REPORT TO THE HORTICULTURAL DEVELOPMENT COUNCIL

FV 187

THE EVALUATION OF TRICKLE IRRIGATION SYSTEMS (CELERY)

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PRACTICAL SECTION FOR GROWERS

Growers Summary

Objectives and background

In the recent dry summers it has become increasingly difficult for growers to ensure crops have a sufficient supply of water to secure optimum growth and quality. There has therefore been considerable interest in developing systems and techniques which give the best return per unit of water applied.

Attention has concentrated on trickle irrigation systems which are in common use in the USA and Mediterranean countries, where they are used on both arable and horticultural crops. Trickle irrigation is widely perceived to be more efficient than overhead irrigation principally because water is applied at or beneath the soil surface thus reducing losses due to evaporation. Additionally, for widely spaced crops, water is placed close to the rows and there is the potential to save water from being needlessly applied to uncropped areas. It is also possible that the 'little and often' applications with trickle may provide a better growing environment for crops, although this is not by any means accepted universally and some horticulturists believe such an approach restricts root growth. It is undoubtedly true that trickle systems are capable of a high uniformity of application, better than the majority of overhead systems. This factor alone may result in improved yield and quality when compared with overhead systems.

The purpose of the experiment conducted at ADAS Gleadthorpe was to investigate whether these perceived advantages present real advantages to growers.

Alongside the field study two further investigations were conducted to determine the practical problems and advantages associated with trickle systems. A questionnaire was designed and circulated to growers known to be using trickle systems seeking information on the types of equipment used and the growers' views on their relative success. Follow up inquiries were made to provide greater detail. The installation and operation of a new trickle system at Mr P Barton's farm was also studied during the course of the summer.

Results, survey and site study.

Postal survey

Sixteen sites were reported in detail featuring the type of trickle irrigation used, number of years experience, cropping, problems, benefits and future plans.

Most growers reported that they had used T tape on non-sloping ground for potatoes, field vegeatables, lettuce and stick beans. There was general agreement that improved produce quality resulted with an overall ability to manage water and fertiliser to meet specific crop needs. Few reports were received on improved yield but the quality reports, taken as an improved quantity of marketable produce, may have led to improved financial returns as well as assisting supply contracts.

The adoption of trickle was not without its problems. These were essentially in laying out the pipe and in lifting it at harvest. The durability of the pipe was questioned by most growers. Where growers have developed their own equipment to lay and lift pipe and had taken care whilst handling, tape life in excess of three years was estimated, though various pipe qualities were reported.

The other main problems found were a) the high labour requirement for connecting up the pipes after laying and for disconnecting, cleaning and storing the pipe, b) the need to extend or shorten the pipe from season to season caused unreliability in the following season.

Only two growers felt that their capital outlay had not been recovered but both these were in their first year of use.

Despite all these issues virtually all growers reported that they would be expanding their area under trickle or remain static whilst further evaluating the technique.

Site study at Mr P Barton's

Courgettes and stick beans were grown with trickle irrigation (Ro-drip) in a 1.3 ha block at Trent Valley Growers, Derbyshire. All the crops were grown under black polythene plastic mulch.

Twin and single trickle pipes were compared on 1.83m beds with both crops grown on a 60cm square. All the trickle performed satisfactorily, but there were some leaks due to human error. The single pipe area did not mature until 14 days after the twin pipe system. The courgette crop was found to perform well but the experience with stick beans was disappointing showing a 15 % reduction in yield compared with the overhead irrigated area.

The pipe was estimated to have 3 further seasons life with water control, labour and uniformity all noted as benefits offered by trickle irrigation.

Results (experiment)

In a fully replicated field experiment trickle irrigation was compared with overhead boom irrigation to determine whether trickle systems require less water to achieve the same yield and quality of produce.

As stated earlier trickle irrigation systems are capable of highly uniform applications which in themselves may improve yield and quality when compared to normal overhead systems. However, in this experiment the overhead irrigation was applied by a specially adapted linear move irrigator capable of accurate applications so that any effect of application uniformity was largely eliminated.

The results at harvest suggest there were no differences in efficiency between trickle and overhead irrigation in terms of yield or quality. In other words a given unit of water applied through the trickle system gave the same yield increases and produce quality as the same amount applied through the overhead system. However, during the growing season the trickle irrigated plots appeared lighter green in colour. Analyses of the leaves suggested a difference in nitrogen levels indicating that trickle irrigated plants may have extracted less nitrogen from the soil. This effect was possibly caused by applied nitrogen remaining on the dry soil surface and not being 'washed in' as would have been the case where overhead irrigation was applied. Therefore growers who use trickle irrigation should consider whether they need to 'wash in' fertilisers should the weather remain dry for a long period after application.

Within the experiment itself the trickle tape system used (supplied by ISC Ltd) worked well. Installation went smoothly using ISC machinery to bury the tape at a depth of approximately 50 mm. No leaks or blockages were reported during the experiment and the very even growth in the trickle irrigated plots indicated a high degree of application uniformity.

<u>Action Points for Growers</u> - choice of trickle system and operation

- Crop type - Is the crop responsive to irrigation? - if not, return on investment is unlikely.
  - Market requirements - benefits are likely to be greater for high value produce.
- Water source - Is water quality appropriate to crop and market requirements? - if not can quality be improved prior to application or is an alternative supply possible?
- Soil type - The lighter the soil the closer the spacing of trickle emitters and tape. Emitter spacing @ 300 mm is common on light soils.
- Pipe spacing - Depends on soil type, distance between crop rows and emitter spacing. In some situations one pipe per row will be necessary.
- Row length - Most trickle pipes or tapes of lengths of up to approximately 250 m offer excellent application uniformity.
- Topography - If land slopes more than 3% then pressure compensated emitters will be required to maintain a high level of application uniformity.
- Pipe position - Surface laying is easy but vulnerable to wind and vermin damage.
  - Buried pipe requires special equipment to install and lift pipe but overcomes problems stated above.

- Pipe life - Affected by pipe wall thickness and the amount and care of handling. Thin walled pipe handled badly may have only one season's use.

- Pipe choice - Will depend on all the practical issues discussed above together with a detailed business appraisal for equipment investment.

- Labour demand - During use trickle demands a very low labour input. However during pipe laying and lifting labour input can be considerable.

- Scheduling - It is important to keep an accurate measure of soil moisture if efficiency savings are to be made.

- Establishment - Trickle irrigation can be used to establish transplants, but may result in a loss of final yield.

- Fertilisers - Consider applying fertilisers through the trickle system to ensure availability of nutrients to the crop.

- Records - Record and measure what you do so that you can assess performance at the end of the season.

Practical and financial benefits of the study

The work has identified that those growers using trickle systems believe produce quality to be superior to overhead irrigated crops. Whilst some suspect that trickle systems may also require less water this was difficult to substantiate from the survey returns. The most common practical problems associated with the use of trickle irrigation involved the handling of the tape or pipe. Any grower considering using trickle systems should consider this aspect carefully before proceeding.

Whilst the field experiment did not indicate efficiency saving in terms of water use with trickle, it did confirm that the technique works well and provides a high level of application uniformity. The field work has highlighted the need to consider the method of fertiliser applications so that nutrients are freely available to the crop. Applying nutrients through trickle systems should enhance nutrient availability.

REPORT OF SURVEY AND CASE STUDY

AUTHOR

W D BASFORD

HDC TRICKLE IRRIGATION STUDY 1996

Introduction

This report summarises the responses returned as part of the commercial evaluation section of the HDC R & D Contract FV 187. A questionnaire was devised and posted with SAE for return by growers from Lancashire to the South Coast known to have owned or operated a trickle irrigation system (Appendix 1). The despatch list included all growers known to ADAS or reported to ADAS by manufacturer's agents in the UK. A one month period was allowed for return of the forms. Following this study a follow up discussion was held with 44% of those growers who completed a questionnaire.

Note: There were several returns where sections were omitted and therefore some data are incomplete. Equally there were dual practices found which affected per cent totals.

The table below summarises the administrative position relating to the postal study.

Table 1. Administration

Number of Questionnaires despatched	57
Number of Questionnaires returned	19
% return	33
Number of Questionnaires blank or defaced	3
Final number reviewed	16
% useful return	28

Cropping

The majority of returns centred on experience with field vegetables. Table 2 details the crops involved.

Table 2. Cropping

Crops irrigated with trickle	Potatoes	Field Veg	Lettuce	Celery	Stick Beans	Other	Total
Area (ha)	21	93.5	28.5	31	31	2	207
% of total	10	46	14	15	15	1	

Experience

Table 3 shows growers experience with trickle.

Table 3

Total years reported experience of trickle	37
Mean years experience per respondent	2.3
Range of experience - years	1 to 5

Soil Types

Seven soil types were reported, often more than one per holding. The soil types reported are shown as a per cent of the total in table 4 below.

Table 4. Soil types (% of total reports)

Coarse sand	Medium sand	Fine sand	Sandy loam	Loamy sand	Heavier soils	Peat
8	13	8	29	8	21	13

Trickle irrigation equipment involved

T tape was used in the majority of cases. This was reflected in both holding numbers and area involved. This bias may result from the despatch listing, because many of the addresses were supplied by that manufacturer's agent. However some growers are known to have experience of different makes but reported on only one type. There could be other reasons for non return i.e. growers with successful systems concerned about a loss of commercial advantage as the result of disclosure.

Note: Streamline and RAM are both from one manufacturer.

Table 5. Equipment by manufacturer

Type of Drip equipment used	T Tape	Ro-drip	Streamline	RAM	Total
Holdings	11	3	1	1	16
% of total	69	19	6	6	100
Area covered by type (ha)	167	15	5	20	207
Area covered % of total reported	81	7	2	10	100

Row and trickle pipe spacings

The wide range of crop row widths reported below was biased by replies from stick beans growers in the sample. The majority of row widths lay between 216 and 915mm. Tables 6 and 7 below summarise the position. Table 7 clearly demonstrates close emitter spacing found, i.e. 92% at or below 300mm. The majority of growers used either one row of tape per row of crop; or one row of tape between two crop rows.

Table 6. Row / pipe details

	mm
Row widths used	216 - 1830
Tape spacing used	200 - 1830
Emitter spacing used	150 - 500

Table 7 Emitter / hole spacing

Emitter spacing % holdings reported	<300mm	300mm	500mm
	23	69	8

Pipe position

There is considerable discussion within the industry as to whether it is necessary to bury the trickle pipe in the soil or to lay it on the surface. The returns confirm that current practice is to bury the pipe, though there is variation in the actual depth preferred. Burial of pipe has several benefits, particularly anchorage, direct placement of water in the rooting zone and protection from vermin. Laying and retrieval of pipe is however more complex and likely to shorten pipe life through mechanical damage.

Table 8. Pipe position

% of holdings burying pipe	69
Depth range of buried pipe mm	25 to 100

Filtration

Most growers reported that filtration equipment was installed. Some reported both mechanical and sand type filter systems.

