INSTITUTE of
HYDROLOGY

Final Report of ODA Project R4378A

SOIL AND PLANT WATER RELATIONS IN LOW-HEAD DRIP IRRIGATION IN SRI LANKA

by

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EXECUTIVE SUMMARY

Project R4378A, "Soil/Plant Relations in Low-Head Drip Irrigation" was undertaken by the Institute of Hydrology (IH) at Maha Illuppallama Agricultural Research Station, Sri Lanka from March to September 1988. The project was funded by ODA Engineering Department Research and Development funds, amounting to £51,855. It was carried out in close coordination with two other projects funded from the same source, namely:

a) Project R4367, "Low-Head Drip Irrigation Field Trials", undertaken by Wimpey Laboratories Ltd. (WLL).

b) Project 14HN, "Radial Collector Well Study Programme", undertaken by the British Geological Survey. (BGS)

The IH project described in this report was directed at gaining preliminary insight into the soil/water relations and crop response to a low-head drip irrigation system developed by WLL. The irrigation water source was a collector well provided by BGS. The crops studied were chilli, tomato, cowpea and onion.

The objectives were:-

1) To provide detailed information on the distribution and movement of soil moisture beneath the driplines to assist in assessing the potential for low-head drip irrigation and explaining the results obtained.

2) To evaluate the irrigation efficiency of the system.

3) To evaluate the crop response to drip irrigation.

4) To assist in the preparation of guidelines for the use of the system.

The main findings were :

1) In these trials, the drip irrigated crops were not grown on raised beds as it was considered unlikely that excessively wet soil conditions would be created by the drip system. This proved to be incorrect.

2) The low-head drip system produced considerable improvements over the furrow irrigated "control" crops in terms of water use efficiency.

3) Yields were lower under the drip system. This is attributed to the fact that although much less water was applied to the drip irrigated plots (calculated by the "FAO-modified" Penman equation, according to standard procedures), excessively wet conditions had been created in the root zone. This appeared to be due to the regime of daily applications and to the absence of ridge-and-furrowing in the drip irrigated system, contrasting with the much less frequent applications under the ridge-and-furrow system. The implication therefore is that application of less water under the drip system would probably improve both water use efficiency and yield, by creating better conditions for root development and reproductive growth.

The main recommendations that can be given following this research are:

1) A small-holder farmer using the low-head drip system will require instruction if the dangers of over-irrigation are to be avoided. To enable this instruction to be given for the wide range of conditions that this system could be used under, it would be necessary to carry out further research to study its management with differing soil types, cultivation systems and irrigation regimes.

2) Further drip irrigation trials should be carried out with reduced irrigation application and with the crops grown on raised beds. It seems likely that these modifications would lead to increased yields. The trial reported here was carried out during the Sri Lankan dry season. Wet season trials will be necessary before a full economic assessment of the low head drip system is possible.

3) A full socio-economic analysis of the use of this system, coupled with more extensive 'on-farm' trials should be carried out to assess the likelihood of its acceptance by smallholder farmers. As low-head drip systems would appear to have considerable potential for improving irrigation efficiencies, they should be considered as an alternative to traditional surface irrigation wherever water is limited or expensive. The scope of this short project was too limited to include any economic evaluation of the results. However, it is clear that a fuller appraisal of the system must include an economic component, taking account not only of the value of the produce but also that of the water, the land, capital costs, daily running costs and many other factors.

1. INTRODUCTION

1.1 Background

This document is the final report from Project R4378A, "Soil/Plant Relations in Low-Head Drip Irrigation", undertaken by the Institute of Hydrology (IH) from March to September 1988. This project was conducted in concert with two other projects also receiving ODA funding in Sri Lanka. These were:-

Project R4367, "Low-Head Drip Irrigation Field Trials", undertaken by Wimpey Laboratories Ltd. (WLL). In this project, the effectiveness and durability of a low-cost, low-pressure drip irrigation system (designed and developed by WLL) was being tested under field conditions in Sri Lanka.

Project 14HN, "Radial Collector Well Study Programme", undertaken by the British Geological Survey (BGS). This project involved the improvement of water yield and recovery rate of shallow, large diameter wells by horizontal drilling into the surrounding regolith at the base of the well.

1.2 Objectives of Project

Drip irrigation has the potential to produce increased yields from reduced irrigation water application, when compared with traditional irrigation techniques. However, the capital and running costs of a drip system have restricted its use by small-holder farmers. Wimpey Laboratories have developed a low-cost, low-head drip system (LHD) (Miller and Tillson,1989) which may be economically feasible for use by smallholder farmers in areas possessing shallow and limited groundwater resources which can be increased by collector wells of the type developed by BGS (Herbert et al., 1989).

During 1988 the Institute of Hydrology studied agronomical and plant/soil water relations in one such low head drip system in the Sri Lankan dry zone, with the following objectives:-

i) To provide detailed information on the distribution and movement of soil moisture beneath the driplines to assist in assessing the potential of low-head drip irrigation.

ii) To evaluate the irrigation efficiency of the WLL system.

iii) To evaluate the crop response to drip irrigation.

iv) To assist in the preparation of practical guidelines.

1.3 The Institute of Hydrology and Drip Irrigation

The Institute of Hydrology has been involved in drip irrigation research since 1982. The bulk of this research has been carried out in collaboration with the Mauritius Sugar Industry Research Institute (MSIRI), funded primarily by ODA (Technical Cooperation and Engineering Division R & D funds). Through this research IH has developed techniques for monitoring, interpreting and evaluating the complex soil moisture conditions created by drip irrigation systems and the crop response to these conditions.

The techniques developed in Mauritius have been very successful in increasing understanding of the processes involved in irrigation by drip systems, and have enabled useful guidelines to be drawn up to improve the design, operation and efficiency of drip irrigation systems.

It was felt that a complete field testing of the WLL low head drip irrigation system should include an investigation into soil and plant water relations created through its use: IH were therefore asked to collaborate with WLL in the evaluation of the system. The scope of the project was limited by the funding made available by ODA, which totalled £ 51,855.

1.4 Agricultural Production in Sri Lanka

Sri Lanka is rapidly approaching self-sufficiency in rice production (Panabokke, 1987). This is mostly due to the development of major irrigation schemes in the dry zone through the Mahaweli Development Programme. Under this programme, the allocation of land differs between areas, but in general a settler farmer receives around 1 hectare (2 acres) of poorly drained 'paddy land' and around 0.5 hectare (1 acre) of well drained 'highland'

Since the late 1960's efforts have been made by the Ministries of Agriculture and Irrigation to promote non-rice crops during the dry-season. Alternative crops that are being promoted through this extension programme are mostly those for which there is a market demand as the increased cost and labour requirement involved in their production means that farmers tend to grow those crops for which there is a reliable financial return. These crops include chilli, onion, tomato, coconut, citrus. Nutrition in Sri Lanka could be improved through increasing protein levels in the diet, from crops such as cowpea and soybean, but these crops are unpopular with farmers due to their low financial return.

The diversification of crop production aims to:

1. reduce the possibility of over-production of rice,
2. reduce the inefficient use of water used for rice production on well-drained land,
3. ensure the production of a crop in those years when rainfall is insufficient to ensure adequate availability of water for rice production,
4. reduce the quantity of food, other than rice, that is presently imported into the country.

Low head, low cost drip irrigation systems could fit in well with these aims.

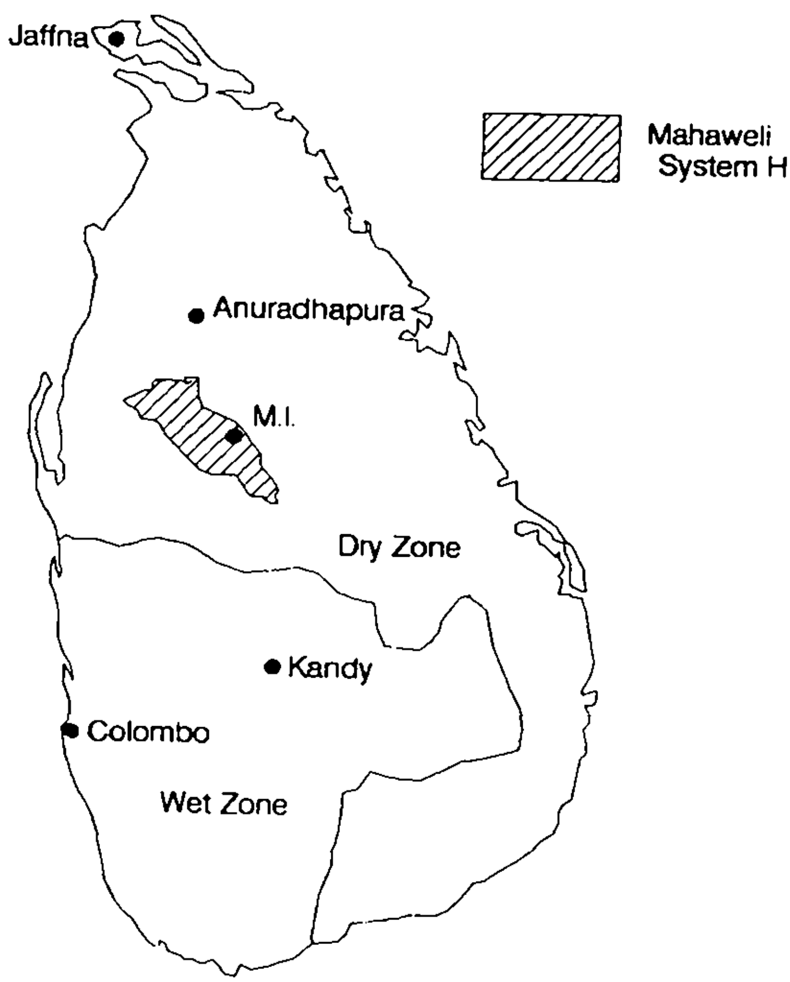
The Ministry of Agriculture in Sri Lanka is determined to achieve self-sufficiency in food production (Goonasekere, 1978). This will be achieved by increasing land productivity, and by increasing the area under cultivation. In the late 1970's, efforts were concentrated on increasing the area under cultivation, as it was felt that this offered a cheaper means of increasing output. However, the continued population expansion has created pressure on land availability, and although the cultivated area continues to be increased each year, more emphasis is being placed upon increasing land productivity.

Sri Lanka has three major climatic zones - the wet zone, the intermediate zone, and the dry zone. The wet and intermediate zones have little scope for expansion of the area available for crop production, due to the high proportion of the land in these two zones presently being cropped. The dry zone, however, offers much potential for increase in areas available for agriculture.

The Mahaweli Development Programme has increased dramatically the area under irrigated crop production (presently about 298,000 ha of land are irrigated under major schemes, and around 185,000 ha under minor schemes), (Dimantha, 1987). However, crop production is limited in many areas of the dry zone by insufficient water availability. The joint project aimed to demonstrate the possibility of increasing the amount of water available for irrigation in these areas by the use of collector wells and of increasing the potential productivity from this water, through low-head drip irrigation

The role of the Institute of Hydrology was to study the soil water conditions and plant response resulting from different treatments and thus to explain the results and be able to make recommendations accordingly.

Figure 1 Map of Sri Lanka showing Maha Illuppallama A.R.S.



2. MATERIALS AND METHODS

2.1 Site

The trial was located at Maha Illuppallama ("MI") Agricultural Research Station (8°07'N, 80°28'E, 137m above sea-level), which is the major Sri Lankan dry-zone research station, situated in Northern Central Province, around 30 km south-west of Anuradhapura. The geographical location of the site can be seen in Fig. 1.

