HORTICULTURE RESEARCH INTERNATIONAL

STOCKBRIDGE HOUSE

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SWEET PEPPERS: FACTORS AFFECTING FRUIT QUALITY

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Summary

Three varieties of sweet pepper harvested red were grown under 4 irrigation regimes, with and without root zone warming in an experiment to evaluate the effect of irrigation and root zone warming on fruit quality.

Root zone warming reduced fine net cracking and increased fruit calcium levels. There was some reduction in Blossom-end rot.

The perlite reservoir system gave the highest yields and increased fruit calcium levels. Blossom-end rot was slightly lower from this treatment in some months.

Fruit grown with standard day irrigation only had poor shelf life.

Objective

To evaluate the effects of irrigation regime and root zone warming on sweet pepper fruit quality, particularly Blossom-end rot.

Introduction

Long season hydroponic sweet pepper production has increased in the UK. Although it is now possible to produce high yields, fruit quality is often reduced by defects such as Blossom-end rot and fine net cracking. These faults cause equal problems for the Dutch pepper industry. Plant breeders have introduced new varieties aimed at reducing fine net cracking and improvements can be seen. Blossom-end rot is also influenced by variety but is closely related to calcium movement in the plant. Factors influencing calcium movement are likely to affect Blossom-end rot

occurrence. The growing environment and the availability of adequate water and nutrients, plus the ability to translocate them to the fruit play an important role.

Root zone warming should improve root activity and therefore influence nutrient and water uptake.

Materials and Methods

Varieties:	Cubico (PTR) Lambada (RZ) Mazurka (RZ)
Sowing Date:	20 November
Blocking on Date:	3 December
Planting Date:	15 January (Plants moved to growing house and slab contact made)
Root Zone Warming Treatments Started:	15 January
Irrigation Treatments Started:	20 May
First Harvest:	11 April
Final Harvest:	14 November All fruit harvested red
Plant Population:	11,000 plants/acre (90 cm row spacing)

Training: 2 leaders per plant
Sideshoots stopped at 1 fruit plus 2 leaves.

Pollination: Bumble bees from March to October

Environment Temperature:
23 °C day, 21 °C night, 27 °C vent until crown fruit aborted, then gradually reduced to 21 °C day, 19 °C night, 26 °C vent.

CO_2: 1000 vpm until end of April then 350 vpm

Treatments

1. Root zone warming, rockwool, standard day watering, no night watering.

2. Root zone warming, rockwool, standard day watering plus night watering.

3. Root zone warming, rockwool, day watering only, but with extra waterings to provide the same 24 hour volume as 2.

4. Root zone warming, perlite with reservoir, irrigation as in treatment 2.

5. No root zone warming, rockwool, standard day watering, no night watering.

6. No root zone warming, rockwool, standard day watering plus night watering.

7. No root zone warming, rockwool, day watering only, but with extra waterings to provide the same 24 hour volume as 6.

8. No root zone warming, perlite with reservoir, irrigation as in treatment 6.

Irrigation Regimes

Standard Day:	Time interval	2 hrs
	Light limit	100 J
	Target run-off	30%
	Irrigation per watering	150 ml/plant
	Daily maximum	5 l/plant

Standard Day plus Night: Standard day plus 4 night waterings, equally spaced through the night.

Extra Day: Standard day plus 4 extra waterings at 7, 8, 9 and 10 am.

Root Zone Warming

Temperature setpoint = 24 °C

Experimental Design

The trial comprised of 24 treatments in a 2 root zone warming x 4 irrigations x 3 varieties factorial structure. Two blocks of 12 double rows were available, each divided into three plots with 20 plants per plot. Irrigation and root zone warming treatments were applied to whole rows on the basis of a block design and the three varieties were randomised within rows.

Records

Fruit was harvested once a week and graded for size and quality. Weight of fruit with Blossom-end rot and fine net cracking was recorded.

Applied and slab solution nutrient levels were monitored daily and analysed weekly. Irrigation volumes applied and running-off were monitored daily.

The calcium content of ripe fruit was measured twice during the season.

Fruit Assessments:

Samples of 6 fruit per treatment were tested for shelf life and detailed fruit quality, 5 times, at monthly intervals.

Fruit Picked	Assessment Dates		
9 May	10 May	13 May	16 May
20 June	21 June	24 June	27 June
18 July	19 July	22 July	25 July
22 August	23 August	27 August	29 August
3 October	4 October	7 October	10 October

Shelf Life Room Conditions: 20 °C, 50-60 % RH
12 hours light per 24 hrs

The following fruit quality factors were assessed:

Flecking: Percentage of surface area affected.

Shrivelling: Score 0-9; where 0 is unaffected and 9 is severe.

Calyx Lifting: Score 0-9; where 9 is severe.

Fine Net Cracking: Score 0-9; where 9 is severe.

Weight Loss: % weight loss over 7 days under shelf life conditions.

Sugar Content: % Sucrose, juice squeezed from fresh fruit on to a hand held refractometer.

Fruit Shine: 3 assessments. Score 0-9; where 0 is poor and 9 is good.

Overall Attractiveness: 3 assessments. Score 0-9; where 9 is good. Includes shape, freedom from blemishes including the individual factors shown above.

Wall Thickness (mm): Measured at the centre of the locule at the beginning and end of the shelf life period.

Fruit Firmness: At beginning and end of shelf life period. Measured using a tensile strength machine.

a. Whole Fruit - Pressure (Newtons) required to deflect the wall of a fruit 8 mm when laid on its side.

b. Pressure (Newtons) required to snap a piece of flesh 5 cm long x 2.5 m wide when stood upright on its narrow end.

Results

Fruit Yield and Quality

Both irrigation regime and variety had significant effects on total marketable yield (Table 1). The perlite reservoir system gave the highest yield of 19.5 kg/m^2, significantly higher than the treatments receiving standard day watering and day and night watering (Table 1). The treatment receiving extra day watering gave the second highest total yield.

The same yield pattern was recorded in August, when differences again reached the 5% significance level, and in October/November. The remainder of the months showed inconsistent yield differences between irrigation treatments.

Differences between varieties were recorded throughout the whole season. Cubico gave a total yield of 20.2 kg/m^2, which was significantly higher than both Lambada and Mazurka. This variety gave the highest weight in every month except April. Yield differences between Mazurka and Lambada were smaller but Mazurka generally gave higher yields, particularly in June and September.

Root zone warming had no significant effect on fruit yield except in the first 2 months. In April use of root zone warming gave a negative effect but in May there was a significant positive benefit.

Table 1: Marketable Yield (kg/m^2)

	Apr	May	Jun	Jul	Aug	Sep	Oct/ Nov	Total
Irrigation								
Standard Day	0.46	4.55	2.72	1.86	3.78	2.28	2.94	18.59
Day + Night	0.44	4.79	2.76	1.69	3.97	2.20	2.97	18.82
Extra Day	0.39	4.72	2.88	1.76	4.03	2.30	3.08	19.17
Reservoir	0.43	4.85	2.76	1.84	4.23	2.10	3.28	19.50
SED (13 df)	0.077	0.197	0.101	0.115	0.131	0.128	0.167	0.280
LSD (P = 0.05)	-	-	-	-	0.28	-	-	0.60
Significance	NS	NS	NS	NS	*	NS	NS	*
Root Zone Warming								
With RZW	0.37	4.88	2.78	1.71	3.98	2.17	3.11	19.00
Without RZW	0.49	4.57	2.78	1.86	4.02	2.27	3.03	19.04
SED (13 df)	0.056	0.139	0.071	0.081	0.093	0.090	0.118	0.198
LSD (P = 0.05)	0.12	0.30	-	-	-	-	-	-
Significance	*	*	NS	NS	NS	NS	NS	NS
Varieties								
Cubico	0.18	5.18	2.92	1.99	4.12	2.42	3.42	20.22
Lambada	0.54	4.45	2.60	1.72	3.88	2.02	2.95	18.16
Mazurka	0.57	4.54	2.82	1.65	4.02	2.22	2.84	18.67
SED (32 df)	0.059	0.116	0.096	0.081	0.118	0.087	0.089	0.302
LSD (P = 0.05)	0.12	0.24	0.20	0.16	-	0.18	0.18	0.61
Significance	***	***	**	***	NS	***	***	***

Key
*** Significant at 0.1% level
** Significant at 1% level
* Significant at 5% level
NS Not Significant

The irrigation treatments did not produce a significant effect on fruit quality over the season as a whole (Table 2), although in September and October/November when percentage Class I was low the reservoir system gave some benefit in terms of improved fruit quality.

Root zone warming gave a small overall increase in percentage Class I fruit although differences in individual months were insignificant. The greatest effect was seen in April and May when the difference in root temperature between treatments was highest (Figure 13).

The greatest differences in fruit quality were between varieties. Mazurka gave a significantly higher percentage Class I fruit in every month except October/November. Differences between Cubico and Lambada were inconsistent but overall Lambada gave more high quality fruit.

The irrigation treatments had no significant effect on production of Class II fruit (Table 3). The day and night watering plots gave a particularly high figure in April but this was unrelated to treatment since irrigation treatments did not begin until the following month.

Use of root zone warming gave an overall decrease in yield of Class II fruit with the most significant effects in May and September.

Between the varieties there was a consistent pattern in production of Class II fruit over the whole season. Cubico gave significantly more downgraded fruit than the other 2 varieties. Lambada was worse than Mazurka although the difference was small.

Table 2: Percentage Class I Fruit (by weight)

	Apr	May	Jun	Jul	Aug	Sep	Oct/ Nov	Average
Irrigation								
Standard Day	95.5	88.7	87.7	77.8	72.7	57.3	59.9	76.1
Day + Night	89.6	89.0	89.6	77.7	73.8	55.2	58.7	76.3
Extra Day	92.4	87.9	89.3	81.4	70.0	55.7	58.0	75.2
Reservoir	96.1	87.3	89.5	79.1	74.9	61.2	64.3	77.7
SED (13 df)	2.18	1.33	1.05	3.50	2.59	3.09	3.49	1.22
LSD (P = 0.05)	4.7	-	-	-	-	-	-	-
Significance	*	NS	NS	NS	NS	NS	NS	NS
Root Zone Warming								
With RZW	94.1	89.3	88.6	78.8	73.8	59.4	61.5	77.2
Without RZW	92.7	87.2	89.4	79.1	71.9	55.3	58.9	75.5
SED (13 df)	1.54	0.94	0.74	2.48	1.83	2.18	2.47	0.86
LSD (P = 0.05)	-	2.0	-	-	-	-	-	1.8
Significance	NS	*	NS	NS	NS	NS	NS	*(7%)
Varieties								
Cubico	88.1	89.9	89.4	78.0	67.5	55.1	52.1	72.4
Lambada	95.2	86.9	86.8	74.8	72.6	52.5	65.2	75.7
Mazurka	96.8	92.9	90.9	84.2	78.3	64.5	63.4	81.0
SED (32 df)	2.42	1.04	1.01	1.73	1.41	2.25	1.70	0.72
LSD (P = 0.05)	4.9	2.1	2.1	3.5	2.8	4.6	3.5	1.5
Significance	**	***	***	***	***	***	***	***

Table 3: Percentage Class II Fruit

	Apr	May	Jun	Jul	Aug	Sep	Oct/ Nov	Average
Irrigation								
Standard Day	4.1	7.9	8.4	16.7	13.1	18.3	24.1	13.5
Day + Night	9.8	8.0	6.8	17.0	14.4	23.4	24.5	14.3
Extra Day	5.7	9.3	7.0	13.0	15.5	19.8	25.2	14.3
Reservoir	3.1	8.8	6.3	15.5	14.2	18.0	22.7	13.5
SED (13 df)	2.38	0.96	1.25	2.44	1.68	2.62	2.46	0.65
LSD (P = 0.05)	5.1	-	-	-	-	-	-	-
Significance	*(6%)	NS	NS	NS	NS	NS	NS	NS
Root Zone Warming								
With RZW	5.5	7.8	7.4	16.2	13.5	17.9	23.6	13.4
Without RZW	5.8	9.2	6.8	15.0	15.1	21.9	24.6	14.5
SED (13 df)	1.68	0.68	0.88	1.72	1.19	1.85	1.74	0.46
LSD (P = 0.05)	-	1.5	-	-	-	4.0	-	1.0
Significance	NS	*(6%)	NS	NS	NS	*	NS	*
Varieties								
Cubico	10.6	11.5	7.1	17.8	18.8	23.1	35.3	18.3
Lambada	3.7	9.1	9.2	18.0	13.3	21.4	17.2	13.3
Mazurka	2.7	4.8	5.1	10.9	10.8	15.2	19.8	10.1
SED (32 df)	2.35	0.76	0.90	1.61	1.38	1.90	1.30	0.64
LSD (P = 0.05)	4.8	1.5	1.8	3.3	2.8	3.9	2.6	1.3
Significance	**	***	***	***	***	***	***	***

Production of waste fruit was not affected by the irrigation treatments (Table 4). Root zone warming only had an effect in April and May when the percentage waste was reduced.

Lambada produced more waste fruit in total than Cubico and Mazurka which were similar. Monthly differences were inconsistent.