Table 9

% of holdings with filters installed	88

Trickle Irrigation performance

By far the majority (81%) of growers were making or had made commercial non-replicated comparisons between trickle irrigation and other irrigation systems. These ranged from comparisons of yield and quality of produce to more complete studies of water used, pipe life, labour input etc. Care should be taken when interpreting these observations as the validity of any comparison may have been affected by factors other than the irrigation method. Tables 10- 14 show the basic response:

Table 10. Growers comparisons - water use

% of holdings where comparisons with other irrigation systems were made	81
% of those holdings reporting less water applied with drip	85
Range of extra water applied compared to drip	25mm to 50%

Crop yield

Table 11. Yield Difference

% of holdings where yield difference was reported	63
% of holdings where no yield difference was reported	37

Table 12. Yield bias

Of above holdings reporting a yield difference

% of holdings reporting yield in favour of drip	46
% of holdings reporting yield in favour of overhead	0

Crop Quality

Table 13. Growers reporting quality difference

% holdings where quality difference was noted	63
% of those holdings reporting quality difference in favour of drip	75
% of those holdings reporting quality difference in favour of overhead	8

Fertiliser Use

Table 14 shows that only half the growers used specific fertiliser injection/diluter equipment. Many of the growers not using fertigation reported that they were in the early stages of adopting trickle irrigation. Of the growers reporting a yield increase 43% had fertiliser injection equipment feeding the trickle system. All of those growers reported an improvement in crop quality.

Table 14. Fertiliser equipment

% of holdings adding fertiliser through drip system	50

Trickle pipe laying - equipment used

Just over half the growers reported that they had laid the trickle pipe out at planting. Although in its early stages of adoption in the UK, simple equipment to assist in laying pipe is available or is easily home made, and 50 % of growers stated that they had made such equipment. In this survey 38% of respondents said they had problems laying out the pipe. This was reflected in the length of time taken to connect to the header pipes. A very wide range of installation time was reported. Further analysis showed that 2 growers with 4 and 5 years experience respectively suggested that 31 and 25 man hours per ha were required. One grower with only 1 year's experience also reported 30 man hours per ha. There was little relation between experience and installation time.

Table 15. Laying out trickle pipe.

Operation	
% holdings laying drip at planting	56
% holdings using specially developed equipment to lay drip	81
% holdings having developed the equipment in house	50
% holdings reporting problems at laying	38
Range of man hours/ha to lay drip	2.5 to 31
Mean man hours/ha reported	15

Hand v machine laying

A check on the data was made to see whether it required more time to lay out the pipe by hand. The range quoted was exactly the same as machine systems.

Scheduling of Irrigation

Most irrigation system managers agreed that knowing when to irrigate or scheduling the water application is one of the most difficult decisions. It is noteworthy that over half the respondents used a scheduling system. Tables 16-17 detail both formal systems and other "practical" measures in use.

Table 16. Scheduling adoption

% holdings using irrigation scheduling system for drip	56

Scheduling systems used	ADAS Irriguide	Other Computer	Neutron probes	Tensiometers
	1	3	3	0

Table 17. Other scheduling techniques

Inspection
When necessary
Auger/Inspection
Experience and Recommendation
Instinct ('Got feeling')
Spade
Experience

Water applied

Trickle irrigation offers the opportunity to apply small quantities of water as part of a 'little and often' approach. An analysis of the returns showed that 50% of growers used amounts below 6mm at each irrigation. In contrast 25 % of growers applied water at a rate greater than 10mm at a time. There was no relationship between soil type and irrigation amount, but 75% of those growers applying less than 6mm at a time were using either neutron probes or a computer based scheduling system.

Table 18. Amounts of water applied at each application.

Amounts of water applied per irrigation through trickle	<2mm	2 to 4	4 to 6	6 to 8	8 to 10	>10mm
% of holdings		31	19	13	19	25

Note: Some holdings reported dual policies

Variations in the overall amount of water applied was considerable, though 44% of growers did not return information on this aspect.

A quarter of all repondents reported having noted a problem with water flow.

Blockage of the fine emitters or labyrinths by algae is often seen as a problem in trickle irrigation systems. This was not found in this study. Table 19 summarises this detail.

Table 19. Total water usage

Range of water amount applied per season through drip	50 - 400mm
Problems	
% holdings reporting problems with water flow	25
Algaecide	
% holdings reported having never used algaecide	94

Trickle tape lifting

It is widely recognised that the lifting of trickle pipe can be linked to high levels of pipe damage and be time consuming. The majority of growers reported machine lifting, often with home developed machinery, but on the smaller holdings hand lifting of small plots (up to 12 ha) was practised. As with pipe laying there was a wide range of labour input reported though in the case of lifting there did seem to be some correlation between experience and time taken. Growers with 4 or more years experience averaged 6.2 man hours/ha to lift whilst growers with 1-2 years experience averaged 15.4 man hours per ha.

Table 20 Hand v Machine lifting

Lifting Tape	% by hand	by machine
	44	69

Note: 1 holding reported both systems

Range of reported labour requirement for lifting by hand (man hours/ha)	4.9 to 7.4

Pipe life

Growers were asked to predict the life of pipe they used, but variation in pipe gauge (sometimes not reported) and type, made it difficult to draw meaningful conclusions. However as a record of the influence on management inputs the forecasted life was as followed.

Table 21

Seasons left	scrap	one	two	longer
% return	22	26	26	26

Overall problems reported

By way of general comments growers were invited to highlight difficult issues with trickle irrigation. The simple statements recorded below centred only around the handling of the pipe. There is a clear difficulty when aiming for re-use that the pipe is difficult to lift and reel up. This is particularly linked to tension on the pipe, soil, weed and haulm adhesion and the harvesting/lifting operation. Most respondents felt that there was considerable scope for developing large internal diameter reels or bobbins onto which the pipe could be wound thus avoiding pipe stressing, kinking and damage. Re-use of joined tape was also seen as difficult and often unreliable. One plea was made for an in field plastic welding kit to solve joining problems.

Table 22. Problems

Problems reported	Spools, connectors, tension
	Hand release sometimes
	Roots, soils, joiners
	Weed growth around pipe
	Lifted on harvester, slowed by 30%
	Pipe stretch, haulm and tuber lift
	Dirty job
	Weak reels, tension, vines
	Needs considerable care, pipe kinks easily
	Keeping crop clean, time taken
	Takes time

Follow up Discussions

Forty four per cent of respondents were contacted further to discuss trickle irrigation adoption (Appendix 2). **Note** all references now refer to 7 of the original 16 respondents. Care should be taken in interpreting these observations both due to the reduced sample size and the possibility that comparisons may have been affected by factors other than the irrigation method.

Crop yield and Quality

Five of the seven growers reported no increase in yield. Where an increase was noted this was in the range 2 - 30%. The largest increase reported did not have integral fertiliser equipment in the trickle system. A similar proportion reported significant increases in quality. This was reported as cleaner crops i.e. with little soil splash and more Class 1 produce. Some of these statements were made in comparison to current boom irrigators rather than raingun types so the quality change can be viewed as already from a high standard.

Other benefits from trickle irrigation use

Five of the seven growers reported that critical control of water and fertiliser contributed to high standards of management required to meet market requirements. On one holding all the trickle was used under a crop fleece enabling early/late cropping to be maintained by good control of soil moisture. Most growers identified improved control and uniformity as major benefits, particularly if water is scarse and the crop is of high value. This was emphasised by those growers using irrigation to control common scab on potatoes and carrots.

Less water usage was reported by growers but verification was not possible. During these follow up discussions reductions of up to 40% compared with overhead were suggested, though it should be noted that only 56% of the original respondents commented on the volumes applied.

Better uniformity of water application compared to both boom and hosereel application was reported, as well as a reduction in both weed and disease levels.

Problems with Trickle pipe use

All the growers involved in the further detailed discussion cited the biggest problem as lifting the pipe, the associated development of equipment to do this, the labour involved and the need for precise careful handling of the pipe to ensure use for future seasons. One grower reported difficulty with pipes knotting on reeling up/laying.

Ease of re-laying of pipe was considered to be directly linked to the ability to reel and tension the pipe correctly on storage spools. Considerable development was seen as necessary to develop pipe re-use.

Pipe length changes from year to year requiring new pipe joints also created problems as pipes often separated or leaked next season.

No experience with sloping ground was reported. Pipe run lengths ranged from 100-285m.

Economics/Future plans

All growers were asked whether they thought their costs had been recovered. Five of the seven growers stated emphatically that they had. The other two felt that this was not the case but both were in their first year of experience with the system. Both of these growers stated that they would be monitoring experience for a further season. All others stated that they would be expanding the area under trickle, one by a four fold increase though the area involved was small.

The absence of the need for an abstraction licence had influenced some growers in their plans to adopt trickle, but others were primarily influenced by potential improvements in efficiency of water use.

Conclusions

The majority of growers were satisfied that trickle irrigation provided a well developed controlled method of applying water. It was acknowledged as a major contributor to improved produce quality across a wide range of crops. It was seen as expensive to install relying on extended pipe life to reduce seasonal overhead costs. Laying and lifting of the pipe was both labour intensive and practically difficult. These latter points dominated managerial thinking on trickle irrigation and demanded high levels of staff time at busy periods. There was no doubt that if these aspects could be significantly improved the adoption of trickle would become more widespread.

TRICKLE IRRIGATION SITE STUDY 1996

Site

Trent Valley Growers Ltd, Bridge Farm, Sinfin Lane, Barrow on Trent, Derbys.
Mr Peter Barton

Detail

A level 1.3 ha site immediately east of the company office and pack house on an Arrow series soil (permeable sandy loam) was planted with courgettes and stick beans and irrigated using trickle irrigation in 1996. Both crops were planted through a black polythene cover/mulch.

All planting was in beds, based on a 1.83 m track width with a bed top dimension of 1.52 m. The mulch was let into the ground so that effectively all the soil was covered except the bed shoulder.

Crop Programme

25/4/96	All ground was prepared after ploughing with a power harrow and beds marked out. Fertilizer applied as surface dressing Nitrogen (N) 150 kg/ha Phosphorous (P_2O_5) 75 kg/ha Potash (K_2O) 225 kg/ha
27/4/96	Site laid out with Ro-drip trickle irrigation tape (Heavy duty 300mm spacing; 290l/hr/100m), 2 pipes per bed at 60 cm spacing all beds covered with black polythene. All trickle filtered by mechanical screen mesh filters and controlled with mechanical flow monitoring cutoff.
2/5/96	Beans planted on a 60cm x 60cm square at average 2 plants/stake
3/5/96	Beans hooped and clear polythene covered Irrigation by overhead sprinklers on bean ground - 15mm applied

18/5/96	Courgettes planted on 60cm x 60cm square
19/5/96	Irrigation by overhead sprinkles to courgette ground - 15mm applied
20/5/96	4 beds of Courgettes had 1 trickle pipe removed and the remaining pipe moved to a central position to test potential of wetting profile
22/5/96 -	Irrigation through trickle system
21/9/96	Plot 1. Courgettes. 1 pipe per bed. 30 applications of 3mm to give 90mm total
	Plot 2. Courgettes. 2 pipes per bed. 30 applications of 6mm to give 180mm total
	Rainfall over this period 92mm
26/6/96	Courgettes, harvesting started
27/7/96	Beans, harvesting started

Note: The irrigation of both crops immediately after planting was considered worthwhile as the seedbed under the plastic was considered fairly coarse. The water applied stood in the wheeltracks for a short time in places but was considered to have assisted the beds in maintaining moisture during the early part of a dry cold season.

Yield

Courgettes	28190kg	ie 30272 kg/ha
Beans	7280kg	22477kg/ha

Trent Valley Growers average yield of beans with overhead irrigation 26577kg/ha ie a 15% reduction.

Note: The beds having only one pipe per bed were considered to lag 2 weeks behind on harvest date. Two weeks after harvesting commenced this crop caught up with the rest of the site. On 6th September a section of the black polythene was lifted on the single pipe courgettes and the wetted zone was observed to only just meet the plants in either row. It was felt that under the 1996 conditions the extreme temperatures within the stick bean crop had led to an unsatisfactory pod set. The use of trickle did not provide aerial cooling and damping possibly, and this may have exacerbated the effect.