Much research has taken place previously at MI on dry-season non-rice crops, and the irrigation water requirements of these crops. This ensured that well-informed agriculturalists were available on site to advise on local husbandry and cultivation techniques.

2.2 Soils

The soils of this region form a catenary sequence within the undulating landscape. The well drained and imperfectly drained Reddish Brown Earths (RBE) are found in the convex uplands and mid-slopes respectively. Poorly drained Low Humic Gley (LHG) soils occur in the concave valleys and bottom lands.

The site soil type was a Reddish Brown Earth (RBE) - consisting of a sandy clay loam surface soil (10 to 15 cm) underlain by a clay loam (40 to 90 cm). A characteristic gravel layer was situated at between 40 to 90 cm. or more below the surface. This generally acted as a boundary to root penetration. Infiltration rates for RBE are relatively low - around 1.3 mm/hr (Joshua, 1985). The soil hydraulic properties were investigated using tensiometer and neutron probe techniques, details of which are given in the results section of this report.

2.3 Climate

The climate of this region is characterised by a bimodal distribution pattern for the monthly rainfall, with two fairly distinct drier periods. The average annual rainfall is 1481 mm, of which nearly 70% occurs from October to mid-January, the maha season (NE. monsoon). The majority of the remaining rainfall occurs from mid-March to mid-May, the yala season (the SW. monsoon). However, rainfall often occurs during the two dry seasons, but in this area is of insufficient quantity and reliability to support rainfed agriculture. During the dry season irrigation is essential to permit cropping.

Pan evaporation varies from 3.5 mm/day to 7.5 mm/day. Comparison of the rainfall and evaporation figures shows excess rainfall during the months of October, November, and December, with an occasional excess in April or May. This can lead to surface waterlogging if fields are improperly prepared, with possible runoff and erosion if the intensity of rainfall exceeds the infiltration capacity of the soil.

The annual average temperature is 26 ^{o}. The minimum temperature varies between 20 ^{o} and 25 ^{o} over the year, while the maximum temperature varies between 27 ^{o} and 34 ^{o}. A daily temperature fluctuation of over 10 ^{o} occurs during the period mid-February to end of April.

2.4 The Low Head Drip Irrigation System.

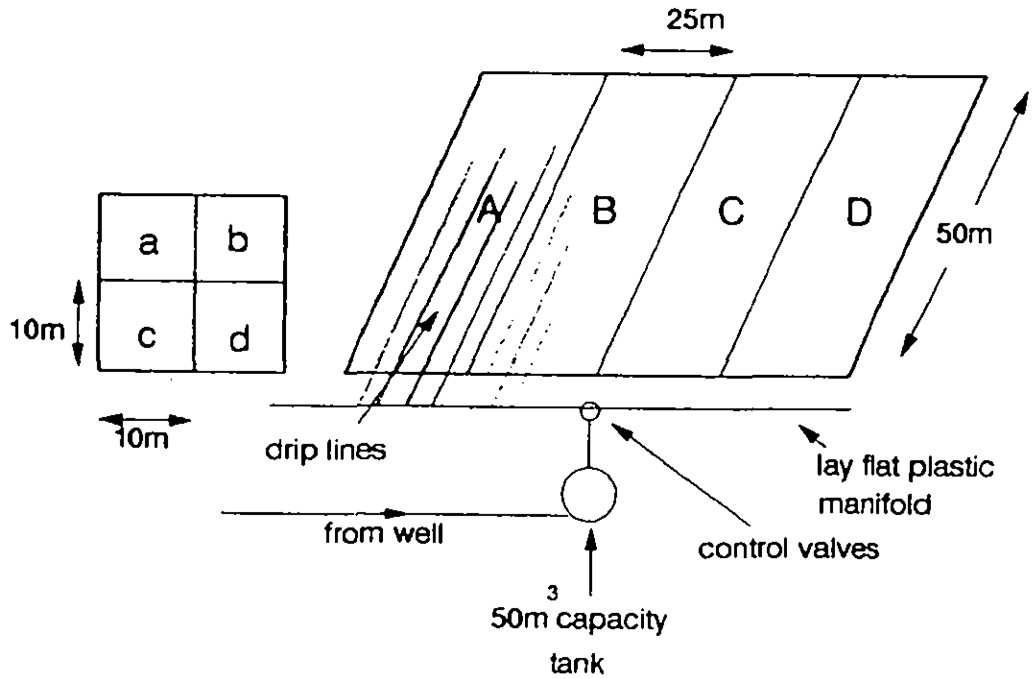
The drip irrigation system under test in this project was designed in an attempt to achieve a compromise between the advantages of conventional drip irrigation systems and affordable costs for a smallholder/farmer.

The low head drip irrigation system (LHD) is designed to operate under a sufficiently low head (water pressure) such that a pressure boosting pump is not required between the system water storage tank and the in-field driplines. The pressure necessary to cause water to flow through the system, and so be delivered to the crop at the emitter is achieved by ensuring that the water storage tank has a head, when full, relative to the dripline emitters, of around 1.5 to 2 metres. The exclusion of a pressure boosting pump from the system dramatically reduces the cost of the system, both in initial capital cost and subsequent running and maintenance costs.

LHD has the potential disadvantage that it is more sensitive to variations in ground level over the area to be cultivated, and more sensitive to 'within system' hydraulic losses than conventional, higher pressure, drip systems. These two factors could lead to unacceptable uniformity of irrigation application over the cultivated area.

The Wimpey LHD system has been designed with the aim of maintaining the system hydraulic losses to an acceptably low level (Miller, 1988). The system installed at the research site consisted of 5 major components:

Figure 2 Experimental block layout of the trial site



1. The water storage tank.

This was a circular corrugated galvanised-iron tank consisting of a number of sections bolted together on site. It had approximate dimensions of height 2 metres and diameter 5.6 metres, giving a total storage capacity of around 50 cubic metres (50,000 litres). The tank was lined with butyl rubber. A 4 inch. outlet was fitted into the liner, through the tank wall. This was located about 30 cm above the base of the tank, thus creating some dead storage volume within the tank, permitting settling out of suspended solids. The outlet was fitted with a 4 inch gate valve. A glass manometer tube was fitted externally to the side of the tank to indicate the water level, so that measurements could be taken of water application quantities to the crops.

Water was obtained from a large diameter BGS "collector well", situated close to the research site. Water was pumped to the storage tank by a petrol start/kerosene run 2 inch water pump and a 2 inch pvc pipe.

2. The filter

To prevent blocking of the dripline emitters filtration of the water is necessary in a drip irrigation system. In the LHD system water flowed from the tank into the outlet through an internally fitted in-line screen filter. The screen filter element was a woven plastic textile material of 100 microns mesh (0.1 mm). This was fitted around 110 mm pvc slotted pipe 1000 mm long. 4 lengths of the filter elements were strung together, and terminated with an end-cap. This arrangement gave an approximate filter screen area of 1 square metre.

3. The irrigation control gate valve block.

The experimental area to be cultivated was divided into four blocks to be drip irrigated, and one further block (control block) to be irrigated by ridge and furrow techniques (Fig. 2). To enable the water application to be controlled individually for each block, a valve system was constructed on the pvc outlet pipe from the tank. The single tank outlet branched into five 110 mm pvc delivery lines by means of T-pieces. 4 inch gate valves were situated on each of these delivery lines, which therefore allowed individual irrigation application to the crops.

4. The manifold.

The manifold acts as a means of distributing water to the driplines. From each of the five control valves runs a length of thin-wall, flexible layflat pipe, of nominal 4 inch diameter. This leads along the end of the block that it is to irrigate, and the driplines lead from it across the block. Large diameter layflat pipe was adopted by Wimpey to reduce internal frictional losses by having pipework of a large diameter, while keeping to an acceptably low cost. The manifold was laid in a shallow trench, so that the dripline connections on the top of it would be at ground level when it was in use. To allow the escape of air from the system once irrigation started, and to prevent air pockets from building up, the driplines were attached to the top of the manifold. They were attached by means of Tee'd outlets. These outlets were spaced along the manifold at 1 m intervals, but it was felt that this dripline spacing would not permit the best performance of the system. To reduce the effective spacing, the driplines were laid at an angle of 45 degrees to the manifold (instead of the usual 90 degrees). This produced an effective dripline spacing of 0.71 m (71 cm).

5. The driplines.

It is the purpose of the driplines (laterals) to conduct the water to the emitters, from which it is delivered to the crop. The LHD system uses commercially available dripline. It was at first intended to test a number of different driplines at the research site but following early clogging problems, it was decided to use only one dripline - Netafim Typhoon 20. This contains internal, long path emitters, with an emitter spacing of 0.4 m. The discharge rate from each emitter is dependent on the operating head of water in the storage tank.

Fuller details of the system are given by WLL (Miller, 1989).

2.5 The Agronomic Trials

The site of 0.5 ha had been uncultivated for six years. The previous crop had been rice, for which the site had been levelled. Before setting out the blocks for this project, the dense vegetation was cleared. The site was then fenced, and final minimal levelling carried out using a tractor-drawn leveller, which brought the land slope to a maximum of 2 %. The site was then ploughed and harrowed.

The trial site layout may be seen in Fig. 2. The design of the trial involved dividing the site into five main blocks. Four of these were irrigated using the LHD system (referred to as blocks A,B,C and D), each 50 x 25 m (0.125 ha). For each of the main blocks A,B,C and D, a control was allocated within block E. Block E was divided into 4 sub-blocks (a,b,c,and d), each 10 x 10 m (0.01 ha) Each sub-block received irrigation using conventional furrow techniques.

Table 1 shows the crop, variety and planting date for the crops grown on the site during the system evaluation. Each control was planted on the same date with the same crop as its corresponding main block. It was not possible to replicate the blocks within the trial as this would have involved making major modifications to the LHD system, which was designed to irrigate a single block of approximately 1.0 ha.

Table 1. Cropping details for the evaluation site, Maha Illuppallama.

Crop		Variety	Planting Date	Harvest period (Days after Planting)
A1	Chilli (Capsicum annuum)	MI2	May 4 (DS)	112 - 142
A2	Tomato (Lycopersicon esculentum)	T145	May 20 (T)	87
B	Vegetable Cowpea (Vigna unguiculata)	BS1,BS3 Local.	May 12 (T)	44 - 71
	Onion (Allium cepa)	Poona Red	April 23 (T)	81
D	Chilli (Capsicum annuum)	MI2	March 27 (T)	81 155

Note: DS=direct seeded, T=transplanted for planting method.

Regular plant measurements were made throughout the trial to evaluate the growth and development of the crop. The parameters measured for each crop were chosen to be indicative of the growth status of the crop.

1. Chilli.

Weekly measurements were made of plant height and canopy diameter on a sub-sample of sixty plants. Root growth and distribution were evaluated throughout the season by the trench-profile method (Bohm, 1979), which involves cutting a trench across the face of the roots, washing the trench face, and then counting the number and distribution of roots across the face. Fresh and dry yield of the crop were evaluated for the entire crop block, along with time to harvest, and length of harvest period.

2. Onion.

Weekly measurements were made of leaf height and number of leaves on 10 sub-sampled plots, and weight and number of bulbs was evaluated at harvest for the same sub-sample. Root distribution was evaluated by plant excavation, and subsequent dry-matter evaluation of the root system.

3. Cowpea.

Weekly plant samples of fifteen plants were taken to evaluate plant total dry matter content. Number and weight of pods was evaluated from ten sub-plots each 3 x 0.7m during harvest.

4. Tomato.

Weekly measurements were made of plant height and number of branches on a sub-sample of 25 plants. Yield was evaluated from number and weight of total yield of fruit.