Table 4: Percentage Waste Fruit

	Apr	May	Jun	Jul	Aug	Sep	Oct/ Nov	Average
Irrigation								
Standard Day	0.5	3.5	4.0	5.5	14.2	24.4	16.0	10.4
Day + Night	0.6	2.9	3.6	5.3	11.9	21.4	16.7	9.4
Extra Day	1.9	2.8	3.6	5.6	14.4	24.4	16.8	10.4
Reservoir	0.7	3.9	4.1	5.4	10.9	20.8	13.1	8.8
SED (13 df)	0.49	0.79	0.59	1.34	1.72	2.75	1.89	0.85
LSD (P = 0.05)	1.1	-	-	-	-	-	-	-
Significance	*	NS	NS	NS	NS	NS	NS	NS
Root Zone Warming								
With RZW	0.4	2.9	3.9	5.0	12.8	22.7	14.9	9.5
Without RZW	1.4	3.6	3.7	5.9	13.0	22.8	16.5	10.0
SED (13 df)	0.34	0.56	0.42	0.94	1.22	1.94	1.34	0.60
LSD (P = 0.05)	0.7	-	-	-	-	-	-	-
Significance	**	NS	NS	NS	NS	NS	NS	NS
Varieties								
Cubico	1.2	3.6	3.5	4.2	13.7	21.8	12.5	9.3
Lambada	1.0	3.9	4.0	5.3	14.0	26.1	17.6	11.0
Mazurka	0.5	2.3	4.0	5.6	10.9	20.1	16.8	8.9
SED (32 df)	0.45	0.60	0.67	1.00	1.06	1.68	1.19	0.50
LSD (P = 0.05)	-	1.2	-	2.0	2.2	3.4	2.4	1.0
Significance	NS	*	NS	*	*	**	***	***

The percentage fruit with Blossom-end rot was calculated by weight. From April to July the amount recorded was very low but from August onwards the problem was severe.

The differences between the irrigation treatments did not reach the 5% significance level but Table 5 shows that in August and September when Blossom-end rot was most prevalent the day and night irrigation treatment and the perlite reservoir system gave the lowest levels.

Use of root zone warming at 24 °C decreased the amount of fruit affected by Blossom-end rot in the early part of the season.

The average for the whole season shows that Cubico and Mazurka had equal susceptibility to Blossom-end rot although figures for the individual months show that they were not affected at the same time.

Lambada was the most susceptible variety and high levels of Blossom-end rot from July onwards made it very highly significantly different from Lambada and Cubico when considering the all season average.

Table 5: Percentage Fruit with Blossom-end Rot

	Apr	May	Jun	Jul	Aug	Sep	Oct/ Nov	Average
Irrigation								
Standard Day	0.5	1.1	1.5	2.7	12.5	22.0	11.0	7.7
Day + Night	0.6	0.7	1.0	2.9	10.1	18.8	12.1	6.8
Extra Day	1.6	1.1	1.1	2.7	12.8	21.3	12.1	7.9
Reservoir	0.3	1.1	1.2	3.3	9.6	18.2	9.2	6.3
SED (13 df)	0.40	0.39	0.50	0.75	2.01	2.63	1.6	1.0
LSD (P = 0.05)	0.9	-	-	-	-	-	-	-
Significance	*	NS	NS	NS	NS	NS	NS	NS
Root Zone Warming								
With RZW	0.2	0.8	0.8	2.6	11.1	20.3	10.8	6.9
Without RZW	1.3	1.2	1.6	3.2	11.5	19.8	11.4	7.3
SED (13 df)	0.28	0.28	0.35	0.53	1.42	1.86	1.14	0.70
LSD (P = 0.05)	0.6	-	0.8	-	-	-	-	-
Significance	**	NS	*(6%)	NS	NS	NS	NS	NS
Varieties								
Cubico	1.2	0.9	0.7	1.7	11.5	17.5	6.9	6.9
Lambada	0.7	1.4	1.3	4.3	12.9	23.7	13.9	8.6
Mazurka	0.3	0.7	1.6	2.8	9.4	18.9	12.5	6.8
SED (32 df)	0.36	0.25	0.39	0.89	1.06	1.71	1.07	0.47
LSD (P = 0.05)	0.7	0.5	0.8	1.8	2.2	3.5	2.2	1.0
Significance	*	*	*(6%)	*	*	***	***	***

From May onwards fruit over 75 mm diameter was divided into two grades; large fruit (75-90 mm) and very large fruit (over 90 mm). In April this fruit was all included in the large fruit category (Table 7).

There was a high percentage of very large fruit from this trial, particularly from the variety Cubico. Over the season as a whole this variety produced 79% fruit over 90 mm, 25% more than the other 2 varieties. There was no significant difference between the season averages for Lambada and Mazurka but in September and October/November the amount of very large fruit decreased more for Lambada than for Mazurka (See Table 6).

The irrigation treatments did not significantly influence the production of very large fruit.

Use of root zone warming tended to reduce the production of fruit over 90 mm diameter.

Root zone warming increased the percentage of fruit in the 75-90 mm class, the preferred grade, (Table 7) although differences were not significant in every month. There was no evidence that the irrigation regimes influenced production of large fruit.

Cubico produced significantly less fruit in the large grade than the other 2 varieties in every month. Differences between Lambada and Mazurka were small and inconsistent.

Neither irrigation regime or root zone warming treatments affected the production of fruit in the medium grade (Table 8).

Lambada produced the most 65-75 mm fruit, followed by Mazurka and then Cubico. Production of small Class I fruit (40-65 mm) was very low.

Table 6: Percentage Very Large Fruit (over 90 mm diam)

	May	Jun	Jul	Aug	Sep	Oct/ Nov	Average
Irrigation							
Standard Day	61.3	80.5	85.1	59.1	48.9	41.3	61.8
Day + Night	67.5	81.8	82.8	59.7	50.8	46.4	64.0
Extra Day	61.6	78.6	85.1	60.2	49.2	42.8	62.1
Reservoir	63.9	80.7	82.0	54.5	49.5	39.9	60.4
SED (13 df)	4.13	2.66	1.69	2.69	3.67	2.71	1.43
LSD (P = 0.05)	-	-	-	-	-	-	-
Significance	NS	NS	NS	NS	NS	NS	NS
Root Zone Warming							
With RZW	61.5	79.6	82.6	55.8	48.2	41.9	60.4
Without RZW	65.7	81.3	84.9	60.9	51.0	43.2	63.8
SED (13 df)	2.92	1.88	1.20	1.90	2.59	1.91	1.01
LSD (P = 0.05)	-	-	2.6	4.1	-	-	2.2
Significance	NS	NS	*(8%)	*	NS	NS	*
Varieties							
Cubico	83.2	93.8	93.3	75.8	67.6	53.4	79.2
Lambada	61.9	76.5	77.8	47.1	34.7	31.4	54.3
Mazurka	45.6	70.9	80.0	52.1	46.5	42.9	52.8
SED (32 df)	1.99	1.42	1.75	2.03	2.88	2.66	1.09
LSD (P = 0.05)	4.0	2.9	3.6	4.1	5.9	5.4	2.2
Significance	***	***	***	***	***	***	***

Note: Very large fruit (over 90 mm diam) was not recorded in April.

Table 7: Percentage Large Fruit (75-90 mm)

	Apr	May	Jun	Jul	Aug	Sep	Oct/ Nov	Average
Irrigation								
Standard Day	87.1	32.7	15.9	13.0	34.6	44.6	44.1	31.7
Day + Night	89.6	26.3	15.4	15.6	34.3	42.1	43.0	30.2
Extra Day	94.7	31.5	17.4	13.1	33.6	41.6	46.0	31.5
Reservoir	92.6	29.5	16.3	15.9	38.5	42.4	44.9	32.7
SED (13 df)	6.39	3.34	2.13	1.63	2.12	2.18	2.01	1.04
LSD (P = 0.05)	-	-	-	-	-	-	-	-
Significance	NS	NS	NS	NS	NS	NS	NS	NS
Root Zone Warming								
With RZW	94.4	31.7	17.3	15.7	36.9	43.7	44.7	32.9
Without RZW	87.6	28.1	15.2	13.1	33.6	41.6	44.3	30.1
SED (13 df)	4.52	2.36	1.51	1.15	1.50	1.54	1.42	0.74
LSD (P = 0.05)	-	-	-	2.5	3.2	-	-	1.6
Significance	NS	NS	NS	*	*	NS	NS	**
Varieties								
Cubico	88.7	14.0	5.1	5.7	20.9	27.6	38.4	17.6
Lambada	94.1	31.3	19.9	20.3	42.9	51.3	49.2	37.1
Mazurka	90.3	44.3	23.7	17.2	42.0	49.1	45.9	39.8
SED (32 df)	5.44	1.72	1.21	1.67	1.77	1.54	1.90	0.82
LSD (P = 0.05)	-	3.5	2.5	3.4	3.6	3.1	3.9	1.7
Significance	NS	***	***	***	***	***	***	**

Note: In April large and very large fruit were graded together.

Table 8: Percentage Medium Fruit (65-75 mm)

	Apr	May	Jun	Jul	Aug	Sep	Oct/ Nov	Total
Irrigation								
Standard Day	12.0	5.5	2.9	1.7	6.0	6.1	13.2	5.8
Day + Night	10.2	5.5	2.1	1.4	5.8	6.4	9.7	5.2
Extra Day	5.1	6.0	3.3	1.5	5.8	8.6	10.1	5.7
Reservoir	6.9	5.8	2.5	1.8	6.4	7.5	14.0	6.2
SED (13 df)	6.35	0.90	0.83	0.62	0.99	2.26	1.64	0.45
LSD (P = 0.05)	-	-	-	-	-	-	3.5	-
Significance	NS	NS	NS	NS	NS	NS	*	NS
Root Zone Warming								
With RZW	5.5	5.9	2.5	1.5	7.0	7.5	12.0	6.0
Without RZW	11.6	5.5	2.9	1.7	5.0	6.7	11.5	5.5
SED (13 df)	4.49	0.64	0.59	0.44	0.70	1.59	1.16	0.32
LSD (P = 0.05)	-	-	-	-	1.5	-	-	-
Significance	NS	NS	NS	NS	*	NS	NS	NS
Varieties								
Cubico	10.9	2.4	0.9	0.9	3.2	4.4	7.4	2.8
Lambada	5.7	6.1	3.0	1.5	9.3	13.0	17.6	7.8
Mazurka	9.1	8.6	4.3	2.3	5.5	4.0	10.3	6.5
SED (32 df)	5.49	0.53	0.52	0.48	0.84	1.68	1.36	0.42
LSD (P = 0.05)	-	1.1	1.1	1.0	1.7	3.4	2.8	0.8
Significance	NS	***	***	*	***	***	***	***

Fruit Calcium Levels

Figure 1 shows average fruit calcium levels. The amount of calcium at the top (stalk end) was approximately 50% higher than the amount at the base (blossom end).

There was a gradual increase in mean fruit calcium level between irrigation treatments A and D, with day only irrigation (A) being the lowest and the reservoir system (D) being the highest. The extra day irrigation treatment (C) had more calcium in the top end than the day and night treatment (B). Treatment D, the perlite reservoir system, was the only treatment to show increased calcium in the base of the fruit (Figure 1).

Fruit from plants grown without root zone warming had slightly higher calcium levels.

Lambada had the lowest fruit calcium level, which probably relates to its increased susceptibility to Blossom-end rot. Cubico had the highest level, particularly at the base end.