Discussion

Trickle Pipe - Installation

No problems were reported in laying out the trickle pipe or with its connection, though the time taken was longer than expected. Whilst this site was small with short run lengths it is suggested from this experience that laying the header mains and connecting up / closing ends would take about 3.7 man hours/ha.

Trickle irrigation -Operation

As the site was supplied from 2 points this involved approx. 10 min per irrigation to "start" the system. The automatic flow monitoring valves controlled shut off. Monitoring of irrigation was done on a routine basis. From this site for a whole season a figure of 3.5 man hours/ha may be relevant to the operational control of trickle irrigation.

Trickle Pipe - Removal

As this site had relatively short runs of pipe (130m) no problems with pipe retrieval were noted. Trent Valley Growers suggested that the trickle pipe would have a further life of 3 years. It is suggested that retrieval of the pipe, disconnection of the headers, coiling the pipes and removing all equipment to store would take 12.4 man hours per ha. (This included cleaning and inspection)

No significant problems were reported on this site with the use of the trickle system. However 5 bursts were reported, all due to human error.

Costs

Care must be taken when interpreting the costs from one small site. The equipment was supplied from ISC* for this trial. Commercially the whole equipment is likely to have cost within the range of approx. £1800 -1900 per ha of which roughly half is the trickle pipe cost. This relates to a "typical" order for 6 - 8 ha equipment. Taking £1850 as the mid range and the manufacturers claim of 5 years life for this pipe a seasonal charge can be calculated. This would include interest at 10% and 6% of capital as repairs each season and suggests £288 per ha for the tape. The control/filter elements written off over 10 years and treated in a similar way add £195 per ha to this figure. Thus the total per ha (excluding pumping) would be £483.

If the life expectancy of the pipe is reduced to 4, 3, 2, or 1 year due to handling/ damage or other reasons then the overall figure/ha rises to £529, £606, £760 and £1223 respectively.

The application of 180 mm over 0.4 ha, at an internal trickle pipe pressure of 0.5 bar required a low pumping energy. This was estimated at 3 kw for this site. This translates to 13kwh for 25mm.

A fully portable sprinkler layout which would allow 25mm application per day would cost approx £4200 per ha for equipment but the line is moved once/twice per day as a minimum applying 25mm over a 7 day cycle. Thus the capital would be spread reducing the capital per ha to £600/£300 respectively. When depreciated over 10 years and considered with interest and capital this is equivalent to £126 or 63 per ha. To this must be added the labour costs of movement which will vary site to site but are likely to be considerably greater than with trickle irrigation.

Equipment costs

	Capital cost/ha	Depreciation
Trickle	£1,850	£483 if pipe life 5 years
		£529 if pipe life 4 years
		£606 if pipe life 3 years
		£760 if pipe life 2 years
		£1223 if pipe life 1 year
Sprinkler	£4,200	£126 if moved once/day
		£63 if moved twice/day

Thus the comparison indicates that costs are likely to be higher for trickle but, if the trickle pipe lasts 5 years, these costs may be offset by the benefits reported earlier.

ADAS acknowledges the help and co-operation given by Mr Peter Barton in the collection of data and discussion concerning this study.

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REPORT OF FIELD EXPERIMENT CONDUCTED AT ADAS GLEADTHORPE

AUTHOR

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THE EVALUATION OF TRICKLE IRRIGATION SYSTEMS.

Introduction and background

Many horticultural crops rely upon a ready supply of irrigation water to ensure both high yield and food quality. With increasing domestic and industrial demand for water, however, and the severe restrictions placed on agriculture and horticulture in dry seasons, there is a need to reduce the volumes of water applied and maximise irrigation efficiency. Trickle or drip irrigation systems are claimed to have the potential to achieve savings in water use, yet still maintain optimum yield and quality.

The history of trickle irrigation goes back as far as 1860 when German researchers used subsurface clay pipes to apply water (Davis, 1974). Attempts at using perforated subsurface pipes were first reported in 1913 but the technique proved too expensive for commercial exploitation. Modern trickle systems originated from work done in Israel by Blass (1964) who developed and patented the first trickle irrigation system. From Israel trickle irrigation spread to North America, Australia and South Africa by the late sixties and subsequently throughout the world.

Much of the research work on trickle systems has been conducted in the USA, although in recent years there has been less fundamental work as the speed of product development has increased. Studies of irrigation efficiency achieved by trickle compared with sprinkler and furrow irrigation have produced a variety of results. Ravelo *et al* (1977) working with Sorghum found no differences, whereas Sammis (1980) reported higher efficiency with trickle irrigation in potatoes but no differences with field lettuce. Hanson and Patterson (1974) reported improved efficiency with trickle for both cereal and onion crops. In a more recent study De Tar *et al*, (1996) found that trickle irrigation of potatoes used 29% less water than sprinkler irrigation but produced 25% more yield. Notwithstanding these reports there has been no published work from this country evaluating the performance of trickle irrigation under the cooler UK climate.

There are four main reasons why trickle irrigation may be better than conventional techniques. 1. Uniformity of application. It is widely accepted that trickle systems are capable of very accurate and uniform delivery of water. 2. Placement. Trickle systems supply water directly to the area of soil in which the roots grow, and not to soil which is unexploited by the crop. Thus there may be considerable potential to reduce the amount of water required to maintain optimum yield. This factor is of greater significance in wide row crops. 3. Evaporation losses. Applying water below the soil surface may reduce evaporation thus reducing wastage. 4. Trickle irrigation also offers the opportunity to improve produce quality by avoiding increased disease risk associated with wet foliage, and the contamination of salad crops by soil splash.

Regardless of the potential benefits, trickle irrigation has not been perceived as being of value in annual U.K. crops. This is primarily a result of the high cost of trickle piping, but this has markedly decreased in real terms in recent years owing to the availability of cheaper plastics. Indeed, Irrigation Systems Company Projects Ltd (ISC) claim comparable costs to raingun irrigators.

Summary

Varying amounts of irrigation were applied to transplanted celery by either an overhead boom or by trickle irrigation system to evaluate the effect on crop establishment, irrigation efficiency, yield and produce quality.

The summer was dry with only 107mm of rainfall recorded during the life of the crop. In response to low rainfall a total of 226mm of irrigation was applied to the most intensively irrigated treatment.

Crop establishment was unaffected by irrigation technique, but subsequent growth was restricted where trickle irrigation was used at establishment. At final harvest total and trimmed yields were found to be linearly related to the amount of water applied regardless of application technique suggesting no difference in irrigation efficiency between trickle and boom irrigation. Produce quality was also unaffected by irrigation technique.

Differences in crop colour and plant % nitrogen content indicate that trickle irrigated treatments may have been N deficient during August. All treatments received similar quantities of fertiliser N (225 kg/ha), suggesting a lower efficiency of crop N uptake associated with trickle irrigation

Objectives

a. To determine whether trickle irrigation systems require less water than conventional overhead irrigation to maintain high yields.

b. To quantify any savings made.

c. To evaluate the effect of trickle and overhead irrigation on produce quality.

Materials and Methods

The experiment was of a randomised block design with four replicates of each treatment. The plots were arranged under a specially adapted linear move irrigator to allow accurate applications of overhead irrigation. Trickle irrigation was supplied by Ro-Drip tape via header pipes to each plot. The supply to each trickle irrigation treatment was individually metered. Overhead irrigation amounts were measured by 'catch cans'. The treatments applied were as described below (irrigation amounts and timings - appendix 3).

Treatments

Overhead irrigation - intended treatment	Total applied (mm)
1. Nil	25
2. 25% of the volume applied to Tr. 5	62
3. 50% of the volume applied to Tr. 5	97
4. 75% of the volume applied to Tr. 5	141
5. Irrigated with 20mm @ trigger SMD (20mm)	170
6. 125% of the volume applied to Tr. 5	226
Trickle irrigation - intended treatment	
7. Nil	25
8. 17% of the volume applied to Tr. 13	50.1
9. 33% of the volume applied to Tr. 13	72.6
10. 49% of the volume applied to Tr. 13	96.2
11. 67% of the volume applied to Tr. 13	121.5

12.	83% of the volume applied to Tr. 13	144.6
13.	Irrigated initially when treatment 5 was irrigated then subsequently to replace evapotranspiration losses	169.0
14.	117% of the volume applied to Tr. 13	193.8
15.	As treatment 13 but also trickle irrigated during establishment	169.0

All treatments except Tr. 15 received overhead irrigation during the first three weeks after planting to ensure complete crop establishment. Treatment 15 received trickle irrigation only.

Irriguide was used to estimate soil moisture deficits and rates of evapotranspiration. Irriguide is a computer model based on a Penman Monteith equation. It uses weather, soil and crop information to estimate rates of evapotranspiration and soil moisture deficits. The model has been described by Bailey & Spackman (1996) and validated in field experiments (Bailey *et al.*, 1996). In this experiment on site weather data was used to provide the Irriguide estimate. The application of water to all plots, including trickle irrigated plots, was triggered whenever the SMD in treatment 5 reached 20mm. This is similar to commercial practice for overhead irrigation of celery. On these occasions the volume of water applied to each treatment was adjusted to produce the different rates. Treatment 13 was irrigated differently, using a 'little and often' approach. It received trickle irrigation every 2 to 3 days, equivalent to the rate of evapotranspiration on the previous days. Water was not applied more frequently than this so that the volumes applied, even at the lower rates, were sufficient to ensure some lateral movement within the soil profile. This approach effectively maintained the SMD in these plots close to the trigger deficit. When rainfall reduced the SMD, applications were withheld until the soil had dried to the trigger SMD. Care was taken in the design and implementation of these treatments to avoid taking the soil beyond field capacity in all but the most intensive treatments. This reduced the likelihood of nutrients being leached from the soil.

The experimental area was ploughed on 24 April prior to the application of seedbed fertilisers on 25 April (appendix 4). Each plot consisted of 3 beds of 1.72m in width and 10m in length. Two lengths of Ro-drip tape were installed to a depth of approximately 50mm in each trickle irrigated bed using tractor mounted machinery supplied by ISC Ltd. The tape used had emitters spaced at 30cm intervals and a flow rate of 298 litres/hour/100m length of tape at a pressure of 0.56 bar. Block raised celery plants were machine planted on 21 May at a spacing of 30cm between each plant and each row with four rows to a bed. Any gaps following machine planting were filled in by hand to ensure consistent plant populations.

Two tensiometers were installed to a depth of 30cm in three plots of treatments 5,9,11 and 13. These were sited in pairs, one centrally and one off set, to investigate the effect on the distribution of water across the width of a bed. Tensiometers were read before each overhead irrigation event.

Plant establishment was assessed on 14 June by recording the number of dead plants within each plot.