Fertiliser and spray applications for all the blocks were carried out in accordance with Department of Agriculture Sri Lanka recommendations, as detailed in "Guidelines for Farmers" (Anon,1986). Cultivation techniques for the furrow irrigated blocks also followed these recommendations, but for the drip irrigated crop, no beds or ridges were raised in which to grow the crop. It was felt that this would be an unnecessary labour requirement, as the drip irrigation system could be managed to avoid excess irrigation application which would necessitate having beds or ridges to improve drainage from the root-zone. It was expected that any rainfall during the crop season would be of insufficient intensity to cause root-zone waterlogging through impaired drainage.

Row and plant spacings were:

A) Tomato. One row per dripline, 5 cm from the dripline. Plant spacing 70 cm.

B) Cowpea. Two rows per dripline, two plants per hill. Rows spaced 10 cm each side of the dripline. Plant spacing 20 cm.

C) Onion. Six rows per dripline, inner rows 5 cm from the dripline, row spacing 10 cm. Plant spacing 10 cm.

D) Chilli. Two rows per dripline, each row 5 cm. from the dripline. Plant spacing 45 cm.

2.6 Instrumentation

Tensiometer arrays were installed on the chilli and onion blocks (blocks C and D) to monitor soil moisture potential throughout the crop season. The tensiometers were read before and after irrigation, 3 days each week, to monitor daily and long term changes in soil moisture potential due to drainage, root extraction, crop-water use and evaporation. The data collected was analysed on a Zenith micro-computer, using programs and methods developed during the IH/MSIRI joint project (Bell, 1989). The construction and installation of the tensiometers is detailed in other publications (Batchelor and Bell, 1985). Each array comprised up to 35 tensiometers, installed in a number of profiles across the driplines. Each profile consisted of five tensiometers (installed at an angle of 14 degrees to vertical), with their cups set in a single vertical profile at five depths (10, 25, 45, 65, 100 cm in block D; 10, 20, 40, 60, 80 cm in block C and sub-block c). An additional number of tensiometers were installed vertically to depth 120 cm to monitor drainage from the root zone.

Tensiometers were not installed on the other blocks (blocks A and B) as funds did not allow the purchase of the necessary instrumentation.

A number of neutron probe access tubes were installed in close proximity to the tensiometer arrays to depth 180 cm. which enabled measurements to be made of soil water content (Bell, 1976). These were read before irrigation, 3 times each week. The calibration equation used for the neutron probe had been found for this soil type, in this location, by researchers from Kandy University (Bolton, 1988). The equation used was:

$$MVF = (0.643\ R/R_w) - 0.0069$$

Where MVF = Moisture volume fraction,
R = Probe count rate,
and Rw = probe water count rate.

2.7 Irrigation

The irrigation water requirement for the drip irrigated blocks was calculated using an estimate of potential evaporation (Penman, 1963), modified using the appropriate crop coefficient obtained from FAO recommendations (Doorenbos and Pruitt, 1977). The drip irrigation application was reduced to 60 % of the calculated requirement to allow for the reduced wetted soil surface area, and consequently reduced water evaporation from the bare soil surface. In normal circumstances, irrigation was applied daily.

The irrigation water requirement for the furrow irrigated sub-blocks was estimated from conventional local practice and MI advice. Generally, irrigation water was applied every five to six days, or sooner if the crop showed signs of water stress.

3. RESULTS AND DISCUSSION

In an interim report (Foster, 1988) a preliminary analysis of the results for the onion crop was presented. The analysis has been completed in this report, and is presented together with the final analysis for the other three crops grown in the trial. It should be noted that the analysis of results concentrates rather more heavily on the onion and chilli crops, as these were the blocks within which the tensiometer arrays were located. This enabled a more complete analysis of the relationship between soil-moisture regime and crop growth status and yield to be carried out for these crops. However, the analysis of results from the cowpea and tomato crops also produced some important information.

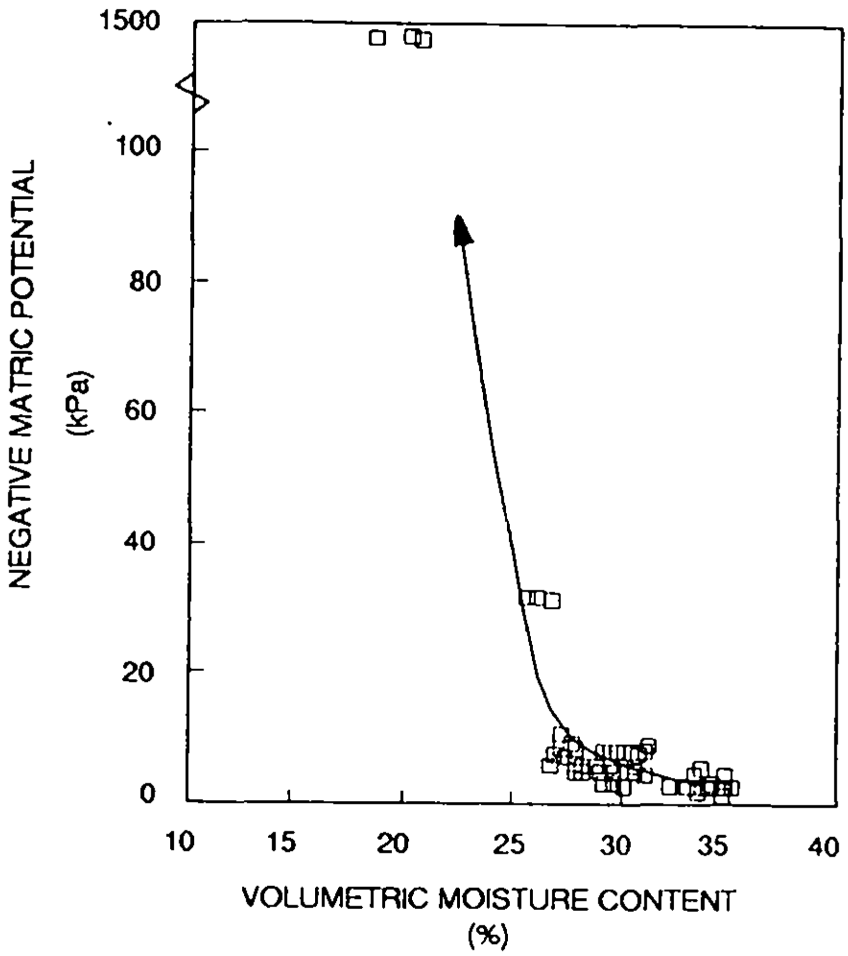
It should be noted that the term 'irrigation efficiency' is expressed in terms of mm/tonne yeild/ha. Thus, the smaller the value, the greater the efficiency and vice versa.

3.1 Trial Site Soil Hydraulic Properties

The relationship between matric potential and moisture content (the "moisture characteristic" or "water release curve") for the trial site soil was determined, and is shown in Fig. 3. A small plot of land, into which had been installed a tensiometer array and a neutron probe access tube, was flooded to saturate the profile. It was then allowed to drain and a sequence of simultaneous readings of the tensiometers and neutron probe were taken throughout a period of several days, until the drainage rate became negligible. Water content data were plotted against soil water potential to produce Fig. 3.

It can be seen that between potentials of 0 and -10 kPa, a large proportion of the water within the soil will be removed, i.e. in this range, there is a large specific capacity. If the reduction of hydraulic conductivity with removal of water is ignored, then a relatively large volume of soil water in this potential range is very readily available to the plant. Below -10 kPa, the specific capacity of the soil decreases markedly and this, coupled with the now much reduced hydraulic conductivity, means that water is less readily available to the plant. An arbitrary threshold of -20kPa had been adopted as the lower limit of significant availability. It can be seen from figure 3 that 50 % depletion of soil moisture occurs in the potential range of 0 20 kPa.

Figure 3 Moisture Release Curve
R.B.E. Maha Illuppallama



3.2 Transplanted Chilli Crop

Fig 4 shows the results of the weekly average plant height measurements for the drip (50 pairs of plants measured) and ridge and furrow (10 pairs of plants measured) irrigated transplanted chilli crop. Measurements were started 32 days after transplanting, to allow time for recovery from transplanting-stress. It can be seen that at 32 days after planting the height of the average drip irrigated chilli plant was 11% greater than the average of the furrow irrigated plants. There was a slight check to the drip chilli plant growth rate around 73 days after planting, but after 1 week they recovered and at the end of the season their height was, on average, 4.8 % greater than the furrow irrigated plants. A regression analysis of plant height (drip) on plant height (furrow) shows a significant difference between initial plant height (32 days after planting), but no significant difference between height growth rates for chilli grown under the two irrigation systems.

A regression analysis of canopy diameter (drip) on canopy diameter (furrow) shows no significant difference between initial canopy diameter or canopy growth rate for chilli grown under the two irrigation systems.

Table 2. Chilli root growth, yield and irrigation efficiency.

	Drip irrigated	Furrow irrigated
Root distribution (%)		
0-10 cm.	93	41
10-20 cm.	3	52
20-30 cm.	5	7
Average fresh yield (t/ha)	4.56	5.70
Average dry yield (t/ha)	1.14	1.48
Dry wt. as % of fresh wt.	25.00	25.96
Irrigation application (mm)	356.0	947.0
Irrigation efficiency (mm/t/ha)	78.1	166.1

Table 2 shows root distribution, fresh and dry yield and irrigation efficiency for the chilli crop. Root distribution as assessed by the trench-profile method 42 days after transplanting

Figure 4 Average Chilli plant height measurements for drip (▲) and furrow (□) irrigation

