QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

DIVISION OF PLANT INDUSTRY BULLETIN No. 782

INFLUENCE OF FIVE WATERING FREQUENCIES REGULATED BY TRICKLE IRRIGATION, ON THE GROWTH AND CROPPING OF APPLE TREES IN QUEENSLAND

by K. R. CHAPMAN, M.Agr.Sc., Q.D.H.(Hons.); and P. CREW, B.Agr.Sc.

SUMMARY

Water applied four times per week with trickle irrigation gave optimum growth and yields with Delicious and Granny Smith applies.

Growth trends were found in the first season to be related to irrigation frequency, and these trends were reflected in later cropping.

Mean yields at year 6 (all watering treatments combined) were 50·51 kg per tree for the variety Delicious and 39·13 kg per tree for the variety Granny Smith. Taking the mean of both varieties, the best watering frequency of four times per week gave 57·96 kg per tree at year 6. Unirrigated controls yielded 30·5 kg per tree (19·8 t ha^{-1}) compared with a district mean of 7·5 t ha^{-1} for unirrigated trees. The best treatment of 37·67 t ha^{-1} was just over five times the district average. A Merton 778 rootstock was used in the trial.

Unirrigated controls yielded twice the district average. This is attributed to the higher planting density, less severe training systems adopted, and better control over nutrition.

Implications relating to early growth, over-watering, tensiometers and slotted piezometer tubes are discussed in relation to practical aspects of irrigation management.

I. INTRODUCTION

Previous studies conducted in Granite Belt apple orchards of south-east Queensland have shown that plant water stress is severe and that growth and cropping are restricted even when evaporation and rainfall approximate normal values (Chapman 1968).

Goode (1967) emphasized the importance of early growth in governing the future cropping potential of apple trees, and Chapman (1973) has previously shown the large effects of plant water stress on growth of young glasshouse-grown apples.

This project was initiated as an extension of earlier glasshouse studies to the field, with the objective of demonstrating the effect of varying water regimes on the growth and cropping of Delicious and Granny Smith apples. Trickle irrigation was the technique chosen to provide these regimes.

C—66535

II. MATERIALS AND METHODS

Soil type

The soil in the gently sloping trial area was a podzolic coarse sandy loam of granitic origin 0·25 m deep overlying a coarse, sandy, slowly-permeable clay. Surface drainage was good.

Trial establishment

Four months before planting in the winter of 1969, banks were formed along intended tree rows. These banks were 1·5 m wide and 0·5 m above the surrounding soil giving an overall depth to the subsoil clay of 0·7 m. Agricultural lime at 5 t ha^{-1} was applied to raise pH to 6·5, and the whole area was fumigated with Diptrapex at a rate of 450 1 ha^{-1}.

Prior to planting in July, 40 kg ha^{-1} of phosphorus as superphosphate and 40 kg ha^{-1} of potassium, as muriate of potash, were applied to the 1·5 m strip along the tree rows, and cultivated into the soil.

Selected Granny Smith and Delicious apple trees grafted on Merton 778 rootstocks were visually graded for size, and planted out at a spacing of 4·6 x 3·3 m, giving a density of 650 trees per hectare and the trees headed to a single "whip" 1 m above ground.

An appropriately designed trickle-irrigation system was installed shortly after planting. The system had two outlets per tree 0·5 m each side of the tree butt. Each outlet had a flow rate of 9 $l\,h^{-1}$, and developed a wetted pattern approximately 1 m in diameter in the surface soil, with greater lateral spread in the region just above the sandy clay subsoil.

In spring approximately 19 kg ha^{-1} of phosphorus and 16 kg ha^{-1} of potassium were applied in conjunction with the establishment of a perennial rye grass and white clover sward between the banks.

Trial design

The trial was a 5 x 2 factorial design with four replicates in an incompletely randomized layout to accommodate the irrigation treatments. Internal and external guard trees were included. The following watering regimes were imposed on the two apple varieties, Granny Smith and Delicious—

(A) Watered five times per week
(B) Watered four times per week
(C) Watered three times per week
(D) Watered once per week
} with a similar total quantity of water
(E) No additional watering—natural rainfall only

Irrigation scheduling

Irrigation was scheduled from Class A pan measurements and rainfall. The quantity of water applied each week was determined by taking 70% of the weekly Class A pan evaporation loss for a predetermined foliage plan area (ground cover), and deducting rainfall received. The quantity so determined for each week was applied during the following week. Rainfalls of less than 2·5 mm were disregarded when operating the system, while larger falls were taken into account and the schedule adjusted accordingly. After rain the treatments recommenced after an evaporative loss of 10·0 mm had occurred.

The foliage cover plan areas for each tree were—

Season 1—1·5 m^2
Season 2—3·0 m^2
Season 3—6·0 m^2
Season 4—15·3 m^2
Season 5—15·3 m^2

Nutrition

Table 1 summarizes the levels of nitrogen, phosphate, potassium and agricultural lime applied each season.