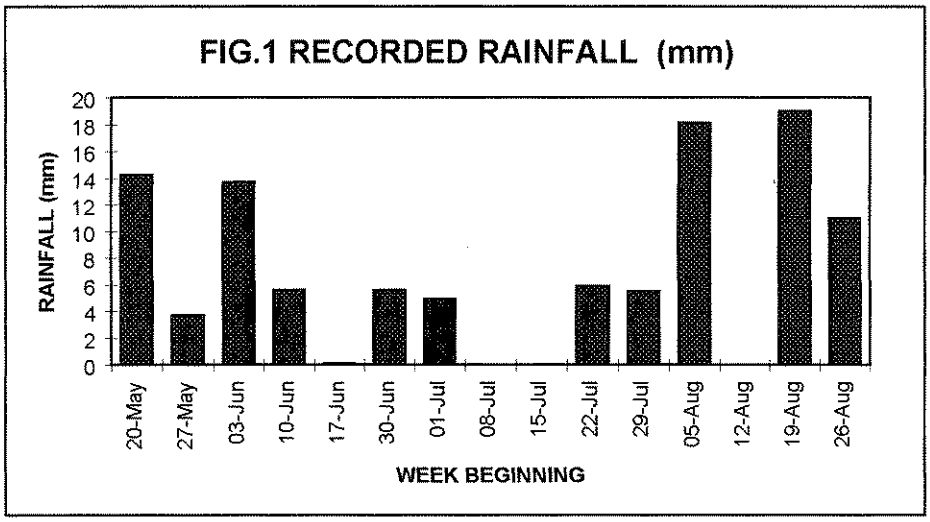
Fertilisers and pesticides were applied in response to crop requirements (appendix 4). N, P and K rates were in accordance with those published in the 'MAFF Fertiliser Recommendations for Agricultural and Horticultural Crops (RB309)'.

Crop ground cover was assessed in each plot on 9 July, 16 July and 2 August.

Final harvest was taken on 3 September. All plants were taken from a 4m length of the central bed of each plot and the total yields were recorded. The plants were then trimmed and re-weighed. Ten plants were taken at random from the adjoining two beds within each plot for further assessments. These plants were then assessed for disease, colour, total number of petioles, number of petioles per trimmed plant, length of trimmed plant and % dry matter.

Results

The crop was planted on 21 May into a moist seedbed. The weather during the week following planting was cool and wet with 14mm of rainfall recorded at the site (fig.1). Mean daily temperatures are shown in Appendix 5. During the second week there was less rainfall and temperatures were considerably higher. Irrigation (15mm) was applied to all plots following this period to aid establishment (appendix 3). This water was applied by overhead irrigation to all plots except treatment 15 where the same quantity was applied by trickle.



Plant establishment assessments conducted on 14 June revealed minimal plant losses in all treatments (< 1.5%). There were no indications that plant losses following trickle irrigation at establishment (0.25%) were any different to those where overhead irrigation had been applied.

Crop cover was assessed on three occasions. Percentage crop cover was then plotted against the amount of irrigation applied to each treatment prior to the assessment (figs. 2,3&4). As expected the data indicate a strong relationship between crop cover development and water supply. The data also suggest little difference between the two irrigation delivery systems.

Final yields were taken on 3 September when the trimmed plant weight in the most forward plots had reached approximately 500-600gm. Using the methods described earlier the following yield and quality parameters were calculated: total yield, mean untrimmed plant weight, trimmed yield, mean trimmed plant weight, % dry matter content, total dry matter yield, mean total number of petioles per plant, mean number of petioles per trimmed plant, trimmed plant length and petiole greenness score. No pest or disease problems were apparent.

These data were subjected to analysis of variance to investigate any differences between treatment 13 and 15 which differed only in technique used to apply establishment irrigation. Table 1 presents all yield and quality data for these treatments. Overhead establishment irrigation produced larger and heavier plants, but little difference remained after trimming. There was no difference in established plant population.

FIG.2 % CROP COVER 9 JULY

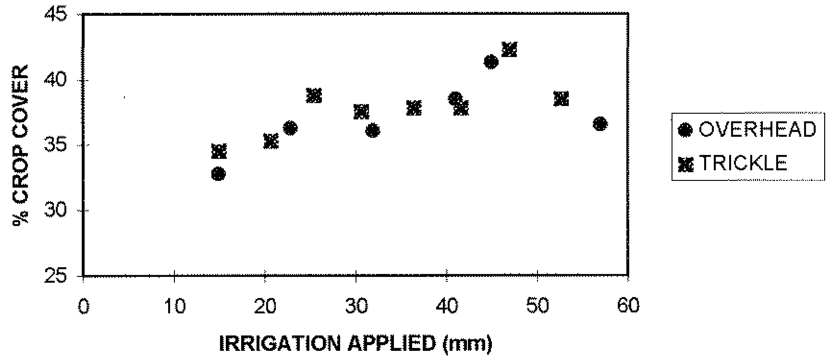


FIG.3 % CROP COVER 17 JULY

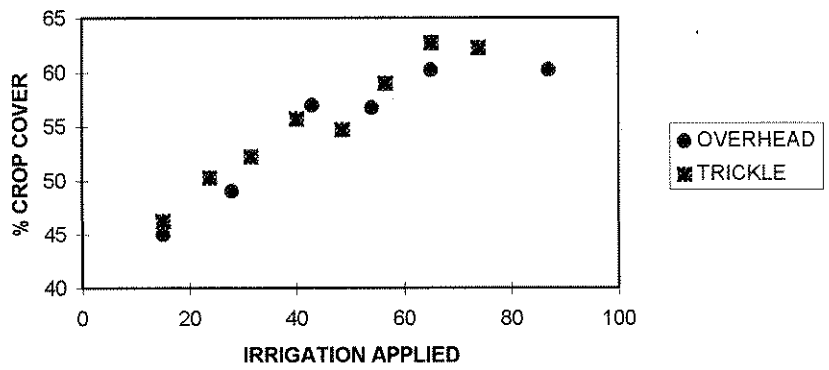


FIG.4 % CROP COVER 2 AUGUST

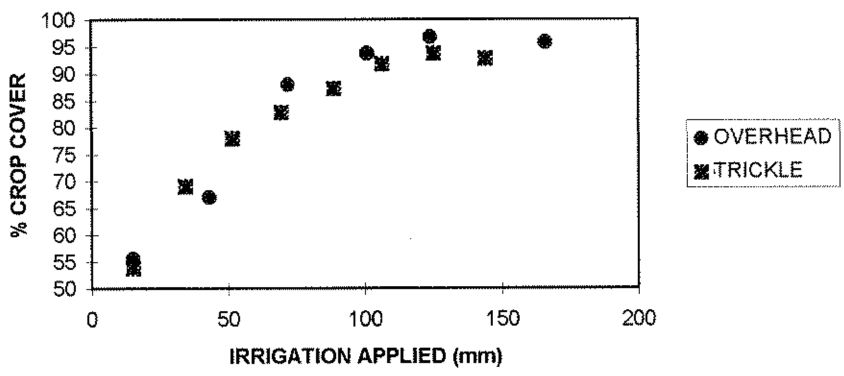


Table 1. Comparison of establishment irrigation method

Measurement	Overhead irrigated at establishment Tr 13	Trickle irrigated at establishment Tr 15	Statistical significance
Plant population at harvest ('000/ha)	69.8	70.9	N.S.
Total yield (t/ha)	87.0	81.9	N.S.
Mean weight of untrimmed plant (kg)	1.25	1.15	$P = 0.05$
Trimmed yield (t/ha)	34.9	32.6	N.S.
Mean weight of trimmed plant (kg)	0.50	0.46	N.S.
% dry matter content	9.2	8.6	N.S.
Dry matter yield (t/ha)	8.0	7.0	$P = 0.05$
Mean number of petioles per trimmed plant	11.6	10.7	N.S.
Trimmed petiole length (cm)	23.2	22.7	N.S.
Petiole greenness score *	3.95	4.35	N.S.

* key:- 1 = white, 10 = dark green.

Treatment means for all measured variables in all treatments were then plotted against the amount of water applied (figs. 5-13). Data in figures 5 to 13 were subjected to regression analysis (table 2).

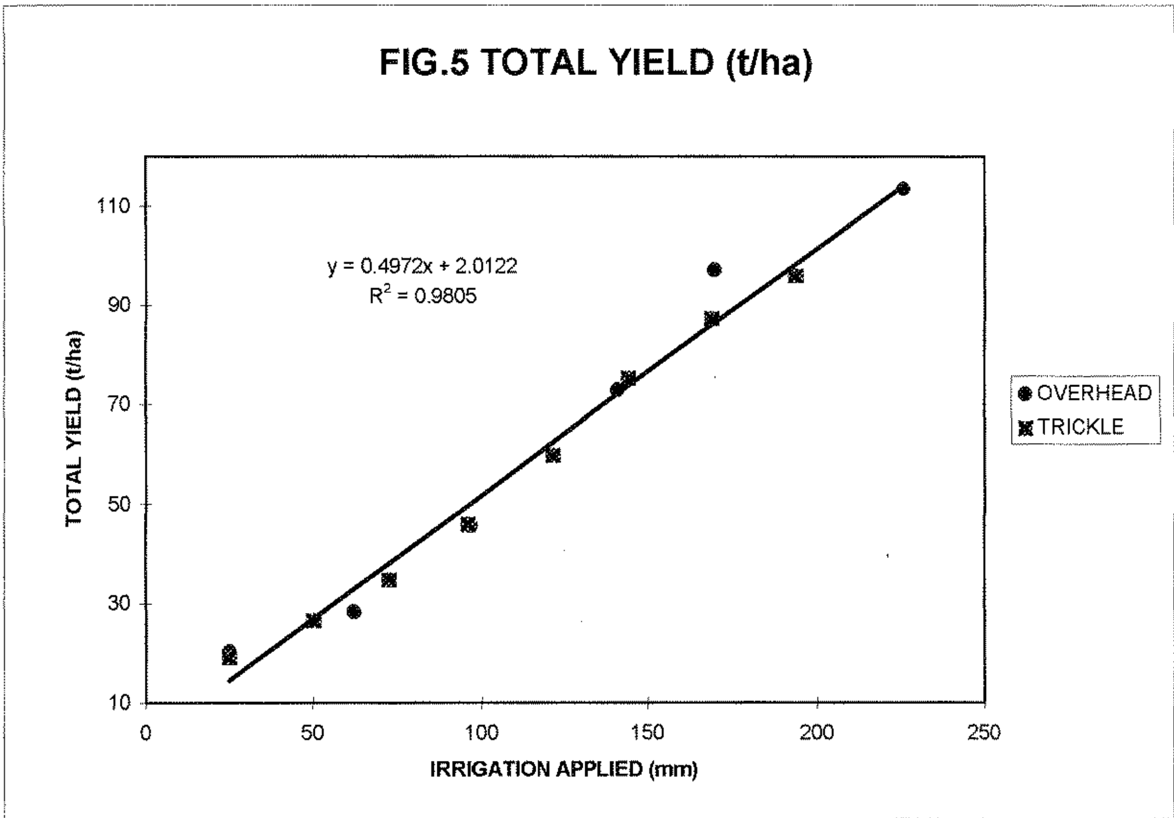


FIG.5 TOTAL YIELD (t/ha)
y = 0.4972x + 2.0122
R² = 0.9805
TOTAL YIELD (t/ha)
110
90
70
50
30
10
0
50
100
150
200
250
IRRIGATION APPLIED (mm)
OVERHEAD
TRICKLE