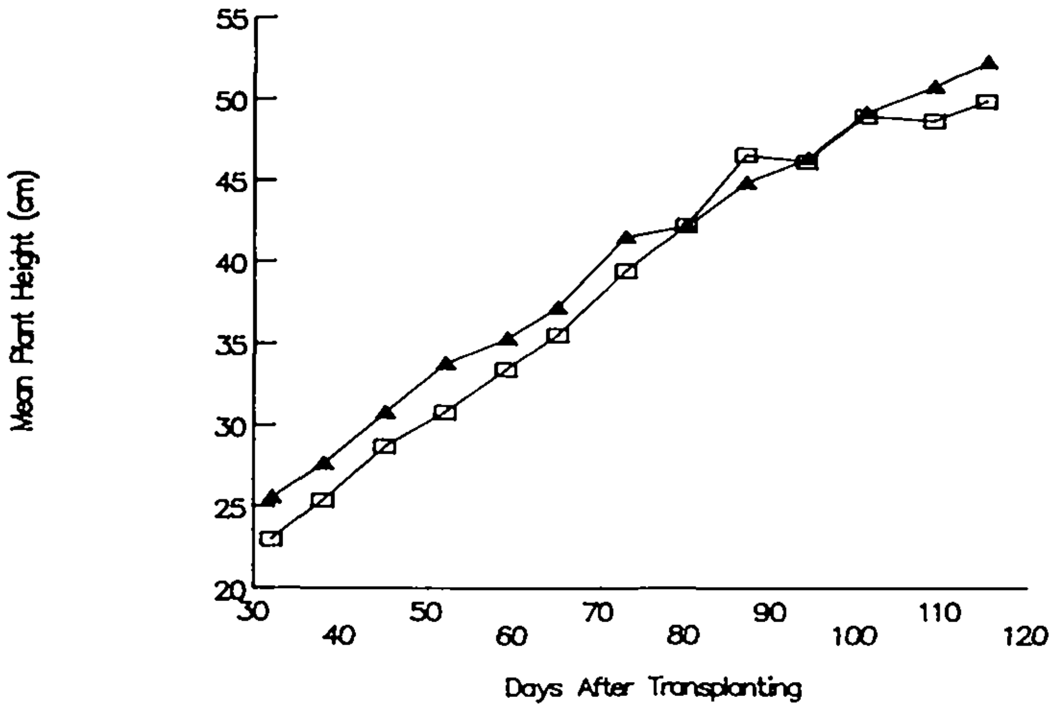
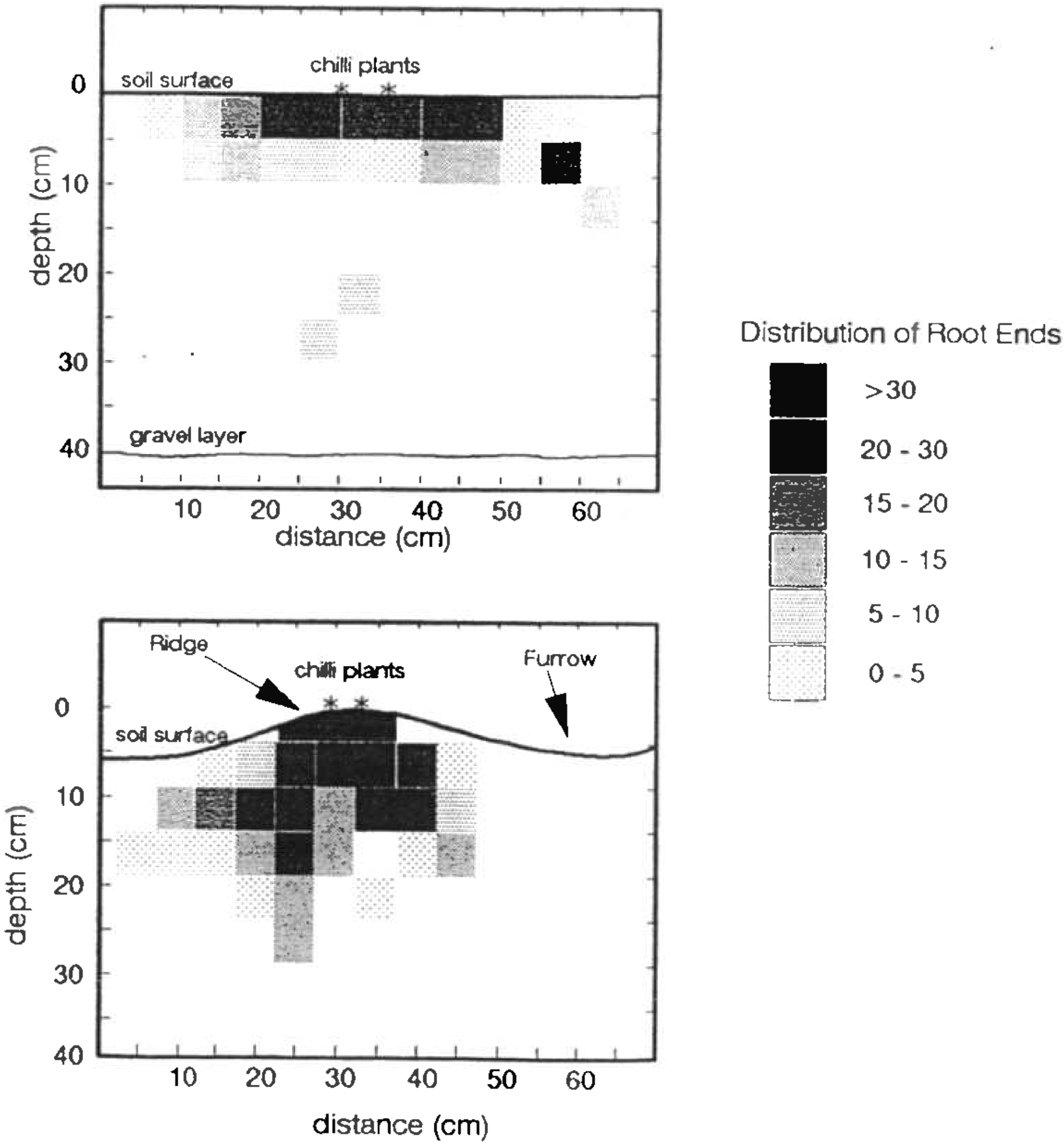


Figure 5 Root end distribution under drip and furrow irrigation



showed that root growth for the furrow-irrigated chilli plants was much deeper than that of the drip-irrigated plants. Fig. 5 clearly shows the shallower, lateral root growth of the drip irrigated crop which is almost certainly a result of over-irrigation. This shallow rooting can lead to a number of problems. Water application from the drip system may cause anaerobic conditions to exist in the root zone if the system is not managed extremely carefully. Any interruption in irrigation (caused perhaps by problems with the LHD system) will rapidly lead to plant water stress because the restricted root zone will be unable to utilise water that remains deeper in the soil profile.

The furrow irrigated crop roots were better developed than than those of the drip irrigated crop due to its 6 day irrigation interval causing occasional water stress to the plants, and thus stimulating root growth.

The root growth may also have been influenced by the improved cultivation of the ridge and furrow irrigated block. This had a final cultivation by manual hoeing which produced a fine, light tilth. Final cultivation on the drip block was by tractor-drawn harrow, which produced a tighter packed, more irregular tilth.

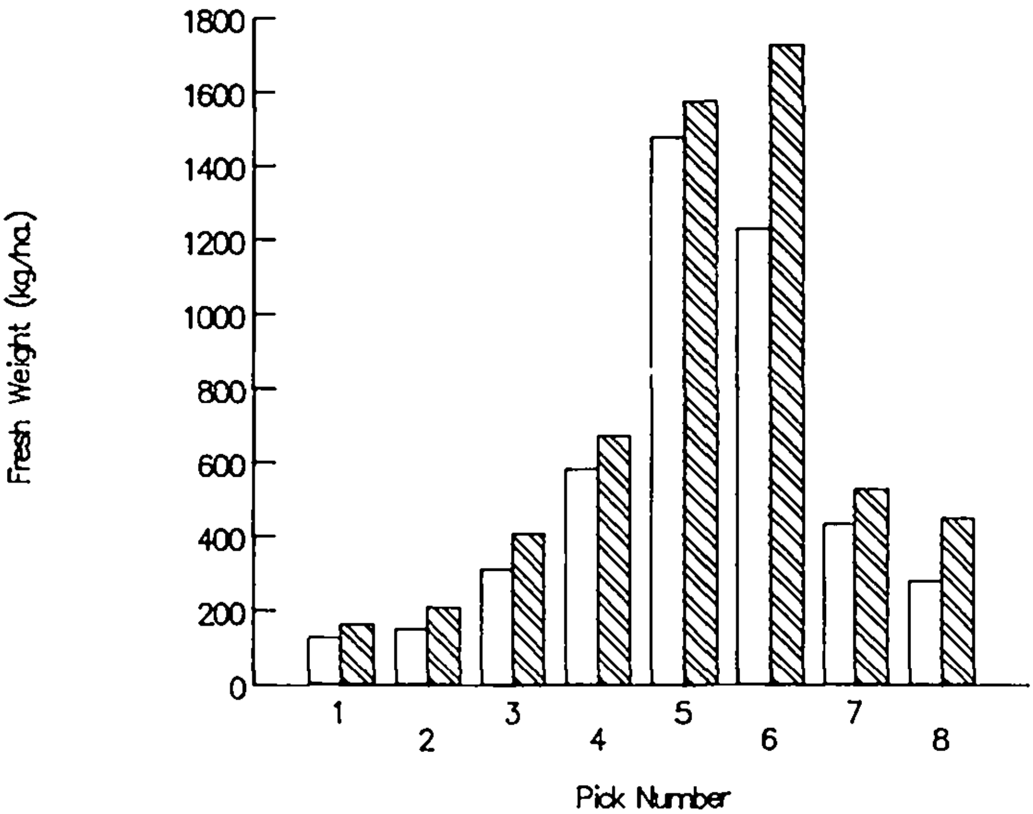
The scope of this project was too limited to follow up these problems, but clearly more work is needed in order to provide proper criteria for attaining optimum soil water distribution, and also to develop simple methods to allow the farmer to confirm that this is being achieved.

Harvest of the crop consisted of 8 pickings between 81 to 155 days after planting. The total yield at each pick was measured for the drip and furrow irrigated blocks. Fig 6 shows the yield of fresh chillies at each pick. It can be seen from the total yield figures given in Table 2 that the drip irrigated crop had a total fresh yield 20 % less than the furrow irrigated crop.

Irrigation water application to the crop, which can be seen from Table 2, was calculated by dividing the total irrigation application by the plot size for each treatment. Thus, the drip irrigated chillies received 62 % less irrigation application than the furrow irrigated crop. The yield response to irrigation (irrigation efficiency) was calculated by dividing the irrigation application by the total yield.

It can be seen from Table 2 that *the efficiency of irrigation of the drip irrigated crop was more than twice that of the furrow irrigated crop.* This is an important result, because a major

Figure 6 Yield data for drip (▯) and furrow (▨) irrigated chilli



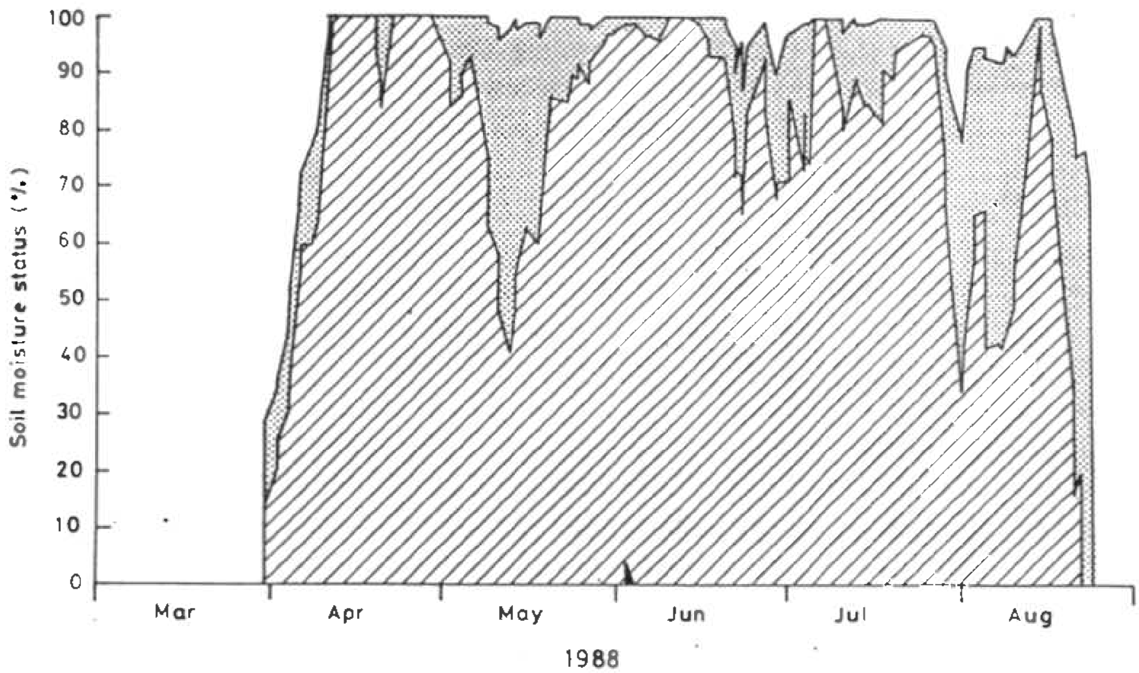
application for the LHD system will be to maximise irrigation efficiency in situations where water (or lack of water) is the limiting or constraining factor to crop growth.

