was significantly superior to k_2 (14.59 Kg ha^{-1} and 16.00 kg ha^{-1}) and k_1 (11.35 kg ha^{-1} and 13.23 kg ha^{-1}).

Table 35. Effect of I, N and K on the uptake of nutrients by fruits (kg ha^{-1})

	Nitrogen		Phosphorus		Potassium	
	Expt. 2	Expt. 3	Expt. 2	Expt. 3	Expt. 2	Expt. 3
i_1	13.73	14.55	2.79	3.09	14.12	15.02
i_2	14.58	16.75	3.64	4.10	15.07	17.31
i_3	14.01	15.33	3.24	3.37	14.44	15.84
$F_{2,22}$	3.89*	50.84**	23.10**	37.61**	4.01*	68.75**
n_1	11.20	12.67	2.60	2.91	11.92	13.59
n_2	16.86	17.31	3.85	3.90	17.33	17.82
n_3	14.26	16.64	3.23	3.76	14.38	16.76
$F_{2,22}$	167.61**	258.06**	50.22**	39.05**	126.47**	246.44**
k_1	11.35	13.23	2.59	2.91	11.20	13.08
k_2	16.38	17.37	3.73	4.01	17.59	18.81
k_3	14.59	16.01	3.37	3.64	14.84	16.28
$F_{2,22}$	135.75**	181.97**	43.38**	42.67**	176.60**	419.27**
SEd	0.310	0.221	0.125	0.121	0.341	0.198
CD	0.643	0.459	0.260	0.250	0.707	0.411

* Significant at 0.05 level ** Significant at 0.01 level

4.2.6.1.2.4. Interaction effect of I, N and K on the uptake of nitrogen by fruits (Table 36)

The interaction effect of IN were found to be significant on the uptake of nitrogen by fruits. The maximum uptake of nitrogen occurred at n_2 level at the different irrigation levels,followed by n_3 and n_1. In Experiment 2, n_1 and n_3 were on par at i_3. The effects due to n_2 and n_3 on the uptake of nitrogen were on par at i_1 and i_2 in Experiment 3.

With respect to IK interactions, k_2 was responsible for the highest uptake of nitrogen at all the irrigation levels, followed by k_3 and k_1, which were on par at i_3. At i_2 level in Experiment 3, k_2 and k_3 were also on par.

The NK interactions on the uptake of nitrogen by fruits were significant. At all nitrogen levels, highest uptake occurred at k_2, followed by k_3 and k_1.

4.2.6.2. Phosphorus

4.2.6.2.1. Phosphorus content in plant parts

4.2.6.2.1.1. Effect of I, N and K on the phosphorus content of the plant (Table 37)

The phosphorus content of plant was significantly influenced by drip irrigation treatments. The drip irrigation level of i_3 recorded the highest content of phosphorus in plant followed by i_2 and i_1.

Table 36. Interaction effect of I, N and K on the uptake of nutrients by fruits (kg ha^{-1})

	Nitrogen		Phosphorus		Potassium	
	Expt. 2	Expt. 3	Expt. 2	Expt. 3	Expt. 2	Expt. 3
i_1n_1	10.48	11.75	1.99	2.16	11.11	12.69
i_1n_2	17.28	17.57	3.41	3.72	17.77	18.21
i_1n_3	14.27	16.96	2.98	3.38	14.43	16.63
i_2n_1	10.81	12.61	2.78	3.28	11.56	13.68
i_2n_2	17.01	18.86	4.25	4.38	17.55	19.23
i_2n_3	15.91	18.77	3.90	4.65	16.10	19.00
i_3n_1	12.29	13.63	3.02	3.28	13.09	14.39
i_3n_2	16.29	15.52	3.90	3.59	16.68	16.00
i_3n_3	12.60	14.49	2.81	3.24	12.60	14.66
$F_{4,22}$	11.70**	31.04**	5.72**	8.71**	10.84**	35.09**
i_1k_1	10.18	12.90	1.89	2.34	10.11	12.73
i_1k_2	15.99	16.71	3.07	3.45	17.06	17.80
i_1k_3	15.86	16.36	3.41	3.47	16.14	17.00
i_2k_1	11.91	13.83	3.07	3.44	11.87	13.87
i_2k_2	17.16	19.37	4.22	4.70	18.48	20.99
i_2k_3	14.68	17.03	3.64	4.16	14.86	17.07
i_3k_1	11.95	12.97	2.79	2.95	11.62	12.64
i_3k_2	15.99	16.04	3.88	3.88	17.22	17.62
i_3k_3	13.25	14.63	3.06	3.28	13.53	14.78
$F_{4,22}$	9.11**	8.08**	5.74**	NS	7.24**	14.37**
n_1k_1	9.73	11.77	2.21	2.70	9.84	12.04
n_1k_2	12.65	13.54	2.82	3.11	14.12	15.32
n_1k_3	11.20	12.69	2.77	2.91	11.80	13.42
n_2k_1	12.34	13.70	2.92	3.06	12.27	13.54
n_2k_2	20.34	19.77	4.53	4.41	21.54	21.18
n_2k_3	17.90	18.47	4.11	4.21	18.19	18.73
n_3k_1	11.96	14.24	2.63	2.97	11.50	13.67
n_3k_2	16.15	18.82	3.83	4.50	17.10	19.92
n_3k_3	14.68	16.86	3.22	3.79	14.54	16.70
$F_{4,22}$	13.55**	20.09**	3.25*	5.14**	10.66**	25.58**
SEd	0.538	0.384	0.217	0.209	0.342	0.344
CD	1.113	0.794	0.450	0.433	0.707	0.712

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

Table 37. Effect of I, N and K on the content of phosphorus in plant (%)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1	0.70	0.32	0.36	0.72	0.33	0.37
i_2	0.68	0.32	0.36	0.70	0.34	0.38
i_3	0.71	0.34	0.39	0.73	0.35	0.39
$F_{2,22}$	3.96^*	9.30^{**}	9.64^{**}	NS	3.66^*	3.61^*
n_1	0.69	0.32	0.36	0.71	0.34	0.38
n_2	0.69	0.33	0.36	0.71	0.34	0.38
n_3	0.70	0.34	0.38	0.72	0.34	0.38
$F_{2,22}$	NS	NS	NS	NS	NS	NS
k_1	0.69	0.33	0.37	0.71	0.33	0.38
k_2	0.70	0.33	0.37	0.72	0.34	0.38
k_3	0.69	0.33	0.37	0.71	0.34	0.38
$F_{2,22}$	NS	NS	NS	NS	NS	NS
SEd	0.012	0.007	0.009	—	0.009	0.010
CD	0.025	0.015	0.018	—	0.018	0.020

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

4.2.6.2.1.2. Interaction effect of I, N and K on the phosphorus content of the plant (Table 38)

The phosphorus content of the plant was found to be significantly influenced by IN interaction at 60 DAS and final harvest stages of both experiments. At 60 DAS, at i_1 level of irrigation, the highest content of phosphorus was at n_2 level, which was on par with n_3. The content of phosphorus in plant parts at n_1 and n_3 level at i_1 were also on par. At i_2, there was no significant difference between the nitrogen level in the content of phosphorus by plant. The highest content of phosphorus was at n_3 when irrigated at i_3 which was on par with n_1. It was further seen that n_1 and n_2 were also on par in this character.

At final harvest stage at i_1, the highest content was at n_2 (0.39%) followed by n_3 and n_1 which were on par in Experiment 2, where as all the nitrogen levels were on par in Experiment 3. At i_2 also all the nitrogen levels were on par with respect to phosphorus content in both experiments. At i_3 , the highest phosphorus content was seen at n_3 followed by n_1 which were on par. In Experiment 2, n_1 was also as par with n_2 in this respect.

4.2.6.2.2. Uptake of phosphorus

4.2.6.2.2.1. Effect of I, N and K on the uptake of phosphorus by the plant (Table 39)

The phosphorus uptake by plant recorded on 30 DAS, 60 DAS and final harvest revealed that drip irrigation influenced phosphorus uptake at 60 DAS in Experiment 2 and at 60 DAS and at final harvest during EXperiment 3. At all stages i_2 recorded highest phosphorus uptake.

Table 38. Interaction effect of I, N and K on the phosphorus content of the plant (%)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1n_1	0.69	0.30	0.33	0.71	0.31	0.35
i_1n_2	0.70	0.35	0.39	0.71	0.35	0.39
i_1n_3	0.71	0.32	0.35	0.73	0.33	0.37
i_2n_1	0.68	0.33	0.37	0.70	0.34	0.39
i_2n_2	0.67	0.31	0.34	0.69	0.34	0.38
i_2n_3	0.68	0.32	0.37	0.71	0.33	0.36
i_3n_1	0.71	0.35	0.39	0.73	0.36	0.41
i_3n_2	0.71	0.33	0.36	0.73	0.33	0.36
i_3n_3	0.71	0.37	0.41	0.73	0.37	0.42
$F_{4,22}$	NS	6.95^{**}	7.22^{**}	NS	4.57^{**}	5.19^{**}
i_1k_1	0.68	0.31	0.35	0.70	0.32	0.36
i_1k_2	0.71	0.32	0.35	0.73	0.33	0.36
i_1k_3	0.70	0.33	0.37	0.72	0.34	0.38
i_2k_1	0.68	0.33	0.37	0.71	0.34	0.38
i_2k_2	0.68	0.31	0.35	0.71	0.35	0.39
i_2k_3	0.67	0.32	0.36	0.69	0.32	0.37
i_3k_1	0.71	0.35	0.39	0.74	0.35	0.38
i_3k_2	0.71	0.36	0.40	0.73	0.36	0.38
i_3k_3	0.70	0.34	0.38	0.73	0.35	0.38
$F_{4,22}$	NS	NS	NS	NS	NS	NS
n_1k_1	0.69	0.32	0.36	0.72	0.33	0.37
n_1k_2	0.70	0.34	0.38	0.72	0.34	0.38
n_1k_3	0.68	0.31	0.36	0.72	0.34	0.39
n_2k_1	0.69	0.33	0.37	0.71	0.33	0.38
n_2k_2	0.70	0.32	0.35	0.71	0.35	0.39
n_2k_3	0.69	0.33	0.37	0.71	0.33	0.37
n_3k_1	0.69	0.33	0.38	0.72	0.33	0.38
n_3k_2	0.72	0.34	0.37	0.73	0.34	0.38
n_3k_3	0.70	0.35	0.38	0.72	0.35	0.38
$F_{4,22}$	NS	NS	NS	NS	NS	NS
SEd	—	0.013	0.015	—	0.015	0.017
CD	—	0.026	0.031	—	0.031	0.035

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

Table 39. Effect of I, N and K on the uptake of phosphorus by plant (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1	1.91	4.15	8.88	3.25	7.27	13.61
i_2	2.04	5.44	9.49	3.30	7.95	14.96
i_3	2.02	5.08	9.16	3.12	7.34	13.81
$F_{2,22}$	NS	55.01**	NS	NS	4.45*	4.18*
n_1	1.65	3.81	7.20	2.84	6.27	11.93
n_2	2.33	5.89	11.14	3.57	8.73	16.29
n_3	2.00	4.96	9.19	3.25	7.56	14.16
$F_{2,22}$	26.93**	133.84**	62.45**	17.60**	46.86**	37.41**
k_1	1.63	3.75	7.09	2.73	5.91	11.17
k_2	2.33	5.90	10.92	3.64	8.94	16.69
k_3	2.02	5.02	9.52	3.29	7.71	14.51
$F_{2,22}$	28.69**	143.04**	60.57**	28.54**	72.24**	60.65**
SE	0.093	0.127	0.352	0.122	0.254	0.505
CD	0.192	0.264	0.731	0.254	0.526	1.047

* Significant at 0.05 level   ** Significant at 0.01 level   NS Not Significant

Different nitrogen levels influenced phosphorus uptake. The highest uptake of phosphorus was at n_2 and this was significantly superior to other levels.

With regard to potassium application also the level of k_2 showed highest and significantly superior uptake values.

4.2.6.2.2.2. Interaction effect of I, N and K on the uptake of phosphorus by the plant (Table 40)

The IN interactions on the uptake of phosphorus by the plant was significant at final harvest stage of Experiment 2 and 60 DAS and final harvest stages of Experiment 3. In Experiment 2, the highest uptake of phosphorus was at n_2 at all the levels of irrigation followed by n_3 and n_1. In Experiment 3 also the same trend was seen. At i_2 during final harvest, the levels of nitrogen n_1 and n_3 were on par with respect to uptake of phosphorus while at i_3, the effects due to n_2 and n_3 were as par in this respect.

The interaction due to irrigation and potassium levels were also significant at final harvest of Experiment 2 and at 60 DAS and final harvest of Experiment 3. At 60 DAS, the highest uptake of phosphorus was at k_3 (8:41 kg ha^{-1}) at i_2 level of irrigation which was as par with k_2 (8.00 kg ha^{-1}). At i_2 and i_3, k_2 recorded the highest uptake of phosphorus followed by k_3 and k_1. During the final harvest stage also at i_1, the highest uptake of phosphorus occurred at k_3 which was as par with k_2.

Table 40. Interaction effect of I, N and K on the uptake of phosphorus by plant (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1n_1	1.57	3.04	6.21	2.76	5.58	10.52
i_1n_2	2.49	5.23	11.97	3.65	9.08	16.98
i_1n_3	2.01	4.17	8.46	3.32	7.13	13.31
i_2n_1	1.75	4.52	8.21	2.97	6.85	13.21
i_2n_2	2.30	6.54	11.15	3.57	9.24	17.19
i_2n_3	2.09	5.26	9.11	3.35	7.78	14.48
i_3n_1	1.62	3.88	7.19	2.80	6.39	12.05
i_3n_2	2.19	5.91	10.31	3.47	7.86	14.71
i_3n_3	1.91	5.46	9.98	3.08	7.76	14.68
$F_{4,22}$	NS	NS	5.36^{**}	NS	3.53^{*}	3.48^{*}
i_1k_1	1.66	3.06	5.82	2.63	5.38	10.29
i_1k_2	2.20	4.93	10.01	3.52	8.00	14.72
i_1k_3	2.21	4.45	10.81	3.59	8.41	15.81
i_2k_1	1.64	4.22	7.87	2.81	6.41	12.04
i_2k_2	2.54	6.61	11.72	3.95	10.16	19.00
i_2k_3	1.95	5.49	8.89	3.14	7.30	13.84
i_3k_1	1.58	3.98	7.58	2.74	5.94	11.19
i_3k_2	2.24	6.15	11.04	3.46	8.66	16.37
i_3k_3	1.90	5.13	8.86	3.15	7.41	13.88
$F_{4,22}$	NS	NS	7.87^{**}	NS	7.42^{**}	6.67^{**}
n_1k_1	1.43	3.14	5.85	2.60	5.37	10.08
n_1k_2	1.81	4.51	8.52	2.98	6.92	13.10
n_1k_3	1.70	3.79	7.24	2.95	6.53	12.61
n_2k_1	1.91	4.44	8.30	2.88	6.55	12.36
n_2k_2	2.74	7.23	13.48	4.18	10.88	20.13
n_2k_3	2.33	6.02	11.65	3.64	8.75	16.40
n_3k_1	1.54	3.68	7.12	2.69	5.80	11.08
n_3k_2	2.44	5.95	10.77	3.77	9.02	16.85
n_3k_3	2.03	5.26	9.67	3.28	7.84	14.54
$F_{4,22}$	NS	6.04^{**}	2.44^{*}	NS	5.23^{**}	3.89^{*}
SEd	—	0.221	0.612	—	0.441	0.876
CD	—	0.458	1.266	—	0.912	1.813

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

At i_2, it was seen that k_2 caused the maximum uptake followed by k_3. At this level of irrigation, k_1 and k_3 were on par. When irrigated at i_3 level, k_2 was seen to record the maximum uptake of phosphorus followed by k_3 and k_1.

The effects due to the interaction of N and K were significant on the uptake of phosphorus by plant at 60 DAS and final harvest stages of both experiments. In Experiment 2, at both stages, k_2 was seen to record the highest uptake at all irrigation levels followed by k_3 and k_1. In Experiment 3, at n_1, k_2 recorded the highest uptake of phosphorus which was as par with k_3. At i_2 and i_3 also , k_2 recorded the highest uptake of phosphorus followed by k_3 and k_1.

4.2.6.2.2.2. Effect of I, N and K on the uptake of phosphorus by fruits (Table 35)

The uptake of phosphorus by fruits was significantly influenced by irrigation, nitrogen and potassium. In both experiments, i_2 recorded highest uptake (3.64 and 4.10 kg ha^{-1}) followed by i_3 (3.24 and 3.37 kg ha^{-1})

Nitrogen level n_2 was found to be significantly superior with respect to phosphorus uptake by fruits in Experiment 2 (3.85 kg ha^{-1}) while in Experiments 3, it was on par with n_3 (3.89 kg ha^{-1} and 3.77 kg ha^{-1} respectively for n_2 and n_3).

Significantly higher phosphorus uptake (3.73 and 4.01 kg ha^{-1}) was recorded by k_2 followed by k_3 (3.37 and 3.64 kg ha^{-1}).

4.2.6.2.2.3. Interaction effect of I, N and K on phosphorus uptake by fruits (Table 36)

IN interactions on the uptake of phosphorus by fruits was significant in both experiments. At i_1 and i_2 levels of irrigation, the uptake of phosphorus due to the effect of n_2 and n_3 were as apr. At i_3 level, in Experiment 2, the highest uptake (3.90 kg ha^{-1}) was at n_2 followed by n_1 and n_3 which were as par.

At i_3 level in Experiment 3, all the nitrogen levels were on par with respect to the uptake of phosphorus by fruits.

The interaction effect of IK as the uptake of phosphorus by fruits was significant in Experiment 2. At i_1, the highest uptake occurred at k_3 (3.41 kg ha^{-1}) which was on par with k_2 (3.07 kg ha^{-1}). At i_2, the level k_2 recorded the highest uptake of phosphorus (4.22 kg ha^{-1}) followed by k_3 and k_1. At i_3 also, k_2 caused the highest uptake phosphorus by fruits (3.88 kg ha^{-1}) followed by k_3 and k_1 which were on par.

It was seen that interaction effect of nitrogen and potassium caused significant difference in the uptake of phosphorus by fruits in both experiments. At n_1, the uptake of phosphorus due to k_2 was highest which was on par with k_3 in Experiment 2 and with k_1 and k_3 in Experiment 3. At i_2 also k_2 recorded highest uptake which was on par with k_3. When different K levels were applied at n_3, k_2 was responsible for highest uptake of phosphorus followed by k_3 and k_1.

4.2.6.3. Potassium

4.2.6.3.1. Potassium content in plant parts

4.2.6.3.1.1. Effect of I, N and K on the potassium content of the plant (Table 41)

Neither drip irrigation nor nitrogen levels had any significant effect during any of the growth stages. However, the different levels of potassium exerted marked influence during all the three stages.

Among the potassium levels k_2 recorded the highest potassium content followed by k_3 and k_1.

4.2.6.3.1.2. Interaction effect of I, N and K on the potassium content of plant (Table 42)

The effect due to the interactions of I, N and K were not significant at any of the stages in both experiments.

Table 41. Effect of I, N and K on the potassium content in plant parts (%)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1	2.40	2.61	2.47	2.48	2.70	2.55
i_2	2.40	2.63	2.48	2.47	2.72	2.57
i_3	2.39	2.61	2.47	2.47	2.69	2.54
$F_{2,22}$	NS	NS	NS	NS	NS	NS
n_1	2.39	2.62	2.47	2.48	2.71	2.56
n_2	2.39	2.61	2.47	2.47	2.69	2.55
n_3	2.40	2.62	2.47	2.47	2.71	2.56
$F_{2,22}$	NS	NS	NS	NS	NS	NS
k_1	2.30	2.49	2.33	2.38	2.58	2.41
k_2	2.50	2.73	2.61	2.57	2.81	2.68
k_3	2.39	2.63	2.49	2.47	2.72	2.57
$F_{2,22}$	7.85**	10.02**	14.99**	NS	4.05*	6.48**
SEd	0.051	0.054	0.051	—	0.080	0.075
CD	0.106	0.113	0.106	—	0.166	0.155

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

Table 42. Interaction effect of I, N and K on the potassium content of plant (%)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1n_1	2.40	2.62	2.47	2.51	2.74	2.59
i_1n_2	2.40	2.60	2.46	2.45	2.64	2.50
i_1n_3	2.39	2.62	2.47	2.48	2.72	2.57
i_2n_1	2.39	2.62	2.48	2.47	2.71	2.56
i_2n_2	2.40	2.63	2.50	2.47	2.72	2.58
i_2n_3	2.40	2.64	2.48	2.47	2.73	2.57
i_3n_1	2.39	2.61	2.47	2.46	2.67	2.53
i_3n_2	2.38	2.62	2.47	2.48	2.71	2.56
i_3n_3	2.41	2.61	2.46	2.47	2.69	2.55
$F_{4,22}$	NS	NS	NS	NS	NS	NS
i_1k_1	2.31	2.51	2.34	2.40	2.60	2.43
i_1k_2	2.51	2.71	2.59	2.58	2.78	2.66
i_1k_3	2.37	2.62	2.47	2.46	2.71	2.56
i_2k_1	2.29	2.48	2.32	2.38	2.58	2.41
i_2k_2	2.49	2.74	2.62	2.55	2.84	2.70
i_2k_3	2.41	2.66	2.52	2.49	2.75	2.59
i_3k_1	2.29	2.48	2.32	2.37	2.57	2.40
i_3k_2	2.49	2.74	2.61	2.58	2.81	2.68
i_3k_3	2.39	2.62	2.48	2.46	2.69	2.54
$F_{4,22}$	NS	NS	NS	NS	NS	NS
n_1k_1	2.30	2.49	2.33	2.39	2.59	2.42
n_1k_2	2.49	2.73	2.60	2.57	2.82	2.69
n_1k_3	2.39	2.64	2.49	2.48	2.71	2.55
n_2k_1	2.30	2.49	2.33	2.39	2.58	2.41
n_2k_2	2.50	2.72	2.60	2.57	2.79	2.67
n_2k_3	2.39	2.63	2.49	2.45	2.71	2.56
n_3k_1	2.29	2.48	2.32	2.38	2.58	2.41
n_3k_2	2.51	2.75	2.62	2.57	2.82	2.69
n_3k_3	2.40	2.63	2.49	2.47	2.73	2.58
$F_{4,22}$	NS	NS	NS	NS	NS	NS

NS Not Significant

4.2.6.3.2. Uptake of potassium by the plant

4.2.6.3.2.1. Effect of I, N and K on the uptake of potassium by the plant (Table 43)

The effect of irrigation levels on potassium uptake was significant at 60 DAS in both experiments and at final harvest at stage of Experiment 2. The highest uptake of potassium at all stages in both the experiments was recorded at i_2.