TABLE 1

RATES (kg ha^{-1}) OF NITROGEN, PHOSPHATE, POTASSIUM AND AGRICULTURAL LIME APPLIED TO APPLE TREES EACH SEASON

Season	Nitrogen	Phosphate	Potassium	Lime
1	0	59	56	5 000
2	74	44	28	Nil
3	89	78	81	1 000
4	215	215	215	Nil
5	100	20	40	1 000

During the first three seasons, fertilizer was applied to the soil as urea, superphosphate and muriate of potash, in a 1·5-m strip along the rows. First season fertilizing was referred to previously. For the second and third seasons nitrogen, phosphate and potassium were applied in August and October, with additional nitrogen applied in November. The August and October dressings containing equivalent amounts of phosphate and potassium, and nitrogen applications were split into three equal amounts applied in August, October and November.

During the fourth and fifth seasons all trees received one-quarter of the nitrogen and potassium requirement for the season in September, and all of the phosphorus requirement in October. Irrigated trees received the remaining three-quarters of their nitrogen and potassium requirements in 30 weekly applications applied through the trickle system. Unirrigated trees received the remaining nitrogen and potassium in two equal applications in November and January.

The heavier application of all elements in the fourth season was designed to coincide with the late spring (November) application of a 2000 ppm Alar spray applied to all trees.

Minor elements, namely Zinc, Copper and Boron were applied as follows:

Zinc—applied in years 2, 3, 4 and 5 as a spray, 25 g l^{-1} of zinc sulphate heptahydrate.

Copper—applied in green tip sprays of Bordeaux mixture each year.

Boron—applied each year in early November as the polyborate spray, 3 g l^{-1}.

Weed, pest and disease control

Weed control was effected in the 1·5-m strip along each row. In the first year, only desiccants were used to control weeds, while in subsequent years a combination of residual herbicides applied in spring and spot-spraying in mid-summer with desiccants provided adequate control. Inter-row areas were mown at approximately 6-week intervals.

A regular spray programme in accord with the Granite Belt Deciduous Fruits Crop Protection Handbook was used throughout the trial and where necessary additional remedial measures were used to suppress powdery mildew, scab and mite outbreaks.

Training and Pruning

The training/pruning system utilized was similar to that described by McKenzie and Mouat (1963), with some modifications.

FIRST YEAR—Trees were headed off to 1 m whips after planting.

SECOND YEAR—Four laterals (in some cases eight) were tied down to 60° from the vertical position for Delicious and 90° for Granny Smiths. The laterals formed the four fruiting arms in each tier. Unwanted laterals were removed and the central leader tipped.

THIRD YEAR—Four more higher laterals were tied down as above, unwanted laterals removed, some tied laterals were tipped to remove fruit buds, cross-over shoots were removed and powdery mildew-infested wood cut out. The central leader was again tipped.

FOURTH YEAR—More laterals were tied down as before to provide fruiting arms, central leaders tipped, cross-over branches thinned out, powdery mildew removed and top laterals tipped to maintain central leader superiority.

FIFTH YEAR—Long side shoots on fruiting arms were shortened back to spurs. The central leader was cut back to a spur, fruiting bud or lateral to limit tree height. Cross-over branches were removed and split or poorly formed scaffold fruiting arms replaced with new lateral growth.

Tying down of fruiting arms was done in early Autumn, while the remainder of the pruning was carried out in mid-winter. Fruiting arms were selected to provide wide branch angles at the intersection with the main trunk.

Data collection

The following data were recorded:

(i) Rainfall
(ii) Evaporation
(iii) Water applied
(iv) Girth, measured annually
(v) Fruit numbers
(vi) Fruit weights

In addition, during the first growing season, weekly records were kept of total shoot growth and girth increment to depict the seasonal growth pattern in relation to variety and treatment.

III. RESULTS

The results of watering frequency and variety on various growth and yield data are contained in figures 1 to 6 and tables 2 to 13 inclusive.

Figures 1 to 4 demonstrate the effect of watering treatment on shoot growth and girth increment of both apple varieties during the first growing season.

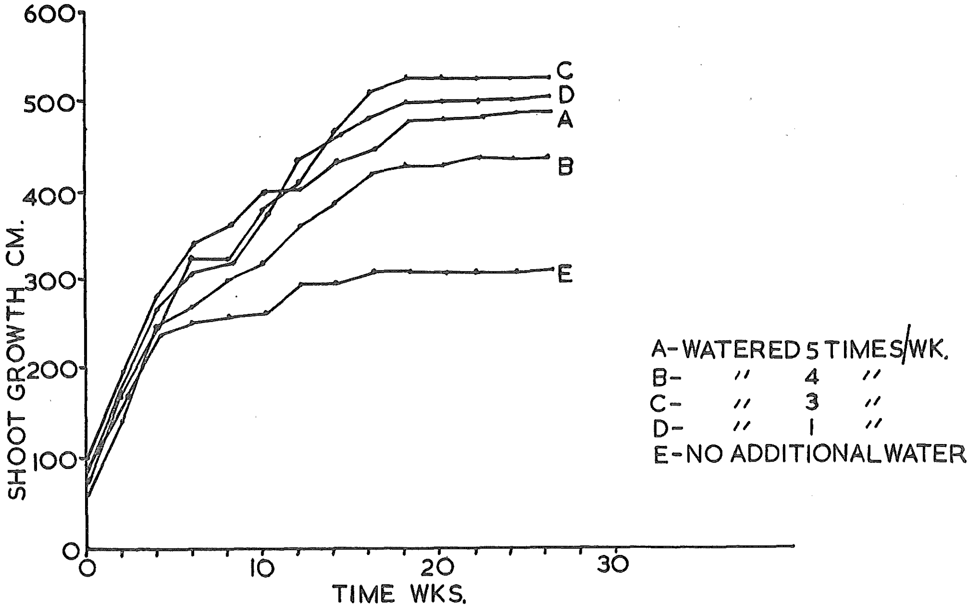

Figure 1. Shoot growth of Delicious apple trees as influenced by watering regime in the first season.