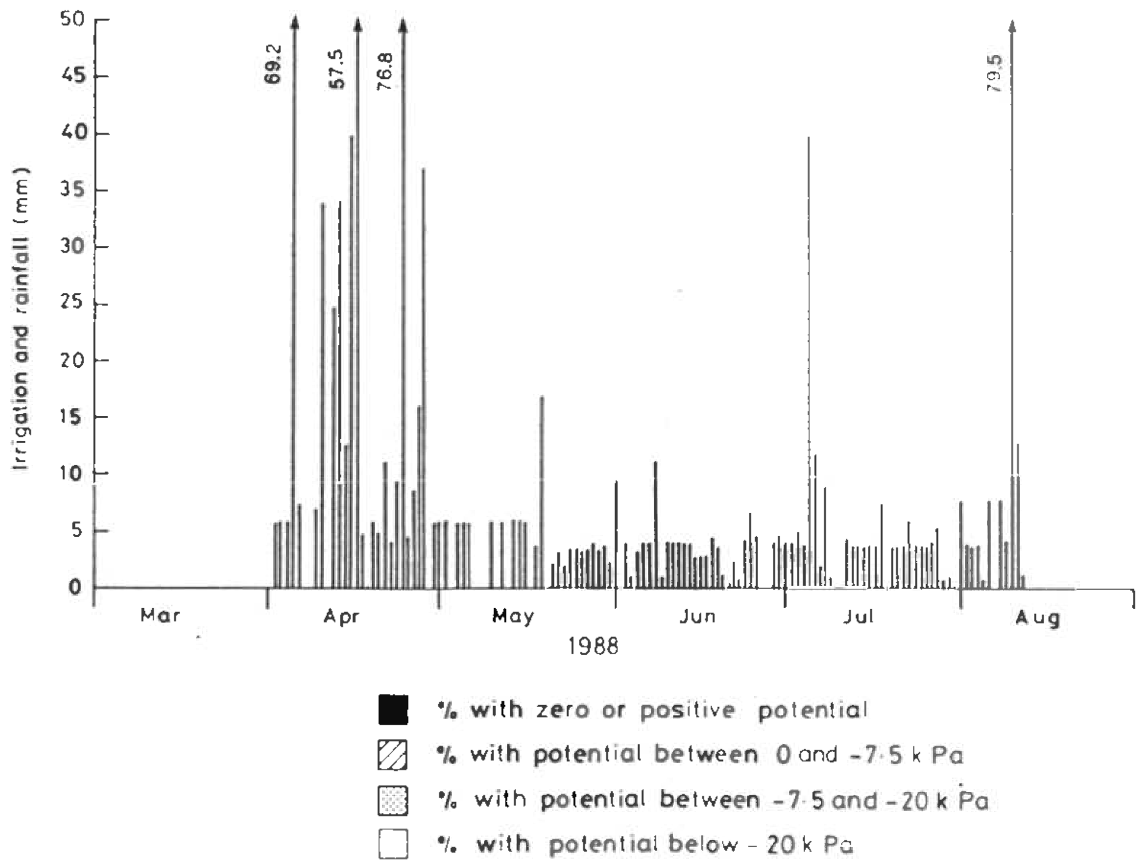
Soil moisture status was evaluated from data collected from the tensiometer arrays over the crop season. Using concepts and software developed during the joint IH/MSIRI project (Bell,1989), soil moisture status diagrams were constructed which show the percentage of the total soil volume, within the tensiometer profile, in which the matric potential is between given limits. These limits were selected by inspection of the water-release characteristic (Fig. 3) as being threshold values defining the quantity of water available to the crop. For this particular soil and crop type the soil matric potential limits were chosen as 0, -7.5 and -20 kPa. Above 0 kPa the soil is saturated; between 0 and -7.5 kPa the soil water is easily available to the crop; between -7.5 and -20 kPa the soil water is less readily available to the crop and below -20 kPa the soil water is relatively unavailable to the crop. Availability of water to the crop is also dependent on soil unsaturated hydraulic conductivity, which will reduce as water is abstracted. The threshold figures given above for ease of water availability assume a linear reduction in hydraulic conductivity with reducing water content. This is a grossly simplistic assumption, but insufficient time prevented a proper determination of hydraulic conductivity to be carried out.

It should be noted that between 0 and -7.5 kPa the specific capacity of the soil ("water availability") may suggest an over-estimate of the water actually useful to the plant because the near-saturated conditions at the upper end of this range can inhibit oxygen diffusion with an adverse effect on crop growth (Meek et al. 1983).

Fig 7 shows the soil moisture status diagram for the drip irrigated chilli crop, and the irrigation and rainfall over the crop season. It can be seen that although the matric potential within a large proportion of the soil volume was maintained at between 0 and -7.5 kPa, saturation occurred only briefly, and then to a negligible degree. It is also evident that only rarely did an appreciable volume of the soil profile attain matric potentials of less than -20 kPa. The soil moisture status was remarkably constant apart from during two periods. One in mid May, when the re-starting of irrigation was delayed after the heavy rains experienced in April, and the other in late July/early August, when problems were experienced with the drip irrigation system.

Figure 7 Soil moisture status diagram for drip irrigated chilli





Plant height and canopy diameter are generally indicative of eventual yield, and these suggested that there was unlikely to be a significant difference between yield from the two irrigation systems. On the contrary, however, the significantly lower yield from the drip irrigated crop suggests that the crop experienced excessive vegetative, rather than reproductive, growth. The response of chilli plant flower initiation and reproductive growth to environmental factors plant is complex but, in common with many other crops, a lack of crop stress at flower initiation may reduce the number of flowers formed (Milthorpe and Moorby, 1986). A high top/root ratio (the ratio of above-ground to below -ground plant dry-matter) may also reduce reproductive growth (Norman et al.,1984). The status diagram shows clearly the high degree of availability of water to the drip irrigated crop, and this is interpreted as having caused a reduction in root growth. It is likely that the high water content maintained within the root zone reduced oxygen diffusion at the air/soil and soil/root interfaces. This suggests the possibility that this high degree of water availability to the drip irrigated crop had the effect of reducing root and reproductive growth, with a consequent reduction in yield.

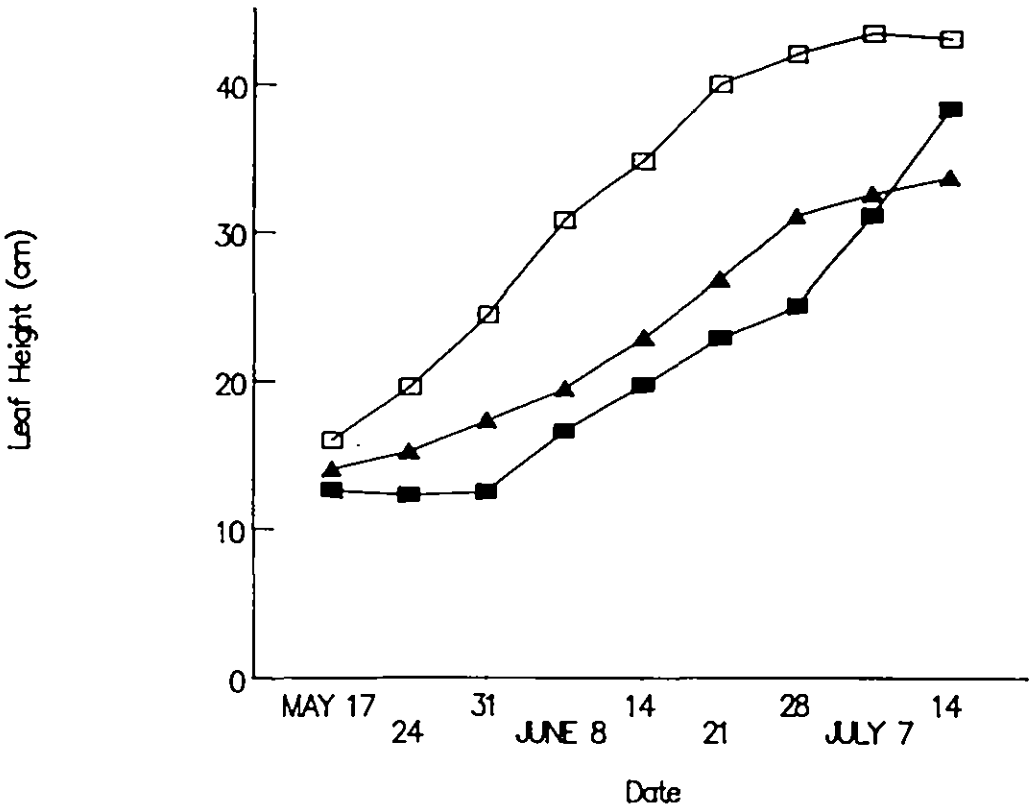
Irrigation water application to the furrow irrigated crop was substantially greater than that given to the drip irrigated crop, but this did not have the effect of increasing yield because the crop still experienced some degree of water-stress between irrigation applications.

Maha Illuppallama Research Station states target yields for irrigated chilli of 9 t/ha (dry weight) (Anon, 1986). The lower average yields obtained in this trial than these target figures are due largely to the unusually heavy and intense rainfall through the crop season. This caused a reduction in yield due to physical damage to the crop (generally, soon after transplanting) and also due to a high incidence of fungal diseases due to the soil splash onto the plants.

3.3 Direct-Seeded Chilli Crop

The results from the direct-seeded chilli crop (block A1) had only limited use in evaluating the performance of the LHD system. It had been planned to plant block A1 with cabbage transplants, but many of these were destroyed in the heavy rains experienced in late April. It was decided to replant half of block A with chilli - which was direct-seeded into the field. Unfortunately, the planting date was delayed, and so this crop had not reached

Figure 8 Leaf height from drip (▲) and two furrow irrigated beds (□,■)



harvest before the onset of the NE. monsoon. This caused a lot of harm to the crop by mechanical damage, water-logging and resulting fungal diseases. However, it does seem that direct-seeding is a practice that could be utilised with a well-managed LHD system which would remove the problem of transplanting stress to the plant seedlings. It must be stressed that the system must be well-managed, because the germinating plant growth rate will be greatly reduced if water-logging occurs in the soil.