Figure 1: Fruit Calcium Levels

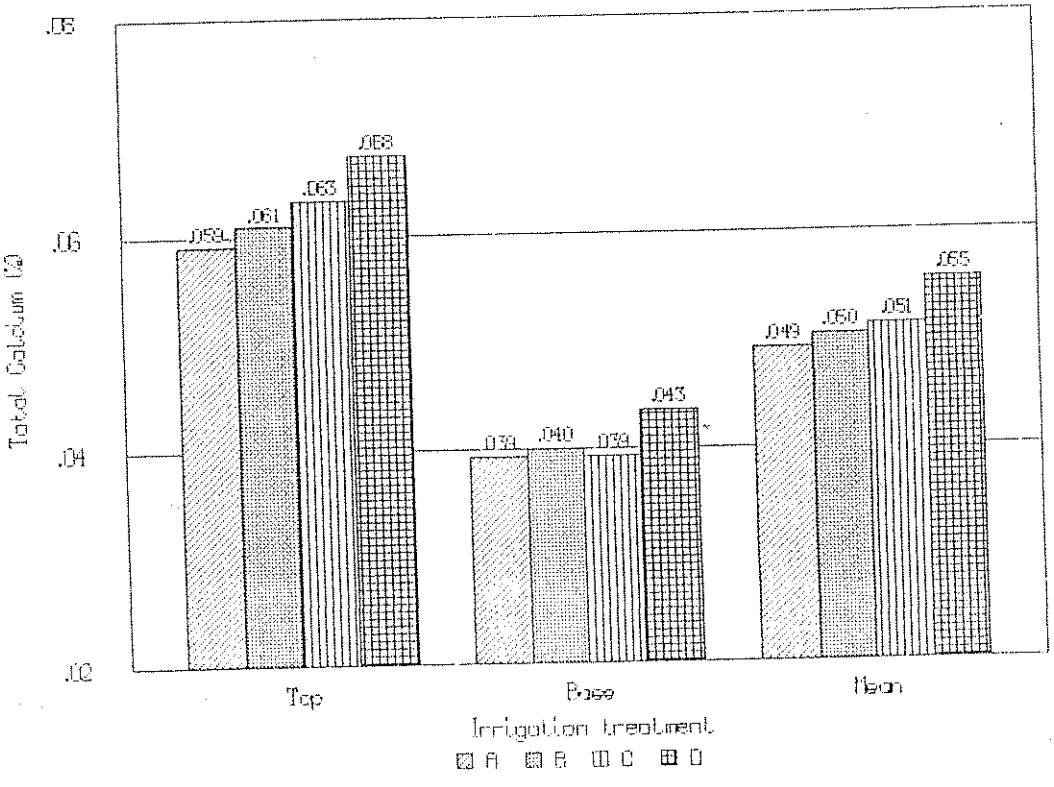
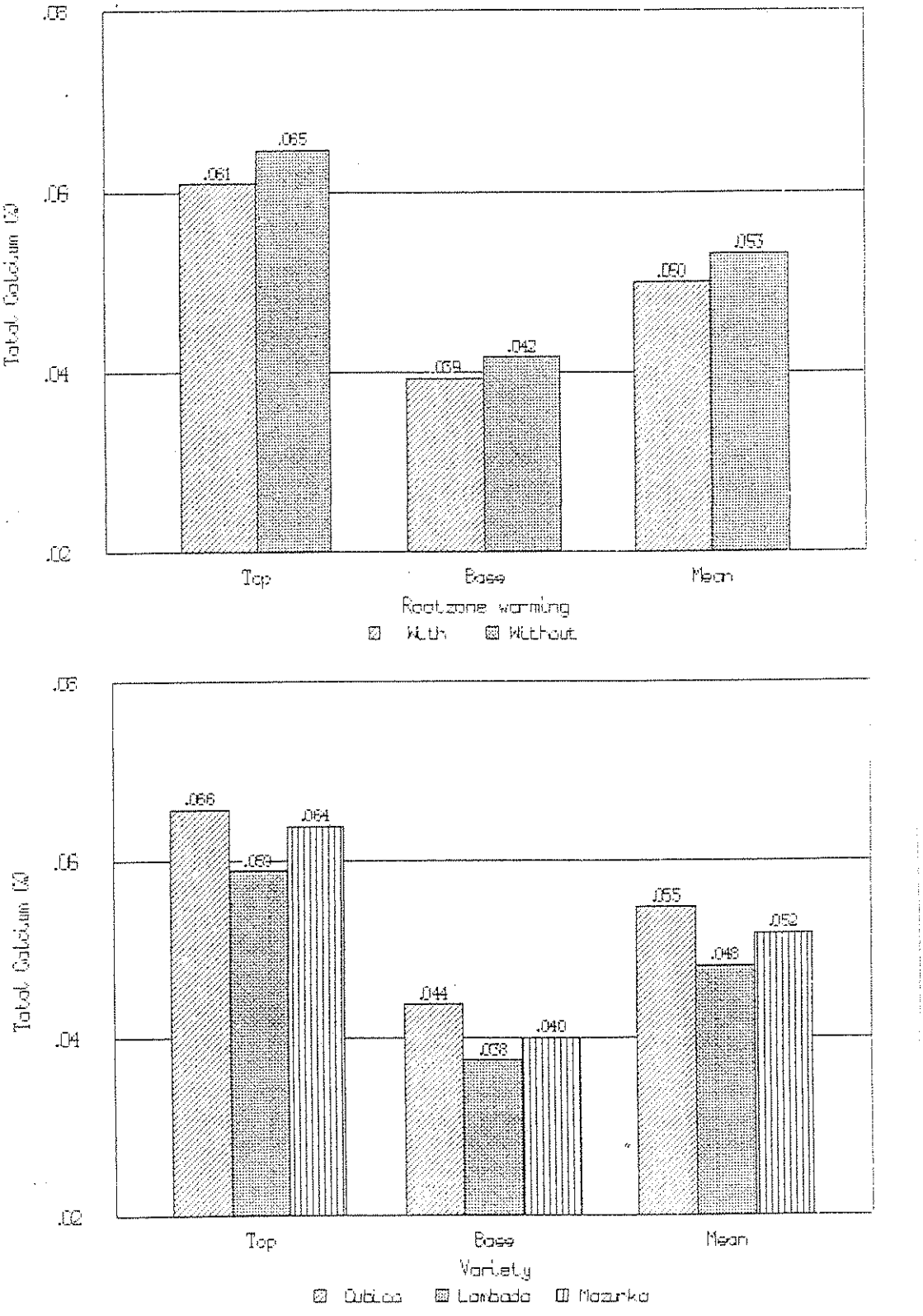


Figure 1: Fruit Calcium Levels



Shelf Life and Fruit Quality

Flecking

Flecking was most prominent in July although it was never a severe problem. There was no relationship between irrigation or root zone warming treatments and flecking (Figure 2). Lambada was less susceptible than Cubico and Mazurka overall although effects varied in some months.

Shrivelling

Cubico showed lower susceptibility to shrivelling than Mazurka or Lambada (Figure 3). From July onwards there was a trend towards more shrivelling from fruit receiving day only (A) or day and night irrigation (B). Extra day irrigation (C) and the perlite reservoir treatment (D) produced fruit with lower susceptibility to shrivelling. Root zone warming did not affect fruit shrivelling.

Calyx Lifting

The main factor affecting calyx lifting was variety. Cubico was affected very much less than the other 2 varieties (Figure 4). Lambada was most severely affected.

Root zone warming had a negative effect on calyx lifting in the early part of the season when slab temperature differences were greatest (Figure 4). In August and October the effect was reversed.

Irrigation had no consistent effect on calyx lifting.

Fine Net Cracking

From July onwards there was evidence of reduced fine net cracking from the perlite reservoir system (D). In July and August there was more cracking from the day only irrigation treatment (A) but this was reversed in October (Figure 5).

Use of root zone warming consistently reduced fine net cracking.

Mazurka was affected less than the other 2 varieties. Cubico was the worst except in June (Figure 5).

Weight Loss

From July onwards weight loss was highest from the treatments receiving day only (A) and day and night watering (B). Extra day water (C) and the reservoir system (D) showed less weight loss over the 7 days shelf life test (Figure 6).

The effect of root zone warming on weight loss was inconsistent.

Cubico gave the lowest percentage weight loss, suggesting there may be closer links between weight loss and calyx lifting than fine net cracking.

Sugar Content

The sugar content of the juice was not influenced by irrigation treatments or use of root zone warming.

Mazurka had much lower sugar levels than Cubico and Lambada, which may contribute to its reputation as a poor tasting variety.

Fruit Shine

Irrigation treatments had no consistent effect on fruit shine, although the day only treatment (A) was generally poor at the third assessment.

Fruit grown without root zone warming tended to show slightly reduced shine when fresh, in some months the difference became much more pronounced over the shelf life period (Figure 8) but this was not consistent.

Difference in shine between varieties were variable but Cubico was generally good when fresh.

Overall Attractiveness

Irrigation treatments did not influence the attractiveness of the fruit when fresh but after 7 days shelf life, fruit from treatment A (day irrigation only) became less attractive than fruit the the other treatments. Treatments B and C looked the best at the third assessment (Figure 9).

Root zone warming had no consistent effect on attractiveness of the fruit.

Variety also had a small effect when fruit was fresh but at the third assessment Cubico was consistently the best, with Lambada second and Mazurka third.

Firmness - Whole Fruit

It was not possible to show differences between irrigation regimes or root zone warming treatments by measuring the firmness of whole fruit (Figure 10). There were however differences between varieties. Cubico was generally the softest variety when fresh but after 7 days under shelf life conditions the other 2 varieties were generally softer.

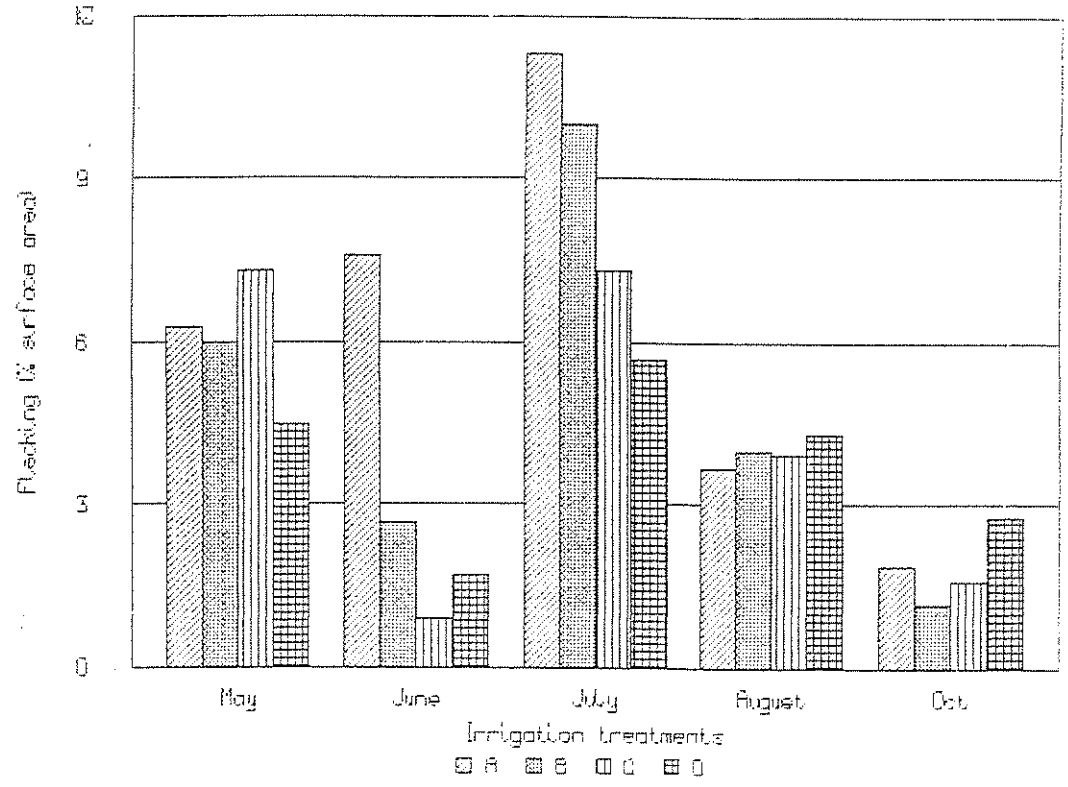
Firmness - Fruit Strips

This technique was tested as a possible means of quantifying fruit deterioration, rather than relying on visual assessments. Figure 11 shows the relationship between the score for shrivelling and the pressure to snap a piece of flesh. There is some evidence to suggest a linear relationship. Softer flesh required more pressure to snap the pieces.

Wall thickness of the strips was measured to evaluate how much this influenced the firmness of the flesh. Figure 12 shows there was no clear relationship. Measurements of wall thickness and flesh firmness are tabulated in Appendix I, Tables A-K.

There were however problems with the technique since very shrivelled fruit failed to snap and were held together by the skin.

Figure 2: Flecking



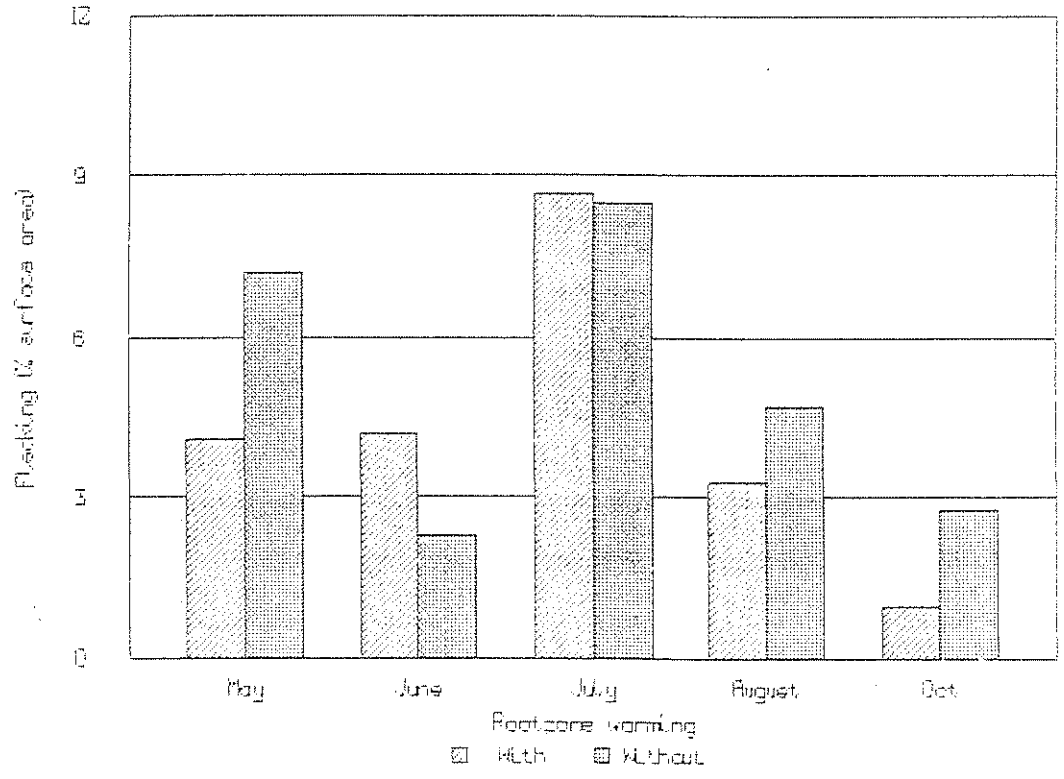


Figure 2: Flecking (continued)