The effect due to nitrogen levels was significant at all stages in both the experiments. The highest uptake was at n_2 which was significantly superior to n_3.

The uptake of potassium was significantly influenced by potassium levels. The highest uptake was at k_2 which was significantly superior to k_3.

4.2.6.3.2.2. Interaction effect of I, N and K on the uptake of potassium by the plant (Table 44)

IN interaction on the uptake of potassium by the plant was significant at 60 DAS in Experiment 2. The highest uptake was at n_2 at all the irrigation levels followed by n_3 and n_1.

At 60 DAS and final harvest stages of both experiments, the effects due to IK interactions were significant on uptake of potassium by the plant.

Table 43. Effect of I, N and K on the uptake of potassium by plant (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1	6.57	33.61	61.30	11.21	59.12	93.61
i_2	7.28	45.65	67.08	11.68	64.61	102.54
i_3	6.95	38.66	58.51	10.61	56.80	90.04
$F_{2,22}$	NS	50.24^{**}	6.03^{**}	NS	6.77^{**}	NS
n_1	5.73	30.84	48.83	9.90	50.65	80.12
n_2	8.10	48.36	76.77	12.44	69.23	109.96
n_3	6.98	38.73	61.29	11.15	60.66	96.11
$F_{2,22}$	22.40^{**}	105.70^{**}	61.69^{**}	14.72^{**}	36.33^{**}	4.08^{*}
k_1	5.53	28.44	44.55	9.11	45.89	71.76
k_2	8.28	49.20	78.70	13.00	72.63	116.26
k_3	6.99	40.28	63.64	11.39	62.01	98.17
$F_{2,22}$	30.02^{**}	149.02^{**}	92.20^{**}	34.73^{**}	76.17^{**}	4.12^{*}
SEd	0.354	1.207	2.520	0.469	2.182	3.415
CD	0.735	2.503	5.227	0.972	4.525	7.083

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

Table 44. Interaction effect of I, N and K on the uptake of potassium by the plant (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1n_1	5.52	26.78	45.86	9.78	49.28	77.92
i_1n_2	8.60	39.49	76.34	12.64	68.35	108.29
i_1n_3	6.73	34.55	61.69	11.22	59.74	94.62
i_2n_1	6.19	36.17	55.30	10.47	54.90	86.78
i_2n_2	8.31	58.00	83.84	12.86	73.69	117.52
i_2n_3	7.33	42.79	62.10	11.71	65.24	103.33
i_3n_1	5.47	29.57	45.32	9.46	47.77	75.67
i_3n_2	7.38	47.58	70.12	11.84	65.64	104.08
i_3n_3	6.86	38.84	60.08	10.52	56.98	90.36
$F_{4,22}$	NS	3.80^{*}	NS	NS	NS	NS
i_1k_1	5.64	24.71	38.55	9.00	44.12	68.89
i_1k_2	7.74	41.11	73.50	12.43	66.54	106.45
i_1k_3	7.47	35.01	71.84	12.20	66.72	105.49
i_2k_1	5.56	31.76	49.60	9.47	48.81	76.51
i_2k_2	9.25	58.85	89.46	14.28	82.42	131.91
i_2k_3	7.03	46.35	62.19	11.28	62.60	99.21
i_3k_1	5.41	28.85	45.51	8.85	44.73	69.89
i_3k_2	7.84	47.65	73.12	12.28	68.93	110.40
i_3k_3	6.64	39.49	56.89	10.69	56.72	89.82
$F_{4,22}$	NS	3.65^{*}	6.21^{**}	NS	3.97^{*}	4.08^{*}
n_1k_1	4.79	24.12	37.90	8.68	42.22	66.00
n_1k_2	6.46	36.56	58.37	10.74	57.26	91.61
n_1k_3	5.92	31.84	50.21	10.29	52.46	82.76
n_2k_1	6.36	33.18	52.01	9.69	50.35	78.97
n_2k_2	9.85	62.66	100.48	15.05	85.70	137.28
n_2k_3	8.08	49.24	77.81	12.59	71.63	113.64
n_3k_1	5.45	28.01	43.75	8.96	45.09	70.32
n_3k_2	8.52	48.39	77.24	13.19	74.94	119.87
n_3k_3	6.96	39.77	62.89	11.29	61.94	98.12
$F_{4,22}$	NS	8.32^{**}	5.16^{**}	NS	3.90^{*}	4.12^{*}
SEd	—	2.094	4.373	—	3.786	5.927
CD	—	4.335	9.053	—	7.837	12.268

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

At 60 DAS, in Experiment 2, k_2 was seen to cause highest uptake at all irrigation levels followed by k_3 and k_1. At 60 DAS in Experiment 3, k_3 recorded the highest uptake of potassium (66.72 kg ha^{-1}) which was on par with k_2 (66.54 kg ha^{-1}). At i_2 and i_3 levels also, k_2 was responsible for highest uptake of potassium by plant parts followed by k_3 and k_1. During final harvest stages of both experiments, the highest uptake of potassium was at k_2 followed by k_3 and k_1. At i_1 the effects due to k_2 and k_3 were on par.

At the later stages of plant growth ie., at 60 DAS and final harvest stages there was significant influence due to NK interactions on the uptake of potassium by plant parts. At 60 DAS in Experiment 2, k_2 recorded the highest uptake of potassium followed by k_3 and k_1 at all nitrogen levels. At the final harvest stage of Experiment 2 and at 60 DAS and final harvest stages of Experiment 3, the highest uptake of potassium was at k_2 followed by k_3 and k_1 at the different nitrogen levels. At n_1, k_2 was on par with k_3.

4.2.6.3.2.3. Effect of I, N and K on the potassium uptake by fruits (Table 35)

The influence of irrigation on the potassium uptake by fruits revealed that i_2 significantly increased the uptake (15.07 and 17.31 kg ha^{-1}).

Nitrogen influenced the uptake at n_2 level (17.33 and 17.82 kg ha^{-1}) followed by n_3 (14.38 and 16.76 kg ha^{-1}).

Potassium levels significantly increased the uptake of potassium by the fruits in both experiments the maximum uptake being at k_2 (17.59 and 18.81 kg ha^{-1}) followed by k_3 (14.84 and 16.28 kg ha^{-1}).

4.2.6.3.2.4. Interaction effect of I, N and K on the potassium uptake by fruits (Table 36)

The uptake of potassium by the fruits were found to be significantly influenced by IN interactions. In Experiment 2, n_2 recorded highest uptake at all the irrigation levels followed by n_3 and n_1. At i_3, n_3 and n_1 were on par. In Experiment 3, n_2 was responsible for highest uptake of potassium at the different irrigation levels followed by n_3 and n_1. At i_2 it was seen that n_2 was on par with n_3 and at i_3, n_3 was on par with n_1.

IK interactions on the uptake of potassium by the fruits were significant in both experiments. At i_1, i_2 and i_3 the effect due to k_2 recorded the highest uptake followed by k_3 and k_1. At i_1 level in Experiment 3, k_2 was on par with k_3.

The interaction effect of nitrogen and potassium produced significant difference in the uptake of potassium by the fruits. At the different levels of nitrogen, k_2 was responsible for significant uptake of potassium by fruits followed by k_3 and k_1.

4.2.7. Soil Analysis

4.2.7.1. Available nitrogen content

4.2.7.1.1. Effect of I, N and K on the available nitrogen content of soil (Table 45)

Irrigation levels did not influence the available nitrogen content of the soil.

Nitrogen levels were found to have significant influence on the available nitrogen content of the soil at 60 DAS and final harvest stages. The highest available nitrogen content in the soil was at n_2 followed by n_3. The lowest available soil nitrogen was at n_1.

Different levels of potassium also did not influence the available nitrogen content of the soil. The highest available nitrogen content of soil was at k_2.

4.2.7.1.2. Interaction effect of I, N and K on the available nitrogen content of soil (Table 46)

The available nitrogen content of the soil was not influenced by any of the interactions.

Table 45. Effect of I, N and K on the available nitrogen content of soil (kg ha^{-1})

	Experiment 2				Experiment 3		
	Initial	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1	272.33	312.78	270.40	235.19	274.17	327.61	292.28
i_2	272.95	313.89	269.79	233.94	273.56	329.37	299.92
i_3	270.95	314.57	274.20	234.12	274.06	329.06	289.68
$F_{2,22}$	NS	NS	NS	NS	NS	NS	NS
n_1	273.07	308.69	254.08	215.81	244.46	294.19	259.38
n_2	272.92	320.72	289.58	253.17	302.87	363.04	307.00
n_3	270.23	311.83	270.72	234.27	274.46	328.80	268.49
$F_{2,22}$	NS	NS	23.07**	25.90**	57.77**	40.67**	19.83**
k_1	270.96	312.71	269.16	234.57	273.10	326.85	292.15
k_2	270.29	314.18	272.17	233.38	274.34	328.82	293.93
k_3	272.98	314.35	273.05	235.30	274.34	330.36	295.79
$F_{2,22}$	NS	NS	NS	NS	NS	NS	NS
SEd	4.596	—	5.230	5.191	5.434	7.634	10.338
CD	9.532	—	10.847	10.767	11.271	15.832	21.440

* Significant at 0.05 level ** Significant at 0.01 level NS Not Significant

Table 46. Interaction effect of I, N and K on the available nitrogen content of soil (kg ha^{-1})

	Experiment 2				Experiment 3		
	Initial	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
i_1n_1	274.80	353.69	217.11	204.76	244.24	294.94	259.38
i_1n_2	274.93	389.80	254.16	220.90	303.81	362.84	327.15
i_1n_3	267.28	367.70	234.29	212.68	274.47	325.05	290.32
i_2n_1	271.80	348.25	215.45	209.41	244.74	293.75	259.19
i_2n_2	275.89	391.22	252.86	220.34	303.16	366.91	333.49
i_2n_3	271.16	369.89	233.50	211.91	272.80	327.45	307.08
i_3n_1	272.63	360.31	214.87	211.90	244.41	293.90	259.59
i_3n_2	267.95	387.73	252.48	220.93	301.65	359.37	311.36
i_3n_3	272.27	374.58	235.02	210.89	276.11	333.91	298.08
$F_{4,22}$	NS	NS	NS	NS	NS	NS	NS
i_1k_1	271.62	366.43	235.62	212.62	272.60	324.78	289.06
i_1k_2	272.51	371.02	234.13	211.73	273.12	328.68	294.20
i_1k_3	272.87	373.74	235.53	213.99	276.79	329.35	293.59
i_2k_1	272.96	368.47	234.65	211.89	272.77	329.45	313.67
i_2k_2	272.10	370.26	232.32	214.33	274.96	329.04	293.45
i_2k_3	273.77	370.63	234.84	215.44	272.96	329.61	292.63
i_3k_1	268.30	372.58	233.16	213.62	273.94	326.31	273.74
i_3k_2	272.25	375.24	233.68	216.48	274.96	328.75	294.13
i_3k_3	272.31	374.79	235.52	213.62	273.28	332.11	301.15
$F_{4,22}$	NS	NS	NS	NS	NS	NS	NS
n_1k_1	269.32	351.92	215.81	206.64	243.72	294.57	260.43
n_1k_2	272.91	353.91	214.33	210.43	246.57	292.38	256.35
n_1k_3	276.99	353.42	217.18	209.00	243.09	295.63	261.38
n_2k_1	271.66	388.20	253.46	219.48	302.47	360.82	310.73
n_2k_2	274.51	389.82	252.19	220.53	302.16	364.38	334.08
n_2k_3	272.61	390.73	253.86	222.15	303.99	363.91	327.18
n_3k_1	271.90	367.37	234.45	212.01	273.12	325.15	305.31
n_3k_2	269.45	372.78	233.51	211.58	274.30	329.71	291.36
n_3k_3	269.35	372.01	234.85	211.89	275.95	331.54	298.82
$F_{4,22}$	NS	NS	NS	NS	NS	NS	NS

NS Not Significant

4.2.7.2. Available phosphorus content of soil

4.2.7.2.1. Effect of I, N and K on the available phosphorus content of soil (Table 47)

The phosphorus content of soil was not influenced by irrigation, nitrogen and potassium levels.

4.2.7.2.2. Interaction effect of I, N and K on the available phosphorus content of soil (Table 48)

No significant difference was noted in the available phosphorus content of the soil due to the interaction effects.

4.2.7.3. Available potassium content of soil

4.2.7.3.1. Effect of I, N and K on the available potassium content of soil (Table 47)

The effects due to irrigation and nitrogen levels did not influence the available potassium content of soil significantly. But the highest content of available potassium in the soil was recorded at i_2 level (30.39 kg ha^{-1} and 51.98 kg ha^{-1}) and at n_2 level. (31.05 kg ha^{-1} and 51.82 kg ha^{-1}). The highest potassium content in the soil was at k_2 (38.13 kg ha^{-1} and 57.07 kg ha^{-1} in Experiments 2 and 3 respectively).

Table 47. Effect of I, N and K on the available phosphorus and potassium content of soil (kg ha^{-1})

	Available P_2O_5 in soil			Available K in soil		
	Initial Expt. 2	Final Expt 2. and Initial Expt. 3	Final Expt. 3	Inital Expt. 2	Final Expt 2. and Initial Expt. 3	Final Expt. 3
i_1	39.33	46.89	49.59	77.80	28.16	48.65
i_2	40.88	47.38	50.34	79.34	30.39	51.98
i_3	40.73	48.31	51.82	79.63	29.27	47.20
$F_{2,22}$	NS	NS	NS	NS	NS	NS
n_1	40.04	47.57	50.57	78.19	27.87	48.50
n_2	40.09	47.11	50.34	79.68	31.05	51.82
n_3	40.81	47.91	50.83	79.30	28.91	47.50
$F_{2,22}$	NS	NS	NS	NS	NS	NS
k_1	40.31	47.21	50.68	77.53	19.64	40.26
k_2	40.17	47.48	50.39	79.73	38.13	57.07
k_3	40.45	47.60	50.68	79.91	30.06	50.50
$F_{2,22}$	NS	NS	NS	NS	77.27^{**}	25.78^{**}
SEd	—	—	—	—	1.491	2.360
CD	—	—	—	—	3.093	4.895

** Significant at 0.01 level NS Not Significant

Table 48. Interaction effect of I, N and K on the available phosphorus and potassium content of soil (kg ha^{-1})

	Available P_2O_5 in soil			Available K in soil		
	Initial Expt. 2	Final Expt 2. and Initial Expt. 3	Final Expt. 3	Inital Expt. 2	Final Expt 2. and Initial Expt. 3	Final Expt. 3
i_1n_1	38.90	47.71	50.98	78.91	25.68	48.73
i_1n_2	38.41	47.40	49.62	76.61	30.88	50.92
i_1n_3	40.69	45.65	48.15	77.87	27.90	46.30
i_2n_1	41.72	46.61	48.93	78.26	30.44	52.37
i_2n_2	41.18	47.14	50.49	80.27	30.61	54.22
i_2n_3	39.73	48.40	51.61	80.68	30.14	49.35
i_3n_1	39.51	48.48	51.79	77.41	27.49	44.41
i_3n_2	40.68	46.78	50.93	82.15	31.65	50.33
i_3n_3	42.00	49.67	52.73	79.34	28.68	46.87
$F_{4,22}$	NS	NS	NS	NS	NS	NS
i_1k_1	39.25	46.82	49.89	77.41	17.85	37.34
i_1k_2	39.43	46.66	49.08	77.92	36.75	58.29
i_1k_3	39.32	47.18	49.78	78.06	29.87	50.30
i_2k_1	41.09	46.72	49.94	77.58	21.38	44.47
i_2k_2	40.43	47.62	51.01	81.12	39.88	59.82
i_2k_3	41.10	47.81	50.07	80.25	29.93	51.66
i_3k_1	40.60	48.99	52.20	77.61	19.68	38.96
i_3k_2	40.64	48.15	51.07	80.15	37.76	53.11
i_3k_3	40.59	47.80	52.19	81.15	30.37	49.53
$F_{4,22}$	NS	NS	NS	NS	NS	NS
n_1k_1	39.69	48.06	50.73	76.42	18.58	38.52
n_1k_2	40.49	47.97	50.23	79.87	36.26	56.46
n_1k_3	39.94	46.66	50.74	78.29	28.77	50.54
n_2k_1	40.05	46.76	50.11	77.62	21.72	44.06
n_2k_2	40.02	47.06	50.27	80.81	40.00	59.12
n_2k_3	40.20	47.51	50.65	80.61	31.42	52.29
n_3k_1	41.20	47.71	51.19	78.56	18.62	38.20
n_3k_2	39.99	47.40	50.66	78.51	38.12	55.65
n_3k_3	41.22	48.61	50.65	80.82	29.98	48.67
$F_{4,22}$	NS	NS	NS	NS	NS	NS

NS Not Significant

4.2.7.3.2. Interaction effect of I, N and K on the available potassium content of the soil (Table 48)

The interactions due to the effects of IN, IK and NK were not significant.

4.2.7.4. Step wise regression on the influence of available N and K content of soil on yield (Table 49 and 50)

Stepwise regression was performed to study the influence of available nitrogen and potassium on the yield of cucumber.

Table 49. Step wise regression of yield on available nitrogen and potassium content of soil

(Experiment 2)

	F	% Variation	Rg.SS.
Final K	379.03	83.30	2977.07
Final K, Final N	208.72	84.77	3029.69
Final K, Final N, 60 DAS N	151.40	85.99	3073.29
Final K, Final N, 60 DAS N, 30 DAS N	120.23	86.82	3103.01
Final K, Final N, 60 DAS N, 30 DAS N, Initial K	99.17	87.32	3120.85

The results of Experiment 2 revealed the influence of available nitrogen content of soil at 30 DAS, 60 DAS and final harvest stage on yield of cucumber. Initial and final potassium status of the soil also influenced the yield. 87.30 per cent of the variation in yield may be explained by these five factors (Table 49). Stepwise regression analysis in Experiment 3 showed the influence of nitrogen content of the soil at initial stage and at 30 DAS and initial potassium status of the soil on the yield of cucumber. 94 per cent of the yield of cucumber may be explained due to the influence of these three factors (Table 50).

Table 50. Stepwise regression of yield on available nitrogen and potassium content of soil

(Experiment 3)

	F	% Variation	Rg.SS.
Initial K	762.36	90.93	3120.64
Initial K, 30 DAS N	522.30	93.30	3201.85
Initial K, 30 DAS N, Initial N	383.58	93.96	3224.39

4.2.8. Economics

The details of the cost of laying out the drip system along with the assumptions made on cost and returns are presented in Table 51.

Table 51. Assumptions made in working out economics of drip irrigation

A. Cost of laying out of drip per ha of cucumber

Materials	Quantity	Cost / Unit Rs.	Total cost Rs.
Pipes			
Mainline (63mm)	300m	Rs. 18.30/m	5500
Submain (16mm)	1800m	Rs. 7.65/m	13,770
Laterals (3mm)	2000m	Rs. 1.65/m	3300
Emitters	5000 Nos	Rs. 1.01/1 No.	5050
Other Accessories			2000
Filter			990
Total			30,610

B. Total investments required for establishing a drip unit in ha of cucumber for irrigating @ 3l plant^{-1} day^{-1}

Item	Cost (Rs.)
Drip irrigation materials	30,610
Tank (20 m^3)	50,000
Pump (1 HP)	13,000
Total	93,610

Interest on the investments - 12%

Life of drip irrigation unit 5 years

Repayment per year Rs. 18700

On an average, the cost of drip unit per. hectare worked out to Rs. 30,610 besides the estimated cost of tank (10,000 litres capacity) at Rs 50000/-

The cost of production of one hectare of cucumber is presented in Table 52.

