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THE EFFECT OF TRICKLE IRRIGATION ON THE DISTRIBUTION OF ROOT GROWTH AND ACTIVITY IN FRUIT TREES

D. Atkinson [1/]

ABSTRACT. Under the climatic conditions of the U.K. irrigation improves shoot growth and cropping of fruit trees and even under total herbicide management, trickle irrigation appears beneficial. Trickle irrigation, however, results in a concentration of roots in the limited region of soil near the nozzle. Several potential long-term problems which may result from this are discussed.

Although trickle irrigation improved the shoot growth of trees its effects upon root growth were more variable. Regardless of planting system, a relatively shallower root system was produced with irrigation.

The responses to alternative localised systems of water application, intermittent mist or fine sprinkler applications, which can be used idependently or in addition to trickle irrigation are discussed in relation to possible effects upon the root system.

INTRODUCTION

The climate of the U.K. is often regarded as wet. However, over 70 % of top fruit is grown in the South East and East of the country where low rainfall frequently results in fruit trees suffering from water stress. Attempts have been made to assess irrigation requirements from longterm climatic data /Hogg, 1967/ which suggest a need for irrigation in the main fruit growing area of the U.K. in 16-19 years out of 20 depending upon the deficit accepted before irrigation is applied. Fruit shows large responses to irrigation /Good and Hyrycz, 1964; Goode et al., 1978a; Atkinson and White, 1980/.

In the U.K., however, as in many other industrial countries, the amount of water available for irrigation is limited. In addition, high costs of abstraction and storage provide a strong incentive for economising. Trickle irrigation, which results in reduced evaporative losses from both soil and leaf surfaces, is an efficient means of applying water, particularly to a tree crop. Localised water applications, however, are likely to have effects on root distribution. This paper discusses the effects and consequences for the root system of the use of trickle irrigation in fruit and examines another system of localised water use, mist application, which also has the potential to increase the efficiency of water use.

1/ Pomology Department, East Malling Research Station, Maidstone, Kent, U.K.

THE IMPACT OF IRRIGATION

The effect of irrigating, from planting, trees of Cox/MM.106 grown in a narrow /0.6 m/ herbicide strip in grass so as to maintain a soil water potential in the range 0 to -0.03 MPa is shown in Table 1. Irrigation increased growth by 120 % and cropping by 86 % during the first five years.

A spacing trial planted adjacent to a root observation laboratory provided the opportunity to relate changes in soil water potential in the zone where root growth was most active /Atkinson and Wilson, 1980/ to changes in the rate of shoot growth in the different treatments. Over a wide range of spacings, shoot growth was reduced when the soil water potential in the principal zone of root activity fell below -0.03 MPa. Thus, while water may be available over the range 0 to -1.5 MPa potential /Veihmeyer, 1972/ the performance of young apple trees can be affected by small changes at the wet end of this range. This susceptibility to water stress may be related to the relatively low root length on fruit trees compared with arable crops /Atkinson and Wilson, 1980/ and consequently potentially high root system resistance.

Table 1. The effect of irrigation on cumulative shoot growth /m/ and crop /kg/ /per tree/ during the first five years of an orchard

Treatment	Shoot growth		Crop weight	
	Nitrogen application			
	High	Normal	High	Normal
Narrow strip	65	55	22.7	17.9
Narrow strip + water	125	142	35.7	39.9

THE EFFECT OF TRICKLE IRRIGATION ON ROOT DISTRIBUTION

Goode et al. /1978b/ investigated the effect of trickle irrigation on root distribution in apple. They found root density highest immediately under the trickle nozzle and root length many times that at a comparable position for an unirrigated tree. In the absence of irrigation roots were most numerous at 0-30 cm depth, while with irrigated trees root density was high down to 60 cm /Table 2/. Away from the zone of wetting the root density in the surface 30 cm soil was higher for the unirrigated trees /Table 2/. As the soil volume not irrigated was much the greater, the total amount of root would therefore have been reduced on the irrigated trees.

Table 2. Weights of roots in a 0.04 m^3 volume of soil on a trickle irrigated and an unirrigated tree of Cox/MM.104

Depth / cm/	Beside nozzle		90 cm from nozzle	
	Irrigated	Unirrigated	Irrigated	Unirrigated
0 - 20	22.8	23.4	13.9	30.0
30 - 60	25,5	13.5	7.6	8.2
60 - 90	10.8	10.8	8.6	5.2
90 - 120	13.7	5.9	5.2	4.5
Total	72.8	53.6	35.3	47.9

Table redrawn from Goode et al. /1978b/

In similar studies, Levin, Assaf and Bravdo /1979, 1980/ also found an increased concentration of roots beside the trickle point. The restriction of roots to a limited part of the soil volume can, however, cause problems. Huguet /1976/ found that where only one trickle point per tree was used an irregular root system was produced which may reduce tree stability and perhaps influence staking requirements.