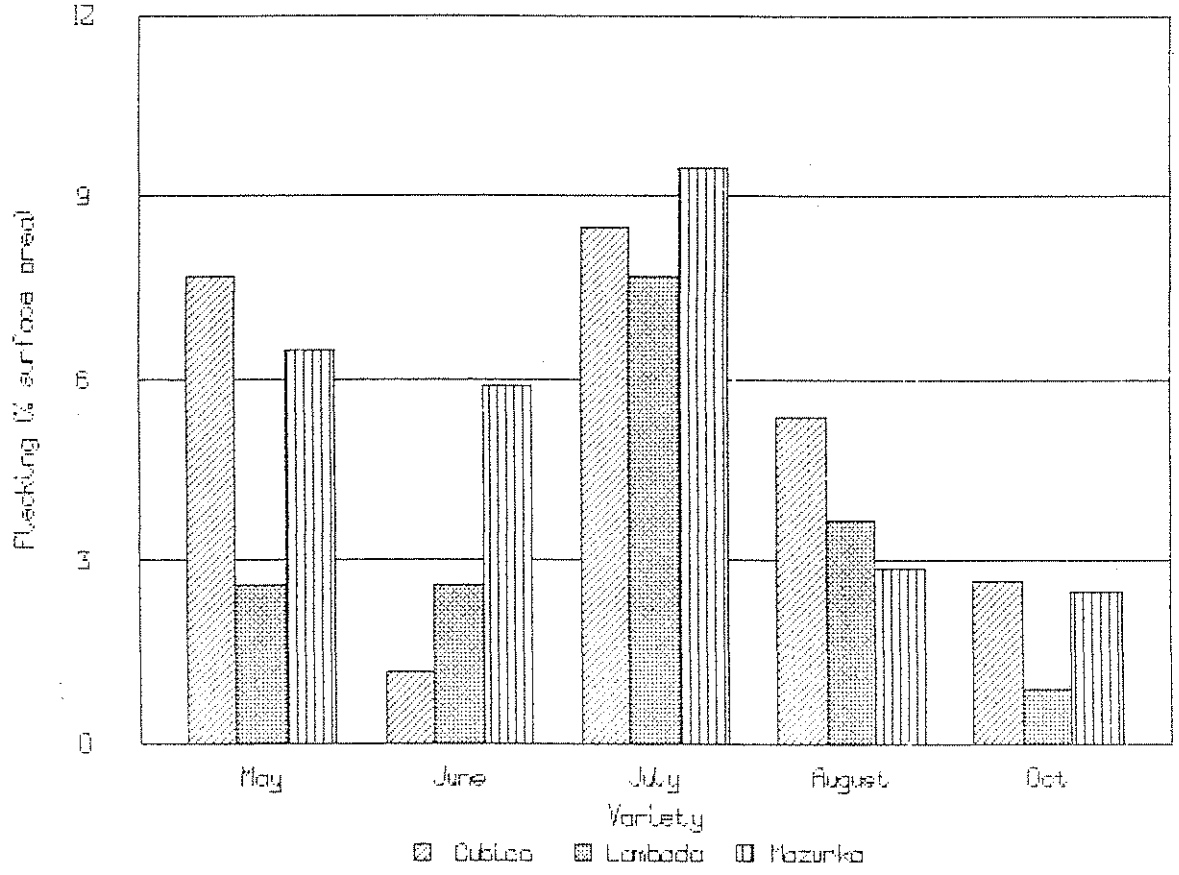
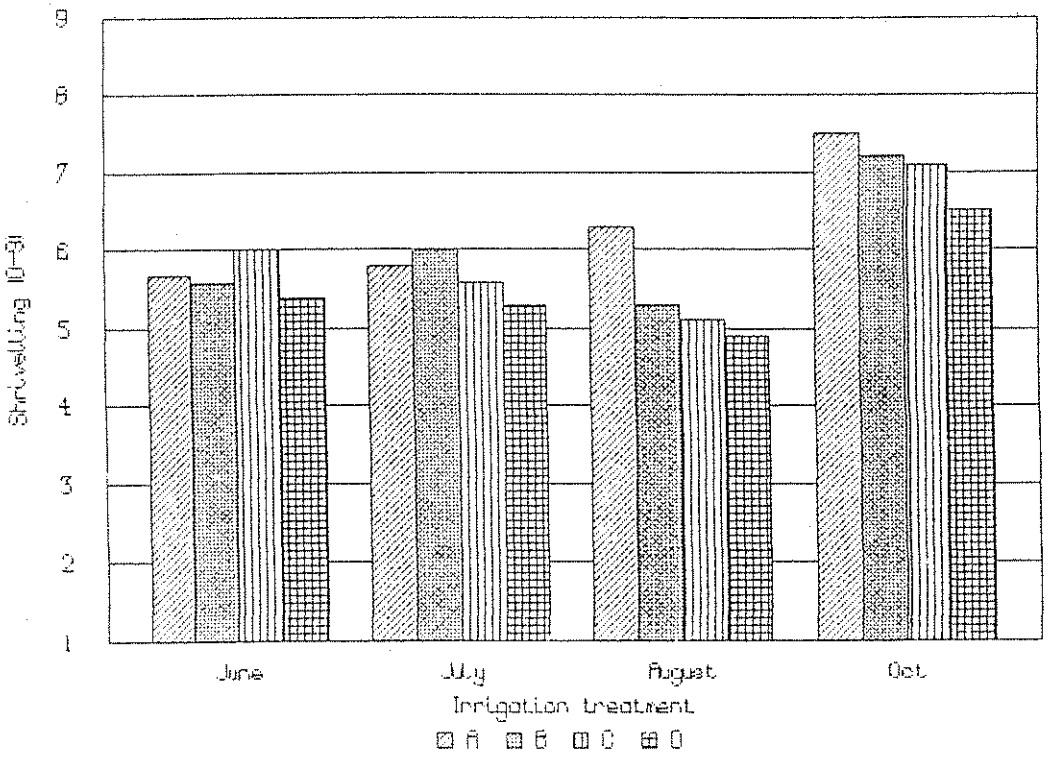
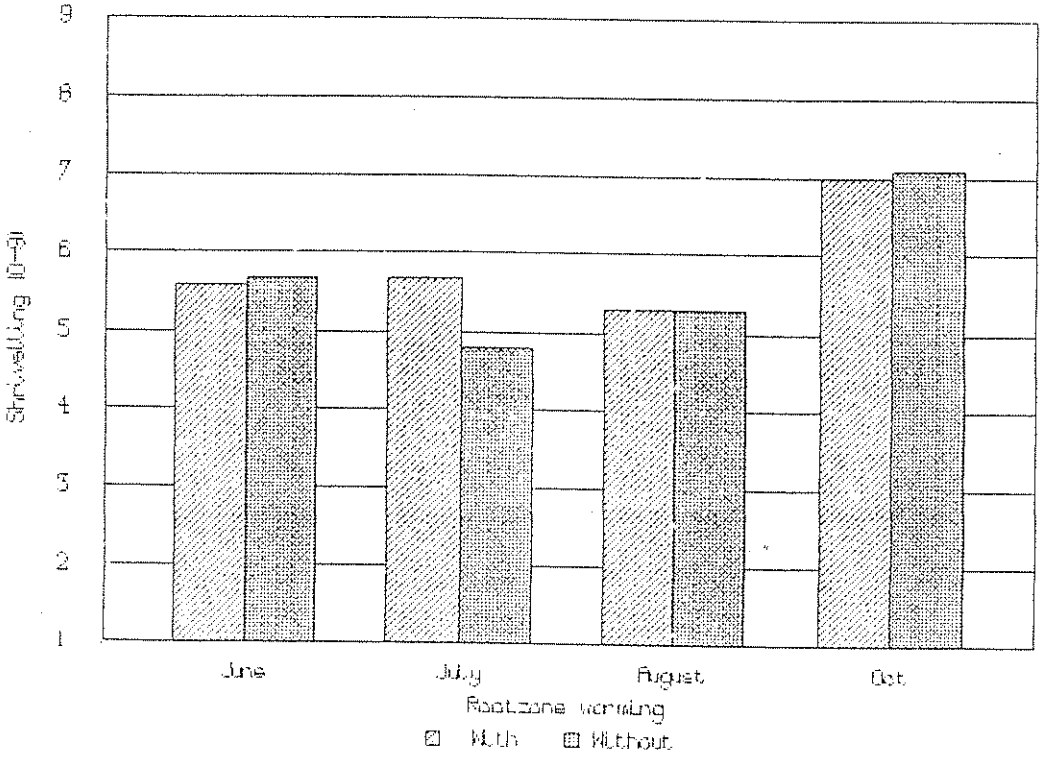


Figure 3: Shrivelling

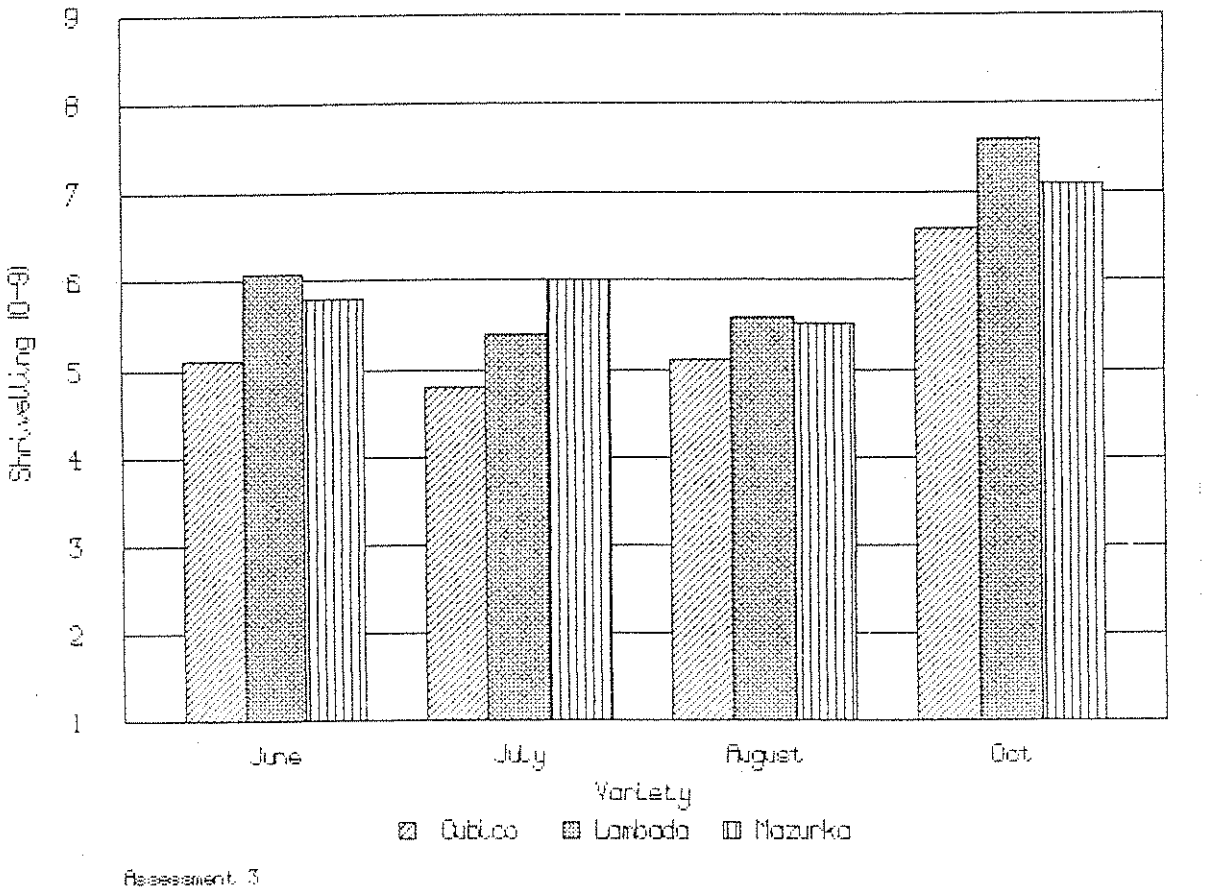


Assessment 3



Assessment 3

Figure 3: Shrivelling (continued)



Assessment 3

Figure 4: Calyx Lifting

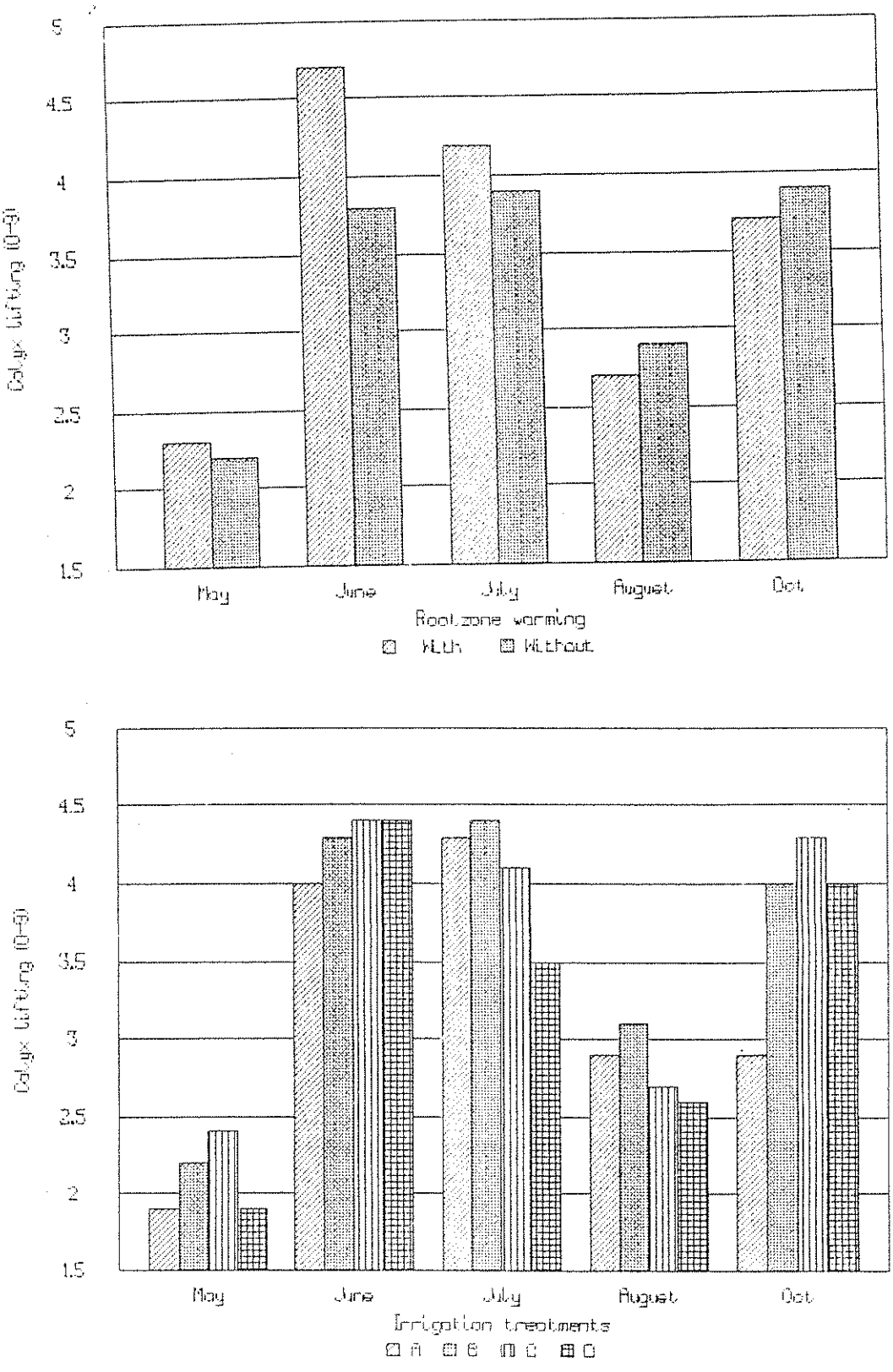


Figure 4: Calyx Lifting (continued)