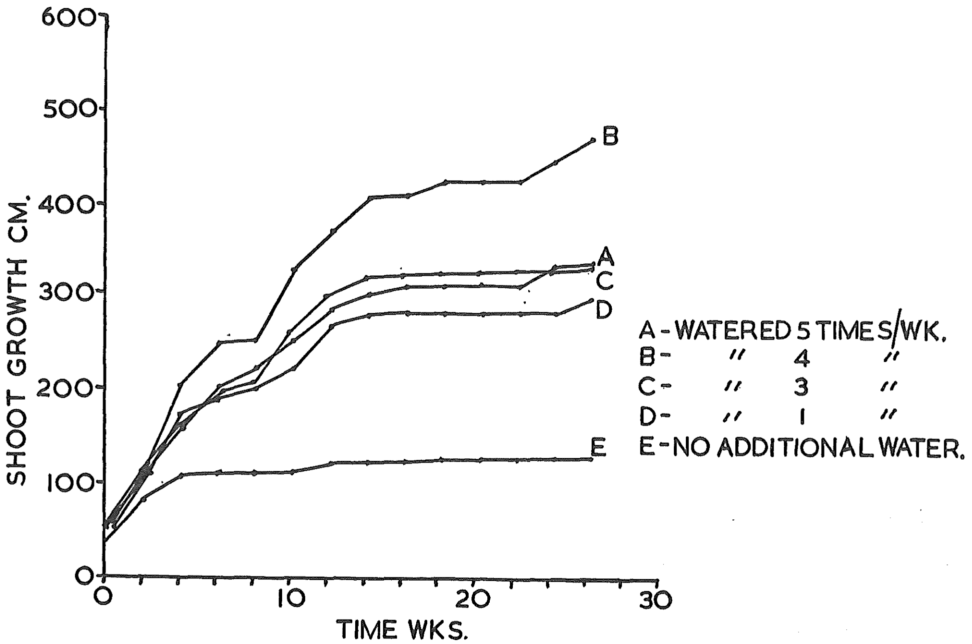

Figure 2. Shoot growth of Granny Smith apple trees as influenced by watering regime in the first season.

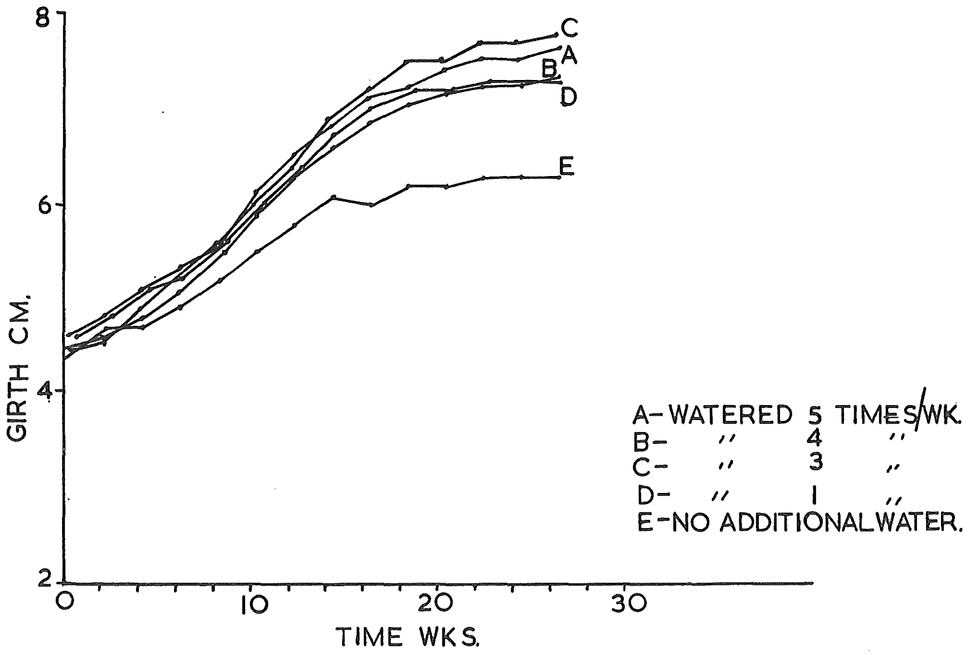

Figure 3. The effect of watering regime on girth increment of Delicious apple trees in the first season.