Goode et al. /1978b/ investigated the nutrient content /mg/leaf/ of leaves taken from sides of the tree adjacent to and perpendicular to the trickle nozzles. They found higher contents of P, Ca, Mg in June, N, P and Ca in July and P in August, in leaves from the side of the tree adjacent to the nozzles. They did not investigate whether these changes were reflected in fruit mineral content. If this occurred, it would result in fruit of variable mineral composition for which it would be difficult to define an optimal storage regime. As a result large amounts of fruit could be stored for shorter periods than their mineral composition would justify.

As roots become restricted to limited parts of the soil volume with trickle irrigation it is particularly important to understand: 1) the effect of previous soil use on subsequent root exploitation of the same soil area, 2) the length of time over which roots continue to function in absorption and 3) effects on soil physical condition which are likely to influence the supply of water to the root surface.

Atkinson and Lewis /1979/ found that the growth of new root through an area containing older roots was substantially reduced. This might have been due to the development of localised dry zones around the older roots, to the accumulation of toxins, or to the presence of pathogenic organisms in the previously exploited area; a „self" specific apple replant disease effect. Irrespective of the mechanism, if new root growth is limited it will be vital for the growth of the tree to maximise the period that roots can continue absorption. It has often been assumed that only the apical areas of white roots can function in absorption. Recent results, for trees grown in water culture, /Atkinson and Wilson, 1979, 1980, Wilson and Atkinson, 1979/ have shown that a range of tree roots, both white and woody /secondarily thickened/, can absorb both water and mineral nutrients /Table 3/, although uptake is slightly higher by white roots. While therefore roots can clearly function after they develop secondary tissues, there is no information on how long they can continue to absorb or how relative performance is affected by the variable and sometimes adverse conditions in soil. This ability to continue functioning is likely to minimise the impact of factors restricting new growth.

Table 3. Absorption of water / ul mm^{-2} hr^{-1}/ and rubidium, as a tracer for potassium /n mol K mm^{-2} hr^{-1}/, by specific segments of F12/1 cherry roots on intact plants

Root type	Water	Rubidium
White	0.18 ± 0.04	0.061 ± 0.035
Woody	0.14 ± 0.01	0.035 ± 0.005

Table redrawn from Atkinson and Wilson /1980/

Recent nutrition studies /Atkinson and White, 1980; Priestley, 1980/, have shown that fruit trees can often be grown without the addition of mineral fertilizers, even of Nitrogen, this being due partly to the low demands of the tree which can thus be matched by soil reserves of P or K or by the mineralisation of N. Whether this will still be possible when a limited volume of soil, subject to substantial leaching, has to supply the total needs of the tree, is not clear.

INTERACTIONS WITH PLANTING ARRANGEMENT

Trees of Cox's Orange Pippin/M.9 were planted in spring 1977 at spacings of /a/ 0.6 x 2.4 m, /b/ 1.2 x 1.2 m, adjacent to the windows of a root observation laboratory and maintained with total herbicide management from planting. There were also some other spacing treatments not described here. Half the trees were supplied with irrigation via a trickle irrigation system so as to maintain the soil water potential within the wetted area above -0.03 MPa. In treatment /a/ the density and distribution of nozzles was such that approximately $^1/_3$ of the soil volume was wetted, i.e. similar to commercial practice while in treatment /b/ approximately 60 % was wetted, so this treatment was more similar to overall irrigation than to trickle. In both cases the nearest nozzle was 60 cm from the observation windows so the situation at the window would not accurately represent that in the vicinity of the nozzle.

Extension shoot growth was affected by both planting arrangement and irrigation /Table 4/. In the initial year, irrigation improved growth, averaged over all applied treatments, by 37 %. In the subsequent years the responses were smaller, 21 % in 1978 and 7 % in 1979. In all of these years, however, water stress was low. The trees began to crop in 1979. The effect of irrigation was generally slightly greater in treatemnt /a/.

Table 4. The effect of planting arrangement and irrigation on shoot growth /m/

Planting distances (m)		1977	1978	1979
/a/ 2.4 x 0.6	Irrigation	5.1	16.2	31.2
	Control	3.3	12.6	27.5
/b/ 1.2 x 1.2	Irrigation	4.0	16.9	34.5
	Control	3.4	13.9	31.4

Detailed analysis of the pattern of shoot growth showed that the rate of growth of individual shoots was similar irrespective of irrigation until mid-July but then decreased in the absence of irrigation while with irrigation it continued at almost the same high rate until mid-August. Given the variation which is normal between root laboratory windows in the initial year /Table 5/ there was little effect of either arrangement or irrigation on either the mean or maximum relative density of white root. The reduced root length recorded for the irrigated trees in treatment /b/ was associated with a delayed appearance of roots at the observation windows. In the year of planting irrigation had no effect on root distribution with depth.