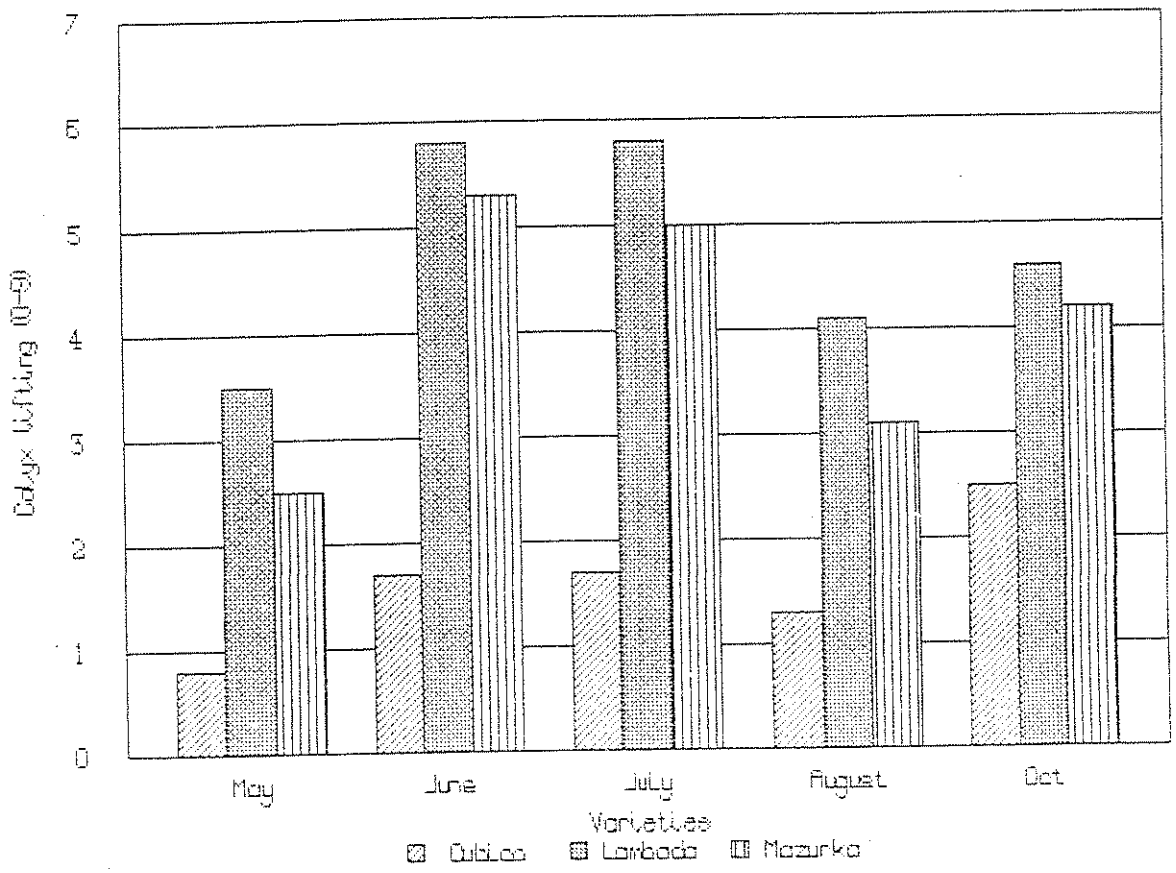
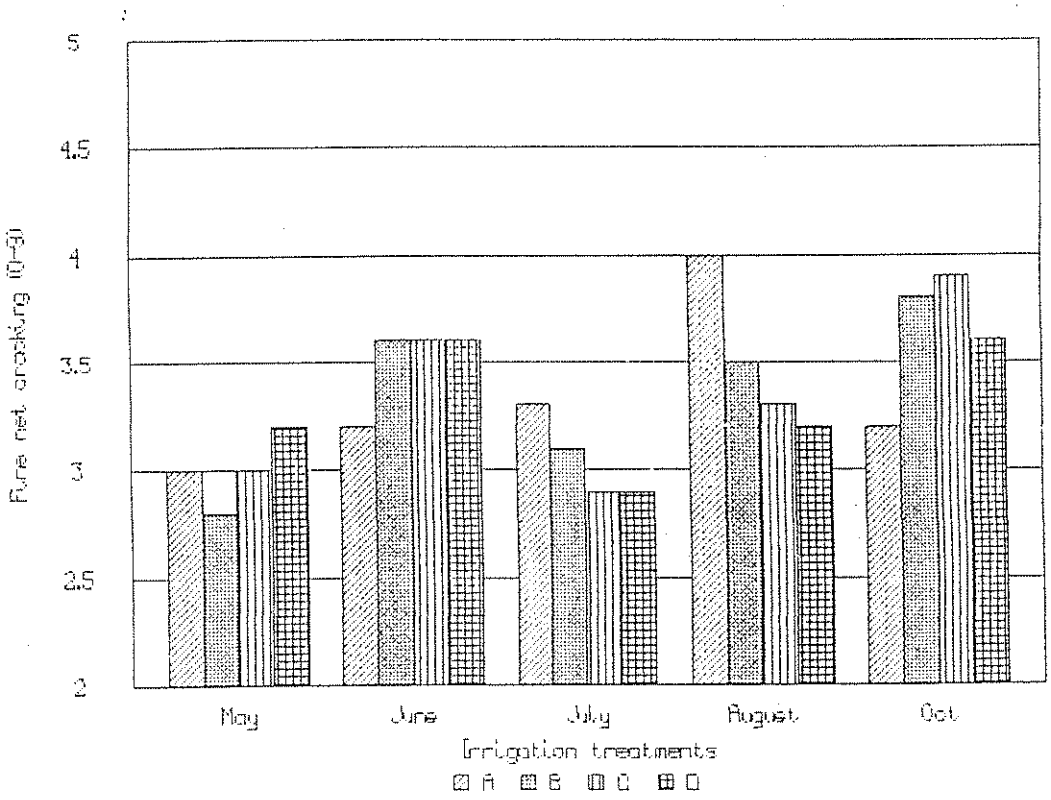


Figure 5: Fine Net Cracking



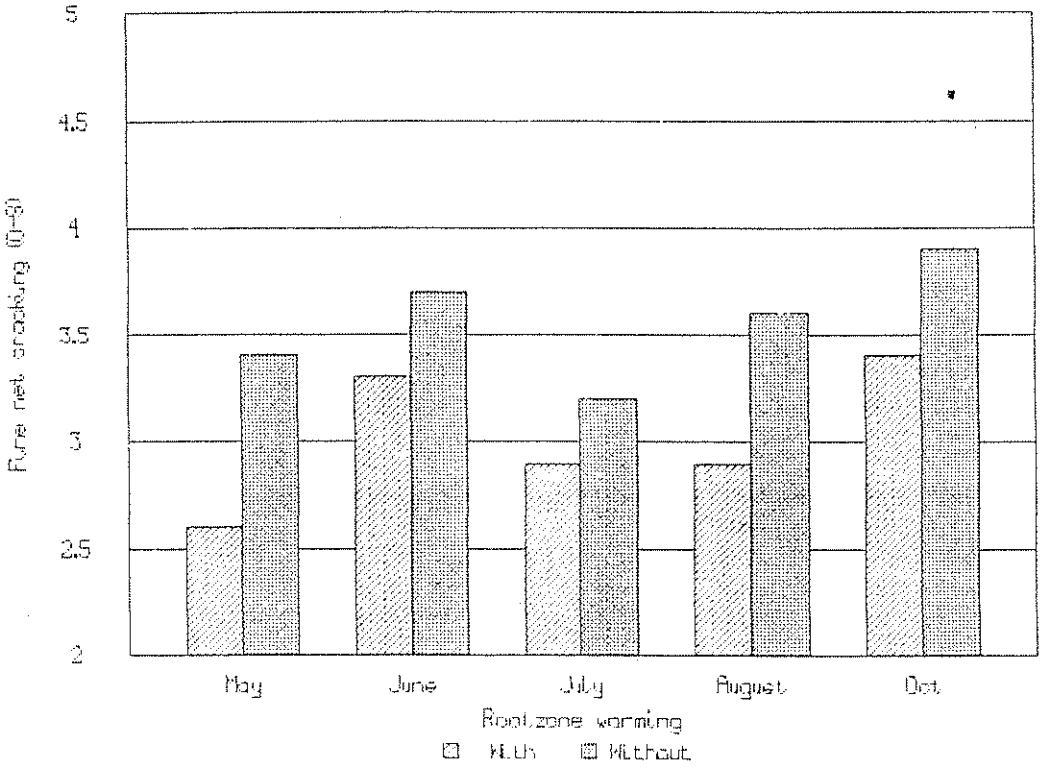


Figure 5: Fine Net Cracking (continued)

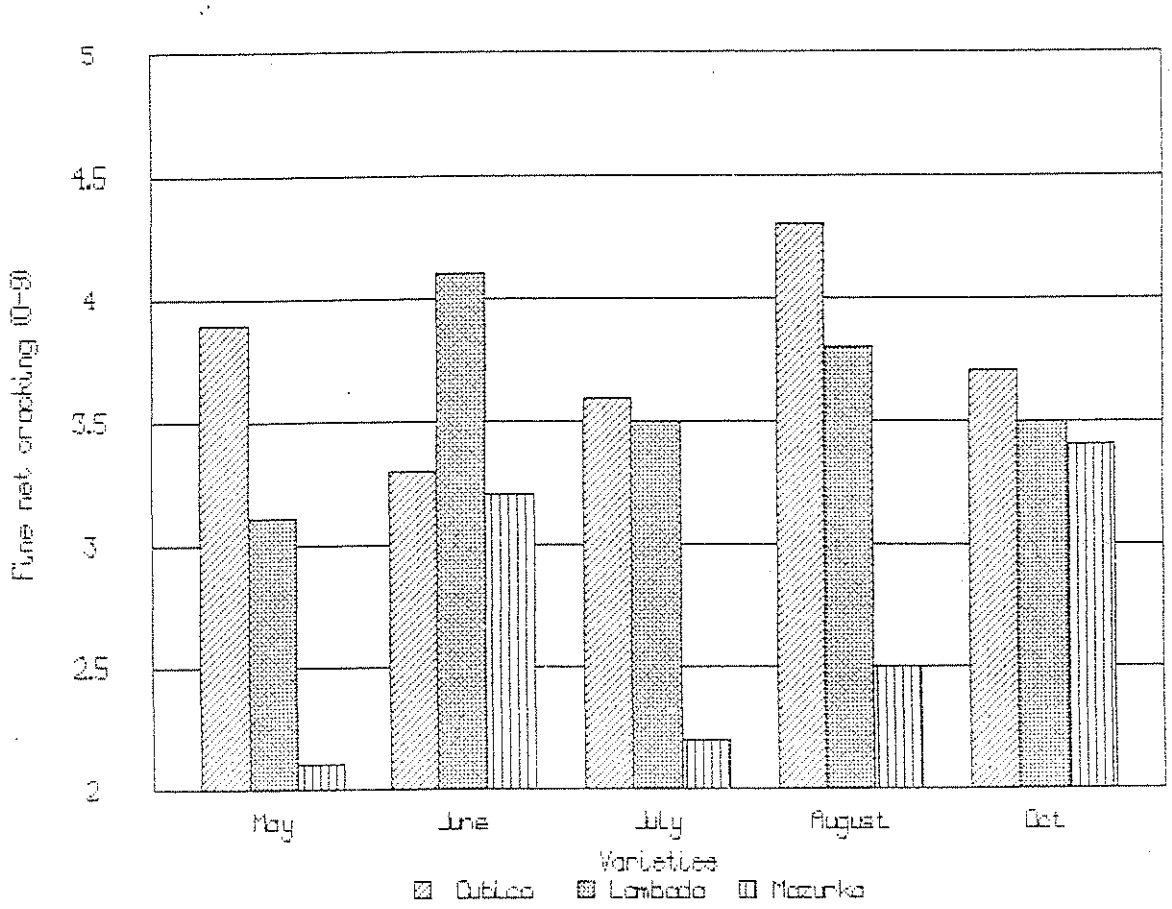
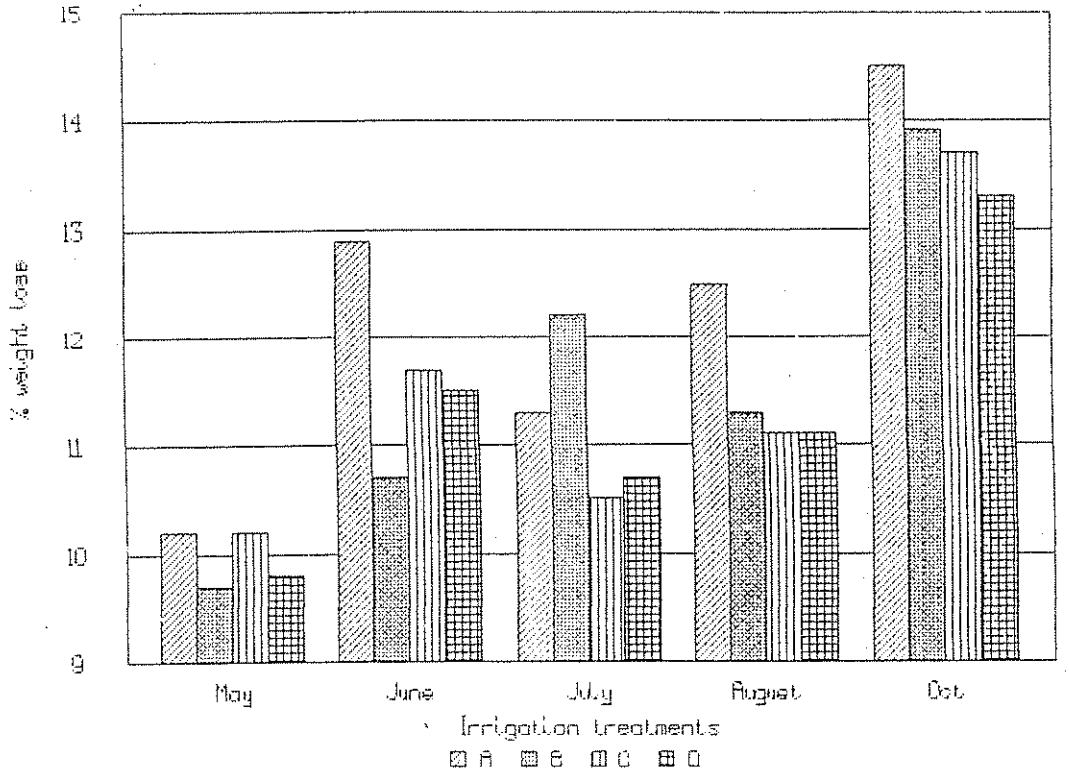