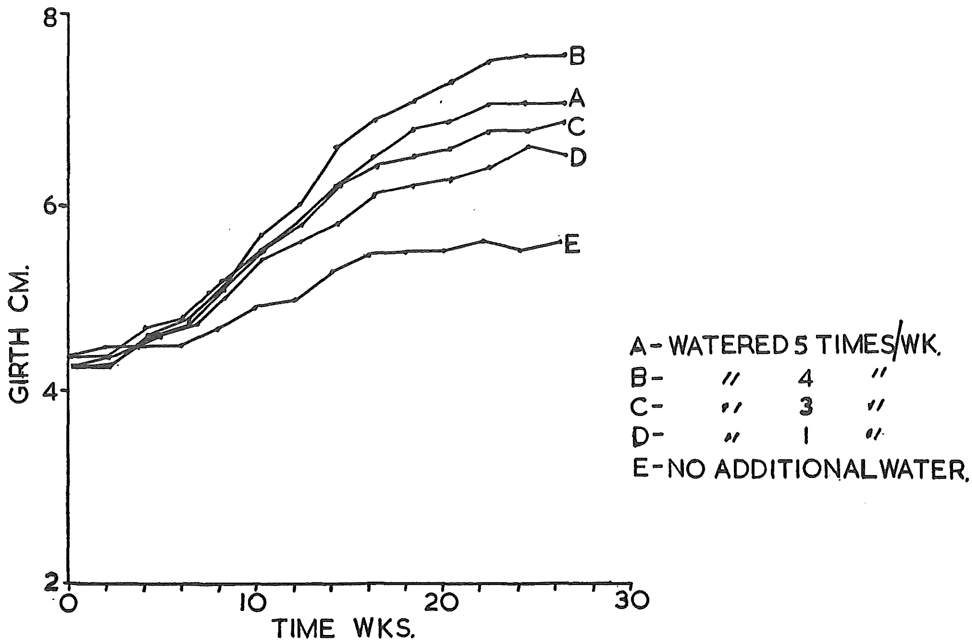

Figure 4. The effect of watering regime on girth increment of Granny Smith apple trees in the first season.

Data on treatment and variety effects on annual girths are shown in figures 5 and 6.

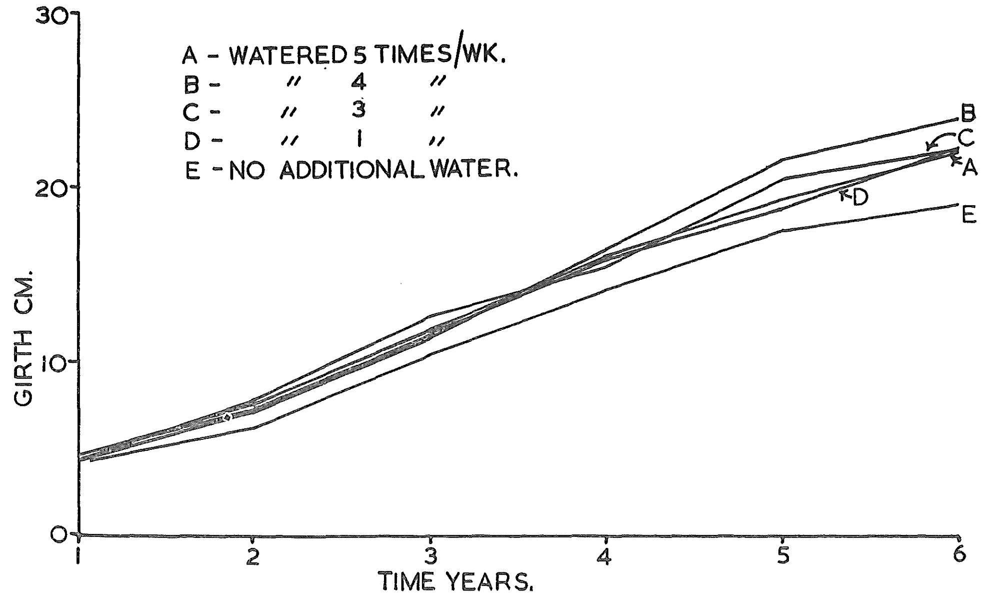

Figure 5. Annual girths of Delicious apple trees in relation to watering treatments.

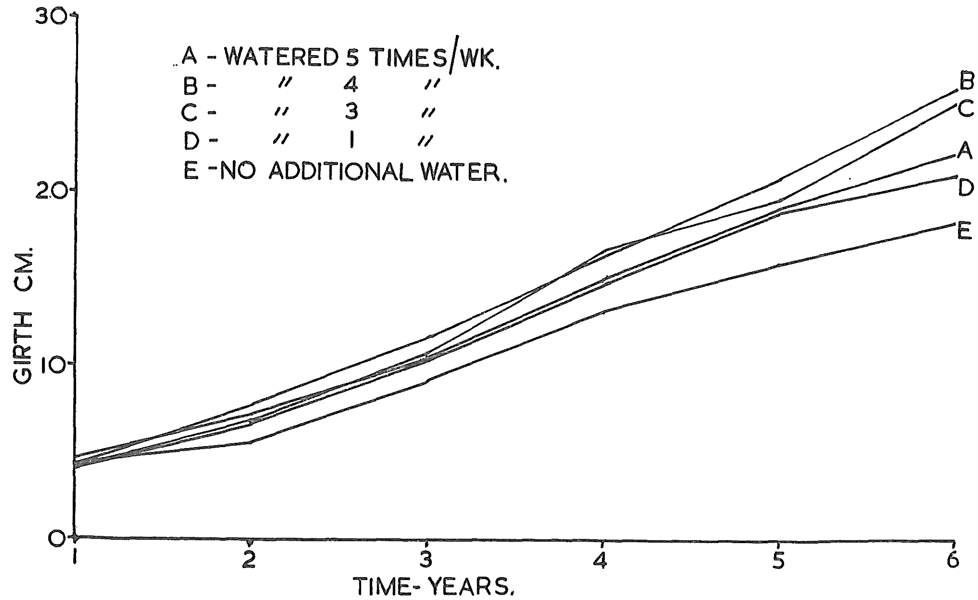

Figure 6. Annual girths of Granny Smith apple trees in relation to watering treatment.