The available cost under drip irrigation comprised of cost of cultivation, interest on initial investment at 12 per cent per annum, marketing and transporting charges imputed at 5 per cent of gross revenue (Table 53). The variable cost under surface irrigation is devoid of interest charges on initial investment but includes additional labour charges required for irrigation. The gross return at all levels of drip irrigation were higher when compared to surface irrigation methods. The additional returns per hectare per season due to drip irrigation over normal surface irrigation amounted to Rs 19,493, Rs. 22,933 and Rs 18,886 in the 4,3 and 2 l discharge rate per plant per day.

The evaluation of investments made on drip system was formulated using discount cash flow technique (Gittinger, 1972). Discounted cash flow was estimated for drip in the treatment receiving 3 litres of water plant^{-1} day^{-1}. The cash flow considered for this analysis comprised only of the profits obtained under this treatment. The normal life expectancy of drip system under the existing condition was considered as five years and two crops were considered normal under drip for each year.

Total 52. Cost of production of one ha cucumber

	Initial cost	Interest on capital @ 12%	Cultivation charges excluding irrigation per season	Cost of making channels / layout drip lines / electricity charges	Irrigation charges	Total cost per season
Drip irrigation						
Drip	30,610	5500 (per season)	5000	2000 (per season)		12,500
Tank	50,000					
Pump	13,000					
	93,610					
Surface						
Pump	13,000	800 (per season)	5000		14,490	20,290

Table 53. Economics of dirp irrigation over surface methods in cucumber at different levels of irrigation in one season

Particulars	Drip irrigation			Surface irrigation
	4l plant^{-1} day^{-1}	3l plant^{-1} day^{-1}	2l plant^{-1} day^{-1}	
Total fixed cost	93,610	93,610	93,610	13,000
Gross yield (t ha^{-1})	18.81	20.63	18.50	12.66
Gross returns (Rs ha^{-1})	37,620	41,260	37,000	25,320
Total variable cost (Total cost per season + marketting charge)	14,363	14,563	14,350	21,556
Gross profit (Rs. ha^{-1})	23,257	26,697	22,650	3,764
Additional Return under drip (Rs. ha^{-1})	19,493	22,933	18,886	
Benefit cost ratio	2.62	2.83	2.58	1.17

Accordingly discounts were made for 10 irrigated crop seasons. The details of the measures used are presented in Table 54.

Table 54. Evaluation of cash flow from drip irrigation level of 3l plant^{-1} day^{-1} for cucumber

Net Present worth (Rs.)	—	25,283
Internal Rate of Returns (%)	—	23
Pay back period (years)	—	1.13

It is evident that the benefit cost ratio was highest at i_2 (2.83) closely followed by i_3 (2.62) and i_1 (2.58), while conventional practice recorded a ratio of 1.17. The IRR at i_2 worked out to 23% which shows that this system is financially viable to the farmer. The pay back period at this level of irrigation was 1.13 years.

DISCUSSION

5. DISCUSSION

The experimental findings on the response of cucumber to drip irrigation, nitrogen and potassium revealed that the crop responded differently to the levels of drip irrigation, nitrogen and potash in terms of growth and yield parameters. The interaction of irrigation and nutrients also revealed significance. Pooled analysis of fruit yield for two crops also recorded significant interactions. The factors controlling the growth and yield of cucumber and performance of drip method of irrigation are discussed in this chapter.

5.1. Experiment 1a. Standardisation of flow rate from the dripper, number of drippers per plant and duration of irrigation

The results indicated that the wetting pattern was governed more by the volume of water added per day and less by the discharge rates (Table 5). This is in conformity with the studies of Bresler *et al.* (1971), Roth *et al.* (1974), Bresler (1977) and Mc Auliffe (1986).

The width and depth of wetting were more when two drippers plant^{-1} was used compared to one dripper plant^{-1}. This is because using two drippers per plant caused more water to get ponded in the wetting zone which might have caused more saturation in the lateral dimension and more

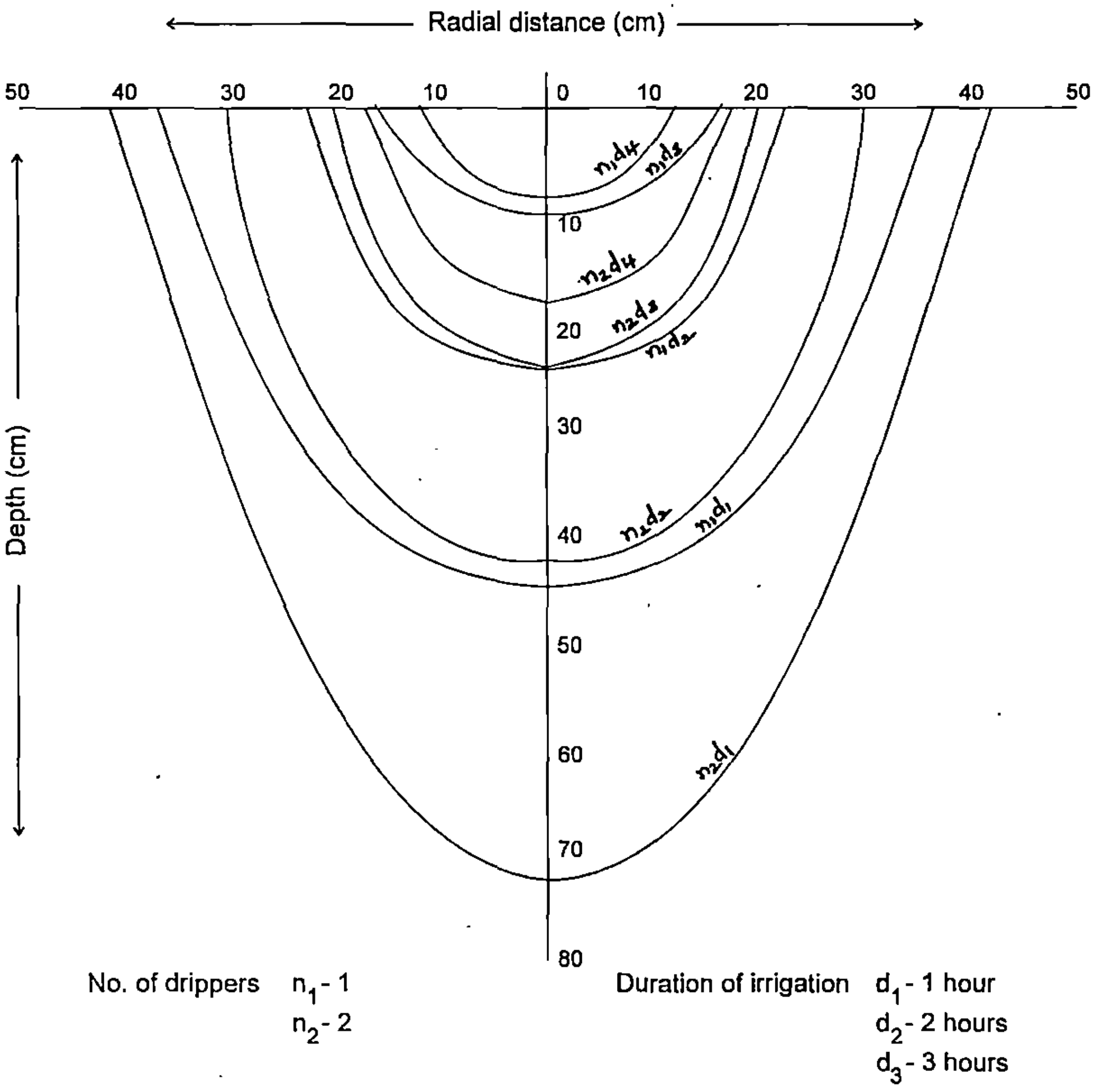


Fig. 1. Wetting front as influenced by number of drippers and duration of irrigation at the drip irrigation level of 2l plant^{-1} day^{-1}

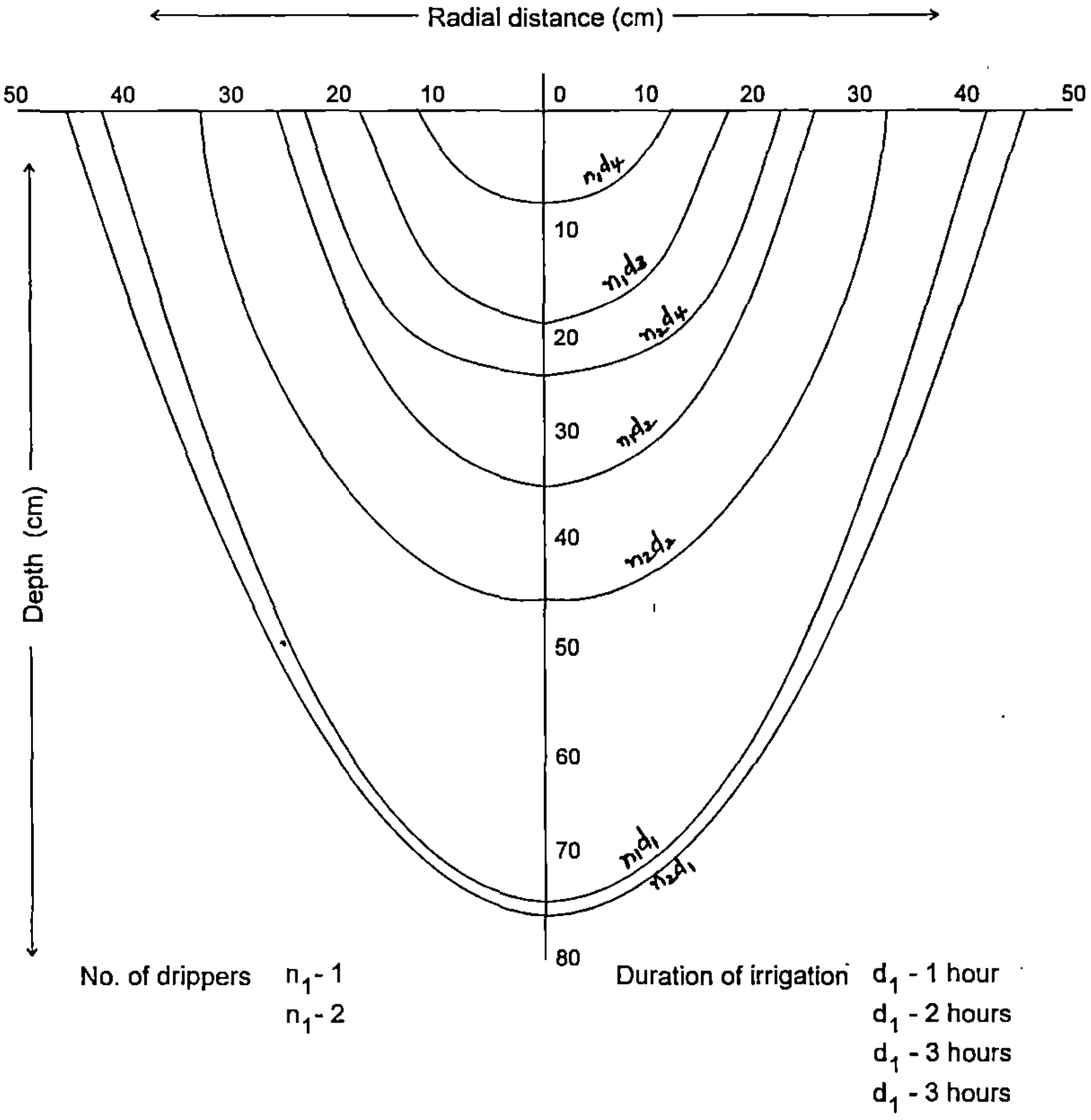


Fig. 2[illegible]. Wetting front as influenced by number of drippers and duration of irrigation at the drip irrigation level of 3 l plant^{-1}day^{-1}

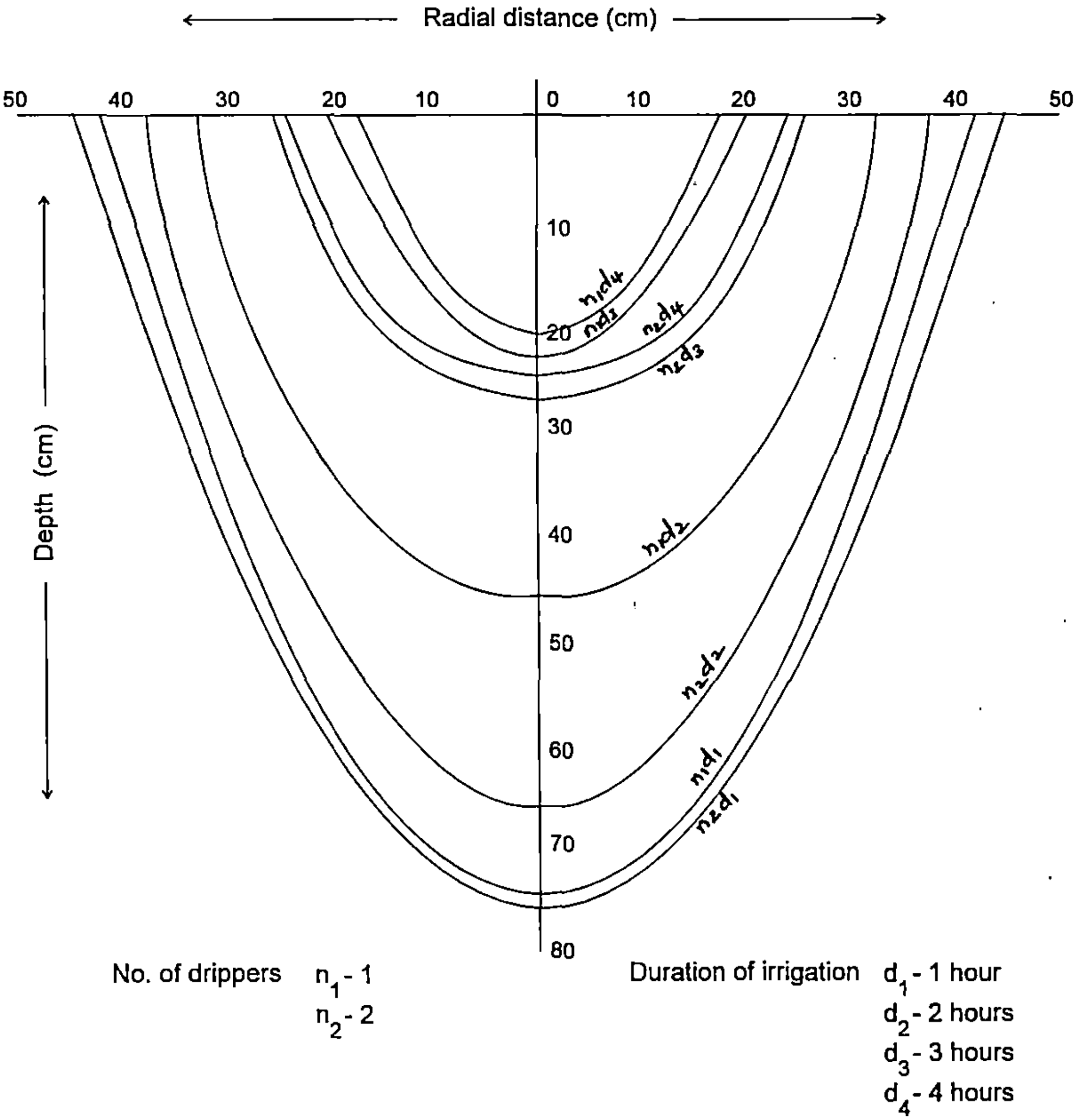


Fig. 2a. Wetting front as influenced by number of drippers and duration of irrigation at the drip irrigation level of 4 l plant^{-1} day^{-1}

penetration into the lower layers of soil due to gravitational force. Similar results have been reported by Roth *et al.* (1974), Mostoghami *et al.* (1982) and Kumar (1984).

When the discharge rate is high, area of saturated zone increases, causing ponding. The ponded water is pushed to either side resulting in larger width of wetting front. At the level of irrigation of 4 l plant^{-1} day^{-1} the width of wetting was 40.12cm and 49.56cm respectively for one and two drippers plant^{-1} each with a discharge rate of 1.33 l hr^{-1}. This view was supported by Bresler *et al.* (1971) in his experimental findings. Roth *et al.* (1974) and Kumar (1984) also reported the same result.

5.2. Experiment 1b. Studies on depth and spread of root system of cucumber under drip irrigation

Drip irrigation induced dense root growth near the emitter in a radius of 15cm and root system was almost confined to 25cm radius and of the same depth. This is in conformity with observations of many others like Goldberg *et al.* (1971), Bernstein and Francois (1973) and Kumar (1984).

5.3. Experiment 2 and Experiment 3. Response of cucumber to drip irrigation under varying levels of nitrogen and potash

5.3.1. Growth parameters

Growth differences existed between the two crops of Experiment 2 and 3 in terms of length of vine, number of leaves per plant, leaf area index and dry matter production. Considering the peak values for growth parameters, plants were of better stature, with more length of vine, more number of leaves per plant, high LAI and higher dry matter production in Experiment 3 than that in experiment 2. This may be due to the favourable climate which reduced the incidence of pests and diseases during Experiment 3. During Experiment 2, the relative humidity in the afternoon was lower than the average values throughout the crop growth while in the forenoon, it was always higher than the average values. More over, the maximum and minimum temperatures recorded were also lower than the average values. These factors might have contributed to higher disease occurrence observed in Experiment 2. Yellow vein, downy mildew and fruit rot were the dominant diseases besides pests like epilachna beetle. This resulted in lower leaf area which led to the reduced length of vine, reduction in number of leaves per plant, LAI and there upon dry matter production.

All these growth parameters were significantly influenced by irrigation, nitrogen and potassium levels.

Growth, the irreversible gain in dry matter, is the sum total of the vital metabolic processes of cell division and cell enlargement. Water deficit and water stress adversely affect both these processes of which cell enlargement is more affected (Begg and Turner, 1976, Cocueci *et al.*, 1976). In general growth is suspended during moisture stress and resumed upon its elimination (Arnon, 1975). The poor growth recorded by plants receiving i_1 level of irrigation may be attributed to the effect of water stress on the above mentioned two vital processes of plant growth. The favourable influence of irrigation at i_2 level observed within 15 days after the application of differential treatments could thus be explained as the stimulation of metabolic activities due to higher moisture availability. Similar results were reported by Flocker *et al.* (1965), Cummins and Kretchman (1974), Escobar and Gausman (1974), Mathew (1981), Ortega and Kretchman (1982), Thomas (1984) and Subba Rao (1989) in various crops.

At the highest level of drip irrigation (i_3) a decline in growth parameters was observed. The width and depth of wetting under this level of irrigation were 40.12cm and 23.04cm respectively (Table 5). From Table 7b it could be observed that 91 per cent of the roots were within a lateral distance of 30cm from the base of the plant. 75 per cent of the roots were within the depth of 25cm from the soil surface. As per the findings of Goldberg *et al.* (1976a), King *et al.* (1979), Bar Yosef *et al.* (1980), Goyal *et al.* (1988) and Chartzoulakis and Michaelakis (1990) the root growth is concentrated at the soil volume close to the dripper. Bar Yosef *et al.* (1980) have reported that relatively more water was taken up from the 0-22.5cm cylindrical soil volume. From the above facts it could be confirmed that the width of wetting of root zone in drip irrigated plants play a significant role in deciding the growth. Sine 91 per cent of the roots were located in a radius of 0-30cm from the base of the plant, water deficiency in this zone could have led to the decline in yield. The width of wetting in this case being 40.12cm, a major portion of water applied might have spread to the periphery of the wetting zone where there roots didnot penetrate. Due to the lack of roots in this area, evaporation losses could also be more from this area.

The results show that among the drip irrigation treatments (i_2) had significantly increased the length of vines, number of leaves, leaf area index and dry matter accumulation. Cucurbits require considerable amount of moisture when making their most vigorous growth and upto the time the fruits are mature (Whitaker and Davis, 1962). There was a reduction of growth parameters in the i_3 level of irrigation for all the growth characters like length of vine (12 per cent), number of leaves (13 per cent), LAI (22 per cent) and dry matter production (11 per cent). The reduced growth in the higher level of irrigation (i_3) could be attributed to the possible increase in width of wetting which caused the movement of water and nutrients beyond the effective root zone leading to a reduction in the uptake of nutrients as observed in the present study.

The treatment receiving drip irrigation at the rate of 2 l plant^{-1} day^{-1} (i_1) might have experienced stress conditions compared to the others. The effect of stress might have reflected on all the growth parameters. The 12 per cent lower LAI than i_2 could be attributed to the fewer number of leaves and lesser leaf area. The process of leaf production and expansion are largely dependent on moisture regimes and nutrient supply (Arnon, 1975). A steep decline in LAI were reported by several workers in crops when the leaf water potential was decreased to a few bars. A reduction in leaf area due to moisture stress was reported by Cummins and Kretchman (1974), Escobar and Gausman (1974) and Ortega and Kretchman (1982) and Subba Rao (1989) in cucumber, while in related crops similar results were reported by Arnon (1975) Begg and Turner (1976) and Thomas (1984).