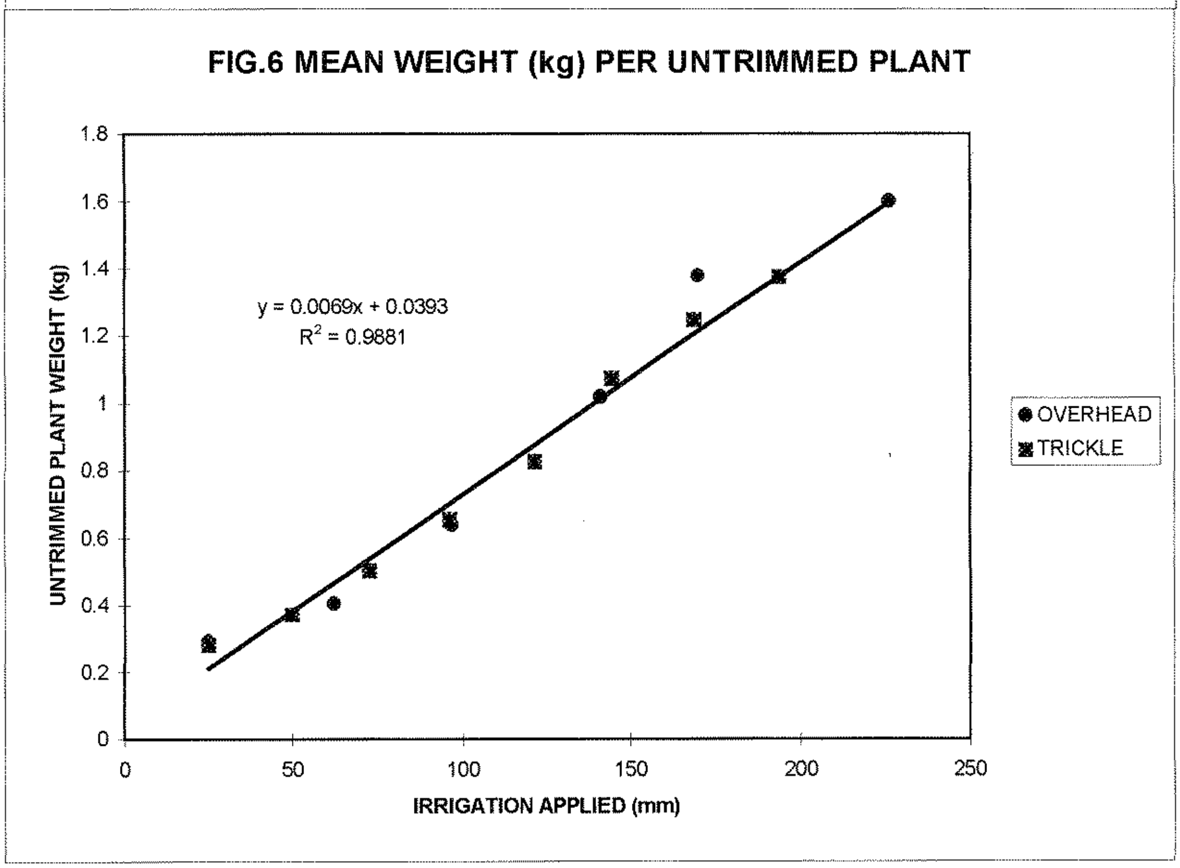


FIG.6 MEAN WEIGHT (kg) PER UNTRIMMED PLANT
y = 0.0069x + 0.0393
R² = 0.9881
UNTRIMMED PLANT WEIGHT (kg)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
IRRIGATION APPLIED (mm)
OVERHEAD
TRICKLE

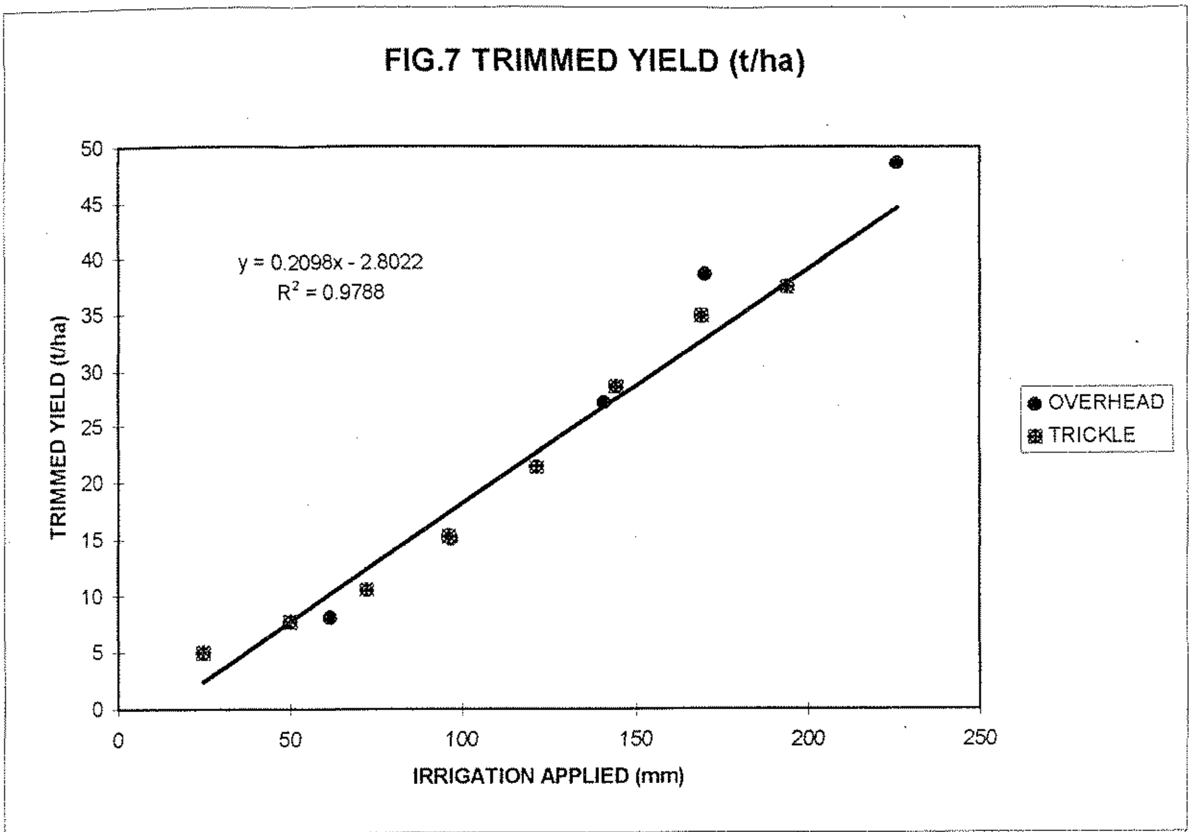


FIG.7 TRIMMED YIELD (t/ha)
y = 0.2098x - 2.8022
R² = 0.9788
TRIMMED YIELD (t/ha)
IRRIGATION APPLIED (mm)
OVERHEAD
TRICKLE

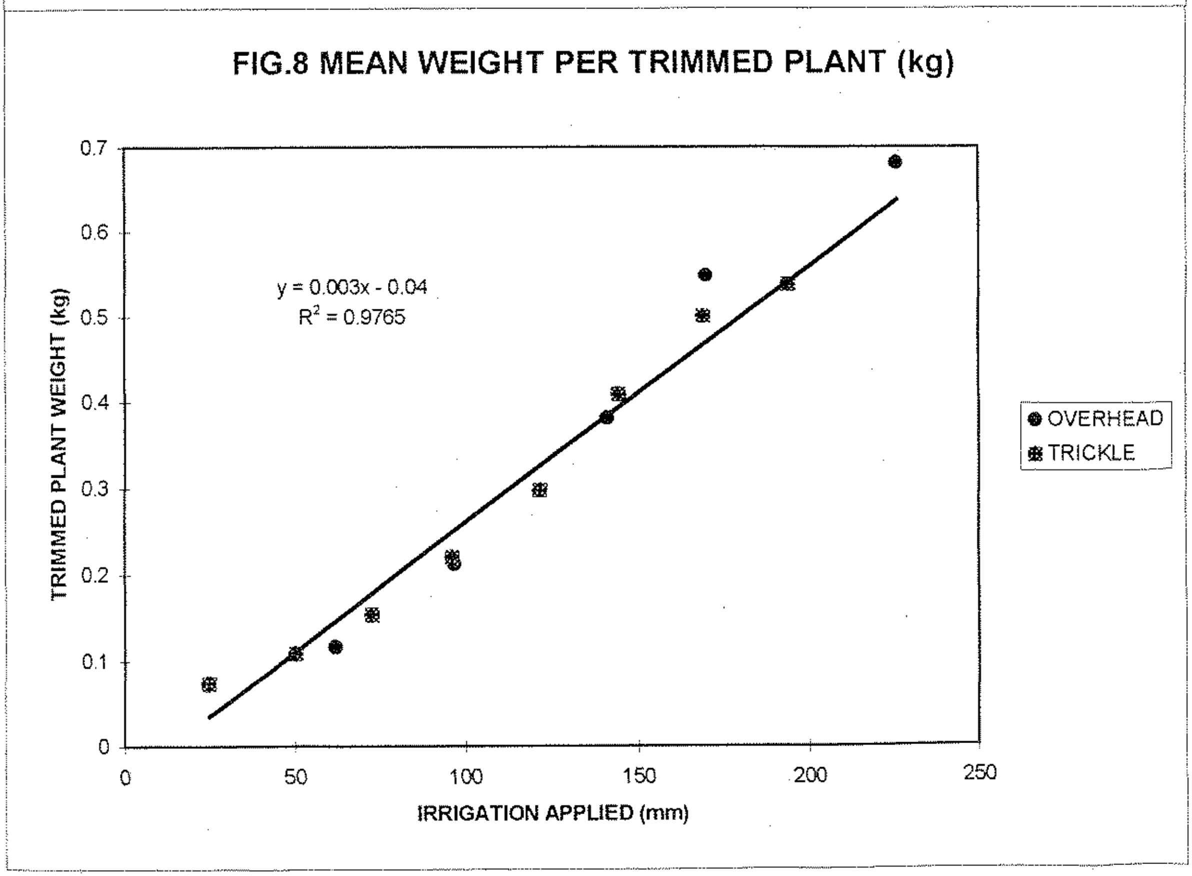


FIG.8 MEAN WEIGHT PER TRIMMED PLANT (kg)
y = 0.003x - 0.04
R² = 0.9765
TRIMMED PLANT WEIGHT (kg)
IRRIGATION APPLIED (mm)
OVERHEAD
TRICKLE

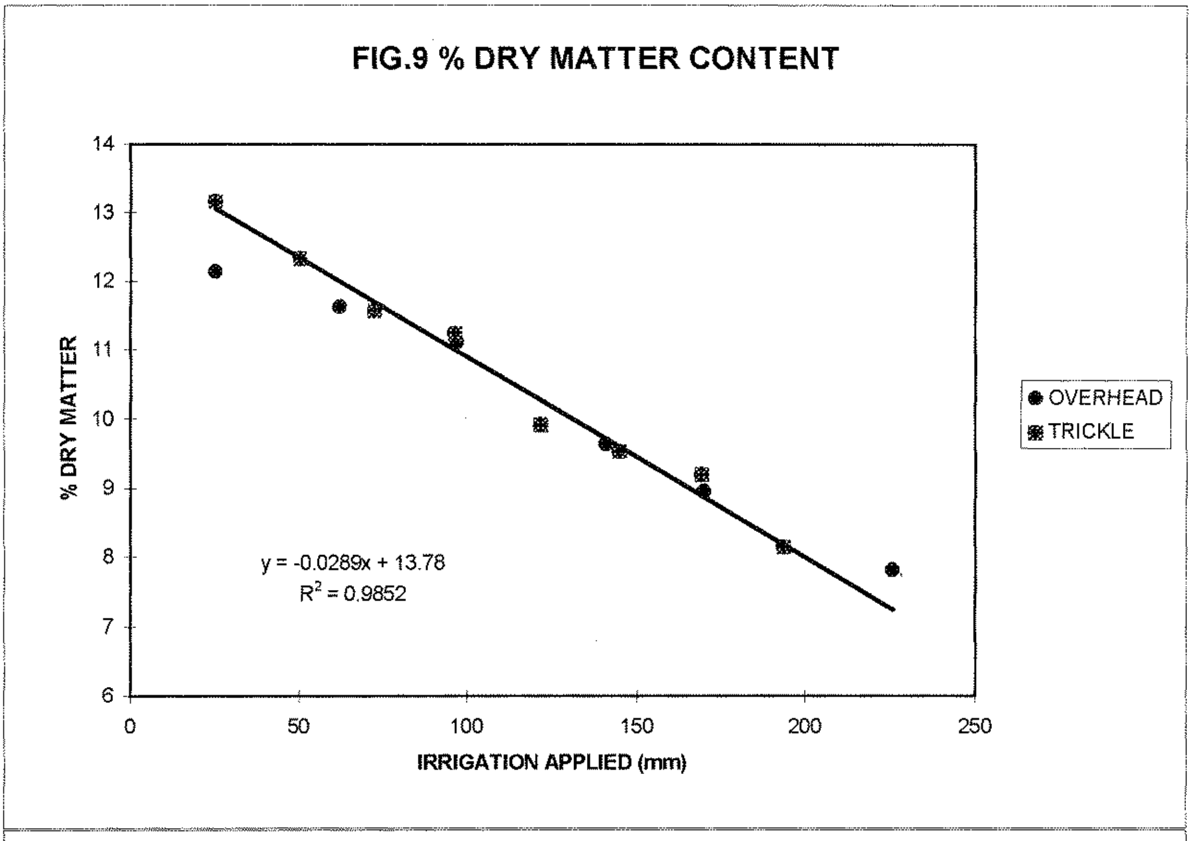


FIG.9 % DRY MATTER CONTENT
% DRY MATTER
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
IRRIGATION APPLIED (mm)
y = -0.0289x + 13.78
R2 = 0.9852
OVERHEAD
TRICKLE