Accumulated fruit yield data for years 3 to 6 inclusive are contained in tables 2 and 3 below.

TABLE 2

ACCUMULATED FRUIT YIELD (kg) FOR YEARS 3 TO 6 INCLUSIVE—VARIETAL EFFECTS

Variety		LSD	
Granny Smith	Delicious	5%	1%
55·10	79·43**	12·34	16·68

TABLE 3

ACCUMULATED FRUIT YIELD (kg) FOR YEARS 3 TO 6 INCLUSIVE—WATER REGIME EFFECTS

Water Regime					LSD	
A Five per Week	B Four per Week	C Three per Week	D One per Week	E Control	5%	1%
64·29	84·60	73·06	68·08	46·29	19·52	26·37

B* > A, E — C*>E — D*>E — B**>E — C**>E

Data on total fruit yield at year 6, accumulated fruit numbers, fruit weight index (accumulated fruit numbers per kilogram of accumulated crop) and butt cross-sectional area are shown in tables 4 to 11 inclusive. Table 12 shows data on accumulated fruit yield for cross-sectional area of butt.

TABLE 4

TOTAL FRUIT YIELD (kg) FOR YEAR 6—VARIETAL EFFECT

Variety		LSD	
Granny Smith	Delicious	5%	1%
39·13	50·51**	8·28	11·19

TABLE 5

TOTAL FRUIT YIELD (kg) FOR YEAR 6—WATER REGIME EFFECT

Water Regime					LSD	
A Five per Week	B Four per Week	C Three per Week	D One per Week	E Control	5%	1%
41·84	57·96	47·91	45·88	30·5	13·10	17·70

B*>A, E — C*>E — D*>E — B**>E

TABLE 6

ACCUMULATED FRUIT NUMBERS FOR YEARS 3 TO 6 INCLUSIVE—VARIETAL EFFECTS

Variety		LSD	
Granny Smith	Delicious	5%	1%
269·10	578·35**	76·61	103·51

TABLE 7

ACCUMULATED FRUIT NUMBERS FOR YEARS 3 TO 6 INCLUSIVE—WATER REGIME EFFECTS

Water Regime					LSD	
A Five per Week	B Four per Week	C Three per Week	D One per Week	E Control	5%	1%
391·75	528·88	468·13	418·50	311·38	121·16	163·71

B>A,E–C>E — B**>E

TABLE 8

FRUIT WEIGHT INDEX (ACCUMULATED FRUIT NUMBERS PER KILOGRAM OF ACCUMULATED CROP)—VARIETAL EFFECTS

Variety		LSD	
Granny Smith	Delicious	5%	1%
4·96	7·28**	0·35	0·47

TABLE 9

FRUIT WEIGHT INDEX (ACCUMULATED FRUIT NUMBERS PER KILOGRAM OF ACCUMULATED CROP)—WATER REGIME EFFECTS

Water Regime					LSD	
A Five per Week	B Four per Week	C Three per Week	D One per Week	E Control	5%	1%
5·87	6·12	6·16	6·06	6·39	N.S.	N.S.

TABLE 10

BUTT CROSS SECTIONAL AREA FOR YEAR 6 (cm²)—VARIETAL EFFECTS

Variety		LSD	
Granny Smith	Delicious	5%	1%
38·60	38·99	N.S.	N.S.

TABLE 11

BUTT CROSS SECTIONAL AREA FOR YEAR 6 (cm^2)—WATER REGIME EFFECTS

Water Regime					LSD	
A Five per Week	B Four per Week	C Three per Week	D One per Week	E Control	5%	1%
40·25	47·34	41·32	37·40	27·67	6·85	9·25

B* > A,D,E — C* > E — A* > E; B** > D,E — C** > E — A** > E — D** > E

TABLE 12

ACCUMULATED FRUIT WEIGHT PER CROSS SECTION AREA OF BUTT (kg cm^{-2}) AT YEAR 6

Variety	Water Regime					LSD	
	A Five per Week	B Four per Week	C Three Per Week	D One per Week	E Control	5%	1%
Delicious† ..	2·001	1·924	2·407	1·875	2·048	0·517	0·698
Granny Smith†† ..	1·223	1·639	1·194	1·688	1·284		

Variety x Water Regime Interaction significant at 1% level

$C^*_D > G_G, A_G, E_G, B_G$, $D_D - A_D, B_D, D_D, E^*_D > G_G, A_G, E_G$

† Subscript D, †† Subscript G

Finally, table 13 summarizes rainfall, evaporation and irrigation water applied during the course of the trial and in addition contains the foliage plan areas used to calculate the volume of water applied.