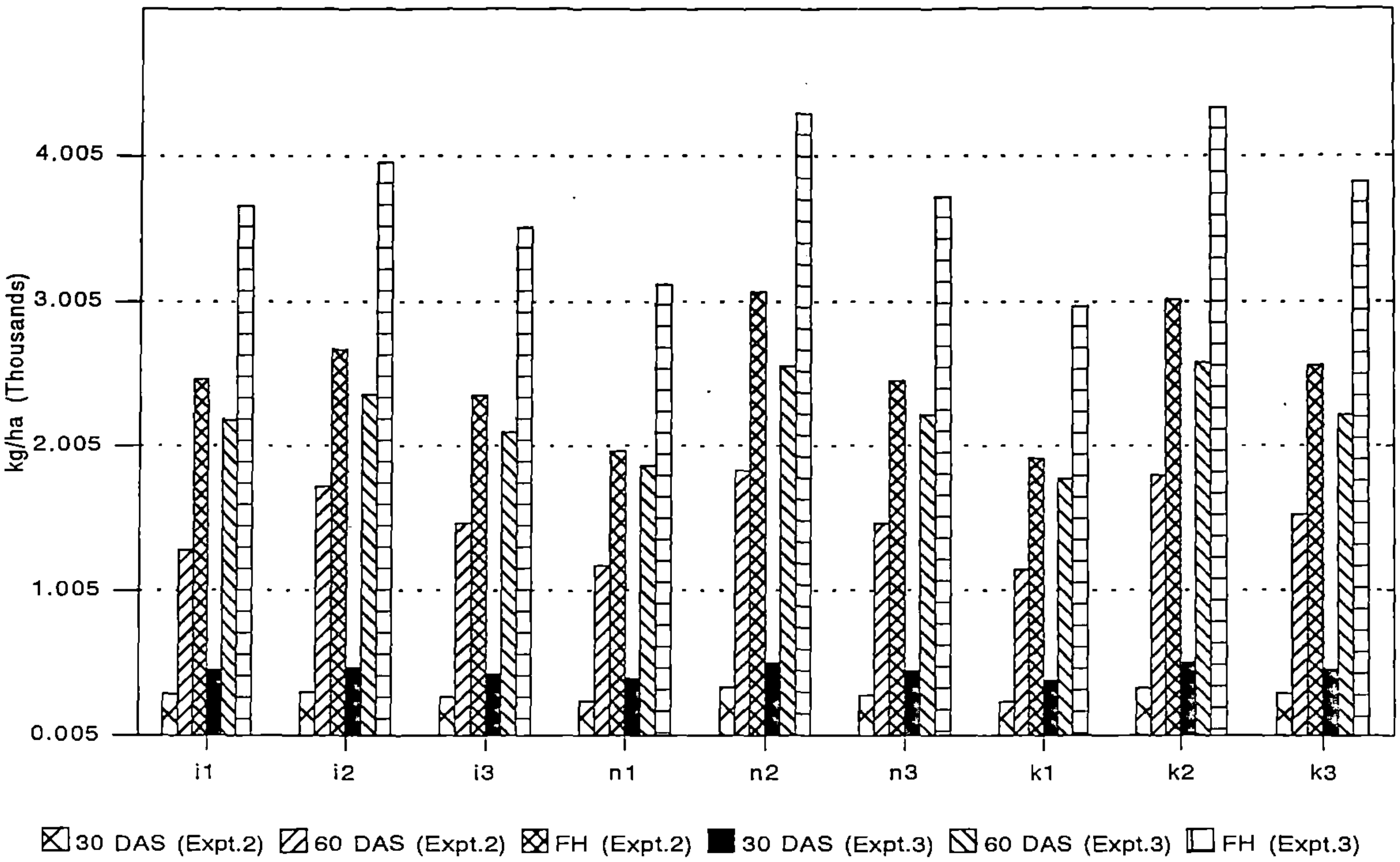


Fig. 4. Effect of I, N and K on the dry matter production per hectare (Experiment 2 and 3)

The dry matter production also followed the same trend. The amount of dry matter production depends upon the the effectiveness of photosynthesis of the crop and further more on plants whose vital activities are functioning effectively (Arnon, 1975). The leaves of a plant are the main organs of photosynthesis and LAI is the best measure of capacity of a crop for producing dry matter. Hence the dry matter production which is dependent on the growth parameters like vine length, leaf number and LAI showed increase in wetter regimes upto i_2. Lower photosynthetic efficiency which was evident from low LAI in i_3 might be a major reason for low dry matter production. Similar results were earlier reported by Cummins and Kretchman (1974), Ortega and Kretchman (1982), Thomas (1984) and Subba Rao (1989) in cucurbits.

Increasing the doses of nitrogen upto 70 kg ha^{-1} and potassium upto 50 kg ha^{-1} resulted in significant increase in the number of leaves, length of vines, LAI and dry matter production. The soil of the experimental site could be rated as medium in available nitrogen, high in available phosphorus and low in available potassium. Significant response to the applied nutrients was reported by Miller (1958), Ermorkhin and Naumenko (1975) and Tserling *et al.* (1979) in cucumber.

The role of nitrogen is important as an essential constituent of chlorophyll, which has got a direct bearing on the rate of photosynthesis and as a constituent of protein for the promotion of growth of meristematic tissues (Tisdale *et al.*, 1985). Higher doses of nitrogen upto n_2 increased its availability to the crop which might have resulted in increased vine length, leaf number and leaf area for higher dry matter production. Similar results have been observed by Randawa *et al.* (1981) in musk melon, Rajendran (1981) in pumpkin, Thomas (1984) in bittergourd, Subba Rao (1989) and Csermi *et al.* (1990) in cucumber.

At the highest dose of n_3, a reduction in all growth parameters compared to n_2 was observed. At this level the content of available nitrogen in the soil at all the stages of growth of the crop was found to be lower than that of n_2 under drip irrigation. The higher level of nitrogen might have caused more lateral and downward movement of nitrogen in the soil which reduced the available nitrogen content in the root zone. Leaching of available nitrogen to areas beyond the root zone under drip irrigation has been reported by several other like Singh *et al.* (1984), Haynes (1990), Christov *et al.* (1991), Antil *et al.* (1992) and Szaloki (1992).

Increasing the levels of potassium upto k_2 significantly increased the growth parameters even from the early stages. The role of potassium as an essential element for promotion of growth of meristematic tissues has been well established (Tisdale *et al.*, 1985). Absence or decreased level of potassium resulted in markedly poor growth right from the seedling stage. This could be attributed to the reduced CO_2 fixation by the leaf like photosynthetic cotyledons of the cucumber seedlings which in turn will result in a lower level of export of photosynthates from the cotyledons to other parts (Cummins and Kretchman 1974). Also a significant influence of irrigation on the role of potassium in increasing leaf area was reported by Khanna Chopra *et al.* (1980).

But at k_3, a reduction in growth parameters like length of vine (15 per cent), number of leaves (23 per cent), LAI (24 per cent) and dry matter product (12 per cent) were observed. At high levels of potassium application in drip irrigation, potassium concentration will be high at distances and depths more than 0.5m from the dripper (Christiansen *et al.*, 1991).

Here also, the potassium content in the root zone at the highest level of potassium (k_3) is found to be 5 per cent lower than at k_2. This also might have resulted in lower potassium uptake by the crop and it also influenced the activities of the growth parameters. Washing out potassium from the root zone due to increased seepage was also reported by Szaloki (1992).

The interaction between irrigation and nitrogen was significant at later stages of growth of plant (60 DAS and at harvest) with respect to all the growth parameters and on dry matter yield at 60 DAS alone. At the level of i_2n_2 the availability of moisture and nitrogen was optimum. The nitrogen use efficiency is found to be optimum, at optimum moisture content in the soil and vice versa. At lower levels of irrigation (i_1) and at the highest levels of irrigation (i_3) also, n_2 was found to be the optimum since at both these levels, the optimum uptake occured at this level of nitrogen.

Irrigation and potassium interactions were also significant the later stages of crop growth (60 DAS and at final harvest). Since the growth parameters were increased progressively at these stages, the optimum moisture content of the soil has given the plant the chance to exploit the optimum potassium content of the soil.

With respect to nitrogen and potassium interactions also, the highest content of these nutrients were found to be there in the soil at n_2 and k_2 levels, at which level the absorption by the plant and its expression on growth parameters were seen. The results corroborate with the findings of Borna (1976), Hartmann and Waldhor (1978), Mathew (1981), Thomas (1984) and Subba Rao (1989).

5.3.2. Yield components and yield

5.3.2.1. Yield components

In general yields were lower in the first crop season (18.30 t ha^{-1}) compared to the second crop season (20.32 t ha^{-1}). As already pointed out weather was more favourable in the second crop season which led to more vegetative growth. This resulted in better performance of yield components and yield.

Drip irrigation treatments significantly influenced the characters contributing to fruit yield namely the number of fruits, mean length of fruit, girth of fruit, fruit setting percentage and sex ratio. Drip irrigation at 3 l $plant^{-1}$ day^{-1} significantly increased all these parameters. Favourable influence of optimum moisture on yield attributes have been reported by

Flocker *et al.* (1965), Molnar (1965), Jassal *et al.* (1970), Neil and Zunino (1972), Goyal and Allison (1983), Kumar (1984), Osorio (1987) and Subba Rao (1989). Considerable amount of photosynthates are transported into the fruit during the period of fruit development and hence that period is very critical in the reproductive cycle of a plant (Kaufman, 1972 and Tisdale *et al.*, 1985). Optimum moisture supply in the i_2 plots would have increased the availability and supply of plant nutrients resulting in better growth and translocation of photosynthates to the fruits.

Moisture stress in i_1 level of drip irrigation might have affected the metabolism of plants resulting in lesser floral primordia development which in turn was reflected by the fewer number of flowers and fruits in that treatment. With respect to i_3, the width of wetting being more than the root spread has caused a decrease in moisture level in the root zone area. This might have adversely affected the fruit set probably through the increased abscission of flowers and fruits. All these might have contributed to the decrease in the number of fruits produced under the highest volume of irrigation. Stress conditions also would have seriously hindered the production and translocation of metabolities to the fruit. Similar results were reported by Czao (1957) and Subba Rao (1989) in cucumber, Molnar (1965) in melons, Kaufman (1972) in various crops, Thomas (1984) in bittergroud and Kumar, (1984) in tomato.

Application of nitrogen significantly increased the number of fruits per plant (39 per cent), mean length (59 per cent), girth (53 per cent) and weight of fruits (6 per cent), fruit setting percentage (22 per cent) and sex ratio (19 per cent). Application of potassium increased the number of fruits per plant by 44 per cent, length of fruit by 55 per cent, girth of fruit by 47 per cent, weight

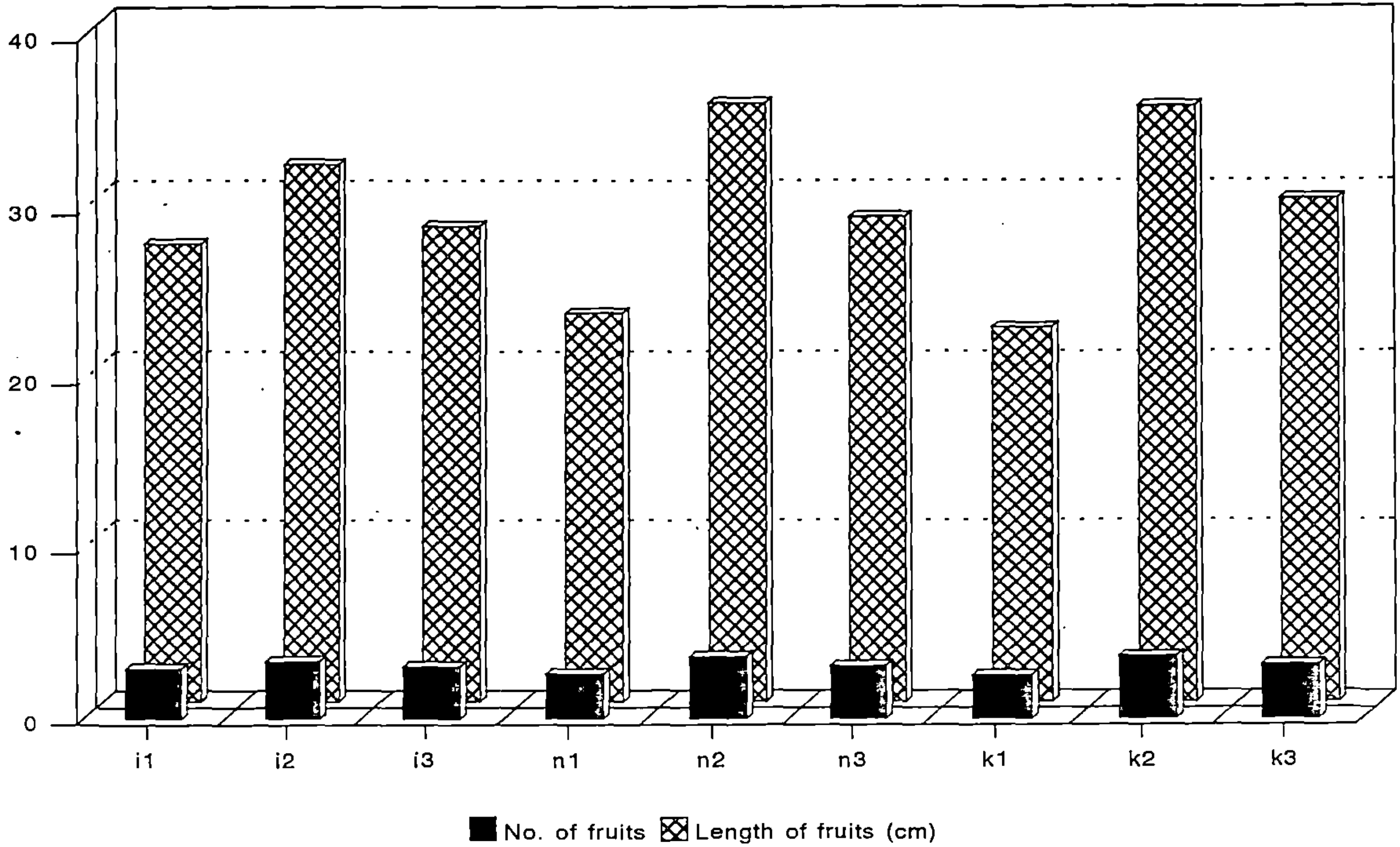


Fig. 5. Effect of I, N and K on the number of fruits and length of fruit (cm) - Pooled data

of fruit by 7 per cent, fruit setting percentage by 25 per cent and sex ratio by 19 per cent.

The favourable influence of nitrogen and potassium on yield attributes can be ascribed to the increased availability and uptake of plant nutrients for the initiation of floral primordia and production of larger amounts of dry matter through photosynthesis. The translocation of a larger quantity of photosynthates to the fruits might have resulted in the higher mean length, girth and weight of fruits. In the second crop season all the yield components recorded higher values compared to the first crop season. Increased evaporation rates during Experiment 3 might have led to greater absorption of water from the soil which might have also facilitated the more uptake of nutrients along with it. Miller and Ries (1958) and Subba Rao (1989) showed that cucumber plant receiving higher level of nitrogen produced more fruits than with the low nitrogen level and that the length to diameter ratio of the fruits was increased by high nitrogen. Favourable results of nitrogen application on yield components were reported by Jassal *et al.* (1970) and Pandey *et al.* (1974) in musk melon, Oguremi (1978) in water melon, Sharma and Shukla (1972) and Rajendran (1981) in pumpkin, Thomas (1984) in bittergourd and Rooda Van Eysinga (1970), Subba Rao (1989) and Csermi *et al.* (1990) in cucumber. Agarwala and Sharma (1976) observed that size of fruits was smaller and maturity advanced when nitrogen supply was a limiting factor.

A positive role of potassium in influencing the yield parameters has been reported by many scientists (Paauw (1958), Sugiyama and Iwata (1974), Ramanathan (1985), Subba Rao (1989) and Menon (1990)).

Potassium significantly influenced all the yield components. Significant effects of potassium on fruit size of peaches were reported by Cummins (1980). Higher fruit length by potassium application may be attributed to the role of potassium in cell expansion and division. Potassium was also found to influence the fruit length of ashgroud by 11.2 per cent over the control (Menon, 1990). Such a role of potassium in providing the necessary pressure for cell wall expansion, a pre-requisite for cell division was reported by Hsiao (1973).

As in the case of nitrogen, for potassium also, the optimum level was found to be k_2. Above this level a decreasing trend in all the yield parameters like number of fruits per plant (13 per cent), length of fruit (15 per cent), girth of fruit (12 per cent), weight of fruit (1 per cent), fruit setting percentage (7 per cent) and sex ratio (7 per cent) was seen. Under drip irrigation the behaviour of potassium in soils follow a different trend. The content of available potassium in the root zone of the plant was found to be 4.18 per cent lower in k_3 compared to k_2. At higher concentration the potassium might have been translocated the outer periphery of the wetted zone which went out the effective root zone. High potassium responses are possible if nitrogen and water supply are not growth limiting (Patiram, 1993).

This conclusion is supported by Christensen *et al.* (1991) who reported that the greatest concentration of potassium was observed directly below the emitter for all levels except the highest level for which potassium concentration was high at 0.5m distance and depth from the emitter.

Hernandez *et al.* (1991) concluded that potassium moved in a hemisphere in the soil which resulted in a high soluble potassium concentration in the 30-40cm soil layer. Szaloki (1992) showed that under increased seepage, potassium was washed out of the root zone.

5.3.2.2. Fruit yield

Drip irrigation at 3 l plant^{-1} day^{-1} (i_2) produced the highest fruit yield which was 10 per cent higher than i_1 and 8.8 per cent higher than i_3. This may be attributed to the maintenance of favourable soil water status in the root zone under this level, which in turn helped the plants to maintain better turgor and utilise moisture as well as nutrients more efficiently from the limited wetted area (Schmueli ad Goldberg, 1971; Phene and Beale, 1976; Bar-Yosef and Sagiv, 1982). Information on optimum wetting area is not yet complete especially for vegetables and earlier reports indicate a wide range of 25 to 66 per cent of the root volume as optimum (Black and West (1974), Frith and Nichols (1974), Bucks *et al.* (1981) and Kumar (1984). In the present study 87 per cent, 47 per cent and 35 per cent of the root volume were wetted in i_1, i_2 and i_3 treatments respectively. In the case of i_1 even if 87 per cent of the root volume was wetted, yield was lower due to the lack of enough water to meet the ET needs of the plant. In the case of i_3, even if more water was added to the soil, the wetting volume of the soil was much lower than the root volume (35 per cent). Both these conditions might have led to a reduced yields in both these treatments. In the case of i_2, even if only 47 per cent of the root volume was wetted, the yield produced was the highest. This may be because the effective root zone of cucumber under drip irrigation is in this zone. Better or equal performance of vegetables using much lower quantity of water has been observed in most of the earlier studies (Goldberg and Schmueli, 1970, Singh *et al.*, 1978, Shivanappan *et al.*, 1974 Doss *et al.*, 1980 and Kumar (1984).

When the area of wetting in considered for i_1, i_2 and i_3, the values are almost the same for i_1 and i_2 (3866.31 sq. cm and 3928.26 sq. cm). Evaporation losses being the same, more water was available for transpiration in i_2 compared to i_1. In the case of i_3, the area of wetting was 5054.19 sq. cm which was about 29 per cent more than that in i_2. More area of wetting might have increased the evaporation losses from the soil, which led to a reduction in water available for transpiration leading to reduced plant growth and yield. One of the main reasons for reduced water requirement under drip irrigation is the reduction in radiation energy available for evaporation (Ben-Asher *et al.*, 1978).