3.4 Onion Crop

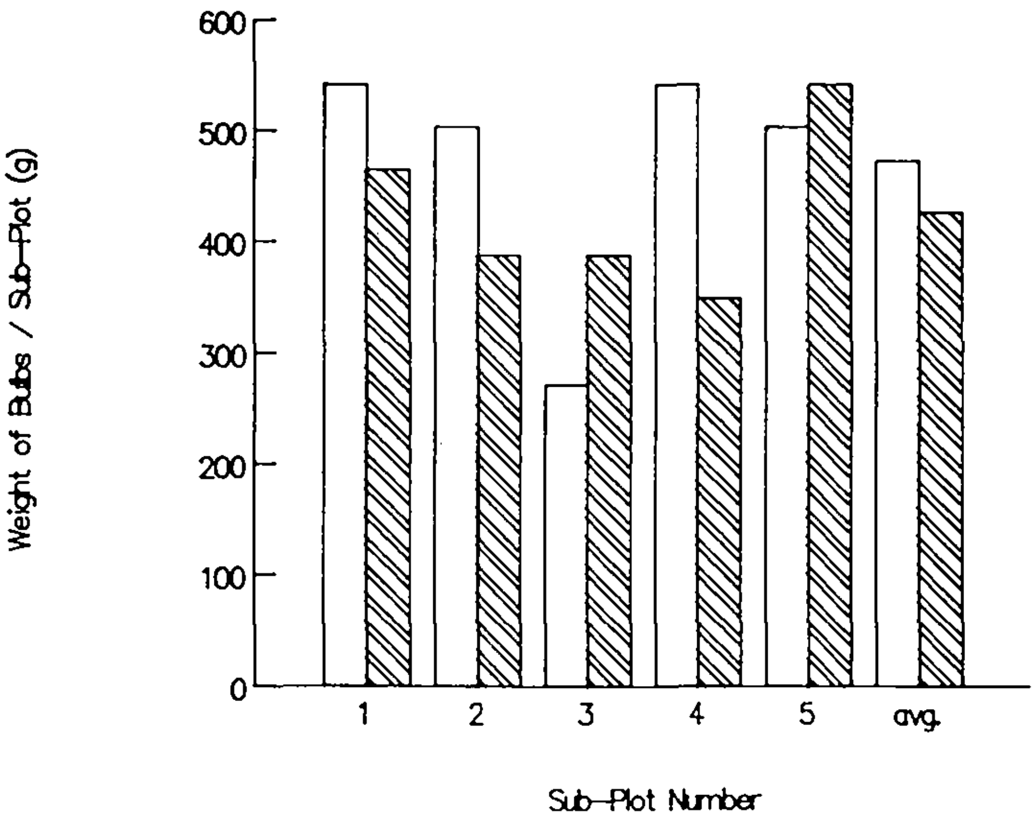
Fig 8 shows the weekly leaf height measurements for plants measured within two of the furrow irrigated beds, and the average of the plants measured within the drip irrigated block. As can be seen, there was considerable variation in leaf height between beds. Those illustrated were selected as showing the maximum range of growth rate between the beds. It can be seen that the average leaf growth rate for the drip irrigated block, over much of the crop season, lay between that of the maximum and minimum bed growth rate. However, a reduction in growth rate of the drip irrigated leaf height around the start of July caused the leaf height to fall below that of the minimum bed height.

Table 3. Onion root growth, yield and irrigation efficiency

	Drip irrig.	Furrow irrig.
Average root length (cm) (C.V.%)	9.6 (21.4)	13.2 (18.0)
Av. root fresh weight(g) (C.V.%)	0.56 (67.5)	1.3 (28.9)
Av.fresh bulb yield (t/ha) (C.V.%)	11.24 (15.7)	16.07 (36.8)
Irrigation application (mm)	223.0	507.0
Av.irrig. efficiency.(mm/t/ha)	19.8	31.6

The root distribution was evaluated by excavating a number of plants complete with root systems and weighing the root material. The results of an evaluation 69 days after transplanting can be seen from Table 3. This shows a much higher stage of development for the root structure of the furrow irrigated plants. There was also a lower variation in both root length and fresh weight between plants within the furrow irrigated block than within the drip irrigated block.

Figure 9 Bulb yield from inner (▧) and outermost (□) rows of drip irrigated onions



Bulb yield was evaluated from 5 sub-plots within the drip irrigated block, and from 5 of the beds within the furrow irrigated block. From Table 3 it can be seen that the average drip irrigated bulb yield was 30 % less than the average furrow irrigated yield, but that the variability of yield per plot was lower.

Fig. 10 shows the results of an evaluation of water movement from the dripline emitters by monitoring crop yield. The onions were planted in 3 rows on each side of each dripline, with between-the-row spacing of 10cm. Bulb weight was measured for a random sample of plants in rows closest to the dripline, and in rows furthest from it. Any difference in bulb weight between these two rows could have been due to poor water availability at the outer row. However, as can be seen from Fig. 9, there was no significant difference between bulb weight in the inner and outer rows. This suggests good lateral movement of water from the dripline emitters.

Lateral movement of water was also evaluated by plotting results from the tensiometer arrays in the form of cross-sectional representations (2-D diagrams) of soil moisture potential. Fig. 10 shows 2-D diagrams which represent the matric potential within the profile for three stages through the onion crop season. From diagram 1 within fig 10 (31 May) the profile matric potentials can be seen to be very uniform across the profile. However, this could be partly due to the very high potentials created by over-irrigation at this stage of the crop season. Diagram 2 (29 June) shows a reduction in average matric potentials, but the uniformity is still relatively good across the profile. Apart from a very small volume of soil midway between the driplines, the matric potential within the root-zone does not fall below -20 kPa. Diagram 3 (13 July) also shows this good uniformity across the profile, and a further reduction in average matric potentials.

The irrigation water applications to the crop during the crop season are given in Table 3. From this it can be seen that the drip irrigated onions received 56 % less irrigation application than the furrow irrigated crop. Table 3 also gives the average irrigation efficiency, from which it can be seen that the drip irrigated crop had an irrigation efficiency over 30 % greater than the furrow irrigated crop.

Fig 11 shows the soil moisture status diagram for the tensiometer array installed within the drip irrigated onion crop, and Fig 12 for two separate arrays installed within two of the beds in the furrow irrigated crop, and the irrigation and