TABLE 13

EVAPORATION, RAINFALL AND IRRIGATION APPLIED DURING EACH GROWING SEASON (mm)—SEPTEMBER TO APRIL INCLUSIVE

Season	Evaporation	Rainfall	Irrigation	Foliage Plan Area (m^2)
1	1359	534	598	1·5
2	1218	727	487	3·0
3	970	396	429	6·0
4	1299	636	535	15·3
5	1038	384	442	15·3
Average Values ..	1258	499	..	..

With all data, because of the incomplete randomized design used to satisfy the trickle-irrigation layout, a measure of the variability across the trial site from East to West guardrows was taken. This confirmed no systematic error. Thus the analyses of variance applied are valid.

IV. DISCUSSION

In non-irrigated plots shoot growth rates fell behind those of irrigated plots as early as 4 to 6 weeks after treatments were imposed (figures 1 and 2). Girth increment showed a similar trend but the divergence in growth rate was less, particularly for Delicious (figures 3 and 4).

The collection of data on shoot and girth increment commenced when treatments started in late November, well after the initial spring (mid-October) growth period. Therefore, it is unlikely that growth measured after treatments commenced would have resulted from carbohydrate reserves (Priestley 1963) and the effects are the apparent result of water stress on leaf growth and photosynthesis. These results are in contrast to those obtained in a glasshouse (Chapman 1973) where treatments commenced prior to the initial growth period, and the divergence in growth rates due to watering frequency did not appear until the eighth to tenth week. In this case early growth made on reserves masked the effect of treatments for a considerable period.

Total shoot growth at the end of the first growing season was significantly greater for Delicious than Granny Smiths and all irrigation treatments produced significantly more shoot growth than controls (figures 1 and 2). Similar effects were noted for the percentage girth increment over the first season, although no varietal differences were apparent.

While no differences between the irrigation frequencies were found with either variety for both shoot growth and girth increment at the end of the first season, a trend was apparent for the Granny Smith variety, where watering four times per week (B) tended to be significantly better than other watering frequencies.

While no total-dry-weight data are available in this trial, it is of interest to note that in previous studies in the glasshouse girth increment provided a closer relationship to total-dry-weight increment than did total shoot growth (Chapman 1973).

It is expected that in the field a similar relationship exists, simply because girth increment is less likely to be confounded by growth made on reserves than is shoot growth. Again previous work in 1973 showed that apple trees can have negative relative growth rates under water-stress conditions, even though the plant shows shoot growth increment. Such plants have changed their form only, and have not grown in the sense of making a positive dry-weight increment.

Total shoot growth data were not recorded in later years but annual girths were continued as shown in figures 5 and 6. The dominance of the irrigated plants was maintained and the B treatment showed the greatest percentage increase in girth from years 1 to 6. Varietal differences were not present, but with both varieties the mid-range watering frequencies of three and four times per week were better than the most frequent and least frequent waterings. Thus an optimal girth response to watering frequency was recorded, with some growth suppression at high and low watering frequencies.

The effects of watering frequencies on accumulated fruit yields (tables 2 and 3) differed from those of girth response, in that varietal differences were apparent (table 2). However, treatments giving highest yields were again B and C, which demonstrates the connection between early growth and later cropping (Goode 1967).

Figures 7 and 8 show some variability in annual fruit weight, but this is to be expected at the commencement of the cropping cycle in the early years of establishment. However, the figures still reflect the trend towards greater annual yields with the irrigated plants, a trend developed in the first cropping year. Varietal responses were different in that the B treatment showed a trend towards dominance in the first cropping year with Granny Smiths and still maintained this position at the sixth year. However, with Delicious the dominance of the B treatment did not appear until year 6, with the C treatment being better in the early cropping years.

Total yields attained in year 6, (tables 4 and 5) significantly exceeded those of the Granite Belt District average for mature trees. Mean yields at year 6 (all watering treatments combined) were 50·51 kg per tree (32·83 t ha^{-1}) for the variety Delicious, and 39·13 kg per tree (25·43 t ha^{-1}) for the variety Granny Smith. Taking the mean of both varieties, the best watering frequency of four times per week gave 57·96 kg per tree (37·67 t ha^{-1}) at year 6. Unirrigated controls yielded 30·5 kg per tree (19·8 t ha^{-1}) compared with a district mean of 7·5 t ha^{-1} for unirrigated trees. Tables 4 and 5 were used to calculate the above values and show the dominance of the B treatment and the Delicious variety at year 6.

As the yields are for trees only 6-years old, it is expected that they will peak at much higher levels than those listed.