The importance of photosynthesis as the basic process to harness sunlight and production of sugars from CO_2 is well established. Leaves act as the main organs for photosynthesis and the effectiveness of dry matter accumulation will therefore depend on the photosynthetic efficiency (Arnon, 1975). The production of higher amounts of photosynthates with the aid of larger leaf area and subsequent translocation of these metabolites to the fruits at a rapid pace due to increased moisture availability in i_2 might have contributed to the higher yields. The observed increase in yield under i_2

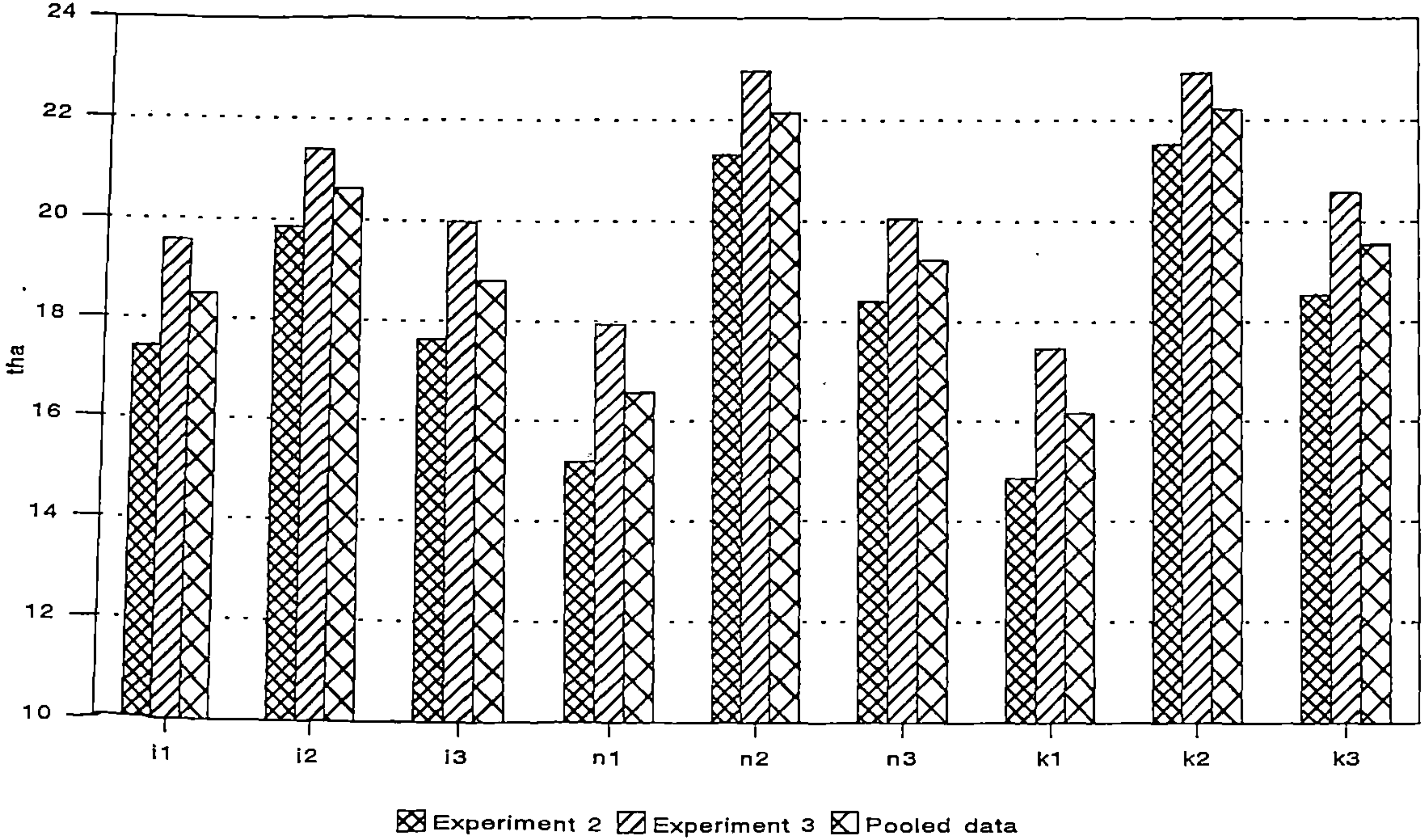


Fig. 6. Effect of I, N and K on the fruit yield (tha)

can be attributed to a more or less similar trend noticed in yield attributes like number of fruits, length girth and weight of fruits, fruit setting percentage and sex ratio. This is to be expected since fruit yield is the manifestation of the cumulative effect of these characters.

Higher yields at optimum moisture regimes under drip irrigation was reported in cucumber by Goyal and Allison (1983), Kumar (1984), Paunel *et al.* (1984), Bhella and Wilcox (1985), Bhella (1985), Osorio (1987), Rubeiz *et al.* (1989) and Chartzoulakis and Michelakis (1990).

The significant reduction in yield in i_1 and i_3 can be ascribed to the low moisture availability which caused adverse effects on the physiology of growth, reproduction and fruit development (Kramer, 1969). Reduction in yield under moisture stress was observed by Varga (1973), Cummins and Kretchman (1974) and Ortega and Kretchman (1982).

The application of both nitrogen and potassium significantly increased the fruit yield. The percentage increase with n_2 and n_3 over n_1 was 34 per cent and 16 per cent and for potassium k_2 and k_3 recorded 38 per cent and 21 per cent increase in yield over k_1 respectively. At higher levels of nitrogen and potassium, there was reduction in yield. Such results of reduction in yield with higher doses of nitrogen were reported by Pandey *et al.* (1974) and Kim *et al.* (1991) in musk melon, Rajendran (1981) in pumpkin and Alan (1984) in cucumber. Reduction in yield at higher and lower doses of potassium were reported by Adams *et al.* (1973) and Goczi (1973) in tomato, Spear *et al.* (1978) in cassava and KAU (1982) in cucumber.

The soil of the experimental field responded favourably to nitrogen and potassium upto n_2 and k_2 levels and hence increased supply of these nutrients to the crop, in general had lead to the increased uptake of these nutrients. This has resulted in better growth and favourably affected the yield attributing characters resulting in higher yields. The importance of the major nutrients on the synthesis of carbohydrates, amino acids, proteins and other metabolic products which contribute to yields has been highlighted by Agarwala and Sharma (1976) and Tisdale *et al.* (1985).

The favourable effect of nitrogen and potassium on the yield of cucumber and other cucurbits have been reported by Ishkaev and Ibragimov (1980), Rajendran (1981), Randawa *et al.* (1981), Anon (1982), Thomas (1984), Subba Rao (1989), Anon (1990), Csermi *et al.* (1990), Kadyrkhodzhaev (1990), Rao and Srinivas (1990), Kim *et al.* (1991), Zhang *et al.* (1991), Rajput *et al.* (1993), Yingjaval and Markmoon (1993) and Swiader *et al.* (1994).

Interactions between nutrients and drip irrigation had significant influence on yield of fruits by its influence on number of fruits per plant, length of fruit, girth of fruit, fruit setting percentage and sex ratio. Increase in yield due to the optimum levels of nitrogen (n_2 and potassium (k_2) were more pronounced and significant with optimum irrigation (i_2). Cucurbits require considerable quantities of moisture coupled with heavy fertilizer application when making their most vigorous growth and upto the time the fruits become mature, if maximum yields are to be obtained (Whitaker and

Davis, 1962 and Subba Rao, 1989). Existence of optimum soil moisture condition is a pre-requisite for the plants to be able to absorb and utilise the applied fertilizers from the soil.

Increased transpiration under high evaporative demand and favourable soil moisture conditions of the soil will increase the rate of uptake of nutrients as a result of mass transfer of ions through the transpiration stream (Ghildyal, 1971). In the present study, at i_2 level of drip irrigation, the wetting area of the root zone being optimum would have increased the availability of nutrients leading to an increased uptake of major nutrients and higher fruit yield. A higher and optimum demand for nitrogen and potassium under irrigated condition due to decrease in tissue nutrient levels has been obtained by O'Sullivan (1980). The results are in agreement with the findings of Molnar (1965), Borna (1976), Hartman and Waldhor (1978), Will (1979) and Subba Rao (1989) in cucurbits.

5.3.2.3. Physical and Economic optimum of I, N and K

The optimum requirement of drip irrigation for highest yield was 3l $plant^{-1}$ day^{-1} in both experiments. Since only a limited area is wetted in both experiments, the optimum was found to be the same.

In the case of nitrogen, the optimum level was 93 kg ha^{-1} in Experiment 2 while it was 75 kg ha^{-1} in Experiment 3. The initial N status of soil in Experiment 3 was higher (Table 45) and as such a part of the nitrogen requirement of the crop might have been from the reserve of the soil. In the case of potassium also, the same trend was observed indicating a reduction of 5 kg ha^{-1} of K in Experiment 3 as compared to Experiment 2. This decrease may be due to the fact that the initial K status of soil in Experiment 3 is higher (Table 47).

The economic optimum doses of N and K are not determinable from the present study.

The physical optimum worked out at the three different levels of drip irrigation revealed the lowest requirement of both nitrogen and potassium at the drip irrigation level of 3l plant^{-1} day^{-1} in both experiments (74 kg ha^{-1} N and 53 kg ha^{-1} K in Experiment 2 and 74 kg ha^{-1} N and 55 kg ha^{-1} K in Experiment 3). However at the lowest drip irrigation level of 2l plant^{-1} day^{-1} the optimum doses of N and K were the highest in both experiments. Thus the indication is that when the water available for irrigation is low, irrigating through drip at @ 2l plant^{-1} day^{-1} for cucumber in order to obtain the optimum yield higher quantities of nitrogen and potassium are to be supplied @ 88 kg ha^{-1} and 75 kg respectively. When the level of drip irrigation was higher (4l plant^{-1} day^{-1}) the optimum nitrogen and potassium requirements were 80 and 55 kg ha^{-1} respectively. At this highest level of drip irrigation the horizontal and vertical spread of water in the root zone being large, more of N and K were required to maintain optimum concentration of these elements in the root zone area. Another observation was that at both the irrigation levels of 21 and 41 plant^{-1} day^{-1} the soil moisture status in the root zone was low (Table 24). As a result of this, there occured reduced uptake of water causing more concentration of solutes inside the cell wall of the root. When the concentration of solutes inside the cell wall is more, there are chances of more uptake of nutrients from the soil solute till the concentration inside and outside the cell gets equalised. In order to maintain this higher concentration outside the cell also, more of nutrient ions are to be present in the soil solution.

5.3.3 Moisture studies

5.3.3.1. Moisture status under drip

As seen from the results, frequent replenishment of water as in daily drip, helped in the maintenance of high time average soil water potential which enabled the plants to fare better and yield high. Similar results were obtained in vegetables by Foster *et al.* (1989), Rubeiz *et al.* (1989) and Moynihan and Haman (1992). Many in their critical review have opined in favour of drip mainly because of its capacity to maintain favourable soil water potential constantly without causing severe aeration problems (Halevy *et al.*, 1973, Bresler, 1977, Bucks *et al.*, 1981 and Howell *et al.*, 1981).

The soil moisture status in the upper layers of 0-15 cm and 15-30cm depth were lowest in the case of i_1, then in i_3 and highest in i_2. In the case of i_2, wetting was mainly concentrated in the 30cm depth of soil layer which made the roots absorb moisture effectively and utilize for dry matter production. Soil moisture status in the top 30cm layer of soil in i_1 was found to be lower and hence poor growth and yield in i_1 compared to i_2 and i_3.

Soil moisture status below 30cm was highest in i_3, less in i_2 and least in i_1. This shows that percolation of water downwards is more with higher level of irrigation. However, root studies indicted concentration of roots in the top 30cm and more so near the emitter within 15cm radius. Thus plants in the drip treatments would have utilized most of their moisture requirement from this depth. Drip irrigation at the level of i_2 was found to be optimum with respect to the maintenance of soil moisture status in the effective root zone layer of the soil which resulted in highest yield. Such type of results have have been earlier pointed out by Phene (1974), Freeman *et al.* (1976), Black (1976) and Kumar (1984) though economic level of irrigation differs.

A probe into soil moisture content at the lowest level of drip irrigation (i_1) indicated that under drip irrigation, even at this level, the soil moisture content was higher than the pot watered plots. The daily replenishment of water didnot allow the deficit to remain longer and thus the system maintained higher water potential. Further, roots were concentrated near the dripper and thus plants were able to achieve their water requirement. The yield obtained in i_1 although not the highest, resulted in maximum economy in water use as indicated by the highest water use efficiency. The yield produced

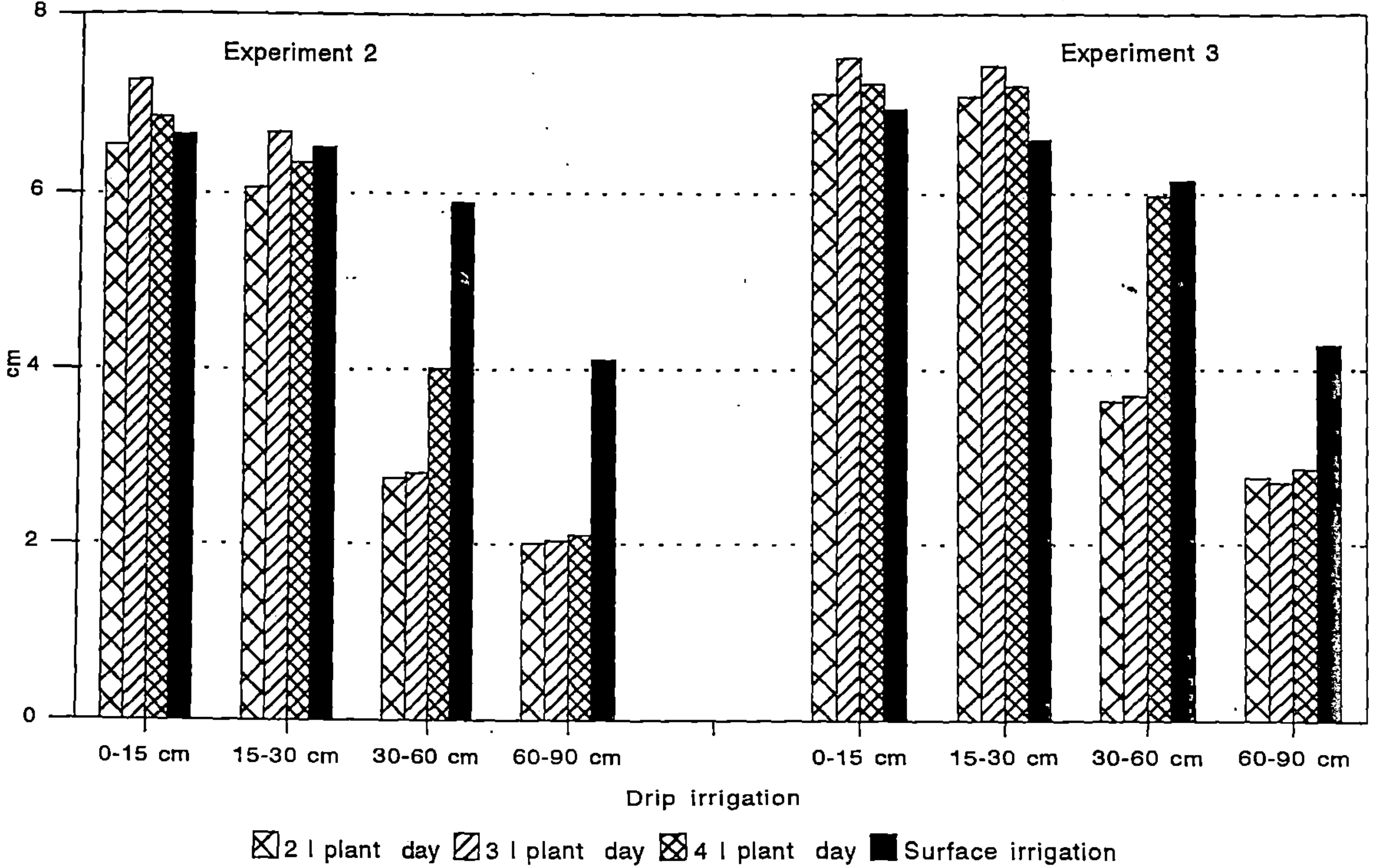


Fig. 7. Soil moisture status (Experiment 2 and 3)

was higher than that obtained in surface irrigation method. Thus drip irrigation consumed almost 50 to 60 per cent less water than surface irrigation to produce comparable yields. Similar responses were observed in several earlier studies (Shivanappan *et al.*, 1974, Singh and Singh, 1978, Doss *et al.*, 1980, Lin *et al.*, 1983 and Kumar, 1984). The possible reduction in soil moisture consumption may be due to the lower evaporation from the soil as pointed out by Ben-Asher *et al.* (1978) who found it to be only 0.3 of Ep in drip irrigated tomato fields as against 0.6 for sprinkler.

5.3.3.2. Water use efficiency

The water use efficiency was highest under drip irrigation at the lowest level of i_1, which indicated more efficient use of water. This was because of the fact that yield reduction was only 10.32 per cent as against 33.33 per cent less irrigation water use at i_1. Higher water use efficiencies under lower regimes are reported by many authors as degree of stress created was relatively low and as such decrease in yield was to a lesser extent compared to reduction in water use. (Lin *et al.*, 1983, Kumar, 1984, and Subba Rao, 1989).

Water use efficiency is likely to increase with decrease in soil moisture supply until it reaches the minimum critical level because plants may actively try to economise water loss in the range from minimum critical level to optimum moisture level. However, total production from a unit area decreases as the available soil moisture falls below the optimum (Singh and Sinha, 1977). Water supplied above the optimum moisture level may be lost in the form of excessive evaporation, excessive transpiration or deep infiltration (Carmi and Plant, 1988).

Lower water use efficiency in the higher moisture regimes (i_3) may be attributed to the higher values of consumptive use and infiltration losses with a lower fruit yield (Prasad and Singh, 1979). These findings are in line with those of Vittum and and Flocker (1967), Borna (1969), Loomis and Crandall (1977), Singh and Singh (1979), Thomás (1984) and Subba Rao (1989).

Application of both nitrogen and potassium revealed significant increase in water use efficiency. Levels of n_2 and k_2 recorded the highest water use efficiency, probably due to the increased yield with the same quantity of water applied. This is in agreement with the results obtained by Prasad and Singh (1979), Sharma and Parashar (1979), Pai and Hukeri (1979), Thomas (1984), Subba Rao (1989) and Menon (1990) in different crops.

5.3.3.3. Consumptive use

The consumptive use increased as the level of irrigation increased. The highest value was recorded by drip irrigation at i_3 of level which received more quantity of irrigation water. Higher moisture supply would have created a condition favourable for an increased rate of transpiration from the plant surface and evaporation from the soil surface. This increase in evapotranspiration would have resulted in a concurrent increase in seasonal consumptive use under highest level of irrigation. The results on soil moisture status in the different soil layers also show that at i_3, the infiltration of water into the lower layers is also high. Similar observations have been reported by Konishi (1974), Loomis and Crandall (1977), Henkel (1978), Prasad and Singh (1979), Thomas (1984) and Subba Rao (1989).

5.3.4. Root characters

Studies on root dry matter and root distribution indicated that it was the root distribution that was subjected severe alteration rather than root dry matter. However, evaluation based on quantitative estimation is difficult, as there is every possibility of fine roots being lost while extraction. It is reported that many roots die at harvest and by the time the extraction was made, the root concentration would have been lower (Russell, 1977 and Kumar, 1984).

Drip irrigation induced dense root growth near the emitter in a radius of 20cm and the root system was almost confined to 30cm radius and depth. Very few roots were noticed beyond this limit. This is in conformity with the observations of many other like Kumar (1984), Bhella (1985), Siderius and Elbersen (1986), Shatawani (1987), Goyal *et al.* (1988), Singh *et al.* (1989), Chartzoulakis and Michaelakis (1990), Hodgson *et al.* (1990), Hernandez *et al.* (1991), Phene *et al.* (1991) and Ben-Asher and Silberbush

(1992). Russell (1977) had observed that root axis will develop in a favourable zone than in the remainder to compensate for the poor growth and uptake in less favourable zones.

When different levels of drip irrigation are compared, lower levels of irrigation resulted in shallower and smaller root system. This is because at a constant frequency, if water supply is only enough to fill up the surface layer, then roots would be more concentrated in the surface. In the present study, levels of i_1 and i_2 resulted in wetting of only the surface layers and these roots were shallow. Even the studies of Weaver (1926) had shown that when wetting was shallow, roots also did not penetrate deeper. Several other studies also support a decrease in root growth as soil moisture tensions increased under drip irrigation (Klepper *et al.*, 1973, Zabara, 1977, Babaloa and Fawasi, 1980 and Salam and Wahid 1993).

At the highest level of irrigation (i_3) the root depth and root spread was found to be highest. With respect to dry matter also, an increase was observed at this level, although not significant. This is because, the wetting pattern studies under different drip irrigation levels show that the width and depth of wetting are highest in this level. This might have lead to the extension of roots to the periphery of the wetted zone. Such results of extension of roots to the periphery of the wetted zone of soil has been reported by several others like Hudson (1962), Willoughby and Cockroft (1974), Hodgson *et al.* (1990) and Salam and Wahid (1993).

Nitrogen was found to influence the spread of roots. Nitrogen being highly soluble in the soil moisture might have dissolved in the irrigation water and spread to that zone which was wetted by the emitter. As the concentration of nitrogen increased, the area of spreading of N in the soil also increased correspondingly. Hence the lowest root spread was observed in n_1 and highest in n_3. Such results have been reported by Frith and Nichols (1974), Black and Mitchell (1970), Willoughby and Cockroft (1974), Siderius and Elbersen (1986), Hodgson *et al.* (1990) and Ben-Asher and.Silberbush (1992).

Potassium was not found to influence any of the root parameters. The displacement of potassium to the different layers may not be much. Hence the root growth was not significantly influenced by potassium. Non significant potassium movement at different positions in soil layers has been reported by Goyal (1987), Hernandez *et al.* (1991) and Torre and Victoria (1992).

5.3.5. Content and uptake of major nutrients

Irrigation levels were found to influence the phosphorus content in the plant, whereas nitrogen and potassium contents were not significantly influenced by the irrigation levels. Phosphorus was supplied to all the irrigation treatments uniformly. This significance seen in the content of phosphorus in the plant parts was not seen expressed in the phosphorus uptake by the plant in any stage of growth. The available phosphorus content of the soil was also not seen to be influenced by the drip irrigation levels. At i_3 level, the area of wetting of the soil was higher compared to i_1 and i_2. The alternate wetting and drying of the soil around the plant might have promoted solubilization of native ferric phosphates. This might have led to the increased uptake of phosphorus by the plant. However significant differences in phosphorus uptake by the plant were not observed in early stages. The absorbed phosphorus was not effectively utilized for dry matter production also probably because the water availability was not adequate at this level. The results indicate that under drip irrigation, there is a possibility for the release of native and applied phosphorus. Since conditions similar to flooding may exist for some time during each drip irrigation cycle which may solubilise the native unavailable phosphates to the available form. This view has been supported by the works done by Bacon and Davey (1982).

Irrigation was found to influence the uptake of nitrogen, phosphorus and uptake of potassium at the later stages of plant growth ie., 60 DAS and final harvest stages. This can be attributed to the higher dry matter production at these stages.