Figure 6: Weight Loss



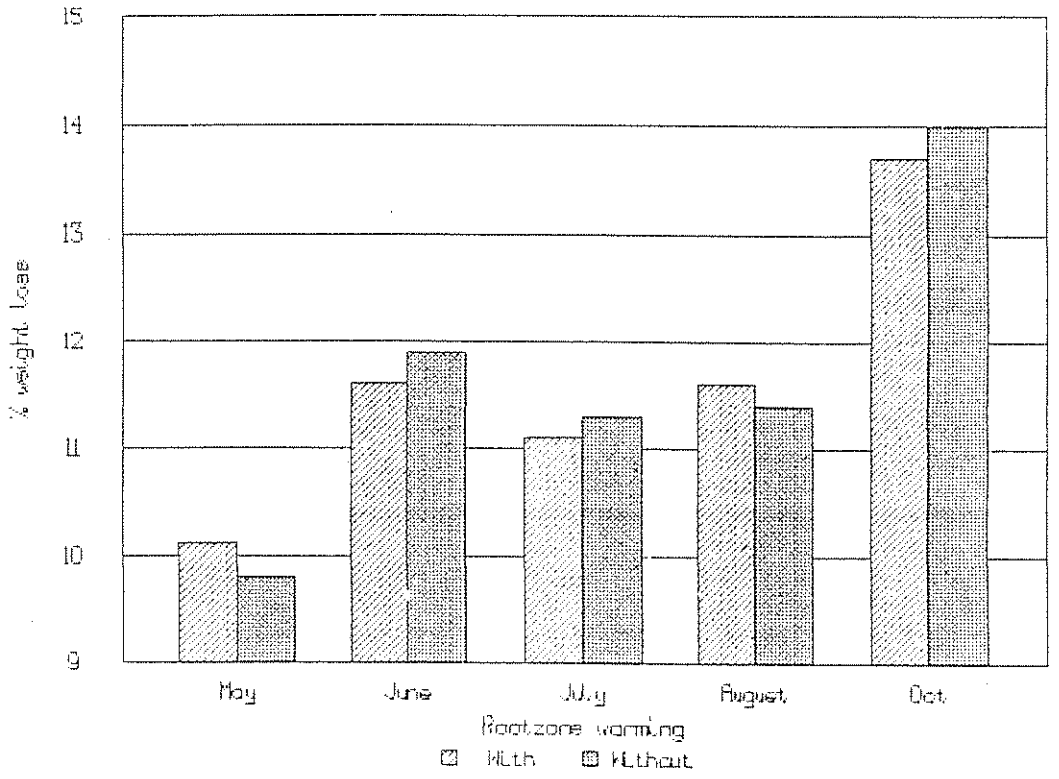


Figure 6: Weight Loss (continued)

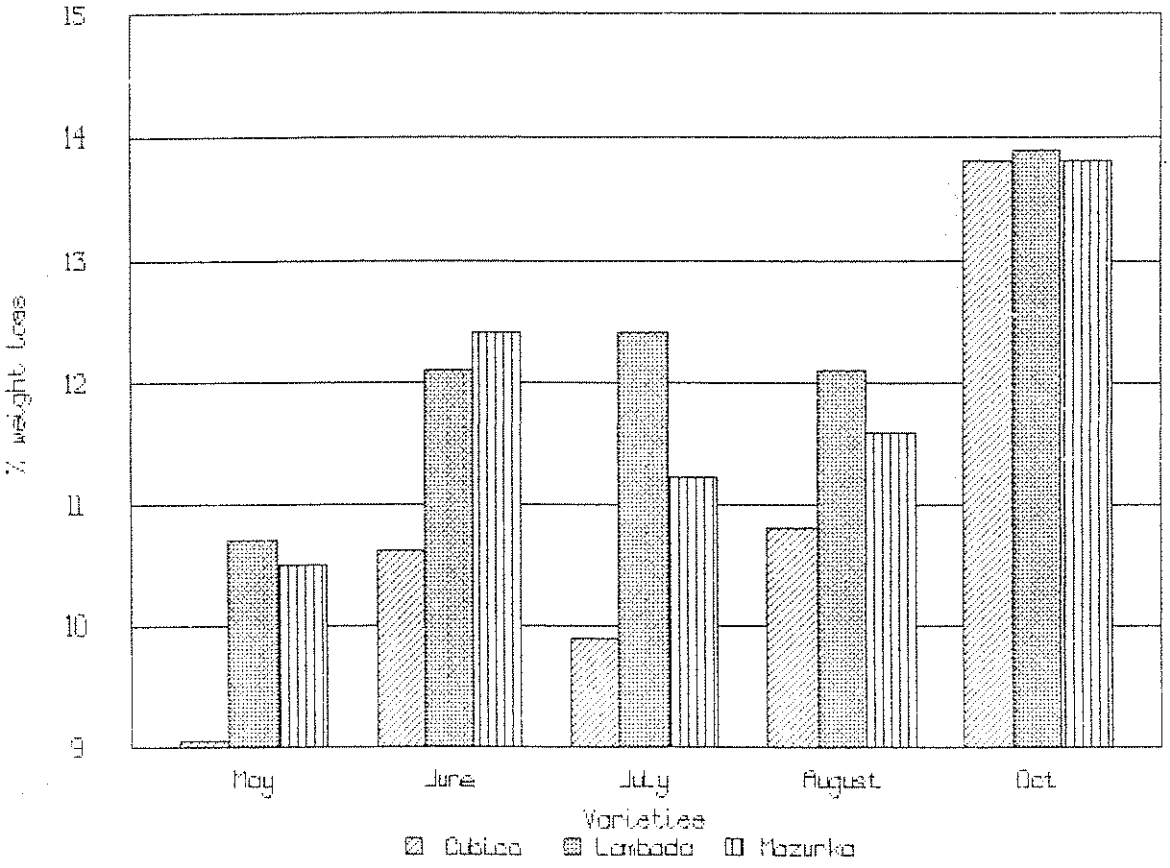


Figure 7: Sugar Content

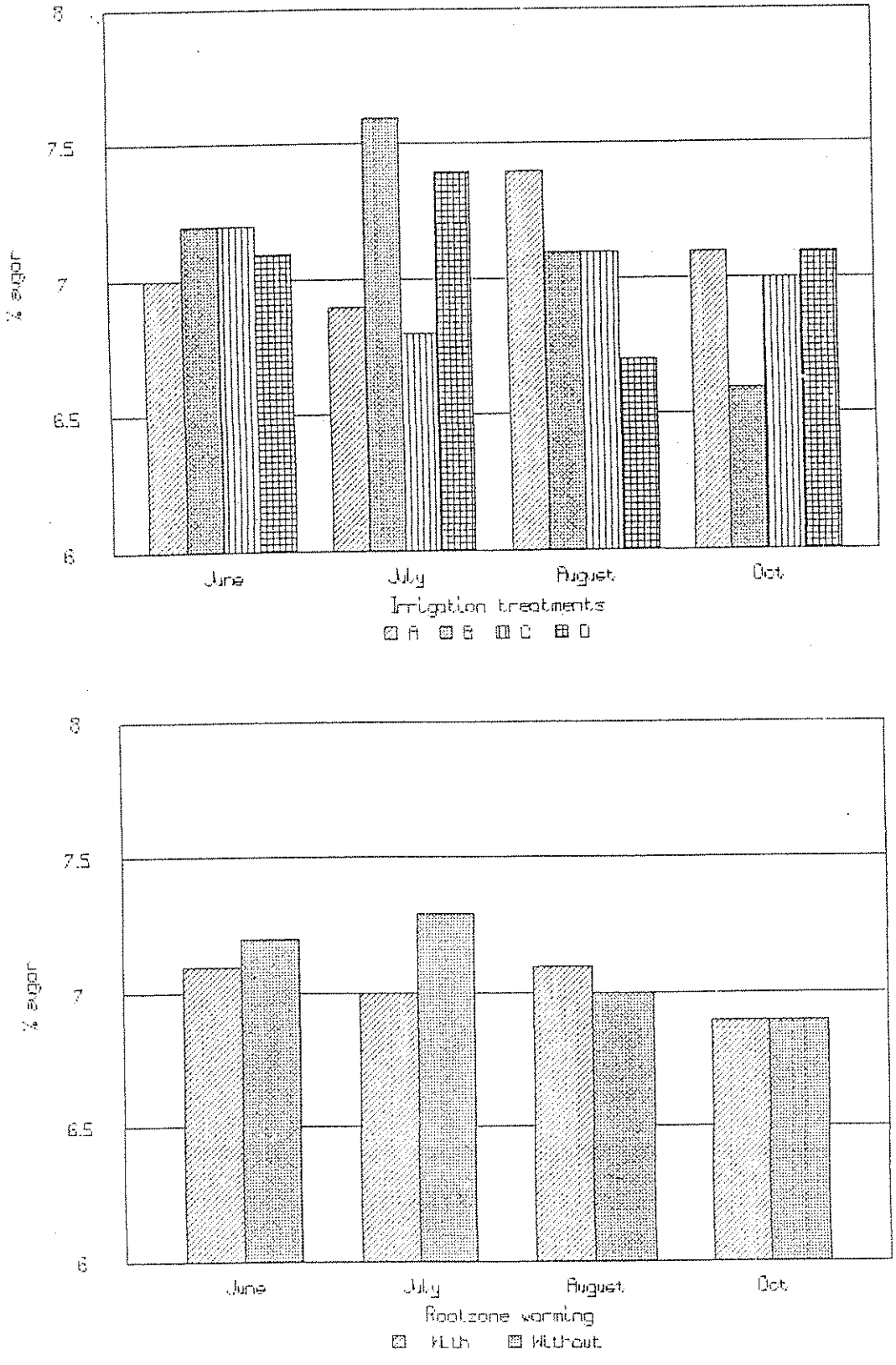


Figure 7: Sugar Content (continued)