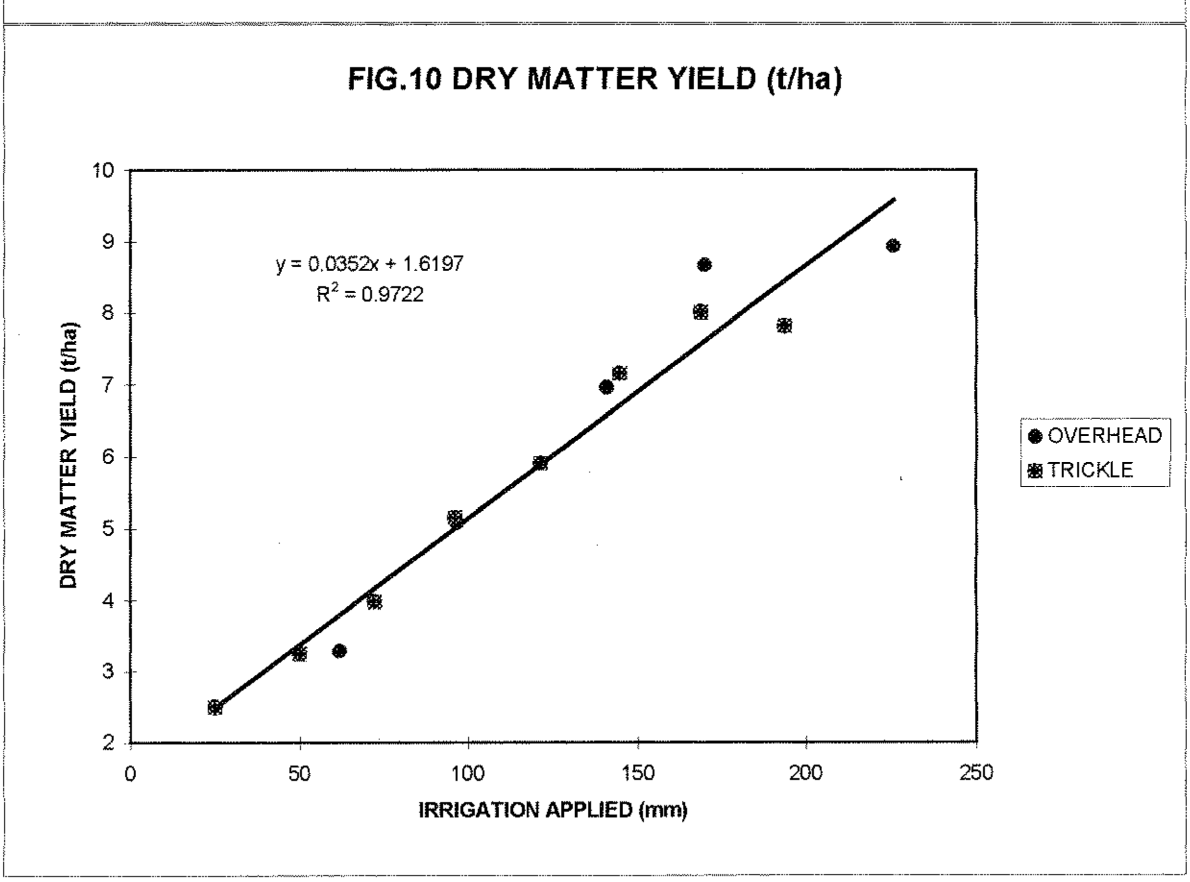


FIG.10 DRY MATTER YIELD (t/ha)
DRY MATTER YIELD (t/ha)
10
9
8
7
6
5
4
3
2
0
50
100
150
200
250
IRRIGATION APPLIED (mm)
y = 0.0352x + 1.6197
R2 = 0.9722
OVERHEAD
TRICKLE

FIG.11 MEAN NUMBER OF PETIOLES PER TRIMMED PLANT

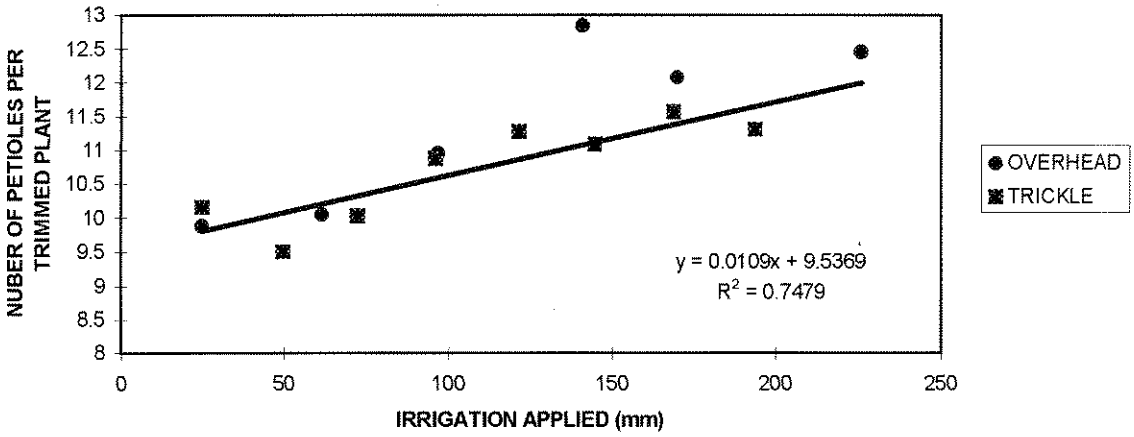


FIG.12 TRIMMED LENGTH (cm)

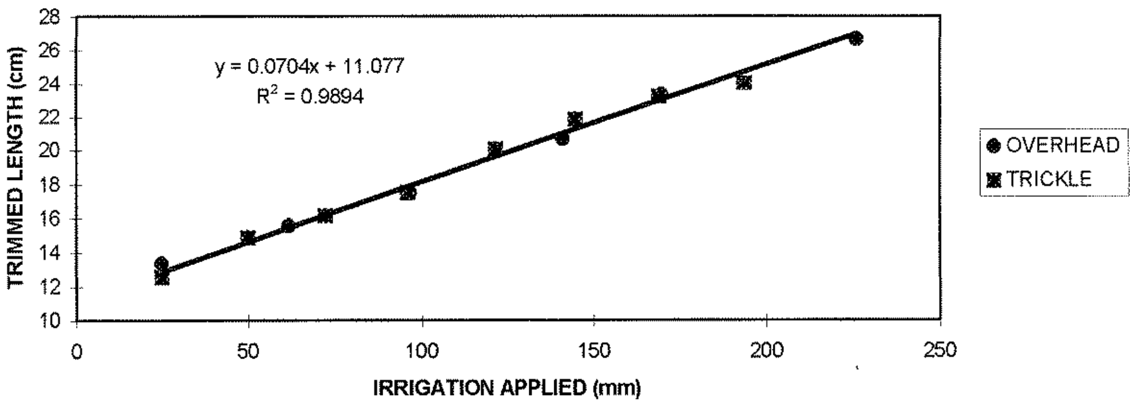


FIG.13 GREENESS SCORE

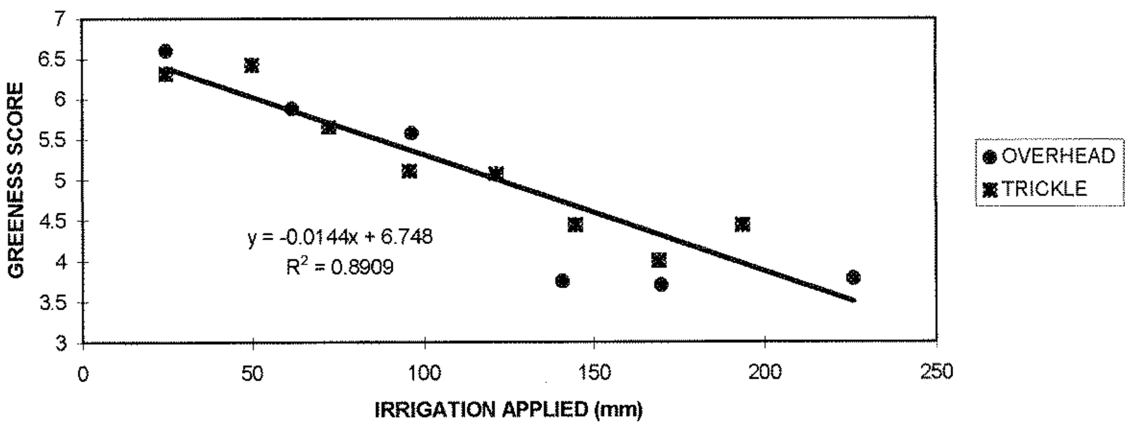


Table 2. Regression analyses for yield and quality variables

Variable	Regression equation	R^2	Statistical significance
Total yield (t/ha)	y = 0.4972x + 2.0122	0.98	*P* = <0.001
Mean weight of untrimmed plant (kg)	y = 0.0069x + 0.0393	0.99	*P* = <0.001
Trimmed yield (t/ha)	y = 0.2098x - 2.8022	0.98	*P* = <0.001
Mean weight of trimmed plant (kg)	y = 0.003x -0.04	0.98	*P* = <0.001
% dry matter content	y = - 0.0289x + 13.78	0.99	*P* = <0.001
Dry matter yield (t/ha)	y = 0.0352x + 1.6197	0.97	*P* = <0.001
Mean number of petioles per trimmed plant	y = 0.0109x + 9.5369	0.75	*P* = <0.001
Trimmed petiole length (cm)	y = 0.0704x + 11.077	0.99	*P* = <0.001
Petiole greenness score *	y = -0.0144x + 6.748	0.89	*P* = <0.001

* key:- 1 = white, 10 = dark green.

All yield related regression analyses were highly significant ($P = < 0.001$). Additionally in these cases a simple regression analysis accounted for more than 97% of the variation in the data indicating that there was no difference in irrigation efficiency between the two application techniques. Petiole colour, trimmed petiole length and the mean number of petioles per trimmed plant were also strongly related to the volume of water applied rather than the method of application. No relationship was established between irrigation treatment and the total number of petioles per untrimmed plant.