Moisture controls the concentration and availability of various nutrients in the soil. So the availability of water is of great importance to plants to absorb nutrients and for the soil to supply them (Tisdale *et al.*, 1985 and Agarwala and Sharma, 1976). Thus in the present experiment

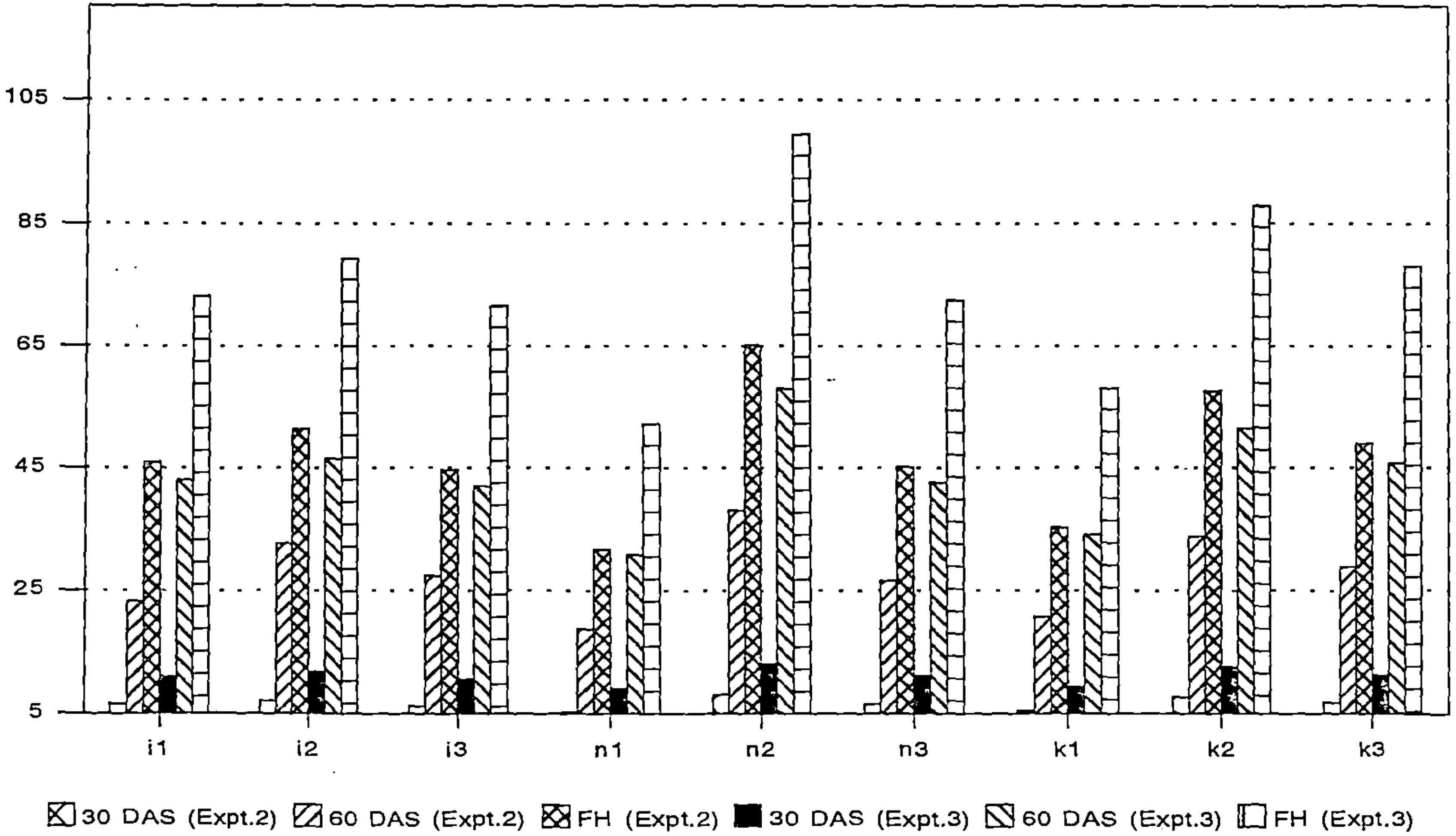


Fig. 8. Effect of I, N and K on the uptake of nitrogen by plant (Experiment 2 and 3)

drip irrigation level of i_2 has resulted in increased availability of nitrogen, phosphorus and potassium in the active root zone.

Application of nitrogen and potassium at n_2 and k_2 levels significantly increased the percentage content of the respective nutrients in plants. In general, fertilizers increase the reserve of mobile nutrients in the soil which in turn favours a higher nutrient content in various plant parts (Largskii, 1971). Increase in plant content of the applied nutrient has been reported by Solntseva (1978), Thomas (1984) and Subba Rao (1989). The available nitrogen and potassium in the root zone was highest at n_2 and k_2 levels. Therefore uptake of these nutrients and content of these nutrients were naturally higher at these levels. It was revealed that the uptake of nitrogen and potassium followed the same trend as that of dry matter production and the nutrient content in plant parts. According to Tanaka *et al.* (1964) the nutrient uptake is controlled by the factors like nutrient availability in the soil, nutrient absorption power of roots and the rate of increase in dry matter. Increased uptake of nutrients due to fertilizer application can thus be ascribed to direct manurial effects and increased tapping of nutrients from the soil on account of increased vigour and growth of roots in the fertilized zone. The findings of Thomas (1984) and Subba Rao (1989) also confirmed the findings.

The phosphorus uptake was significantly influenced by drip irrigation levels at later stages of growth (60 DAS and final harvest) and by nitrogen and potassium at all the stages. The differential dry matter production recorded in the various irrigation and nutrient levels, without any appreciable variation in the content of phosphorus in the plant parts is the main reason for the significant variation in phosphorus uptake at different stages. Moreover available phosphorus content of the soil is reported to increase with increased level of irrigation by Sharma and Yadav (1976) resulting in higher plant uptake. Similar variations in the uptake of phosphorus with change in moisture regimes and nutrient status of the soil was reported by Largskii (1971), Muthuvel and Krishnamoorthy (1980), Thomas (1984) and Subba Rao (1989).

Interaction between nutrients and drip irrigation in the uptake of nitrogen and potassium followed the trend similar to that of dry matter production. Increased uptake of nitrogen and potassium due to the application of these nutrients at optimum levels could be obtained with drip irrigation level of i_2.

Requirements of higher doses of nitrogen and potassium under optimum soil moisture content was reported by Mengal and Braucschweig (1972), Will (1979) and Subba Rao (1989) in cucumber. Similar results were reported by Czao (1957), Borna (1976), Hartmann and Waldhor (1978), O'Sullivan (1980), Thomas (1984) and Subba Rao (1989) in cucurbits.

5.3.6. Soil fertility status

The soil chemical properties determined after the final harvest revealed significant increase in available nitrogen and potassium in treatments

n_2 and k_2 respectively. The soil analysed for the fertility status was sampled from the effective root zone of the plant ie., within a radius of 25cm and depth of 20cm from the base of the plant. The significant increase may be attributed to the direct effect of the applied fertilizers that was not utilized by the crop. Similar arguments were put forward by Downes and Lucas (1966), Bains (1967), Largskii (1971), Mani and Ramanathan (1980), Mathew (1981), Thomas (1984) and Subba Rao (1989) in various crops. When the physical optimum was worked out, the optimum requirement of N was reduced from 93 kg ha^{-1} in Experiment 2 to 75 kg ha^{-1} in Experiment 3. A similar trend was also seen in the case of potassium where by a reduction of 5 kg ha^{-1} of K was seen in Experiment 3 compared to Experiment 2. When repeated cultivation of cucumber in the same area is done, the nitrogen and potassium application can be reduced if the content in the soil is high.

5.3.7. Economics

The superiority of drip irrigation in terms of water economy and better crop response has already been discussed. However, a technically feasible proposition should be financially viable for its successful adoption in the field. One of the main constraints under drip is its high initial investment in the form of plastic pipes, filters, tank and accessories to design the unit.

It is observed from this study that the investment made on drip can be re-couped with the additional returns obtained from the two crops.

However, the high initial cost of over Rs. 93,610/- per hectare for installation of the system appears to be the major bottleneck in adoption of drip irrigation. But drip assumes greater importance at limited water supply considering water as an important economic input. Besides drip irrigation could provide irrigation for additional area by way of water saving. However, the returns can be higher under sandy soil and lands with undulations and high slopes where other methods are less feasible.

The management practices should be tailored to maintain high yield potential or otherwise the additional returns obtained under drip can be lower and in turn result in lower Benefit Cost Ratio (BCR) and Internal Rate of Return (IRR).

SUMMARY

6. SUMMARY

Two observational trails and two field trials were conducted at Instructional Farm, College of Agriculture, Vellayani during 1992 and 1993 to standardise the flow rate from drippers, number of drippers per plant and duration of drip irrigation, to study the effect of drip irrigation and application of nitrogen and potassium fertilizers on the growth and yield of cucumber and to work out the economics for evolving suitable drip irrigation recommendations for cucumber.

As per Experiment 1a an observational trial was conducted in the field during April 92 with three levels of drip irrigation, four timings of irrigation and two number of drippers per plant. Based on the results obtained from the present study the flow rate from the dripper, number of drippers per plant and duration of drip irrigation were standardized for Experiments 2 and 3.

Experiment 1b included another observational trial to find out the depth and spread of root system of cucumber. Based on this study, the method of application of fertilizers in Experiments 2 and 3 were standardized. This study was conducted during April and May 1992.

Experiments 2 and 3 involved three levels of drip irrigation (2, 3 and 4 litres of water per plant per day), three levels of nitrogen (35, 70 and 105 kg ha^{-1} and three levels of potassium (25, 50 and 75 kg ha^{-1}) with three drip irrigation controls (drip irrigation @ 2, 3 and 4 litres of water per plant per day without nitrogen and potash) and farmer's practice on irrigation laid out in a $3^3 + 1 + 3$ confounded factorial experiment confounding INK in Replication I and IN^2K^2 in Replication II. These experiments were conducted during the summer season of 1992-93. The findings of the study are summarised hereunder :

1. Irrigating through drip for a period of 3 hrs with one dripper plant was found the best

2. The flow rate from the drippers were found to to be uniform @ 1.33, 1.00 and 0.67 litres of water per plant per hour respectively for the treatments 4, 3 and 2 litres of water $plant^{-1}$ day^{-1}

3. The fertilizers are to be applied in a ring at a distance of 20cm from the base of the plant in the case of cucumber irrigated through drip.

4. Drip irrigation @ 3l $plant^{-1}$ day^{-1} was found to produce the highest vegetative growth with respect to length of vine, number of leaves per plant, LAI and dry matter production at all stages of growth.

5. The different components of yield viz., number of fruits harvested

per plant, length of fruit, girth of fruit and weight of fruit, fruit getting percentage and sex ratio were also the highest and significantly superior at the drip irrigation level of 3l plant^{-1} day^{-1}

6. The yield of cucumber grown under drip irrigation was the highest (19.85 t ha^{-1} and 21.40 t ha^{-1} for Experiment 2 and Experiment 3 respectively) at the drip irrigation level of 3l plant^{-1} day^{-1}.

7. The vine yield of cucumber was maximum at the drip irrigation level of 3l plant^{-1} day^{-1}.

8. The shelf life of fruits harvested from the plots receiving drip irrigation @ 2l plant^{-1} day^{-1} was the longest.

9. The different rates of drip irrigation tried, did not influence root dry matter

10. The highest root depth and root spread were observed with drip irrigation @ 4l plant^{-1} day^{-1}.

11. The highest length of vine, number of leaves per plant, LAI and dry matter production were observed at the nitrogen application rate of 70 kg ha^{-1}

12. Nitrogen @ 70 kg ha^{-1} recorded maximum number of fruits harvested per plant, length of fruit, girth of fruit, fruit setting percentage and sex ratio.

13. The weight of fruits were not influenced by nitrogen.

13. The weight of fruits were not influenced by nitrogen.

14. Significantly higher fruit yield and vine yield were recorded at 70 kg ha^{-1} of nitrogen.

15. The highest shelf life of fruits were observed at the lowest level of nitrogen (35 kg ha^{-1})

16. Root dry matter and root depth were not influenced by nitrogen.

17. Root spread increased with increasing levels of nitrogen and highest was at the level of 105 kg ha^{-1}.

18. Potassium influenced the vegetative characters of the plant significantly and the maximum length of vine, number of leaves per plant, LAI and dry matter production were observed at the level of 50 kg ha^{-1} of potassium

19. Potassium @ 50 kg ha^{-1} influenced significantly the yield components viz., number of fruits harvested per plant, length of fruit, girth of fruit, fruit setting percentage and sex ratio.

20. Potassium had no influence on the weight of fruits

21. The fruit yield and vine yield of cucumber were highest at 50 kg ha^{-1} of potassium

22. The shelf life of fruits was maximum in the treatment receiving potassium at 50 kg ha^{-1}

23. Potassium did not influence the root characters viz., root dry matter, root depth and root spread.

24. The soil moisture status of 0-15cm and 15-30cm depth was the highest compared to that at 30-60cm and 60-90cm depth in drip irrigated treatments. Among this, drip irrigation @ 4l $plant^{-1}$ day^{-1} recorded the highest soil moisture status in all the layers.

25. The soil moisture status in pot watered treatments was lower at the surface layers of 0-15cm and 15-30cm and higher at lower depths of 30-60cm and 60-90cm compared to drip irrigated treatments.

26. Field water use efficiency was highest at drip irrigation level of 3l $plant^{-1}$ day^{-1}, nitrogen @ 70 kg ha^{-1} and potassium @ 50 kg ha^{-1}

27. Seasonal comsumptive use was highest at the drip irrigation level of 3l $plant^{-1}$ day^{-1}.

28. The nitrogen content and uptake by plants were influenced by the nitrogen levels. Nitrogen applied @ 70 kg ha^{-1} recorded higher content and uptake by plant

29. Nitrogen uptake of plant was also influenced by drip irrigation and potassium. The highest uptake of nitrogen was obtained at drip irrigation level of 3l $plant^{-1}$ day and potassium @ 50 kg ha^{-1}.

30. The highest phosphorus uptake by plant and fruits was observed at the drip irrigation level of 3l $plant^{-1}$ day^{-1}, nitrogen @ 70 kg ha^{-1} and potassium @ 50 kg ha^{-1}.

31. Potassium uptake by plant and fruits was highest at the drip irrigation level of 3l $plant^{-1}$ day^{-1}, nitrogen @ 70 kg ha^{-1} and potassium @ 50 kg ha^{-1}.

32. The available nitrogen content in the soil was highest at nitrogen level of 70 kg ha^{-1}

33. The available potassium content of the soil was influenced by the different levels of potassium applied and highest level was observed at the highest level of K applied (K50)

34. Drip irrigation @ 3l $plant^{-1}$ day^{-1} resulted in higher benefit cost ratio of 2.83 and internal rate of returns of 23%. The pay back period was 1.13 years.

Thus it can be inferred that drip irrigation in cucumber results in higher yield and greater water use efficiency without altering the quality of fruits. This irrigation method provides greater scope under limited water supply. The results of the present study indicated that drip irrigation is technically feasible and economically viable and sustainable in the case of cucumber.

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APPENDICES

Appendix Ia. Weather data during the cropping period

Standard Week	Rainfall (mm)	Maximum temp (°C)	Minimum temp (°C)	Relative Humidity (%)		Evaporation (mm/day)
				Forenoon	Afternoon	
1992						
15	—	33.1	26.1	84	67	5.9
16	1.0	33.2	26.1	88	63	6.1
17	5.0	33.3	25.2	86	67	4.5
51	3.5	30.9	22.4	91	73	2.5
52	—	30.5	19.3	90	67	3.9
1993						
1	—	3.5	18.6	91	55	3.3
2	—	30.4	21.1	93	62	3.9
3	—	29.9	20.7	94	65	2.9
4	—	30.9	21.7	93	59	3.7
5	—	31.0	19.6	92	50	4.3
6	—	30.8	20.3	92	58	4.0
7	—	31.4	21.9	91	61	4.0
8	2.8	31.1	22.9	89	80	4.8
9	—	31.6	22.3	90	64	4.7
10	—	32.8	21.1	89	60	5.0
11	—	32.7	24.2	91	66	5.0
12	36.3	32.3	24.0	86	63	3.9
13	8.0	32.3	24.1	83	68	5.0
14	12.7	32.1	24.6	91	72	4.5
15	—	32.3	24.4	93	72	4.9
16	12.5	32.7	24.7	88	75	5.0
17	6.4	33.2	25.1	88	79	5.1
18	—	33.0	26.0	90	80	4.4
19	17.7	32.8	26.0	91	83	4.1

Appendix Ib. Mean weather data for 15 years (1977-1992)

Standard Week	Rainfall (mm)	Maximum temp (°C)	Minimum temp (°C)	Relative Humidity (%)		Evaporation (mm/day)
				Forenoon	Afternoon	
15	33.5	24.9	86	74	8.7	5.8
16	33.1	25.2	87	77	18.8	5.1
17	33.2	25.3	87	76	23.4	5.5
51	31.1	22.7	83	65	14.4	4.3
52	31.2	22.2	84	64	6.3	4.8
1	31.2	22.1	85	63	11.8	4.3
2	30.9	21.3	86	68	0.1	4.1
3	31.4	21.1	83	69	1.6	4.1
4	31.2	20.8	84	75	0.9	4.3
5	31.4	21.4	84	70	4.0	4.5
6	31.3	21.1	87	71	1.0	4.5
7	31.9	21.5	85	70	1.3	4.9
8	32.0	22.5	82	67	0.3	5.0
9	32.3	23.2	84	62	6.4	5.3
10	32.6	23.0	84	65	8.5	5.3
11	32.6	23.5	82	61	0.8	5.3
12	32.9	24.3	81	60	11.0	5.4
13	33.3	24.6	83	65	2.2	5.6
14	33.3	26.8	85	66	2.5	5.7
15	33.3	24.9	87	72	8.8	5.7
16	33.2	25.5	87	70	10.0	5.5
17	33.2	25.2	88	70	23.8	5.3
18	33.2	25.1	85	68	26.3	5.3
19	32.8	25.6	87	67	17.7	4.8

Appendix 2. Treatments means - Length of vine at 30DAS, 60 DAS and Final harvest (Experiment 2 and 3)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
$i_1n_1k_1$	115.11	168.28	221.26	168.28	191.44	252.40
$i_1n_1k_2$	145.38	235.98	303.12	235.98	242.36	301.24
$i_1n_1k_3$	148.54	240.61	266.31	240.61	242.17	268.62
$i_1n_2k_1$	122.77	102.27	238.13	102.27	218.56	262.86
$i_1n_2k_2$	182.78	258.49	315.31	258.49	322.61	454.28
$i_1n_2k_3$	181.17	257.09	296.53	257.09	313.80	420.92
$i_1n_3k_1$	132.59	209.44	244.65	209.44	229.40	268.09
$i_1n_3k_2$	166.61	249.24	302.96	249.24	273.66	332.31
$i_1n_3k_3$	166.19	244.23	312.79	244.23	259.90	331.73
$i_2n_1k_1$	134.58	214.06	250.28	214.06	228.35	267.67
$i_2n_1k_2$	164.80	246.67	302.52	246.67	273.72	336.77
$i_2n_1k_3$	141.76	235.29	271.75	235.29	254.57	295.17
$i_2n_2k_1$	165.03	247.91	320.66	247.91	277.15	360.51
$i_2n_2k_2$	211.65	382.08	434.07	382.08	491.91	576.55
$i_2n_2k_3$	193.51	266.57	412.41	266.57	332.75	492.65
$i_2n_3k_1$	152.65	253.19	305.75	253.19	256.29	309.26
$i_2n_3k_2$	197.28	273.97	401.57	273.97	335.20	491.92
$i_2n_3k_3$	172.10	253.45	332.66	253.45	285.80	374.74
$i_3n_1k_1$	126.18	203.97	248.76	203.97	217.27	264.97
$i_3n_1k_2$	151.42	249.75	296.37	249.75	256.50	304.00
$i_3n_1k_3$	134.35	211.77	245.92	211.77	229.56	265.90
$i_3n_2k_1$	157.03	242.58	282.59	242.58	260.18	303.59
$i_3n_2k_2$	202.14	277.43	412.26	277.43	356.94	529.86
$i_3n_2k_3$	173.16	242.19	330.22	242.19	284.18	387.03
$i_3n_3k_1$	138.60	215.78	262.02	215.78	226.15	274.70
$i_3n_3k_2$	175.25	240.26	313.20	240.26	297.80	389.47
$i_3n_3k_3$	153.16	234.80	290.82	234.80	258.69	307.44
c_1	83.78	131.77	195.53	111.63	174.56	212.48
c_2	86.17	122.40	164.63	133.79	179.17	223.75
c_3	81.26	139.76	176.30	90.69	157.20	195.21
f_1	104.89	150.35	198.79	134.34	188.67	241.35