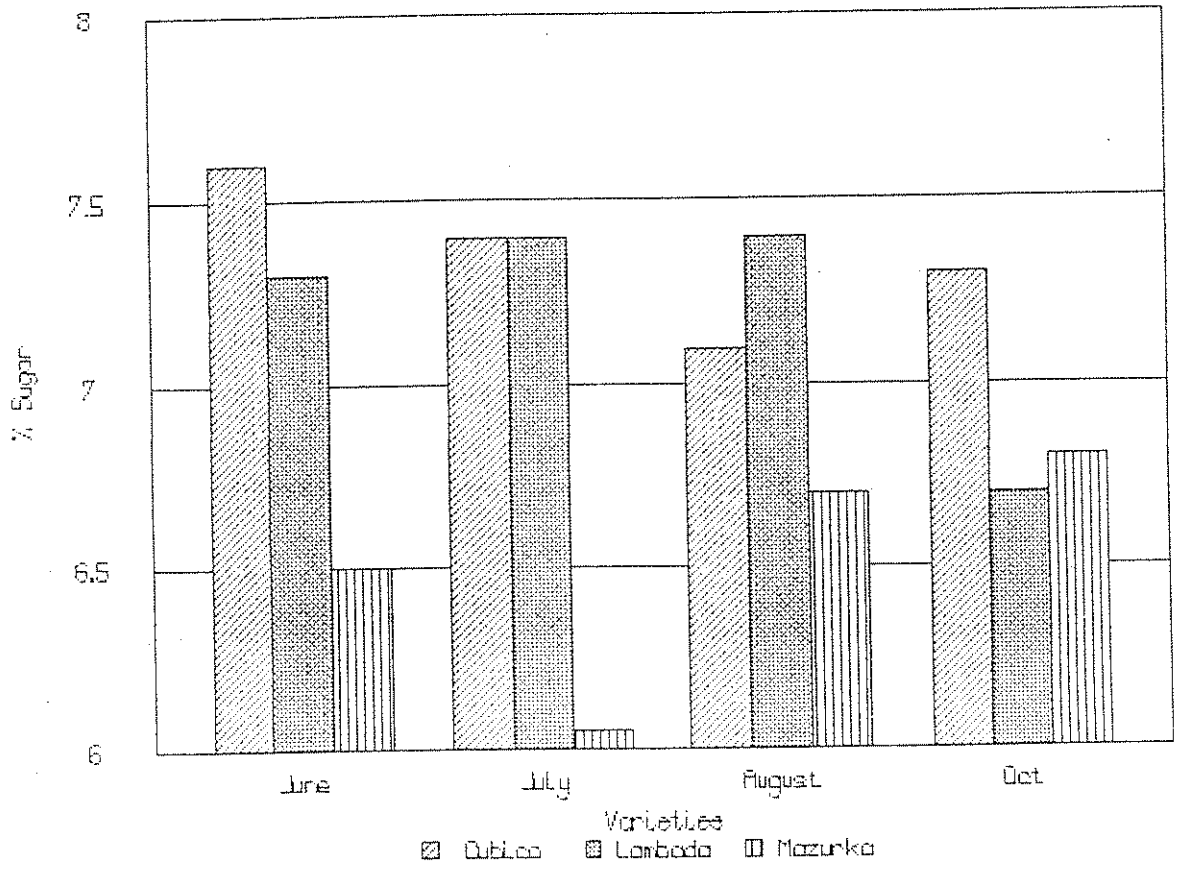
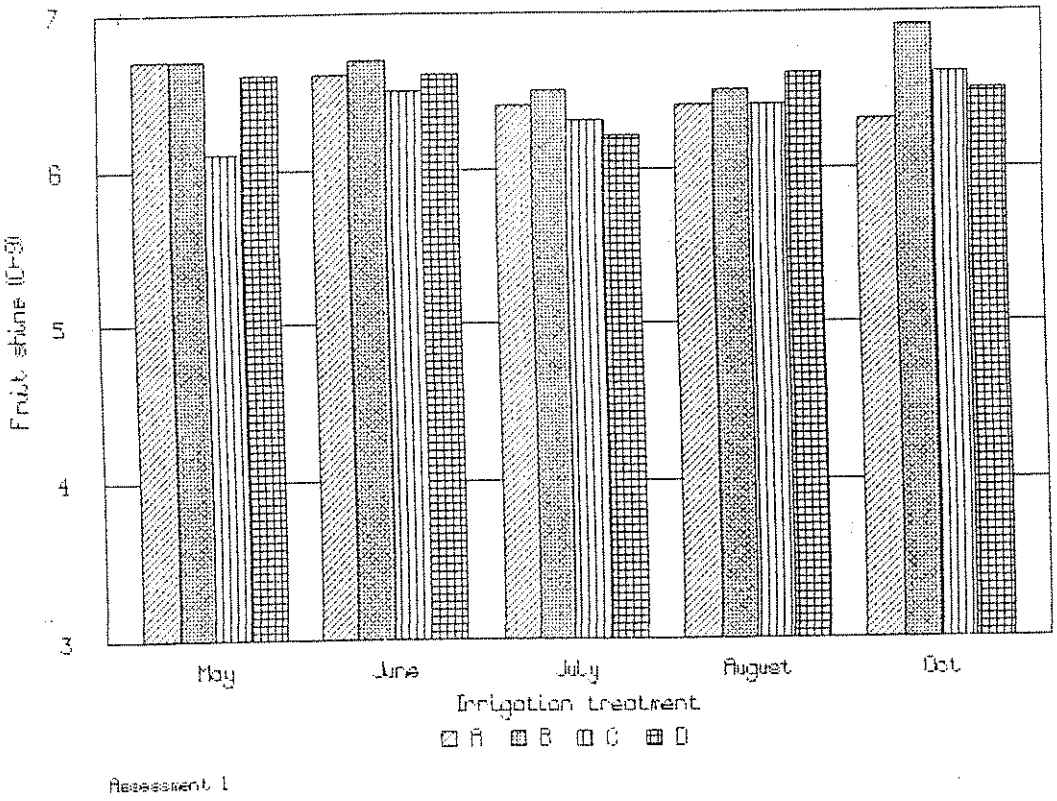


Figure 8: Fruit Shine



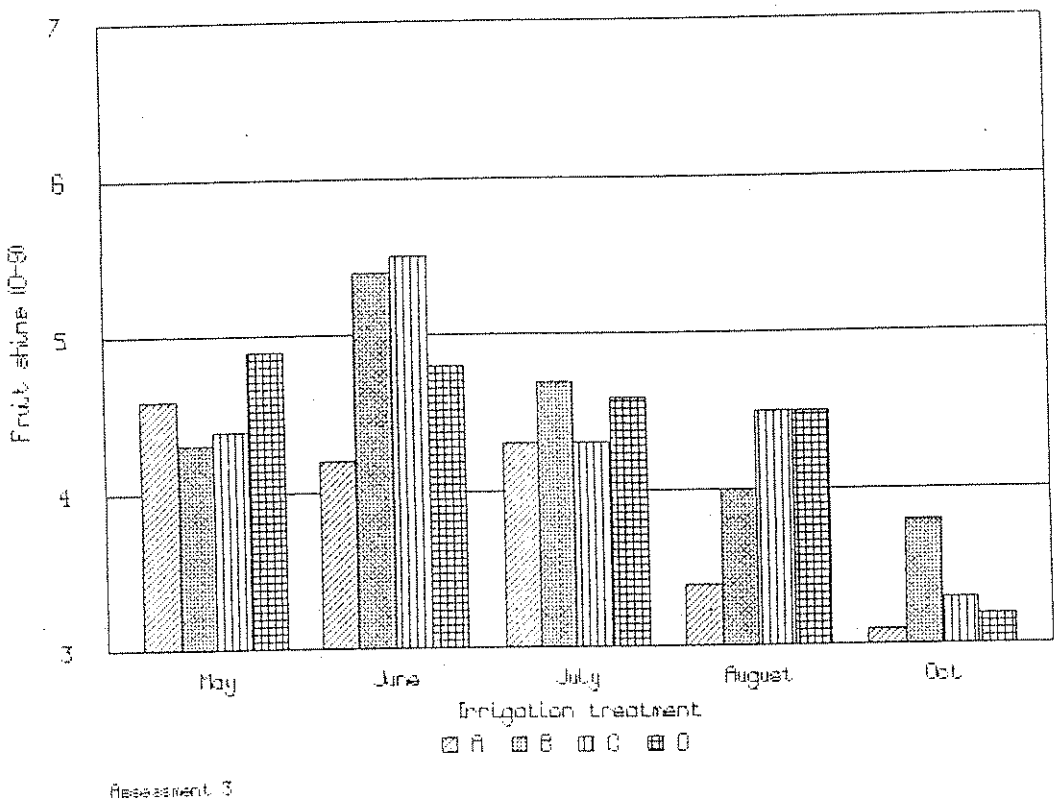
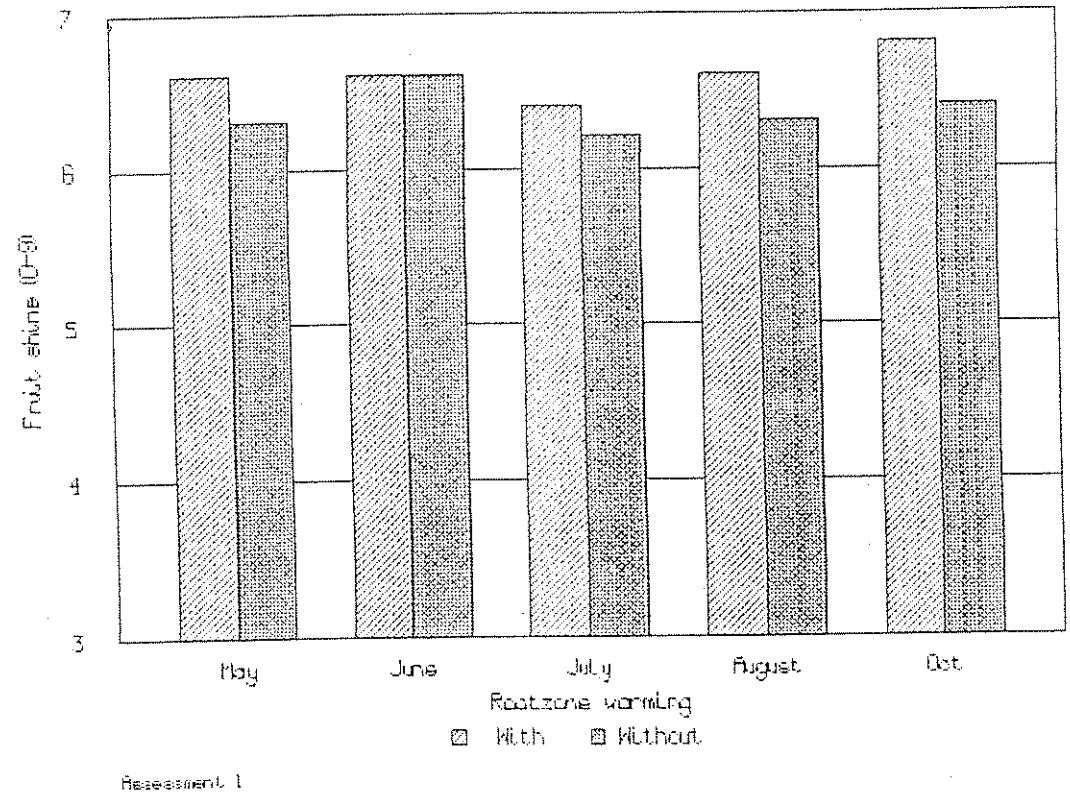


Figure 8: Fruit Shine (continued)



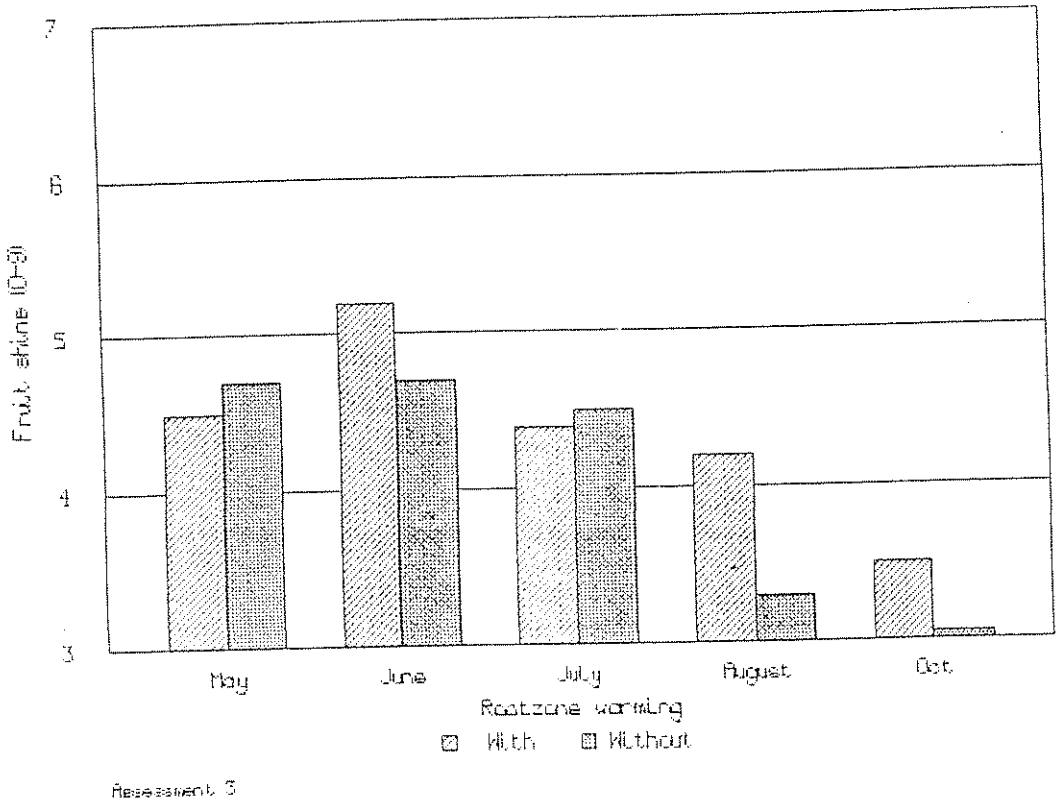
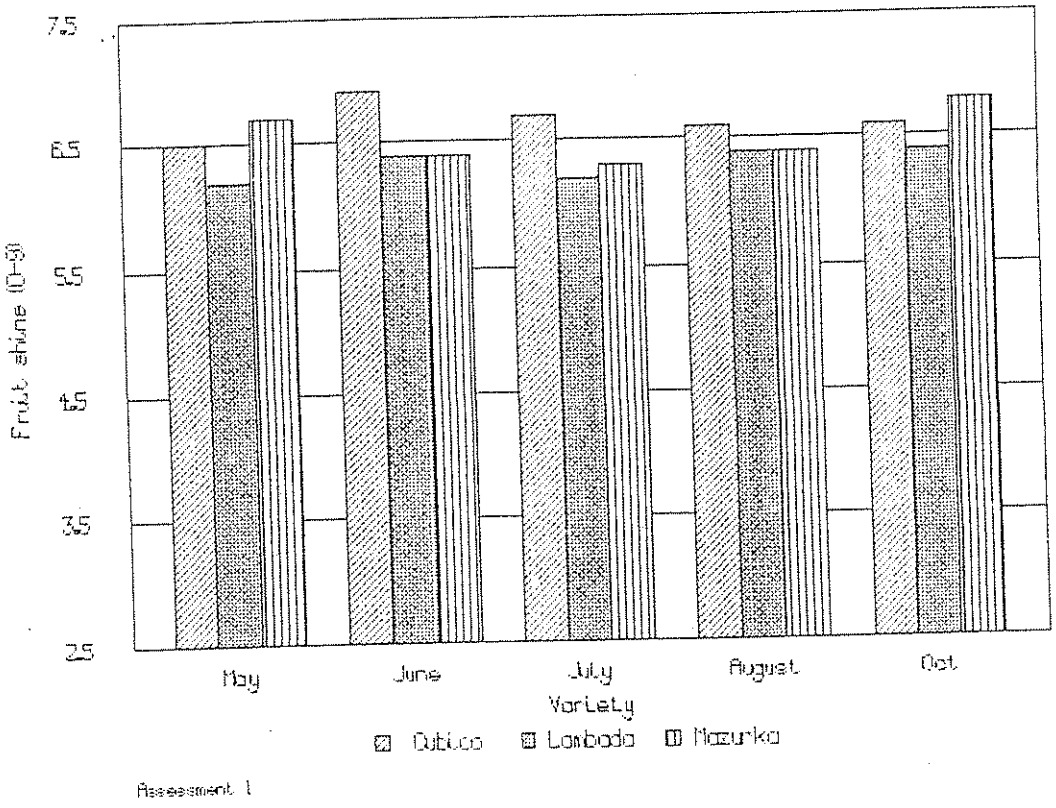