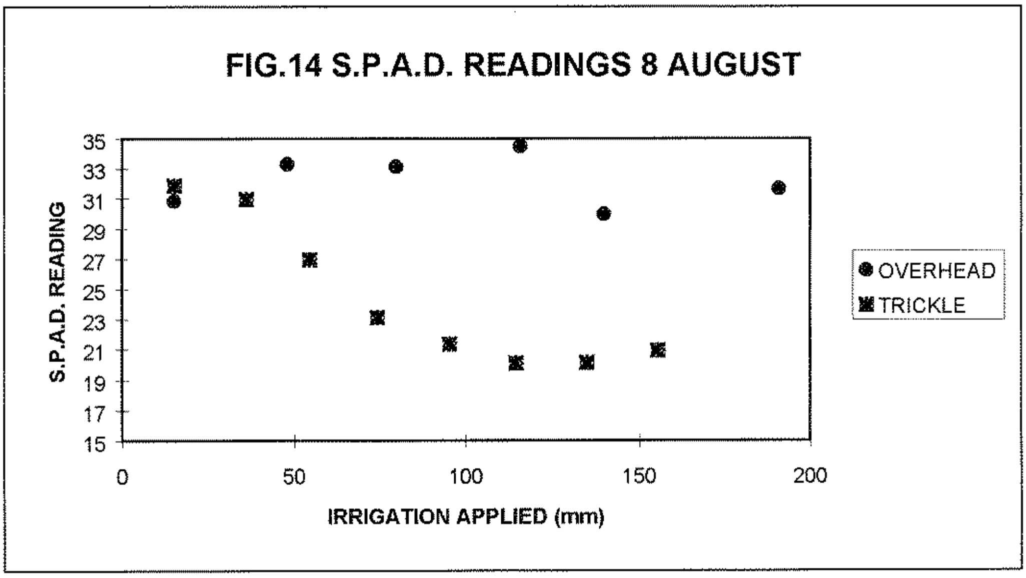
Due to unforeseen circumstances the tensiometer data collected proved to be inaccurate and regrettably has had to be discounted.

Discussion

The installation of the trickle equipment went smoothly with few problem leaks despite the large number of couplings used. The machine supplied by ISC to install the tape worked particularly well providing a constant burial depth for the tape in all plots. No emitter blockages were encountered.

The weather during the week immediately post planting was cool and wet. Crop establishment was unaffected by application method, but final yields were lower where trickle irrigation rather than overhead irrigation had been applied at establishment (table 1).

Crop growth as measured by canopy development appeared to have been unaffected by application method (figs. 2-4). However by the second week in August trickle irrigated plots appeared light green in colour when compared with overhead irrigated treatments. To measure this effect a S.P.A.D. meter was used to measure the greenness of the foliage in all plots (fig. 14). The meter uses a light source and sensor to measure the transmittance of two wavelengths of light and thereby estimate plant chlorophyll content.



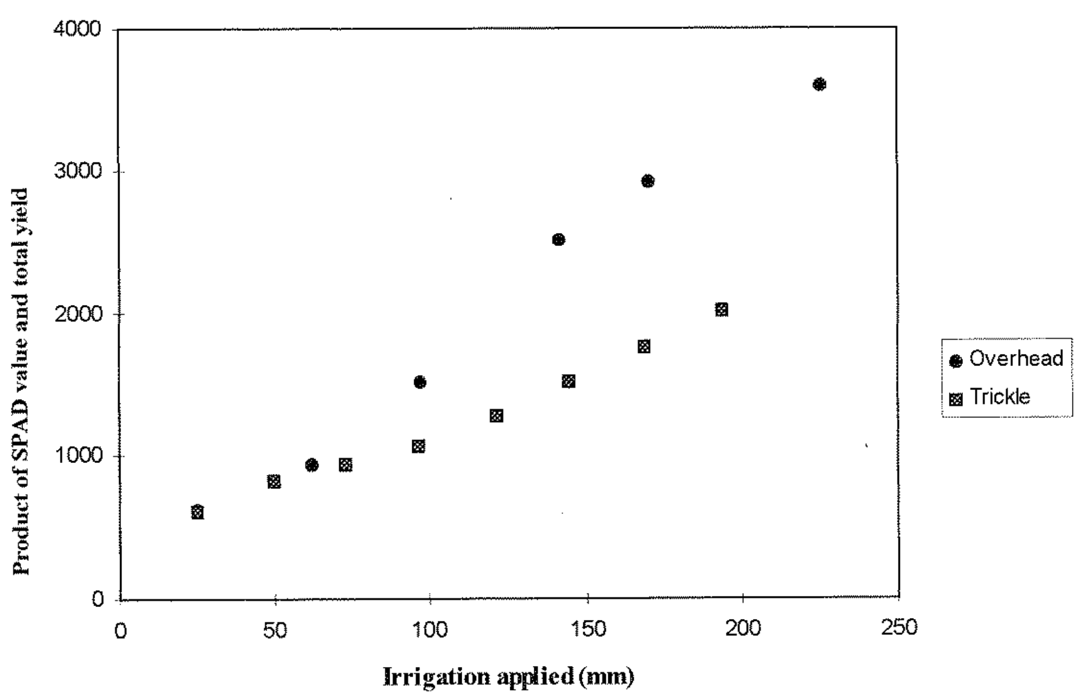
These data clearly indicate that overhead irrigated plots remained consistently green but plots receiving trickle irrigation were more yellow in colour. These data raised suspicions that the trickle irrigated plots were short of nitrogen although they had received a quantity of fertiliser equal to the other plots. Young leaf samples were taken on 13 August from treatment 5 and 13 and analysed by the 'Dumas' technique for % N at the ADAS Laboratories. These analyses confirmed a difference in nitrogen concentration (3.85 and 3.19% respectively), albeit both were still within the normal range for the species at that stage of growth. There are three possible reasons for nitrogen deficiency.

1. The level of applied fertiliser could have been inadequate, and nitrogen could have been limiting. This is unlikely as there was no indication of nitrogen deficiency in the overhead irrigated plots, including those producing a high yield, although all plots were treated with a similar level of nitrogen.
2. A second possible explanation is that the trickle irrigation in some way leached the available nitrogen beyond the reach of crop roots and thus reduced uptake. This is also unlikely. Any leaching effect could be expected to become more pronounced as the level of irrigation was increased. In this case, total nitrogen uptake, as represented crudely by

$$\text{total N uptake} \propto \text{S.P.A.D. reading} \times \text{Yield}$$

did not decrease with higher irrigation rates but actually increased somewhat.

Fig. 15 Estimate of N offtake against irrigation applied



3. The third explanation is that much of the applied fertiliser nitrogen remained in the upper layers of the soil, because there was insufficient rain to dissolve and transport it to the roots. Overhead irrigation performed this function satisfactorily, but trickle irrigation water was distributed below the surface layers and by-passed the nitrogen. This would account for the difference between trickle and overhead, and also for the fact that the total nitrogen uptake did not decrease with higher levels of trickle irrigation. It is, therefore, the most likely explanation of the results.

To try and ensure that nitrogen was subsequently non-limiting in all plots, a further top dressing of N was applied on 19 August followed by 10mm of overhead irrigation to all plots. The last two weeks of August were quite wet (30mm of rain) and by final harvest on 3 September the crop colour difference was noticeably reduced.

All final yield and produce quality data were linearly related to the amount of irrigation applied and were unaffected by the irrigation method (table 2). In this experiment, there were no efficiency savings associated with trickle irrigation. Indeed the high r^2 values (table 2) obtained for all regression analyses show that there was little variation in the data left unaccounted for.

These findings contrast with reports in the literature which have identified savings from using trickle irrigation systems. However, these reports originate from experiments conducted in arid countries such as Israel, Spain and the Southern States of the USA where evaporation rates are very high. It is believed that the increased efficiency reported in these countries is related to a reduction in the amount of evaporation from the soil surface. In the cooler climate of the UK, rates of evaporation are much lower and the potential for saving water may be reduced. Grower reports in this country also suggest savings where trickle irrigation is used, but it is important to consider the basis upon which these comparisons are made. In the experiment at Gleadthorpe all irrigation was carefully scheduled to avoid drainage and overhead irrigation was applied by a specially modified linear move irrigator capable of accurate and uniform delivery. In a commercial situation irrigation systems are likely to be less precise leading to possible wastage. Also the need to apply overhead irrigation in doses of 10 to 15mm may result in drainage losses in situations where the chosen irrigation schedule attempts to keep the soil close to field capacity. It is possible that a perceived increased efficiency from trickle irrigation systems is a function of an increased uniformity of application and flexibility of application amounts rather than any physical or biological effect.

Although the yield results do not indicate any difference in efficiency between the two techniques the results may have been confounded in some way by the possible water nitrogen interaction discussed earlier. If trickle irrigated plots were nitrogen deficient during August, growth may have been restricted thus reducing efficiency. This uncertainty introduces an element of doubt into the main conclusion that there was no difference in irrigation efficiency. Unfortunately, the scale and design of this experiment did not allow the impact of such interactions to be investigated, therefore any future work should urgently address this issue.

Conclusions and Recommendations

The results clearly show that trickle irrigation was no more efficient than overhead irrigation within the limits of this experiment. Many growers have already invested in trickle irrigation systems in the belief that they would reduce their irrigation requirement. Whilst there may be many advantages to trickle irrigation systems in terms of accuracy, flexibility and energy savings, the results from this experiment do not support the view that less water is required. However, it is difficult to make any firm conclusions or recommendations to growers based on only one year's data using one crop species, especially as the results run contrary to expectations. For this reason it is particularly important that this work should be continued so that the industry has a full picture of the potential value of trickle irrigation.

The question of nitrogen-water interactions also needs to be addressed. The data from this experiment suggest that an adjustment to fertiliser policy may be needed where only trickle irrigation is applied. Further work is required to study this aspect. Potentially the use of fertigation techniques may provide the way forward, but more research will be required to determine how, or whether, this is the best approach.