Appendix 3. Treatment means, Number of leaves per plant at 30 DAS, 60 DAS and Final harvest. (Experiment 2 and 3)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
$i_1n_1k_1$	20.1	33.01	8.24	32.96	57.65	25.65
$i_1n_1k_2$	26.12	43.67	20.88	37.02	70.34	61.31
$i_1n_1k_3$	25.25	46.12	21.93	35.58	72.78	62.81
$i_1n_2k_1$	21.85	35.89	10.11	30.50	68.72	30.85
$i_1n_2k_2$	45.71	92.57	52.53	64.06	156.75	131.90
$i_1n_2k_3$	43.26	89.94	56.83	65.35	166.56	137.65
$i_1n_3k_1$	20.70	35.50	11.22	28.68	73.60	35.26
$i_1n_3k_2$	35.24	77.50	37.01	48.70	89.77	89.35
$i_1n_3k_3$	32.50	63.70	32.08	44.61	91.45	84.45
$i_2n_1k_1$	22.50	34.45	14.55	30.64	65.86	46.10
$i_2n_1k_2$	35.10	80.79	40.06	48.68	114.30	95.95
$i_2n_1k_3$	26.84	45.26	20.55	37.10	87.17	61.95
$i_2n_2k_1$	36.53	72.94	37.24	50.91	124.73	98.70
$i_2n_2k_2$	69.52	207.46	108.13	96.43	250.71	243.81
$i_2n_2k_3$	46.21	100.36	53.78	64.23	167.00	129.81
$i_2n_3k_1$	28.12	49.13	21.34	38.68	102.45	64.50
$i_2n_3k_2$	51.30	116.23	68.28	70.69	123.59	160.60
$i_2n_3k_3$	39.05	77.74	41.51	53.99	105.10	101.98
$i_3n_1k_1$	19.55	34.15	9.50	26.46	55.57	30.20
$i_3n_1k_2$	29.10	54.71	25.03	40.02	89.94	76.75
$i_3n_1k_3$	23.35	35.82	16.08	31.92	78.28	49.90
$i_3n_2k_1$	30.80	57.58	28.02	42.82	109.22	78.35
$i_3n_2k_2$	58.30	120.17	102.15	80.97	232.38	219.60
$i_3n_2k_3$	40.96	88.30	50.66	56.82	104.87	119.00
$i_3n_3k_1$	23.47	36.53	14.98	32.57	66.97	48.97
$i_3n_3k_2$	43.12	89.12	49.85	65.27	146.76	117.20
$i_3n_3k_3$	30.85	64.08	29.73	43.07	105.50	79.48
c_1	16.70	26.56	2.70	22.79	43.55	12.18
c_2	17.33	25.54	2.01	25.89	61.11	8.17
c_3	11.30	19.43	1.40	15.58	33.19	7.70
f_1	18.40	29.04	4.16	25.97	61.04	14.61

Appendix 4. Treatment means - Leaf Area Indix at 30 DAS, 60 DAS and Final harvest (Experiment 2 and 3)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
$i_1n_1k_1$	0.22	0.32	0.18	0.33	0.39	0.26
$i_1n_1k_2$	0.28	0.38	0.25	0.46	0.58	0.34
$i_1n_1k_3$	0.30	0.44	0.25	0.44	0.69	0.28
$i_1n_2k_1$	0.24	0.37	0.15	0.35	0.56	0.23
$i_1n_2k_2$	0.36	0.92	0.41	0.54	1.40	0.57
$i_1n_2k_3$	0.37	0.90	0.44	0.55	1.33	0.53
$i_1n_3k_1$	0.24	0.37	0.11	0.36	0.51	0.16
$i_1n_3k_2$	0.35	0.60	0.37	0.51	0.93	0.48
$i_1n_3k_3$	0.35	0.47	0.34	0.52	0.70	0.46
$i_2n_1k_1$	0.26	0.37	0.15	0.38	0.55	0.23
$i_2n_1k_2$	0.35	0.65	0.38	0.51	0.96	0.48
$i_2n_1k_3$	0.32	0.38	0.22	0.47	0.48	0.32
$i_2n_2k_1$	0.37	0.52	0.37	0.53	0.79	0.48
$i_2n_2k_2$	0.46	1.62	1.10	0.66	1.76	1.60
$i_2n_2k_3$	0.38	1.02	0.42	0.57	1.50	0.53
$i_2n_3k_1$	0.37	0.40	0.23	0.53	0.60	0.35
$i_2n_3k_2$	0.39	1.15	0.48	0.55	1.61	0.68
$i_2n_3k_3$	0.38	0.58	0.38	0.56	0.87	0.54
$i_3n_1k_1$	0.23	0.36	0.10	0.34	0.45	0.14
$i_3n_1k_2$	0.34	0.42	0.28	0.46	0.72	0.41
$i_3n_1k_3$	0.23	0.37	0.17	0.34	0.48	0.25
$i_3n_2k_1$	0.35	0.43	0.30	0.53	0.64	0.45
$i_3n_2k_2$	0.43	1.17	0.86	0.64	1.40	1.28
$i_3n_2k_3$	0.38	0.82	0.40	0.54	1.03	0.55
$i_3n_3k_1$	0.28	0.37	0.16	0.41	0.61	0.23
$i_3n_3k_2$	0.38	0.78	0.41	0.60	0.99	0.56
$i_3n_3k_3$	0.35	0.45	0.32	0.53	0.78	0.47
c_1	0.15	0.31	0.02	0.22	0.35	0.03
c_2	0.16	0.29	0.05	0.23	0.44	0.06
c_3	0.14	0.20	0.04	0.19	0.30	0.05
f_1	0.16	0.30	0.07	0.23	0.44	0.09

Appendix 5. Treatment means, Dry matter production at 30 DAS, 60 DAS and FH (Experiment 2 and 3)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
$i_1n_1k_1$	212.76	835.70	1395.70	373.27	1659.85	2773.86
$i_1n_1k_2$	223.14	1141.01	1909.79	366.75	1741.26	2915.33
$i_1n_1k_3$	254.82	1081.02	2240.78	428.86	1991.79	3331.92
$i_1n_2k_1$	296.91	1071.35	1791.24	373.50	1699.01	2840.73
$i_1n_2k_2$	380.72	1892.49	3635.54	571.38	2941.61	4904.23
$i_1n_2k_3$	395.48	1571.57	3814.39	599.58	3087.85	5187.37
$i_1n_3k_1$	222.18	1052.17	1759.47	381.69	1733.55	2899.28
$i_1n_3k_2$	321.63	1521.95	2972.44	508.35	2511.79	4209.69
$i_1n_3k_3$	296.64	1364.18	2679.92	464.77	2317.86	3885.32
$i_2n_1k_1$	219.40	1113.26	1861.47	377.44	1714.71	2866.64
$i_2n_1k_2$	306.11	1675.27	2807.25	483.25	1938.00	3244.35
$i_2n_1k_3$	248.00	1339.21	1988.47	408.25	1938.00	3244.35
$i_2n_2k_1$	280.90	1560.00	2616.98	441.59	2194.89	3681.35
$i_2n_2k_2$	436.16	2715.38	4559.78	645.29	3408.02	5727.90
$i_2n_2k_3$	315.39	2272.73	2799.71	469.50	2464.46	4138.28
$i_2n_3k_1$	227.84	1181.69	1927.33	375.80	1780.25	2980.57
$i_2n_3k_2$	372.48	2041.62	2886.91	554.68	2910.24	4887.03
$i_2n_3k_3$	311.23	1606.79	2629.49	483.00	2432.43	4078.84
$i_3n_1k_1$	193.67	978.73	1634.52	340.24	1513.12	2529.28
$i_3n_1k_2$	250.05	1210.78	2027.40	402.86	1954.31	3273.20
$i_3n_1k_3$	242.11	1196.62	1823.27	406.61	1892.05	3165.52
$i_3n_2k_1$	252.29	1365.07	2286.22	407.18	1971.53	3302.41
$i_3n_2k_2$	366.34	2289.17	3383.40	545.42	2862.57	4805.87
$i_3n_2k_3$	305.54	1758.95	2786.28	473.30	2387.49	4004.15
$i_3n_3k_1$	221.06	1151.38	1976.41	371.84	1727.48	2890.14
$i_3n_3k_2$	325.25	1724.14	3003.58	480.00	2541.60	4267.64
$i_3n_3k_3$	261.76	1560.53	2285.34	422.25	2045.06	3426.33
c_1	31.53	165.01	242.85	110.70	352.84	502.23
c_2	104.90	324.03	403.62	138.11	388.78	483.44
c_3	59.26	206.81	249.69	117.28	410.38	497.09
f_1	180.12	792.13	1318.11	346.59	1530.36	2556.91

Appendix 6. Treatment means, No. of fruits harvested plant^1, Length of fruit(cm), Girth of fruit (cm)

	Number of fruits/ harvest per plant		Length of fruit (cm)		Girth of fruit (cm)	
	Expt.2	Expt.3	Expt.2	Expt.3	Expt.2	Expt.3
$i_1n_1k_1$	1.76	2.53	15.24	19.29	12.65	17.09
$i_1n_1k_2$	2.53	2.89	22.87	24.87	19.96	20.80
$i_1n_1k_3$	2.52	2.78	23.02	23.85	19.47	20.16
$i_1n_2k_1$	2.20	2.65	19.28	21.04	19.60	19.11
$i_1n_2k_2$	3.74	3.94	36.00	40.62	33.30	32.00
$i_1n_2k_3$	3.75	3.89	35.96	39.70	33.20	36.21
$i_1n_3k_1$	2.12	2.61	18.69	20.66	15.56	17.64
$i_1n_3k_2$	3.20	3.37	30.50	33.00	27.18	27.02
$i_1n_3k_3$	3.05	3.26	29.04	31.41	25.65	25.86
$i_2n_1k_1$	2.22	2.65	19.18	20.59	16.24	17.50
$i_2n_1k_2$	3.16	3.31	30.32	32.39	27.14	26.38
$i_2n_1k_3$	2.48	2.93	22.13	25.55	19.29	21.32
$i_2n_2k_1$	3.12	3.32	30.03	32.85	26.88	27.53
$i_2n_2k_2$	4.69	4.94	44.97	50.97	34.39	37.90
$i_2n_2k_3$	3.80	4.12	34.85	40.52	32.75	31.71
$i_2n_3k_1$	2.48	2.77	22.30	23.27	19.47	19.20
$i_2n_3k_2$	3.80	4.16	35.07	41.23	33.55	32.23
$i_2n_3k_3$	3.14	3.44	29.53	33.25	26.55	26.62
$i_3n_1k_1$	2.15	2.48	19.13	19.62	15.86	17.35
$i_3n_1k_2$	2.58	3.10	23.27	27.21	20.41	22.61
$i_3n_1k_3$	2.25	2.92	19.78	23.56	16.95	20.04
$i_3n_2k_1$	2.60	3.06	23.56	26.79	20.69	22.13
$i_3n_2k_2$	4.34	4.38	41.69	46.03	30.23	34.64
$i_3n_2k_3$	3.29	3.64	31.16	35.94	28.09	28.25
$i_3n_3k_1$	2.42	2.69	22.20	22.85	19.06	24.40
$i_3n_3k_2$	3.43	3.94	30.85	37.23	27.94	29.17
$i_3n_3k_3$	2.67	2.95	25.36	27.38	22.34	22.58
c_1	0.61	1.07	15.08	15.22	12.01	15.68
c_2	0.95	1.01	18.55	13.62	15.29	18.69
c_3	0.60	0.96	16.28	13.79	13.44	16.45
f_1	1.62	2.40	23.83	26.85	19.53	19.94

Appendix 7. Treatment means, Mean weight of fruit (kg), Fruit setting percentage and sex ratio

	Mean weight of		Fruit setting fruit (kg)		Sex Ratio (%)	
	Expt.2	Expt.3	Expt.2	Expt.3	Expt.2	Expt.3
$i_1n_1k_1$	1.73	1.72	33.64	49.94	12.90	17.65
$i_1n_1k_2$	1.60	1.60	45.78	52.30	15.35	18.82
$i_1n_1k_3$	1.63	1.63	45.93	52.12	15.39	19.63
$i_1n_2k_1$	1.63	1.65	41.51	47.70	14.27	15.23
$i_1n_2k_2$	1.75	1.74	60.92	61.66	20.22	22.12
$i_1n_2k_3$	1.75	1.74	61.65	58.79	20.54	21.25
$i_1n_3k_1$	1.62	1.65	39.81	47.33	14.36	16.30
$i_1n_3k_2$	1.70	1.70	55.02	59.04	18.50	19.98
$i_1n_3k_3$	1..72	1.72	52.83	55.89	17.55	20.83
$i_2n_1k_1$	1.67	1.67	41.31	56.77	14.06	17.25
$i_2n_1k_2$	1.88	1.91	53.92	60.30	17.61	19.83
$i_2n_1k_3$	1.87	1.86	44.55	62.47	15.12	17.74
$i_2n_2k_1$	1.91	1.82	52.84	58.60	17.43	19.66
$i_2n_2k_2$	1.79	1.85	74.06	78.74	23.84	27.57
$i_2n_2k_3$	1.75	1.82	61.40	71.78	20.36	24.69
$i_2n_3k_1$	1.86	1.84	44.23	57.95	15.06	19.39
$i_2n_3k_2$	1.75	1.79	60.91	70.32	19.16	20.78
$i_2n_3k_3$	1.85	1.85	52.76	61.65	16.71	18.41
$i_3n_1k_1$	1.82	1.91	40.84	54.87	13.11	17.17
$i_3n_1k_2$	1.85	1.79	45.77	57.82	14.61	16.33
$i_3n_1k_3$	1.82	1.75	41.58	56.64	13.37	17.81
$i_3n_2k_1$	1.84	1.86	45.70	56.65	14.60	18.01
$i_3n_2k_2$	1.79	1.75	69.10	71.60	21.65	19.37
$i_3n_2k_3$	1.85	1.85	54.86	69.48	17.42	19.57
$i_3n_3k_1$	1.90	1.90	44.50	51.99	14.21	18.38
$i_3n_3k_2$	1.74	1.74	56.84	63.47	17.96	21.34
$i_3n_3k_3$	1.88	1.88	46.67	61.60	14.96	18.25
c_1	1.23	1.94	12.38	16.25	4.14	6.10
c_2	2.04	2.05	18.48	23.79	5.27	6.51
c_3	1.34	2.08	12.80	19.89	4.27	6.91
f_1	1.85	1.82	31.76	55.95	10.95	17.40

Appendix 8. Treatment means, fruit yeild (t ha^{-1}) vine yeild (t ha^{-1}) and shelf life (days)

	Fruit yield (t ha^{-1})		Vine yield (t ha^{-1})		Shelf life of fruits (days)	
	Expt.2	Expt.3	Expt.2	Expt.3	Expt.2	Expt.3
$i_1n_1k_1$	11.21	16.26	4.40	8.97	7.09	7.03
$i_1n_1k_2$	15.99	18.28	6.04	9.60	9.18	8.91
$i_1n_1k_3$	16.21	17.85	7.10	11.11	8.17	7.84
$i_1n_2k_1$	14.07	16.98	5.70	9.33	5.34	4.73
$i_1n_2k_2$	22.93	24.18	11.60	17.12	6.88	7.15
$i_1n_2k_3$	23.05	23.89	11.86	18.23	5.23	5.75
$i_1n_3k_1$	13.54	16.65	5.47	9.54	5.80	5.78
$i_1n_3k_2$	20.26	21.29	9.26	14.43	8.11	7.69
$i_1n_3k_3$	19.49	20.83	8.36	13.16	6.84	7.25
$i_2n_1k_1$	13.79	16.49	5.82	9.42	5.24	5.12
$i_2n_1k_2$	20.06	21.03	8.79	13.64	7.26	6.79
$i_2n_1k_3$	15.35	18.13	6.24	10.80	5.83	5.58
$i_2n_2k_1$	19.80	21.13	8.22	12.41	3.08	2.88
$i_2n_2k_2$	27.90	29.38	14.35	20.46	5.19	5.12
$i_2n_2k_3$	22.04	23.96	8.84	14.12	4.12	4.24
$i_2n_3k_1$	15.37	17.20	6.01	9.83	4.24	3.66
$i_2n_3k_2$	25.04	24.15	9.01	17.05	5.66	6.21
$i_2n_3k_3$	19.28	21.18	8.21	13.91	5.21	5.37
$i_3n_1k_1$	14.05	16.21	5.10	8.23	6.37	6.09
$i_3n_1k_2$	15.92	19.10	6.33	10.91	8.09	7.98
$i_3n_1k_3$	13.98	18.15	5.70	10.51	6.98	7.21
$i_3n_2k_1$	16.01	18.75	7.15	10.73	4.21	3.75
$i_3n_2k_2$	25.81	26.02	10.58	16.74	5.75	5.72
$i_3n_2k_3$	20.21	22.36	8.72	13.62	4.72	4.91
$i_3n_3k_1$	15.73	17.46	6.18	9.50	4.91	5.03
$i_3n_3k_2$	19.88	22.83	9.40	15.20	7.03	7.37
$i_3n_3k_3$	17.12	18.13	7.15	11.46	6.37	5.99
c_1	3.88	5.85	0.75	1.59	11.49	9.92
c_2	6.48	5.83	1.30	1.52	8.98	9.17
c_3	4.06	6.05	0.81	1.15	10.08	9.38
f_1	10.32	15.01	4.14	7.95	4.8	4.59

Appendix 9. Treatment means, Root dry matter (g), Root depth (cm) and Root spread (cm)

	Root dry matter (g)		Root depth (cm)		Root spread (cm)	
	Expt.2	Expt.3	Expt.2	Expt.3	Expt.2	Expt.3
$i_1n_1k_1$	11.47	11.58	40.26	37.66	25.69	22.20
$i_1n_1k_2$	10.42	11.81	35.12	41.36	22.16	26.32
$i_1n_1k_3$	10.89	11.86	40.22	36.54	25.39	24.15
$i_1n_2k_1$	10.53	12.08	37.89	39.40	23.24	22.45
$i_1n_2k_2$	10.81	12.00	37.89	39.35	25.36	25.12
$i_1n_2k_3$	10.51	12.15	39.12	41.03	26.20	32.26
$i_1n_3k_1$	10.87	12.25	43.03	39.89	24.48	24.59
$i_1n_3k_2$	10.91	11.75	39.89	38.60	28.03	30.39
$i_1n_3k_3$	11.09	12.03	37.03	40.29	26.82	27.83
$i_2n_1k_1$	10.77	11.96	47.17	51.69	34.14	31.55
$i_2n_1k_2$	10.87	12.19	49.84	53.10	31.16	36.22
$i_2n_1k_3$	11.25	11.87	49.88	48.59	31.32	33.23
$i_2n_2k_1$	10.71	12.18	46.46	50.22	37.04	35.30
$i_2n_2k_2$	11.94	11.81	50.43	49.09	35.36	38.67
$i_2n_2k_3$	11.27	11.63	51.41	48.72	38.46	39.87
$i_2n_3k_1$	10.61	12.39	49.24	51.55	34.46	39.57
$i_2n_3k_2$	11.08	11.84	51.75	52.26	39.57	40.58
$i_2n_3k_3$	11.04	12.29	46.58	50.79	35.63	38.12
$i_3n_1k_1$	10.67	12.64	51.55	55.26	41.46	39.22
$i_3n_1k_2$	10.99	12.28	53.13	60.99	39.40	41.53
$i_3n_1k_3$	10.53	12.19	50.99	59.70	43.55	40.96
$i_3n_2k_1$	10.88	12.10	57.51	60.82	40.78	42.61
$i_3n_2k_2$	12.51	12.34	60.34	58.60	42.87	45.88
$i_3n_2k_3$	11.61	12.13	59.29	62.55	48.93	43.69
$i_3n_3k_1$	10.91	12.10	60.57	60.68	44.31	46.95
$i_3n_3k_2$	12.35	12.46	60.21	62.12	43.25	44.81
$i_3n_3k_3$	12.28	12.53	60.73	62.19	47.47	48.14
c_1	5.97	9.29	38.49	37.91	19.80	18.25
c_2	6.17	9.45	46.67	45.20	20.82	18.01
c_3	5.94	8.44	50.22	50.23	21.16	21.73
f_1	14.41	16.73	73.96	77.18	90.21	95.29

Appendix 10. Treatment means, field water use effeciency (kg hamm^{-1})

	Field water use effeciency (kg ha mm^{-1})	
	Expt. 2	Expt. 3
$i_1n_1k_1$	40.04	63.25
$i_1n_1k_2$	56.70	71.11
$i_1n_1k_3$	57.48	69.44
$i_1n_2k_1$	49.90	66.05
$i_1n_2k_2$	81.31	94.13
$i_1n_2k_3$	81.74	92.96
$i_1n_3k_1$	48.02	64.77
$i_1n_3k_2$	71.85	82.83
$i_1n_3k_3$	69.11	81.46
$i_2n_1k_1$	30.85	40.52
$i_2n_1k_2$	44.88	51.67
$i_2n_1k_3$	34.34	44.54
$i_2n_2k_1$	44.30	51.91
$i_2n_2k_2$	62.42	72.18
$i_2n_2k_3$	49.31	58.87
$i_2n_3k_1$	34.39	42.25
$i_2n_3k_2$	49.31	59.33
$i_2n_3k_3$	43.14	52.04
$i_3n_1k_1$	31.43	39.82
$i_3n_1k_2$	35.62	46.85
$i_3n_1k_3$	31.28	44.58
$i_3n_2k_1$	35.82	46.07
$i_3n_2k_2$	57.34	63.93
$i_3n_2k_3$	45.21	54.93
$i_3n_3k_1$	35.19	42.89
$i_3n_3k_2$	44.48	56.09
$i_3n_3k_3$	38.30	46.50
c_1	13.75	22.38
c_2	14.49	14.33
c_3	9.08	14.86
f_1	34.39	55.16