Table 5. The effect of planting arrangement and irrigation on the length of white root (cm/observation window)

Planting distances (m)	Irrigation	Mean root length 1977	Mean root length 1978	Maximum root length 1977	Maximum root length 1978
(a) 2.4 x 0.6	Trickle	42	40	53	98
	Control	26	24	44	26
(b) 1.2 x 1.2	Trickle	12	28	28	96
	Control	15	40	45	141

A similar pattern, due mainly to the length of root present in the early part of the year /both as a result of early season growth and carry-over of root from 1977/, was shown for mean root length in 1978. In 1978 the maximum density of white root on the irrigated trees of treatment (a) was higher, although generally effects on root growth were relatively small. In 1978 roots were relatively deeper in the unirrigated treatments irrespective of planting arrangement. For example with treatment b most new root growth occurred at 40-60 cm in the absence of irrigation but at 0-20 cm depth with irrigation. At the end of the 1979 season /table 6/ in treatment (a) growth was absolutely and relatively higher below 80 cm.

This was also true for treatment (b). This situation is dissimilar to that found by Goode et al. /1978b/ for root distribution near the trickle nozzles. In the present study root distribution was effectively averaged over the whole soil volume rather than merely for the area adjacent to the nozzle. In addition the present trees were younger than those studied by Goode et al. 1978b. Thus trickle irrigation, even under the good growing conditions provided with total herbicide management, improves shoot growth while having much less effect on the amount of root growth but a consistent effect on distribution which may change with increasing age.

Table 6. The effect of planting arrangement and trickle irrigation on the distribution of white root with depth beside a root laboratory (cm/observation window) on 9th October 1978

Planting distance (m)	Irrigation	Root length at: 0-40	40-80	80-120
(a) 2.4 x 0.6	Trickle	14	15	7
	Control	9	7	10
(b) 1.2 x 1.2	Trickle	51	10	3
	Control	5	41	21

ALTERNATIVE SYSTEMS OF LOCALISED IRRIGATION

The loss of water by transpiration is governed by solar radiation, air temperature, humidity and wind speed. On most days transpiration occurs faster than the replacement of water by movement through the tree from the soil. As a result water deficits related to the rate of transpiration develop in the tree and there is a loss of turgor which can result in a diurnal pattern of shrinkage and re-expansion of tree trunks and fruits /Schröeder and Wieland, 1956/. This occurs because of restricted water flow in the roots, the soil or at the root soil interface. Thus, during the day as transpiration increases deficits progressively develop and a midday depression in leaf water potential /Powell, 1974/ is ubiquitous on sunny days, even in plants receiving optimum soil applied irrigation. These diurnal depressions in plant water potential can be large in relation to those /Hsiao et al., 1976/ which have been shown to affect growth adversely.

Although these depressions cannot be eliminated by adding water to the soil they can be affected by a reduction in transpiration, such as occurs when free water covers the leaf surface. Here the latent heat term of the leaf's energy budget can be satisfied by the evaporation of free water and the rate of transpiration is greatly reduced /Anon, 1979/. This effect can be brought about by the intermittent wetting of leaves using either mist or mini sprinkler nozzles. Effects of a treatment of this type have been described by Goode et al. /1979/ who obtained substantial increases in both growth and cropping using this technique.

The application of mist for two minutes in every thirty minutes, to trees grown under total herbicide management, increased leaf water potential, particularly in the middle of the day /Table 7/.

Head /1967/ investigated relationships between root and shoot growth and found that both shoot growth and cropping reduced root growth. Thus increased growth and cropping resulting from mist application together with reduced transpiration and so a lesser need for water supply from the roct system may result in a much smaller root system. This may influence the ability of this system to supply mineral nutrients, e.g. phosphorus, which could have important consequences in relation to the storage potential of the fruit produced.

Table 7. The efffect of trickle irrigation and trickle irrigation + mist on leaf water potential (MPa)

Treatment	Time (GTM) 8.00	10.00	12.00
	Water potential		
Control	-0.9	-1.2	-1.3
Trickle irrigation	-0.8	-1.0	-1.1
Trickle + mist	-0.6	-0.7	-0.8

CONCLUSIONS

Results from a number of experiments /Goode and Hyrycz, 1964; Goode et al., 1978a; Atkinson and White, 1980/, have shown that irrigation can substantially increase tree growth and cropping under U.K. conditions. The application of trickle irrigation, even under good growing conditions, can also increase growth /Table 4/. However, this system of water application may result in a concentration of roots in the limited soil volume beside the nozzle /Table 2/, which may lead to a range of new problems with respect to the maintenance of an „active root system" and fruit mineral composition.

In assessing the optimum siting or number of trickle nozzles the principal questions with respect to the root system are the size of root system needed in wet soil to supply the needs of the tree under varied conditions of evaporative demand and the proportion of the root system length able to function during the year. The first is related to the effects of rates of water flow on root resistances which will be the more important for a plant with a limited root length, and the second to the abilities of root of different ages to continue functioning under varied soil conditions.

The restriction of the root system to a fraction of the potential soil volume which seems likely to adversely affect new growth will make it vital to understand more clearly the accumulation of toxic products or organisms in the rhizosphere /i.e. specific apple replant disease/ and the factors which influence the ability of roots to function in absorption for extended periods. An understanding of the long term effects of both localised irrigation treatments, trickle and mist, on soil physical conditions, important both in relation to root growth and the ability of the soil to supply water and mineral nutrients, will perhaps be of even greater importance with these systems of irrigation than in many other situations.

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