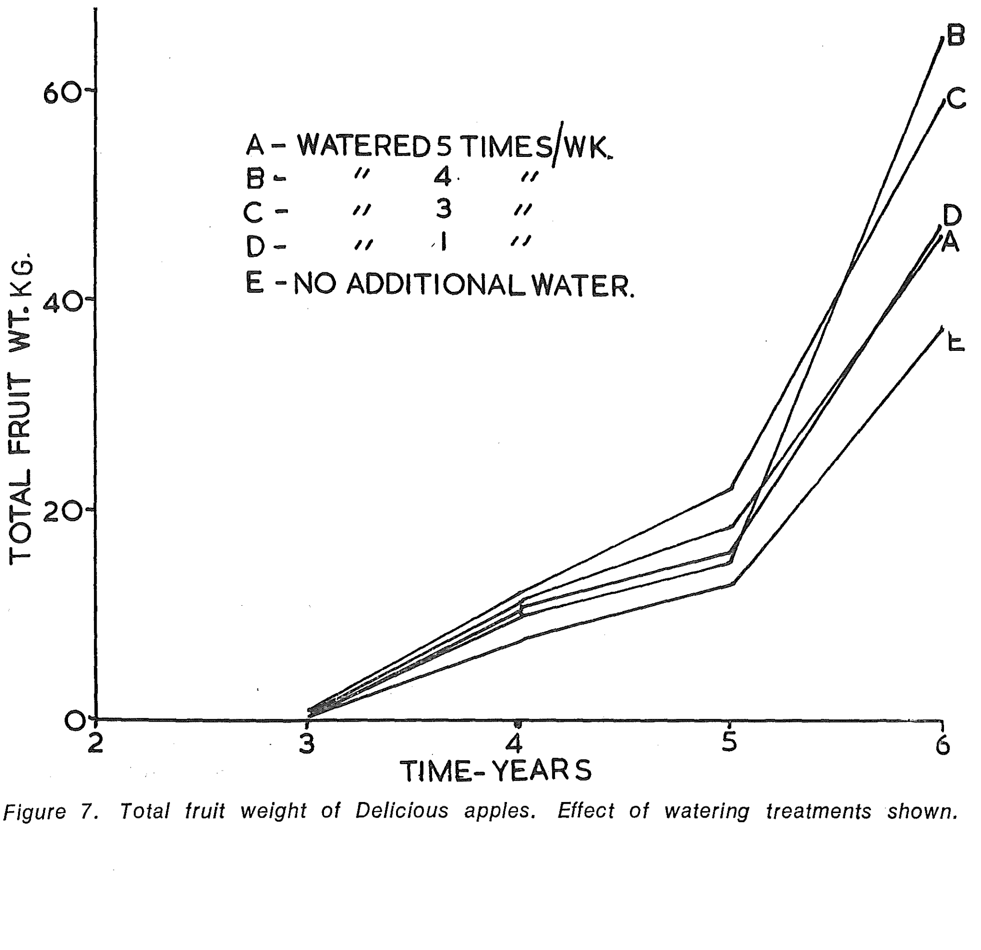

Figure 7. Total fruit weight of Delicious apples. Effect of watering treatments shown.

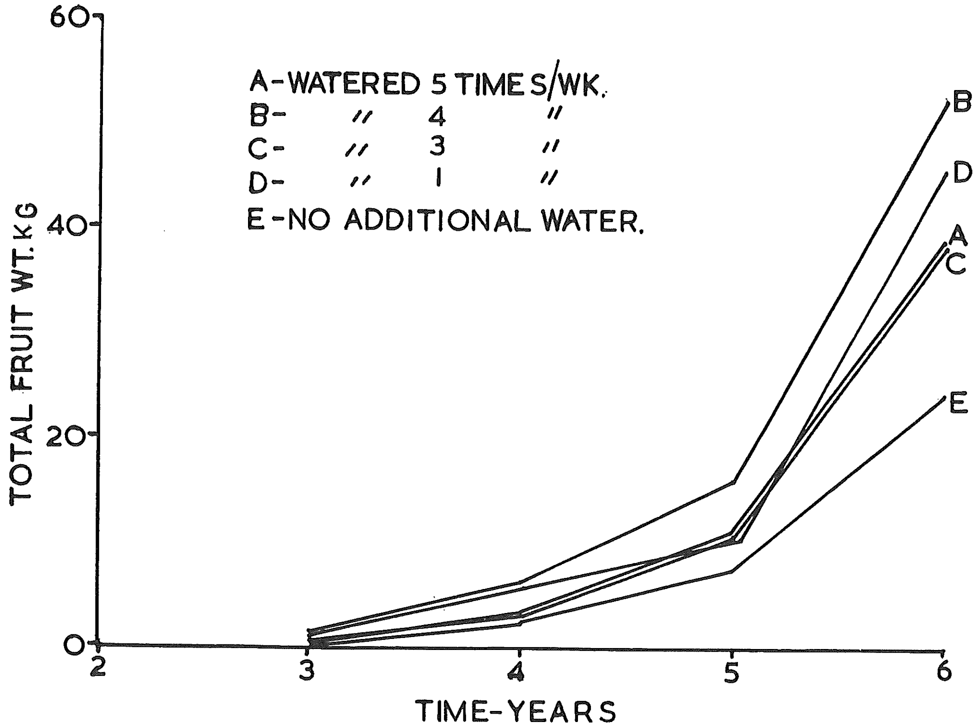

Figure 8. Total fruit weight of Granny Smith apples. Effect of watering treatment shown.

Yields are higher for the unirrigated trial plants, than those of the district. This is attributed to the higher planting density (650 trees per hectare compared with the district mean of 270 trees per hectare) and the better overall management of trial plots and the less severe training system adopted, since the rootstock used was similar.

Accumulated fruit numbers (tables 6 and 7) for the cropping years 3 to 6 show that yield increases with irrigation have been brought about by increased fruit numbers, and this is accentuated for the Delicious variety. Examination of the fruit-weight index (tables 8 and 9) shows that Delicious had lighter fruits than Granny Smiths. However, the fruit-weight index was similar for all treatments suggesting that unirrigated plants adjusted crop loading by way of fruit-bud initiation, fruit set and tree size.