Appendix 11. Treatment means, Nitrogen content of plant parts (%)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
$i_1n_1k_1$	2.14	1.51	1.53	2.25	1.59	1.61
$i_1n_1k_2$	2.19	1.59	1.61	2.23	1.61	1.63
$i_1n_1k_3$	2.16	1.61	1.63	2.22	1.63	1.65
$i_1n_2k_1$	2.37	2.02	2.07	2.42	2.07	2.12
$i_1n_2k_2$	2.38	2.03	2.09	2.62	2.29	2.34
$i_1n_2k_3$	2.36	2.02	2.08	2.62	2.34	2.39
$i_1n_3k_1$	2.24	1.74	1.77	2.43	1.88	1.91
$i_1n_3k_2$	2.22	1.76	1.79	2.40	1.90	1.93
$i_1n_3k_3$	2.20	1.77	1.80	2.42	1.95	1.98
$i_2n_1k_1$	2.19	1.54	1.56	2.30	1.63	1.65
$i_2n_1k_2$	2.21	1.60	1.62	2.33	1.69	1.71
$i_2n_1k_3$	2.17	1.63	1.65	2.32	1.73	1.75
$i_2n_2k_1$	2.38	2.05	2.09	2.60	2.23	2.28
$i_2n_2k_2$	2.41	2.12	2.17	2.61	2.22	2.27
$i_2n_2k_3$	2.46	2.16	2.21	2.61	2.34	2.39
$i_2n_3k_1$	2.34	1.81	1.84	2.50	1.93	1.96
$i_2n_3k_2$	2.35	1.86	1.89	2.52	1.90	1.93
$i_2n_3k_3$	2.33	1.88	1.91	2.51	1.83	1.86
$i_3n_1k_1$	2.20	1.55	1.57	2.25	1.59	1.61
$i_3n_1k_2$	2.20	1.61	1.63	2.35	1.71	1.73
$i_3n_1k_3$	2.21	1.63	1.65	2.22	1.66	1.68
$i_3n_2k_1$	2.37	2.03	2.07	2.63	2.25	2.30
$i_3n_2k_2$	2.40	2.10	2.15	2.63	2.30	2.35
$i_3n_2k_3$	2.43	2.09	2.12	2.61	2.33	2.38
$i_3n_3k_1$	2.32	1.80	1.83	2.53	1.96	1.99
$i_3n_3k_2$	2.29	1.78	1.81	2.51	1.96	2.00
$i_3n_3k_3$	2.32	1.86	1.89	2.47	1.94	1.98
c_1	1.38	0.93	0.95	2.21	1.26	1.28
c_2	1.36	0.91	0.93	1.91	1.28	1.30
c_3	1.21	1.16	0.84	1.75	1.17	1.19
f_1	2.04	1.41	1.43	2.06	1.52	1.94

Appendix 12. Treatment means, uptake of nitrogen by the plant (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
$i_1n_1k_1$	4.55	12.57	21.27	8.39	26.29	44.50
$i_1n_1k_2$	4.88	18.10	30.66	8.18	27.96	47.39
$i_1n_1k_3$	5.49	17.40	36.59	9.50	32.38	54.83
$i_1n_2k_1$	7.05	21.64	37.08	9.02	35.08	60.08
$i_1n_2k_2$	9.07	38.41	75.94	14.94	67.38	114.78
$i_1n_2k_3$	9.32	31.67	79.13	15.68	72.26	123.99
$i_1n_3k_1$	4.97	18.26	31.06	9.25	32.59	55.38
$i_1n_3k_2$	7.14	26.71	53.03	12.19	47.58	81.01
$i_1n_3k_3$	6.53	24.18	48.27	11.22	45.10	76.94
$i_2n_1k_1$	4.80	17.15	29.04	8.68	27.87	47.16
$i_2n_1k_2$	6.75	26.82	45.50	9.27	40.45	68.61
$i_2n_1k_3$	5.38	21.77	32.72	9.45	33.47	56.67
$i_2n_2k_1$	6.68	31.90	54.54	11.48	48.85	83.77
$i_2n_2k_2$	10.51	57.60	19.01	16.84	75.66	130.03
$i_2n_2k_3$	7.76	49.06	61.70	12.23	57.54	98.68
$i_2n_3k_1$	5.33	21.39	35.45	9.37	34.36	58.02
$i_2n_3k_2$	8.73	37.88	54.43	13.95	55.42	94.53
$i_2n_3k_3$	7.25	30.13	50.08	12.10	44.53	75.90
$i_3n_1k_1$	4.25	15.14	25.60	7.65	23.98	40.59
$i_3n_1k_2$	5.50	19.44	32.95	9.45	33.28	56.39
$i_3n_1k_3$	5.35	19.45	29.99	9.01	31.30	53.00
$i_3n_2k_1$	5.99	27.70	47.42	10.71	44.27	75.80
$i_3n_2k_2$	8.78	48.12	72.64	14.31	65.66	112.63
$i_3n_2k_3$	7.43	36.32	58.92	12.33	55.63	95.30
$i_3n_3k_1$	5.12	20.68	36.08	9.39	33.76	57.34
$i_3n_3k_2$	7.43	30.69	54.45	12.05	49.81	85.34
$i_3n_3k_3$	6.06	29.16	43.25	10.41	39.06	67.72
c_1	0.73	1.57	2.34	2.01	4.32	6.28
c_2	1.62	3.02	3.74	2.65	4.97	6.23
c_3	0.75	1.87	2.13	1.79	4.82	5.89
r_1	3.73	10.87	18.33	7.07	22.95	38.86

Appendix 13. Treatment means, uptake of nutrients by fruits (kg ha^{-1})

	Nitrogen		Phosphorus		Potassium	
	Expt.2	Expt.3	Expt.2	Expt.3	Expt.2	Expt.3
$i_1n_1k_1$	7.89	10.30	1.45	1.90	8.07	10.78
$i_1n_1k_2$	11.73	12.52	1.98	2.10	12.83	13.83
$i_1n_1k_3$	11.82	12.44	2.56	2.49	12.42	13.45
$i_1n_2k_1$	11.14	13.12	2.15	2.70	10.99	12.89
$i_1n_2k_2$	19.90	19.47	3.55	3.90	21.13	21.00
$i_1n_2k_3$	20.79	20.10	4.52	4.55	21.20	20.73
$i_1n_3k_1$	11.51	15.28	2.08	2.43	11.26	14.53
$i_1n_3k_2$	16.34	18.15	3.71	4.33	17.22	18.58
$i_1n_3k_3$	14.97	16.55	3.17	3.38	14.80	16.80
$i_2n_1k_1$	9.45	11.81	2.27	3.00	9.57	12.17
$i_2n_1k_2$	12.72	13.99	3.15	3.61	14.34	16.13
$i_2n_1k_3$	10.27	12.04	2.93	3.22	10.77	12.79
$i_2n_2k_1$	13.59	14.40	3.74	3.44	13.83	14.63
$i_2n_2k_2$	20.51	22.29	4.99	5.15	21.61	23.40
$i_2n_2k_3$	16.93	19.88	4.01	4.54	17.20	19.67
$i_2n_3k_1$	12.68	15.30	3.21	3.89	12.22	14.82
$i_2n_3k_2$	18.24	21.82	4.53	5.34	19.48	23.43
$i_2n_3k_3$	16.82	19.19	3.96	4.72	16.61	18.75
$i_3n_1k_1$	11.86	13.20	2.91	3.21	11.87	13.16
$i_3n_1k_2$	13.50	14.09	3.34	3.62	15.18	16.00
$i_3n_1k_3$	11.52	13.59	2.81	3.03	12.21	14.00
$i_3n_2k_1$	12.30	13.57	2.85	2.05	11.98	13.10
$i_3n_2k_2$	20.62	17.54	5.04	4.18	21.88	19.12
$i_3n_2k_3$	15.97	15.44	3.81	3.54	16.17	15.79
$i_3n_3k_1$	11.70	12.14	2.60	2.61	11.01	11.67
$i_3n_3k_2$	13.86	16.49	3.26	3.84	14.60	17.76
$i_3n_3k_3$	12.25	14.86	2.56	3.26	12.20	14.55
c_1	2.41	3.89	0.26	0.39	2.35	3.71
c_2	4.75	4.47	0.52	0.52	4.50	4.23
c_3	3.02	4.43	0.37	0.49	2.80	4.11
f_1	6.85	10.27	1.15	1.55	6.41	9.96

Appendix 14. Treatment means, content of phosphours in plant (%)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
$i_1n_1k_1$	0.63	0.26	0.29	0.67	0.28	0.32
$i_1n_1k_2$	0.72	0.31	0.35	0.73	0.32	0.35
$i_1n_1k_3$	0.69	0.32	0.36	0.73	0.33	0.38
$i_1n_2k_1$	0.71	0.34	0.39	0.71	0.34	0.39
$i_1n_2k_2$	0.70	0.35	0.38	0.72	0.36	0.39
$i_1n_2k_3$	0.69	0.36	0.40	0.71	0.36	0.40
$i_1n_3k_1$	0.69	0.33	0.37	0.72	0.34	0.38
$i_1n_3k_2$	0.73	0.31	0.32	0.75	0.32	0.35
$i_1n_3k_3$	0.72	0.32	0.35	0.74	0.33	0.37
$i_2n_1k_1$	0.71	0.33	0.36	0.73	0.34	0.39
$i_2n_1k_2$	0.68	0.33	0.37	0.71	0.34	0.39
$i_2n_1k_3$	0.65	0.33	0.38	0.68	0.34	0.40
$i_2n_2k_1$	0.67	0.36	0.39	0.70	0.37	0.40
$i_2n_2k_2$	0.68	0.28	0.31	0.69	0.38	0.42
$i_2n_2k_3$	0.66	0.29	0.33	0.68	0.28	0.32
$i_2n_3k_1$	0.66	0.30	0.35	0.69	0.30	0.35
$i_2n_3k_2$	0.70	0.33	0.37	0.72	0.33	0.36
$i_2n_3k_3$	0.70	0.35	0.38	0.72	0.35	0.38
$i_3n_1k_1$	0.72	0.37	0.42	0.75	0.37	0.41
$i_3n_1k_2$	0.70	0.37	0.42	0.71	0.37	0.41
$i_3n_1k_3$	0.71	0.30	0.34	0.74	0.35	0.40
$i_3n_2k_1$	0.70	0.31	0.34	0.72	0.30	0.34
$i_3n_2k_2$	0.72	0.33	0.37	0.74	0.33	0.37
$i_3n_2k_3$	0.72	0.34	0.39	0.74	0.35	0.39
$i_3n_3k_1$	0.73	0.36	0.42	0.75	0.37	0.42
$i_3n_3k_2$	0.72	0.37	0.41	0.73	0.37	0.43
$i_3n_3k_3$	0.69	0.38	0.42	0.70	0.37	0.41
c_1	0.53	0.20	0.21	0.54	0.20	0.22
c_2	0.51	0.19	0.20	0.50	0.17	0.18
c_3	0.46	0.17	0.18	0.48	0.18	0.19
f_1	0.59	0.25	0.27	0.62	0.25	0.27

Appendix 15. Treatment means, uptake of phosphorus by the palnt (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
$i_1n_1k_1$	1.35	2.18	3.99	2.51	4.67	8.84
$i_1n_1k_2$	1.60	3.54	6.68	2.66	5.49	10.23
$i_1n_1k_3$	1.76	3.41	7.96	3.11	6.58	12.51
$i_1n_2k_1$	2.09	3.59	6.98	2.65	5.69	11.06
$i_1n_2k_2$	2.65	6.53	13.86	4.08	10.45	19.14
$i_1n_2k_3$	2.73	5.59	15.08	4.23	11.12	20.75
$i_1n_3k_1$	1.53	3.41	6.50	2.73	5.79	10.97
$i_1n_3k_2$	2.36	4.73	9.51	3.82	8.07	14.79
$i_1n_3k_3$	2.14	4.37	9.38	3.42	7.54	14.19
$i_2n_1k_1$	1.55	3.63	6.72	2.76	5.84	11.05
$i_2n_1k_2$	2.08	5.52	10.36	3.40	8.12	15.61
$i_2n_1k_3$	1.61	4.42	7.56	2.75	6.59	12.98
$i_2n_2k_1$	1.89	5.56	10.24	3.08	8.04	14.79
$i_2n_2k_2$	2.95	7.59	14.11	4.45	12.78	23.77
$i_2n_2k_3$	2.07	6.49	9.09	3.19	6.90	13.03
$i_2n_3k_1$	1.49	3.48	6.65	2.59	5.34	10.29
$i_2n_3k_2$	2.61	6.74	10.68	3.99	9.59	17.62
$i_2n_3k_3$	2.17	5.55	10.01	3.48	8.40	15.53
$i_3n_1k_1$	1.40	3.62	6.84	2.54	5.60	10.37
$i_3n_1k_2$	1.75	4.49	8.53	2.87	7.15	13.47
$i_3n_1k_3$	1.72	3.54	6.19	2.98	6.42	12.33
$i_3n_2k_1$	1.76	4.17	7.67	2.92	5.93	11.23
$i_3n_2k_2$	2.64	7.57	12.49	4.00	9.42	17.48
$i_3n_2k_3$	2.19	5.99	10.76	3.51	8.24	15.43
$i_3n_3k_1$	1.60	4.16	8.22	2.77	6.30	11.99
$i_3n_3k_2$	2.35	6.38	12.10	3.51	9.41	18.16
$i_3n_3k_3$	1.80	5.86	9.62	2.95	7.57	13.89
c_1	0.27	0.34	0.52	0.60	0.72	1.08
c_2	0.58	0.61	0.80	0.69	0.63	0.84
c_3	0.27	0.35	0.44	0.48	0.71	0.92
f_1	1.40	1.93	3.48	2.12	3.84	0.93

Appendix 16. Treatment means, Potassium content in parts (%)

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
$i_1n_1k_1$	2.32	2.51	2.34	2.42	2.62	2.44
$i_1n_1k_2$	2.51	2.72	2.59	2.62	2.84	2.71
$i_1n_1k_3$	2.37	2.62	2.48	2.50	2.76	2.61
$i_1n_2k_1$	2.31	2.50	2.34	2.37	2.57	2.41
$i_1n_2k_2$	2.51	2.67	2.56	2.58	2.71	2.60
$i_1n_2k_3$	2.38	2.63	2.47	2.40	2.65	2.49
$i_1n_3k_1$	2.31	2.51	2.34	2.40	2.61	2.44
$i_1n_3k_2$	2.51	2.75	2.63	2.56	2.81	2.68
$i_1n_3k_3$	2.37	2.60	0.46	2.48	2.73	2.58
$i_2n_1k_1$	2.31	2.46	2.31	2.39	2.59	2.43
$i_2n_1k_2$	2.51	2.73	2.59	2.55	2.82	2.68
$i_2n_1k_3$	2.38	2.68	2.53	2.47	2.72	2.56
$i_2n_2k_1$	2.31	2.49	2.34	2.38	2.57	2.42
$i_2n_2k_2$	2.52	2.75	2.63	2.53	2.84	2.72
$i_2n_2k_3$	2.36	2.66	2.52	2.50	2.76	2.62
$i_2n_3k_1$	2.27	2.50	2.33	2.37	2.57	2.39
$i_2n_3k_2$	2.48	2.76	2.63	2.57	2.85	2.72
$i_2n_3k_3$	2.42	2.65	2.50	2.49	2.76	2.61
$i_3n_1k_1$	2.30	2.50	2.34	2.36	2.57	2.40
$i_3n_1k_2$	2.50	2.73	2.62	2.56	2.81	2.70
$i_3n_1k_3$	2.41	2.62	2.46	2.48	2.64	2.48
$i_3n_2k_1$	2.30	2.49	2.32	2.39	2.59	2.41
$i_3n_2k_2$	2.49	2.75	2.62	2.59	2.82	2.69
$i_3n_2k_3$	2.37	2.67	2.47	2.47	2.73	2.59
$i_3n_3k_1$	2.26	2.45	2.30	2.38	2.57	2.40
$i_3n_3k_2$	2.52	2.73	2.60	2.58	2.80	2.67
$i_3n_3k_3$	2.44	2.65	2.50	2.45	2.71	2.57
c_1	1.37	1.46	1.37	1.85	1.94	1.79
c_2	1.37	1.46	1.36	1.88	1.93	1.78
c_3	1.26	1.34	1.25	1.90	1.95	1.81
f_1	2.26	2.41	2.26	2.34	2.53	2.35

Appendix 17. Treatment means, Uptake of potassium by the plant (kg ha^{-1})

	Experiment 2			Experiment 3		
	30 DAS	60 DAS	FH	30 DAS	60 DAS	FH
$i_1n_1k_1$	4.93	20.98	32.67	9.00	43.46	67.64
$i_1n_1k_2$	5.60	31.04	49.47	9.61	49.38	79.14
$i_1n_1k_3$	6.04	28.32	55.45	10.73	54.98	86.99
$i_1n_2k_1$	6.86	26.79	41.92	8.85	43.65	68.45
$i_1n_2k_2$	9.54	50.43	92.95	14.71	79.55	127.24
$i_1n_2k_3$	9.39	41.25	94.16	14.36	81.85	129.20
$i_1n_3k_1$	5.12	26.35	41.07	9.16	45.24	70.59
$i_1n_3k_2$	8.09	41.86	78.09	1.98	70.68	112.98
$i_1n_3k_3$	7.00	35.46	65.91	11.51	63.31	100.30
$i_2n_1k_1$	4.98	29.98	42.90	9.02	44.41	69.65
$i_2n_1k_2$	7.58	45.63	72.68	12.30	37.50	107.52
$i_2n_1k_3$	6.01	35.90	50.32	10.08	52.79	83.17
$i_2n_2k_1$	6.45	38.77	61.10	10.51	56.39	88.83
$i_2n_2k_2$	10.89	74.68	119.92	16.33	96.79	155.51
$i_2n_2k_3$	7.60	60.56	70.50	11.74	67.90	108.22
$i_2n_3k_1$	5.24	29.53	44.80	8.88	45.65	71.06
$i_2n_3k_2$	9.29	56.25	75.78	14.22	82.97	132.71
$i_2n_3k_3$	7.48	42.58	65.74	12.02	67.12	106.24
$i_3n_1k_1$	4.48	24.41	38.14	8.01	38.82	60.70
$i_3n_1k_2$	6.21	33.02	52.96	10.31	54.89	88.19
$i_3n_1k_3$	5.73	31.29	44.85	10.06	49.62	78.12
$i_3n_2k_1$	5.78	33.98	53.02	9.72	51.01	79.65
$i_3n_2k_2$	9.13	62.87	88.57	14.13	80.75	129.10
$i_3n_2k_3$	7.24	45.90	68.78	11.66	65.15	103.50
$i_3n_3k_1$	5.98	28.16	45.37	8.82	44.37	69.33
$i_3n_3k_2$	8.20	47.08	77.84	12.38	71.16	113.93
$i_3n_3k_3$	6.40	41.29	57.03	10.34	55.40	87.84
c_1	0.71	2.40	3.32	2.06	6.87	9.04
c_2	1.58	4.74	5.48	2.67	7.66	8.71
c_3	0.74	2.469	3.08	2.03	7.98	8.93
f_1	4.07	19.28	29.79	8.10	38.69	60.01

RESPONSE OF CUCUMBER (*Cucumis melo* L.) TO DRIP IRRIGATION UNDER VARYING LEVELS OF NITROGEN AND POTASH

By

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ABSTRACT

Two field experiments and one observational trial were conducted in the Instructional Farm, College of Agriculture, Vellayani during 1992 and 1993 to study the effect of drip irrigation and application of N and K fertilizers on the growth and yield of cucumber.

In the preliminary observation trial (Experiment 1a) three levels of drip irrigation, (2, 3 and 4 l plant^{-1} day^{-1}) four timings of irrigation (1, 2, 3 and 4 hours) and two number of drippers per plant (1 and 2 dripper plant^{-1}) were evaluated and based on the results of this experiment, the number of drippers per plant and duration of drip irrigation was standardised.

Experiment 1b was conducted to standardise the method of application of fertilizers in Experiment 2 and 3 for which cucumber plants raised under different levels of drip irrigation (2, 3 and 4 l plant^{-1} day^{-1}). This was conducted during April 1992.

The results of these experiments indicated the duration for drip irrigation as 3 hours per day and one number of dripper per plant to be the best. The spread and depth of root system of cucumber plants raised under drip irrigation pointed out that the fertilizers as a ring around the base of the plant at a distance of 20 cm will be within the root zone of the plant.

The nitrogen, phosphorus and potassium uptake by the plants and fruits were highest at the drip irrigation level of 3l plant^{-1} day^{1}, 70 kg N ha^{-1} and 50 kg K ha^{-1}.

The physical optium levels of drip irrigation was 3l plant^{-1} day^{-1}, 93 kg N ha^{-1} and 65 kg K ha^{-1} in the first season. When another crop is repeatedly grown in the same field, the N and K levels can be reduced to 75 kg ha^{-1} and 60 kg ha^{-1} but drip irrigation is required at the rate of 3l plant^{-1} day^{-1}. This resulted in higher benefit cost ratio of 2.83 and internal rate of returns of 23%. The payback period of this project worked out to 1.13 years.