Figure 10 2 D diagrams of matric potential across driplines

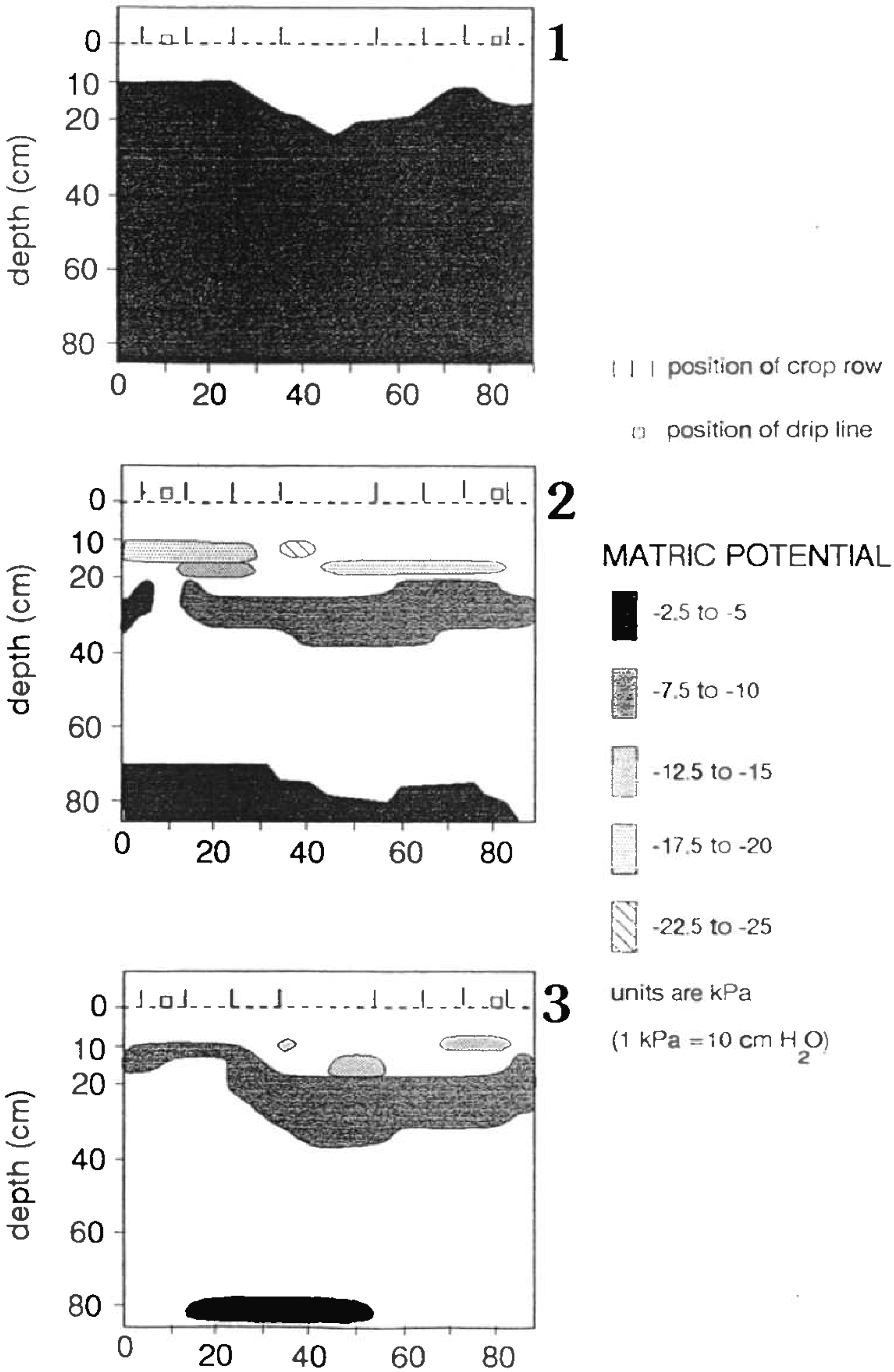


Figure 11 Soil moisture status diagram for drip irrigated onion

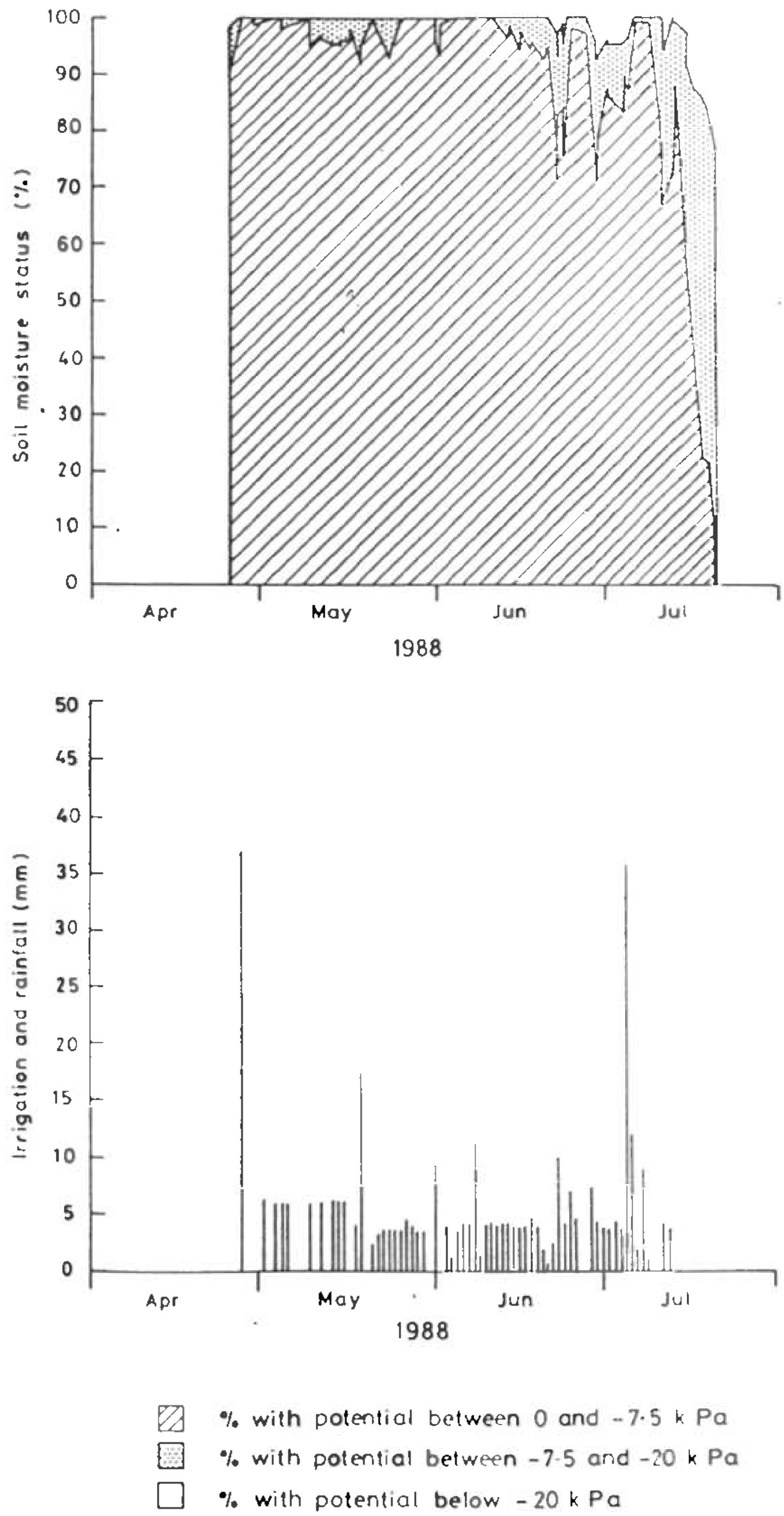
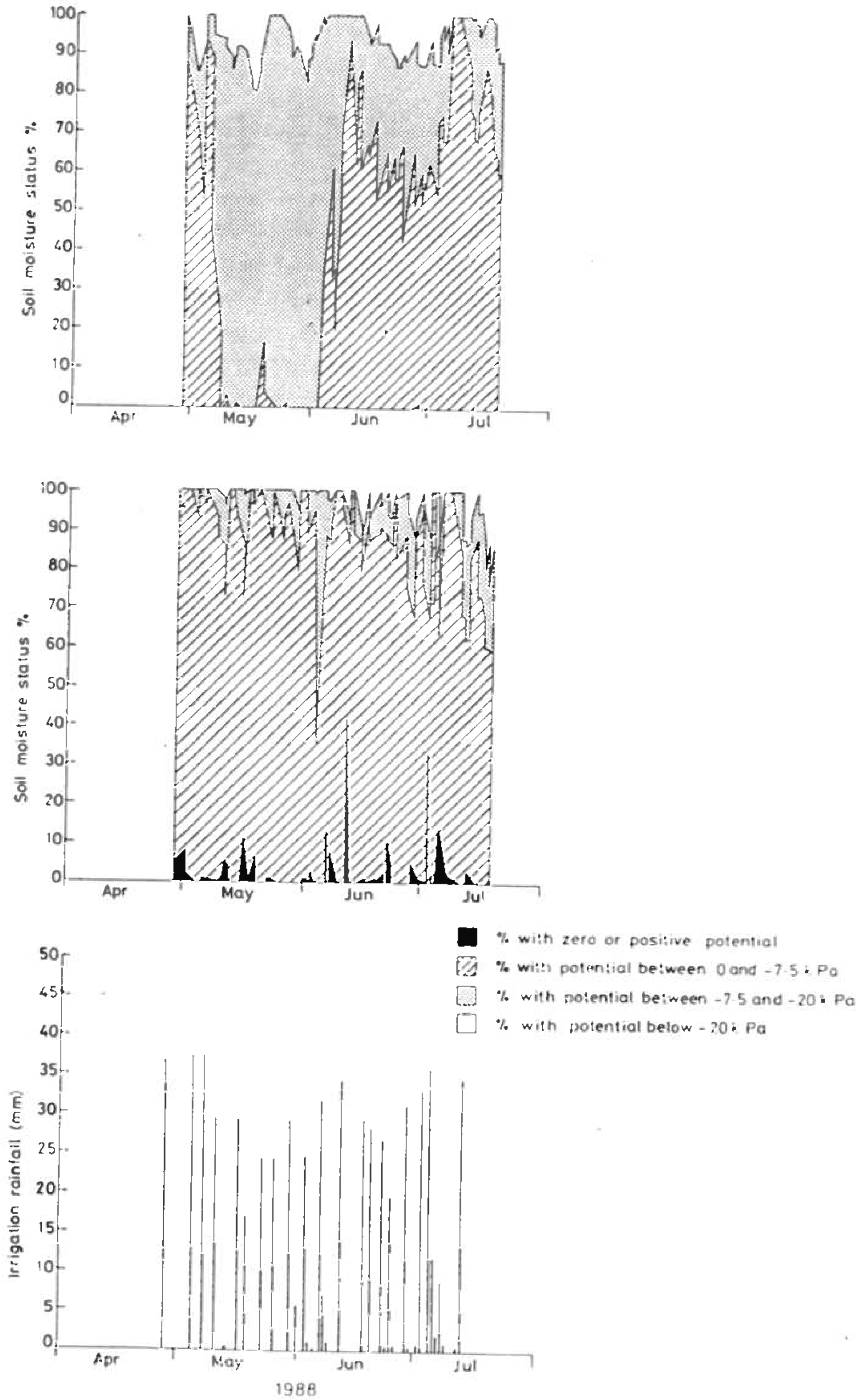


Figure 12 Soil moisture status diagrams for furrow irrigated onion



rainfall over the crop season. The matric potential values chosen for the status diagrams were the same as for the chilli crop.

Fig 11 shows that the matric potential within a large proportion of the soil profile was maintained at between 0 and -7.5 kPa, and that saturation never occurred throughout the crop season. Rarely did an appreciable volume of the soil profile have a matric potential of less than -20 kPa. The soil moisture potential was maintained at a relatively constant level, apart from late June/early July, when problems with the low-head drip irrigation system and heavy rainfall resulted in some fluctuation in soil matric potential.

Fig 12 shows the much greater fluctuations in matric potential in the profile experienced in the furrow irrigated beds over the crop season. Cycling of soil moisture status due to the 6 day irrigation interval is very apparent. The tensiometer arrays were installed in two beds, and the figure clearly shows the large difference in soil moisture status between them. One bed had a significant percentage of the soil volume saturated at times, and a potential of 0 to -7.5 kPa being maintained for möst of the soil throughout the season. The other bed however, showed little saturation, a soil moisture status of between -7.5 and -20 kPa for much of May, and up to 20 % of the profile experiencing a matric potential less than -20 kPa throughout the season.

The onion crop can be seen to be similar to the chilli crop in that the irrigation water application to the drip irrigated block was lower than that to the furrow irrigated block, but the average yield was also lower. The main limiting factor to yield of the drip irrigated crop was felt to be soil cultivation and preparation. The furrow irrigated crop was grown on 20 cm. high beds of 3 x 1 m, with irrigation furrows between them. In contrast, the drip irrigated crop was grown on the flat soil surface. The rainfall that was experienced in late April and mid-May caused localised water-logging, run-off and soil erosion to the drip irrigated crop, but the furrow irrigated crop was relatively unharmed due to the improved drainage of the beds. This is illustrated by the status diagrams for this crop, which show clearly the excessive soil wetness of the drip irrigated crop, as compared with the furrow irrigated crop. Also, the high variability in water status between furrow irrigated beds can be seen, which is confirmed by the high coefficient of variation for bulb yield from a number of furrow irrigated beds.

It is evident that drip irrigation application should have been reduced to improve root development and gas transfer with the aim of increasing eventual bulb yield. This aim would also have been furthered by raising beds for the drip irrigated crop to improve drainage and ensure better conditions for root development.

3.5 Vegetable Cowpea Crop

The growing period for this variety of cowpea is very short, as the pods are harvested green, and eaten as a vegetable. Figure 13 shows the results of the weekly determination of plant dry matter up to the beginning of harvest. The dry matter shown is for the total plant, excluding pods. The much greater dry matter for the drip irrigated plants can be clearly seen from this figure.

Table 4. Cowpea yield (fresh weight) and irrigation efficiency

	Total Yield (t/ha)	Irrigation Applic.(mm)	Irrigation Effic.(mm/t/ha)
Drip Irrigated			
BS1 var.	11.31		13.79
BS3	6.43		24.26
Local	9.58		16.28
Average	9.11	156.0	18.11
Furrow Irrigated			
BS1 var.	14.29		31.49
BS3	15.89		28.32
Local	19.64		22.91
Average	16.61	450.0	27.57

Table 4 shows a similar picture to the onion and chilli crops a much lower yield from the drip irrigated crop, but a higher water use efficiency. The situation that was observed in the chilli crop, that the drip irrigated plants favour vegetative growth, can again be seen with the cowpea crop. As no tensiometers were installed within this crop block, the effect of soil moisture potential on yield cannot be stated definitely for the cowpea crop. However, the effect is likely to be similar, that the continuous and excessively high soil moisture potential for the drip irrigated crop have caused poor soil aeration and impaired root growth.

Figure 13 Cowpea plant dry matter (excluding pods) for drip (▲) and furrow (□) irrigated plants