Cross-sectional butt area for year 6 was constant between varieties, as was the case for girth increment in the first season and girth increase for years 1 to 6. Westwood and Roberts (1970) found a linear relationship between butt or trunk cross-sectional area and total above-ground weight of apple trees. They also contended that these butt measurements can be used to estimate potential bearing surface of any orchard tree provided it has not been pruned heavily to prevent crowding.

As the cross-sectional area of butt was significantly greater for all irrigated treatments (table 11), then the potential bearing surface of these treatments would also be greater, in view of the light pruning system adopted. Thus the bigger and heavier yielding irrigated trees could be expected to continue bearing heavier crops in the future.

Accumulated fruit weight per cross-sectional area of butt is a calculation of yield efficiency (Westwood and Roberts 1970) or an index of fruitfulness. This index showed an interaction between variety and irrigation treatments (table 12), with the largest values for Delicious watered three times per week and the smallest for Granny Smiths watered three times per week. The effect of variety on this index is to be expected and is a reflection of fruitfulness and precocity of bearing of the varieties concerned in this trial on the Mertan 778 rootstock (figures 7 and 8). However the influence of irrigation frequency is of interest as it seems that the frequency of irrigation has had a slight effect on fruitfulness and thus yield, beyond the establishment of larger trees in the first season which tended to set the overall yield trend. Just how this effect of watering frequency on fruitfulness is mediated beyond the establishment year is unclear, but factors relating to tree size and precocity of bearing as well as leaching of nutrients have probably played a role.

Table 13 shows that in the five growing seasons, above-average evaporation losses occurred in two, and below-average rainfall was recorded for a further two (but not corresponding) seasons. Because of these climatic effects the differences between irrigated and non-irrigated treatments are probably larger than would be expected if normal seasons had prevailed throughout.

Many factors influence frequency of irrigation including those pertaining to the plant, the soil, the climate and the irrigation system itself. These factors are numerous and complex, interacting under given conditions to produce the integrated end result. In the trial we made no attempt to isolate or study these factors, but quite obviously there is considerable scope for detailed studies in this area.

The trial results show that there is likely to be an optimum response to trickle-irrigation frequency even at a very early stage in the life of an apple tree, thereby demonstrating a fine line of distinction between under and overwatering on this particular and common granite soil. The effects of overwatering were confirmed by a subsequent trickle-irrigated close-planted apple trial adjacent to this trial area, which showed water-logging at an irrigation frequency of five times per week. These trees were restored to health by reducing the frequency from five to three times per week, reducing the amount of water applied, and by moving the outlets to the outside of the canopy.

As a point of interest, in this project we found that soil moisture tensiometers or osmotic tensiometers were of little or no use at all in gauging frequency or amounts of water to apply, since no idea could be gained of the quantity of water passing through the soil. Rawlings (1973) elaborates on such findings.

Finally, we have found that observation or test wells (slotted piezometer tubes) are an invaluable guide to monitoring for overwatering with trickle systems. Underwatering is more difficult to monitor, but the use of early-morning infiltration scoring (Chapman 1970) does provide a measure of leaf water potentials in apples, which are predominantly influenced by soil water stress at this time of the day.

V. ACKNOWLEDGEMENTS

The authors wish to thank Biometry Branch which provided assistance with statistical analyses, and the staff at the Granite Belt Horticultural Research Station, Applethorpe, for their help with much of the trial work.

REFERENCES

CHAPMAN, K. R. (1968).—Irrigation requirements of apple trees—field variation in plant water status and its measurement. Master of Agricultural Science Thesis, University of Queensland.

CHAPMAN, K. R. (1970).—Plant water status of apple trees and its measurement in the field. 4. Stomatal aperture, determined by infiltration scoring as an index of leaf water potential. *Queensland Journal of Agricultural and Animal Sciences* 27:219-224.

CHAPMAN, K. R. (1973).—Effect of four water regimes on performance of glasshouse-grown nursery apple trees. *Queensland Journal of Agricultural and Animal Sciences* 30:125-135.

GOODE, J. E. (1967).—Perennial crops. *In* 'Crop Responses to Water at Different Stages of Growth'. Commonwealth Bureau of Horticultural Plantation Crops Research Review 2.

McKENZIE, D. W., and MOUAT, H. M. (1963).—Semi-intensive planting and orchard management—A new approach to apple growing. Supplement to *The Orchardist of New Zealand.* March, 1973.

PRIESTLEY, C. A. (1963).—The carbohydrate resources of young apple trees under four levels of illumination. *Annals of Botany New Series* 27:435.

RAWLINGS, S. L. (1973).—Principles of managing high frequency irrigation. *Proceedings. Soil Science Society of America* 37:626-629.

WESTWOOD, M. N., and ROBERTS, A. N. (1970).—The relationship between trunk cross-Sectional area and weight of apple trees. *Journal of the American Society for Horticultural Science* 95:28-30.

(Received for publication 30 May 1977.)

The authors are officers of the Queensland Department of Primary Industries, Mr P. Crew is stationed at the Granite Belt Horticultural Research Station, Applethorpe and Mr K. R. Chapman formerly stationed at Applethorpe is now at the Maroochy Horticultural Research Station, Nambour, Q. 4560.