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Appendix 1

HORTICULTURAL DEVELOPMENT COUNCIL SURVEY CONDUCTED BY ADAS

<u>Trickle Irrigation, its adoption and use.</u>

Name ______________________________

Address ______________________________

____

Post Code ______________________________

Phone No - Daytime: ______________ Evening: ______________

Crop served by trickle

Answer either acres or hectares

	Acres	Ha
strawberries		
cane fruit		
bush fruit		
top fruit		
field veg		
potatoes		
Other please specify		

How many years have you used Trickle? ______________

(Please tick one)

Trickle type

T Tape	
Ro Drip	
Streamline	
Seephose	
Other please specify	

If not known state manufacturer: ______________

Row width of crop ______________

Tape row spacing ______________

Tape emitter spacing ______________

Tape/pipe gauge or code ______________

No of pipes per row/bed ______________ or crop rows/pipe

Is the pipe buried Yes/No if buried how deep ______________

Filtration equipment installed Yes/No

(Please tick one)

Mechanical	
Sand	
Other	
Filter mesh equivalent if known	

(Please tick one)
Soil type:

Coarse sand	
Medium sand	
Fine sand	
Sandy loam	
Loamy sand	
Heavier soils	

Water Sources	**price per m^3**
River	
Reservoirs	
Borehole	
Mains	

Were you able to compare overhead and trickle irrigated areas? Yes/No

If yes:

Was there a difference in the amount of water applied? Yes/No

If yes, what was the difference and which system received the most. Trickle/Overhead
Difference............mm

Was there a yield difference? Yes/No

Which system gave the greater yield? Trickle/Overhead

Was there a difference in produce quality? Yes/No

Which system produced the best quality? Trickle/Overhead

Was fertiliser equipment coupled to Trickle? Yes/No
If yes what type of equipment? ______________________________

What fertilisers were used (formulation and amounts)? ______________________________

Installation

Was the trickle laid at planting? Yes/No

Did you use any special equipment Yes/No

If yes, was this hired or loaned to you Yes/No

Did you develop it yourself? Yes/No

Where there any problems with installation, if so please specify ____________

____

____

____

Labour involvement

Please estimate how long it took to layout the system in staff hours

or

hours/acre	hours/ha

Operation

Do you use an irrigation scheduling system? Yes/No

(Please tick one)
If yes, which

Irriguide	
other computerised systems	
neutron probes	
tensiometers	

If no, how did you decide when to apply water? ____________________

(Please tick one)
How much water did you apply by trickle at each irrigation event

< 2 mm	2-4 mm	4-6 mm	6-8 mm	8-10 mm	> 10 mm

How much water did you apply in total through the trickle system to each crop in 1996

Have you noted any problems with water flow? Yes/No

If yes, please describe ____________________

Have you ever used an Algaecide in the system Yes/No

Comments:

Pipe Lifting - at end of season

(Please tick one)
How do you lift the pipe

hand	
machine	

Please estimate how long this took in staff hours?

hours/acre	or hours/ha

Was there any problems at lifting, if so please specify? ____________________

(Please tick one)
What do you estimate the condition of the pipe as after 1 season's use

scrap	
1 season left	
2 seasons left	
longer	

If you have any further comments please add in the space below:

____

____

____

Thank you for your time.

W D Basford
ADAS Gleadthorpe Grange
Meden Vale
Mansfield
Notts
NG20 9PD

Tel: 01623 846742
Fax: 01623 847424

Appendix 2

HDC Trickle/Drip Irrigation Study

Follow up Questionnaire

Code no

1 Yield - Can any increase be quantified - ie how much more?

2 Quality - What improvements were noted?

3 What is the greatest benefit of using trickle/drip?

4 What is the most significant problem with trickle/drip?

5 What is the maximum length of run used?

6 Are their significant slopes on the holding?

7 Has any non uniformity of application been noticed ie crop effect?

8 Economics - Are the costs recovered?

9 Will you be expanding or contracting the area under drip?

10 Has the absence of the Licence requirement influenced your decision to adopt drip/trickle?

Appendix 3

Diary of irrigation applications.

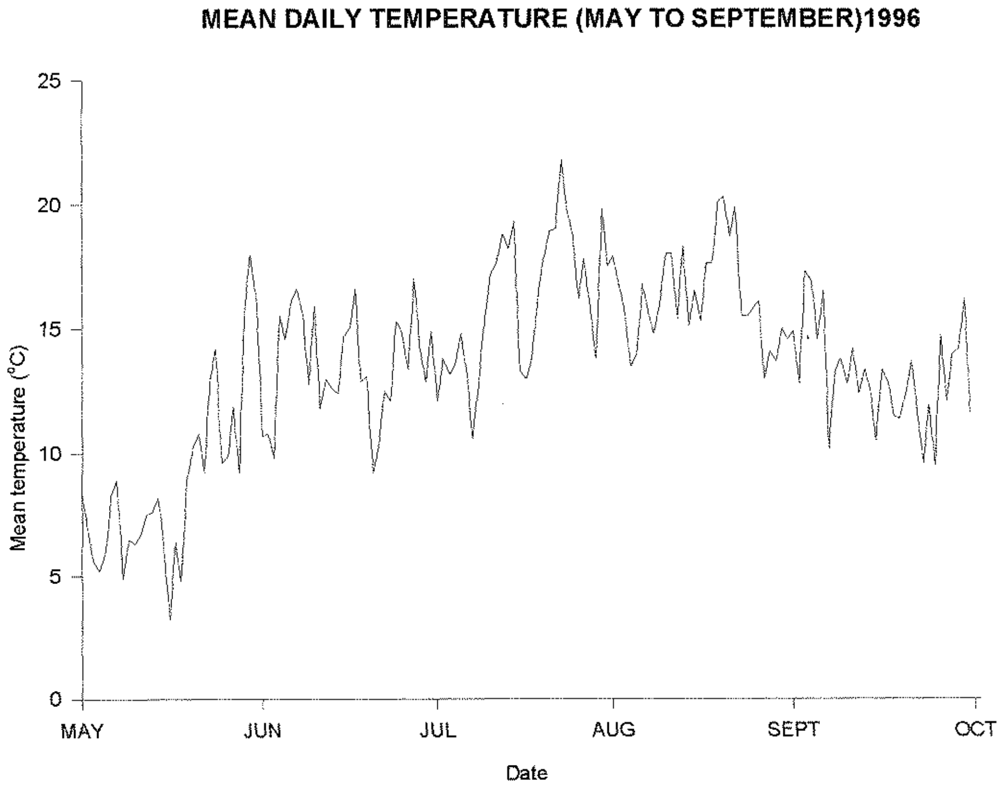
Treatment number	Dates of application & amount applied (mm)							Total applied
1	3/6(5)	5/6(5)	7/6(5)	19/8(10)				25.0
2	3/6(5)	5/6(5)	7/6(5)	19/6(3)	26/6(5)	10/7(5)	17/7(5)	62.0
	19/7(5)	26/7(5)	5/8(5)	15/8(4)	19/8(10)			
3	3/6(5)	5/6(5)	7/6(5)	19/6(5)	26/6(12)	10/7(11)	17/7(10)	97.0
	19/7(9)	26/7(10)	5/8(8)	15/8(7)	19/8(10)			
4	3/6(5)	5/6(5)	7/6(5)	19/6(7)	26/6(19)	10/7(13)	17/7(13)	141.0
	19/7(15)	26/7(19)	5/8(15)	15/8(15)	19/8(10)			
5	3/6(5)	5/6(5)	7/6(5)	19/6(9)	26/6(21)	10/7(20)	17/7(17)	170.0
	19/7(20)	26/7(22)	5/8(16)	15/8(20)	19/8(10)			
6	3/6(5)	5/6(5)	7/6(5)	19/6(13)	26/6(29)	10/7(30)	17/7(26)	226.0
	19/7(28)	26/7(25)	5/8(25)	15/8(25)	19/8(10)			
7	3/6(5)	5/6(5)	7/6(5)	19/8(10)				25.0
8	3/6(5)	5/6(5)	7/6(5)	19/6(1.7)	26/6(1.1)	4/7(1.0)	8/7(1.9)	50.1
	10/7(1.0)	12/7(1.0)	15/7(1.0)	17/7(1.7)	19/7(2.6)	22/7(2.5)	24/7(1.0)	
	26/7(1.0)	2/8(1.6)	5/8(1.7)	13/8(1.0)	15/8(2.0)	19/8(10)	21/8(1.0)	
9	3/6(5)	5/6(5)	7/6(5)	19/6(3.3)	26/6(2.0)	4/7(2.0)	8/7(3.3)	72.6
	10/7(2.0)	12/7(2.0)	15/7(2.0)	17/7(3.3)	19/7(5.0)	22/7(5.0)	24/7(2.0)	
	26/7(2.0)	2/8(2.6)	5/8(3.3)	13/8(2.0)	15/8(4.0)	19/8(10)	21/8(2.0)	
10	3/6(5)	5/6(5)	7/6(5)	19/6(4.9)	26/6(2.9)	4/7(2.9)	8/7(4.9)	96.2
	10/7(2.9)	12/7(2.9)	15/7(3.6)	17/7(4.9)	19/7(7.4)	22/7(7.4)	24/7(2.9)	
	26/7(2.9)	2/8(3.9)	5/8(4.9)	13/8(2.9)	15/8(5.9)	19/8(10)	21/8(2.9)	
11	3/6(5)	5/6(5)	7/6(5)	19/6(6.7)	26/6(4.0)	4/7(4.0)	8/7(6.7)	121.5
	10/7(4.0)	12/7(4.0)	15/7(4.0)	17/7(6.7)	19/7(10.1)	22/7(10.0)	24/7(4)	
	26/7(4)	2/8(5.4)	5/8(6.7)	13/8(4.0)	15/8(8.0)	19/8(10)	21/8(4.0)	
12	3/6(5)	5/6(5)	7/6(5)	19/6(8.3)	26/6(5.0)	4/7(5.0)	8/7(8.3)	144.6
	10/7(5.0)	12/7(5.0)	15/7(5.0)	17/7(8.3)	19/7(12.4)	22/7(12.4)	24/7(5.0)	
	26/7(5)	2/8(6.7)	5/8(8.3)	13/8(5.0)	15/8(10.0)	19/8(10)	21/8(5.0)	
13	3/6(5.0)	5/6(5.0)	7/6(5.0)	19/6(10.0)	26/6(6.0)	4/7(6.0)	8/7(10.0)	169.0
	10/7(6.0)	12/7(6.0)	15/7(6.0)	17/7(10.0)	19/7(15.0)	22/7(15.0)	24/7(6.0)	
	26/7(6.0)	2/8(8.0)	5/8(10.0)	13/8(6.0)	15/8(12.0)	19/8(10)	21/8(6)	
14	3/6(5)	5/6(5)	7/6(5)	19/6(11.7)	26/6(7.3)	4/7(7)	8/7(11.7)	193.8
	10/7(7.0)	12/7(7.0)	15/7(7.0)	17/7(11.7)	19/7(17.6)	22/7(17.6)	24/7(7.0)	
	26/7(7.0)	2/8(9.4)	5/8(11.7)	13/8(7.0)	15/8(14.0)	19/8(10)	21/8(7)	
15	3/6(5)	5/6(5)	7/6(5)	19/6(10.0)	26/6(6.0)	4/7(6.0)	8/7(10.0)	169.0
	10/7(6.0)	12/7(6.0)	15/7(6.0)	17/7(10.0)	19/7(15.0)	22/7(15.0)	24/7(6.0)	
	26/7(6.0)	2/8(8.0)	5/8(10.0)	13/8(6.0)	15/8(12.0)	19/8(10)	21/8(6)	

Appendix 4

Cropping details

Previous cropping:	1993: Potatoes 1994: Carrots 1995: Spring Wheat
Soil series:	Cuckney
Soil texture:	Loamy sand over sand
Soil analyses:	pH = 7.0, P = 44 (Index 3), K = 77 (1), Mg = 100 (2)
Cultivations:	Ploughed 24 April, harrowed 29 April.
Cultivar:	Celebrity
Planting date:	21 May 1996
Fertilisers:	25 April:- 100 kg/ha P_2O_5 as 217 kg/ha Triple superphosphate, 350 kg/ha K_2O as 350 kg/ha muriate of potash, 75 kg/ha N as 217 kg/ha ammonium nitrate. 27 June:- 100 kg/ha N as 290 kg/ha ammonium nitrate 19 August:- 50kg/ha N as 145 kg/ha ammonium nitrate
Pesticides:	1 June:- 25 l/ha Liquid Curb Cropspray 6 June:- 1.25 l/ha Linuron Flowable 14 June:- 11 l/ha Atlas Brown 18 July:- 2.5 l/ha Hostathion
Harvest date:	3-4 September 1996

Appendix 5



MEAN DAILY TEMPERATURE (MAY TO SEPTEMBER)1996
25
20
15
10
5
0
Mean temperature (°C)
MAY
JUN
JUL
AUG
SEPT
OCT
Date