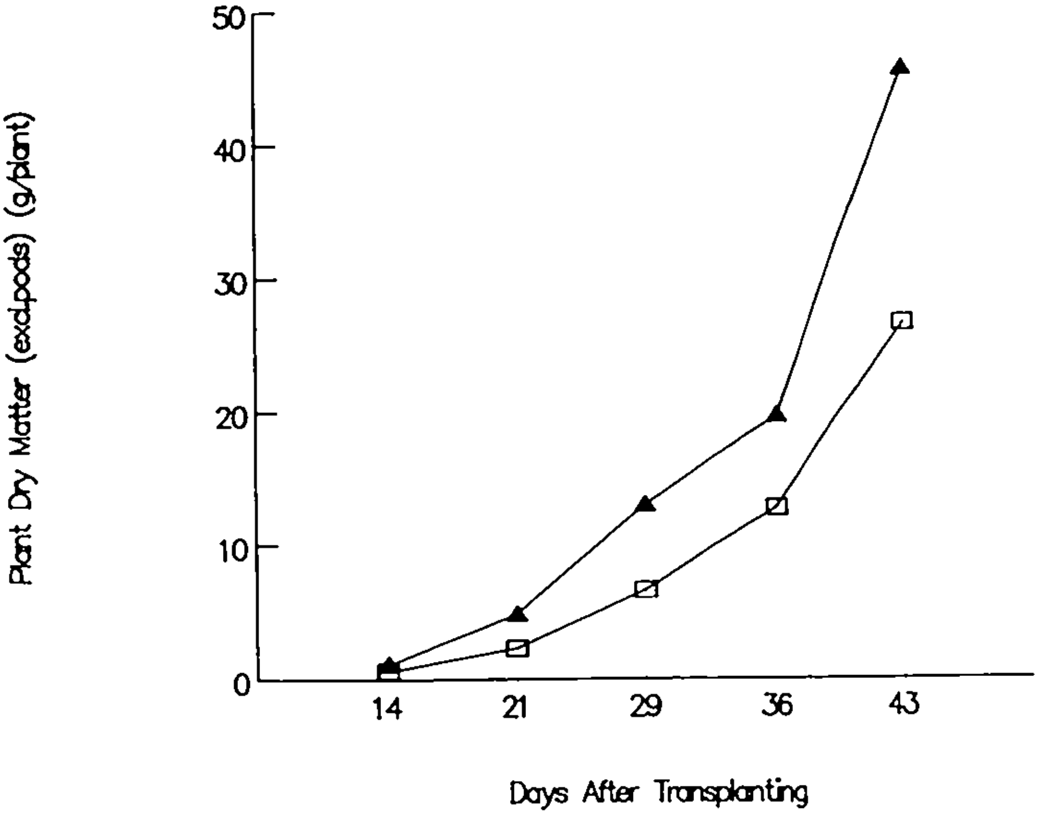
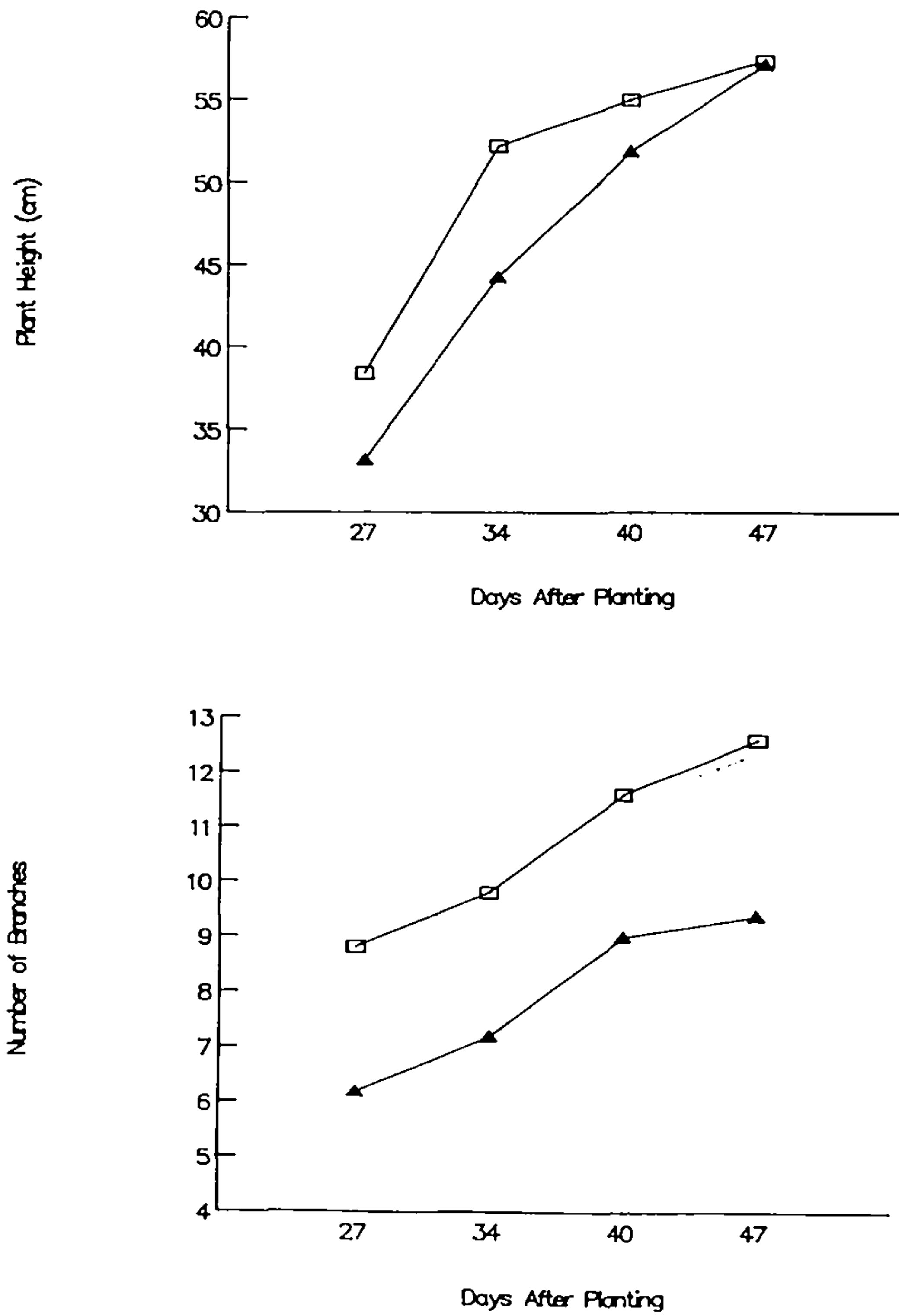


Figure 14 Plant height and number of branches for drip (▲) and furrow (□) irrigated tomatoes

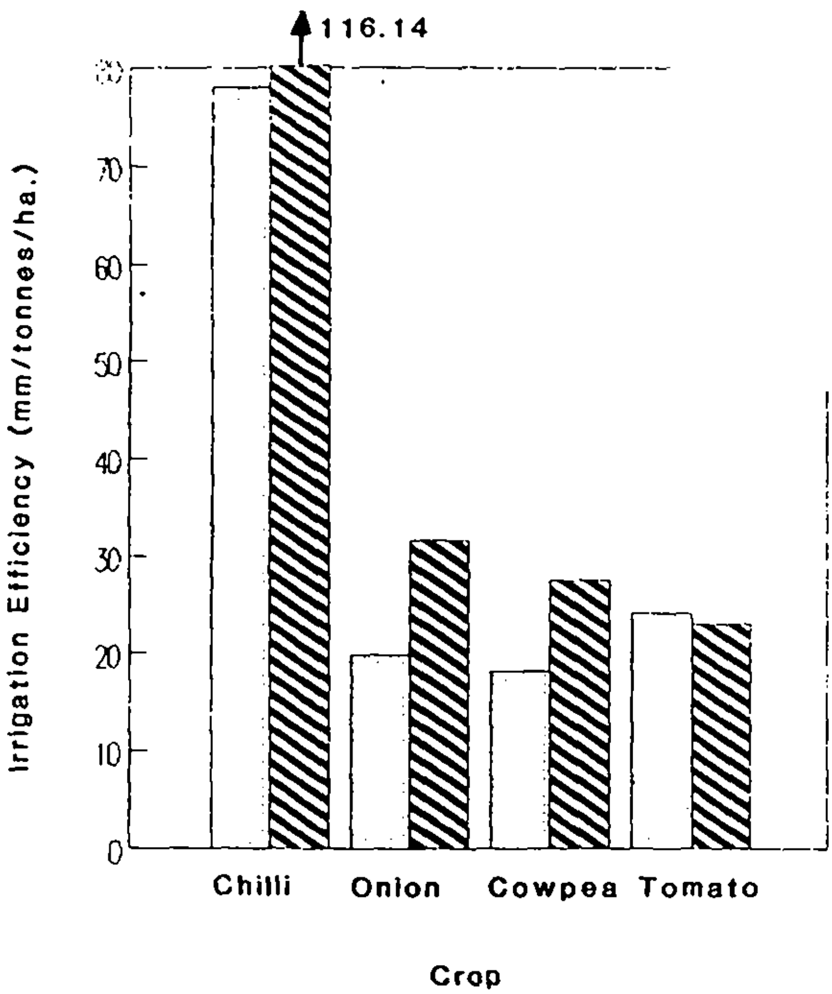


It has been shown that moderate moisture stress during the vegetative phase may act to stimulate the reproductive phase in some legumes (Richards and Wadleigh, 1952). During this project, pod setting was so poor for the drip irrigated cowpea crop, that on 14 June daily irrigation application was halved for 4 days to encourage this to occur. However, this action was taken too late to have a markedly beneficial effect on pod setting, and average number of pods, at harvest, was 42.7 % less for the drip, as compared with the furrow irrigated crop.

3.6 Tomato Crop

Fig. 14 a and b show the results from the weekly monitoring of tomato plant growth. These measurements were halted 47 days after planting as from then onwards counting the number of branches could not be carried out without risk of handling damage to the crop. This crop is unusual in that amongst all the crops grown in this trial, this was the only one for which plant growth was superior for the furrow irrigated block. It was also unusual in that there was no significant difference in irrigation efficiency between the drip and furrow irrigated crops (24.12 and 23.02 mm/tonnes/ha. respectively). Yields of fruit from the tomato crop were very low (drip - 11.1t/ha., furrow - 22.7t/ha.) due to a very high incidence of fungal diseases within the crop due, once again, to unusually high rainfall throughout the crop season.

Figure 15 Irrigation efficiency for a number of crops grown under drip (▯) and furrow (▨) irrigation



Note: Irrigation efficiency is expressed as millimeters of water per tonne yeild, per hectare. Thus, a low value indicates a high efficiency, and vice versa.

4. CONCLUSIONS

These trials showed that low head drip irrigation has the potential for improving considerably the irrigation efficiency of vegetable crops, as compared with those grown under conventional, flood irrigation systems. Fig. 15 shows the irrigation efficiencies evaluated during the trial. The irrigation efficiency for the transplanted chilli crop showed an exceptionally large improvement under the LHD system (an improvement of 53 % compared with the furrow irrigated crop).

However, it is very evident that correct management of the LHD irrigation system is essential to ensure that maximum yields are achieved while also maintaining these improvements in irrigation efficiency. Because under correct management the soil surface is mostly dry, there is very little visual evidènce that the crop is receiving the correct amount of water and many farmers are unable to resist the temptation to over-irrigate. The following areas are critical:-

i) Matching irrigation application to soil type. Care must be taken to avoid creating excessively wet conditions which may occur in poorly-drained soils if irrigation application is in excess of plant requirements. In on-farm use of the LHD system it may be difficult to prevent farmers from applying excess water. Should this occur, plant growth conditions might be improved by extending the irrigation interval to perhaps two or three days. Significant soil water deficits could then develop between applications and thus facilitate aeration, preventing continuous anaerobic conditions in the root zone.

In well-drained soils, excessively wet conditions are unlikely to persist, and accurate application of irrigation requirement is less critical. However, even in these circumstances, irrigation application in excess of plant requirement will reduce irrigation efficiency through loss of water to drainage, and fertiliser effectiveness through leaching.

ii) Matching irrigation application to individual crop water requirements. at different growth stages. The problem of excessively wet conditions was seen to be greater for some of the crops in the trial than for others. For example, pod setting in the drip irrigated cowpea crop was severely reduced, and it is felt that moderate moisture stress at this stage would have produced an improved yield.

iii) Matching irrigation application to weather conditions. It is essential that farmers respond quickly to weather changes, and modify irrigation applications as appropriate. When heavy rainfall is experienced, irrigation must be reduced or halted.

In this first trial of a drip irrigation system at Maha Illuppallama irrigation application for the drip system was calculated using the FAO modified Penman equation, and only 60 % of this amount was applied to allow for the reduced wetted soil surface area. However, it is evident from the trial results that this was still in excess of the true crop water requirements. It is felt that crop factors as given by Doorenbos and Pruitt (1977) require modification for use with high efficiency irrigation systems such as LHD.

It is vital not to neglect other aspects of crop management when using drip irrigation systems. In particular, a well prepared seedbed is essential to ensure that root development is not hindered. The results of the trials reported here suggest it would be better to grow drip irrigated crops on this soil type on raised beds so as to permit good drainage during intense rainfall, and to mitigate the effects of persistent excess irrigation.

Thus, to achieve the full potential value of drip irrigation, in terms both of increased water use efficiency and of increased yields, responsible management, coupled with a good knowledge of crop and soil characteristics, is essential.

5. RECOMMENDATIONS FOR FUTURE WORK

From the conclusions listed in the previous section several areas of this work can be identified that would greatly benefit from further research:-

i) A reduction in irrigation application for the crops grown under the LHD system has been discussed. It is likely that reduced irrigation application would increase yield and further improve irrigation efficiency. However, it is necessary to carry out further trials in order to determine the amount of reduction possible before crop growth is adversely affected. The improved water-use efficiency, possible through the use of LHD, is a crucial part of its attraction to the smallholder-farmer in areas of limited water availability, and so it is important to gain a better understanding of possible water savings.

ii) There is a need to develop a very simple and practical technique to provide the farmer with a day-to-day indication of soil water status, to reassure him that he is neither under- or over-irrigating, or to correct this situation should it occur.

iii) Further research is warranted to determine optimum seedbed conditions for crops grown under the low-head drip system.

iv) The need to stress certain crops during the vegetative phase in order to promote floral initiation requires further study. Irrigating with the LHD system every two or three days instead of daily may be of benefit in improving root development as well as reducing excessive vegetative growth.

v) A full economic analysis of the use of this system should be carried out as it is obvious that the adoption of low head drip by a smallholder will be influenced strongly by its financial attraction.

6. ACKNOWLEDGEMENTS

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