Figure 8: Fruit Shine (continued)



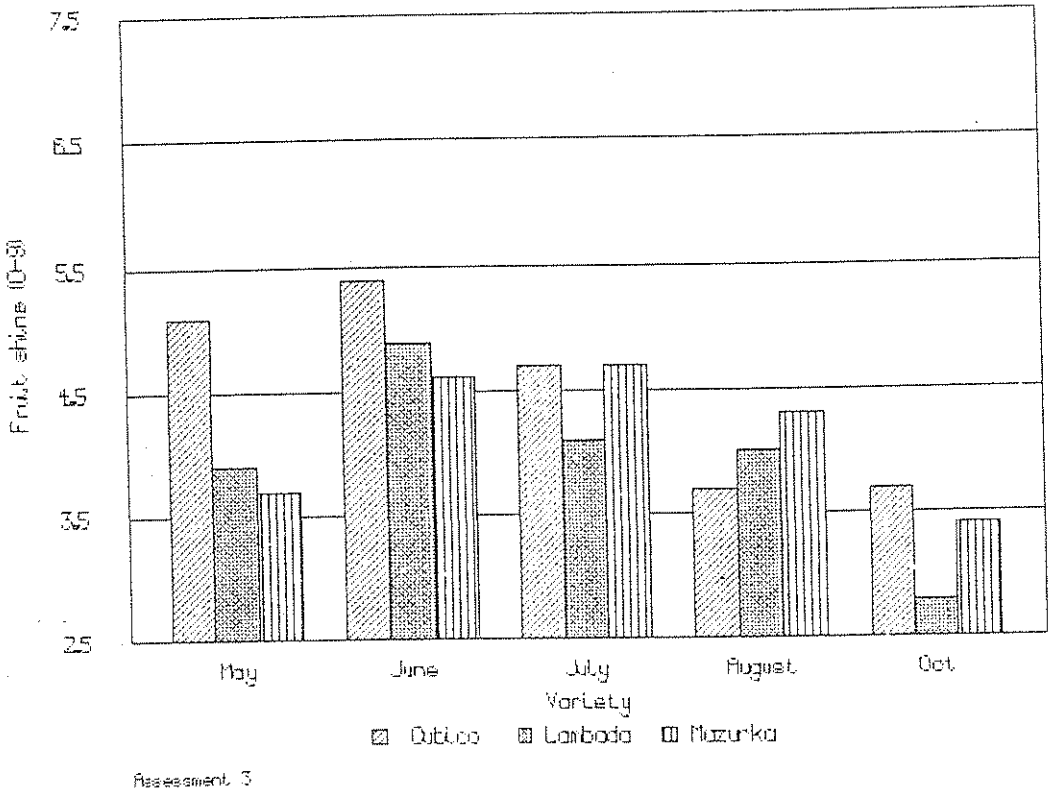
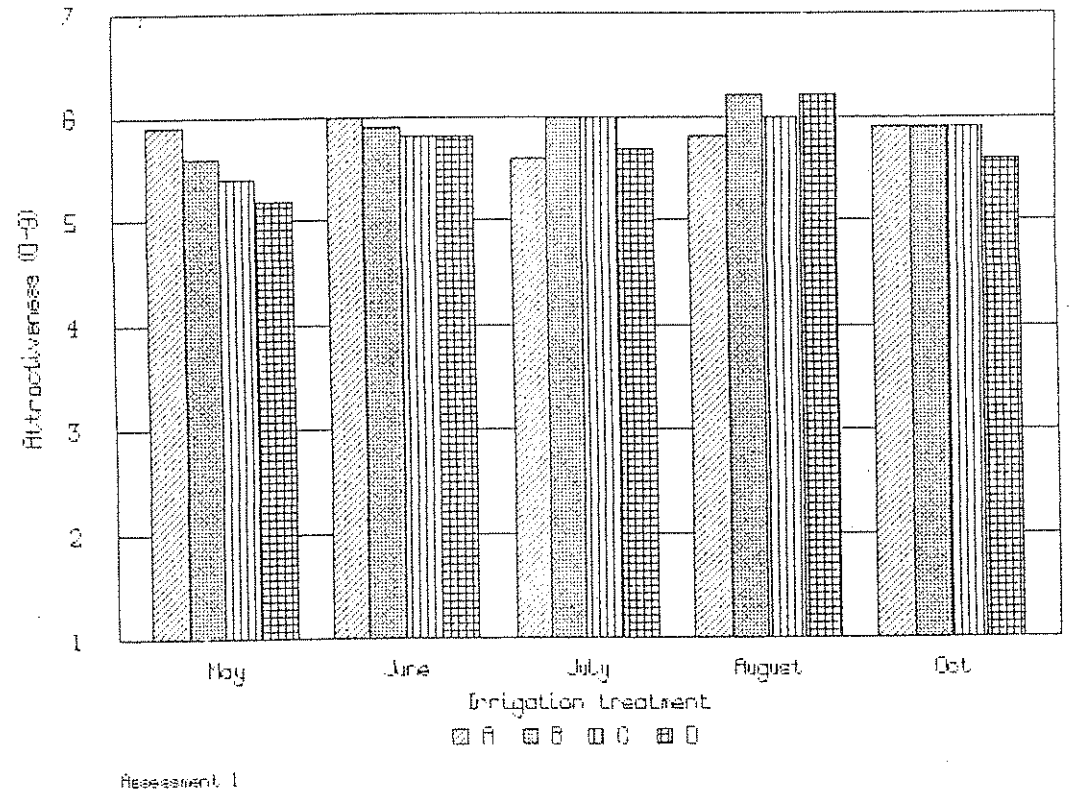


Figure 9: Overall Attractiveness



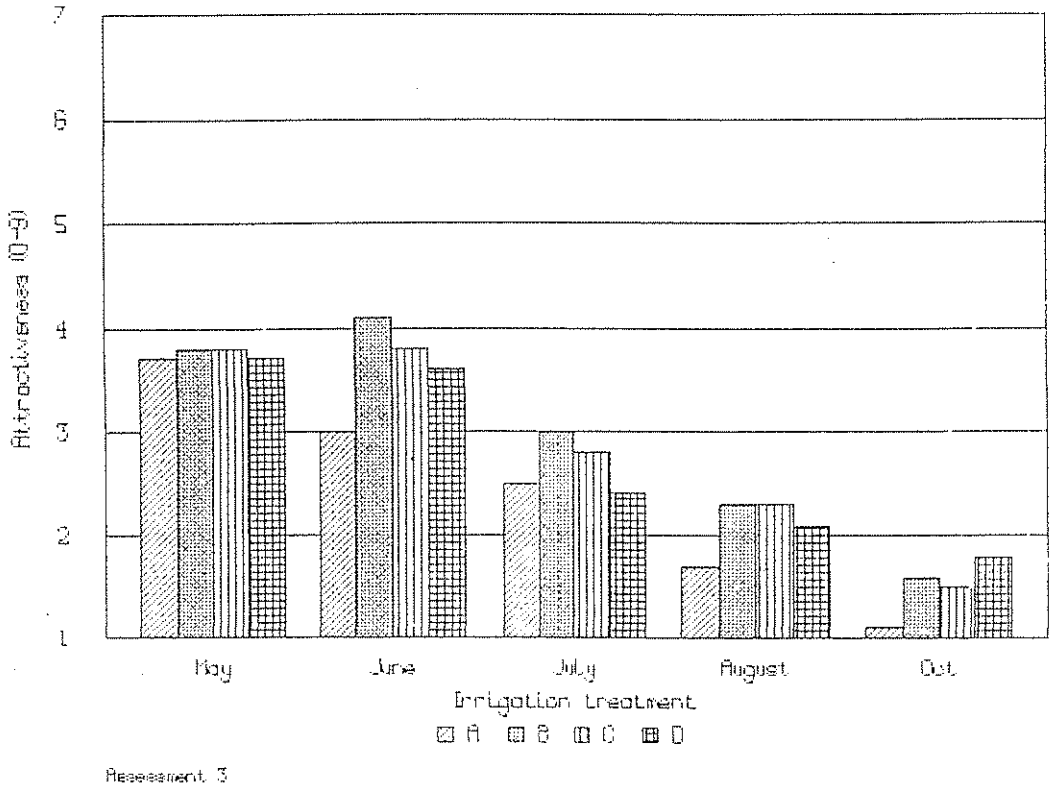
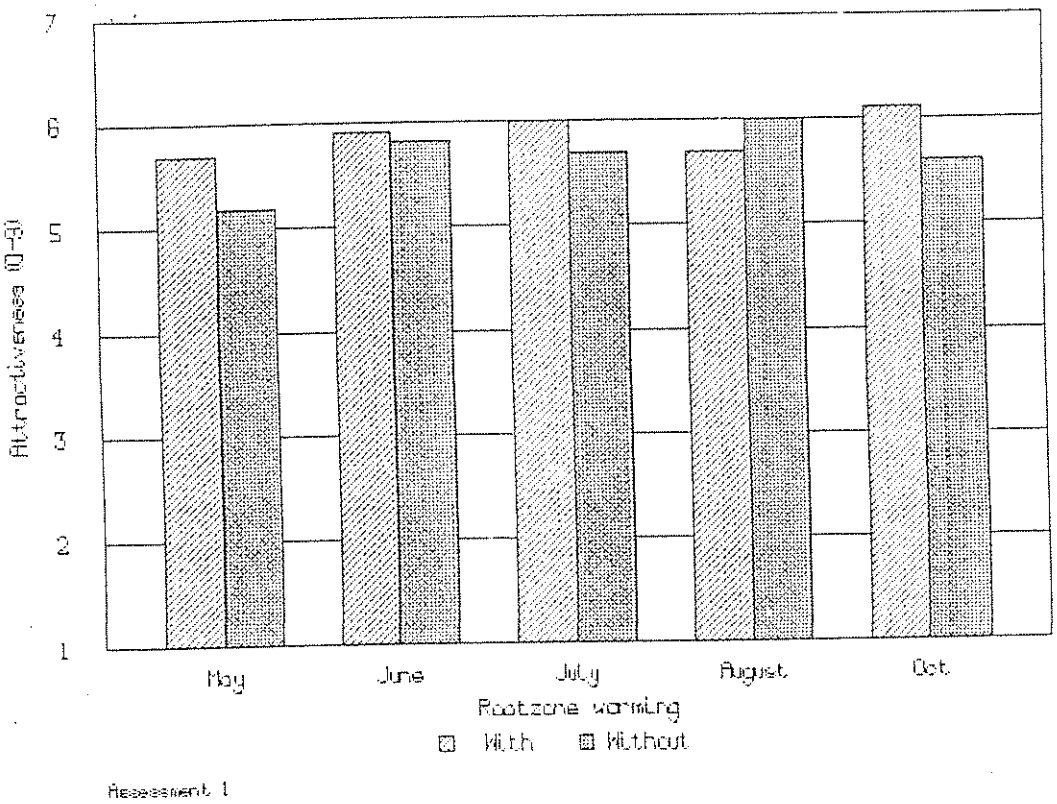
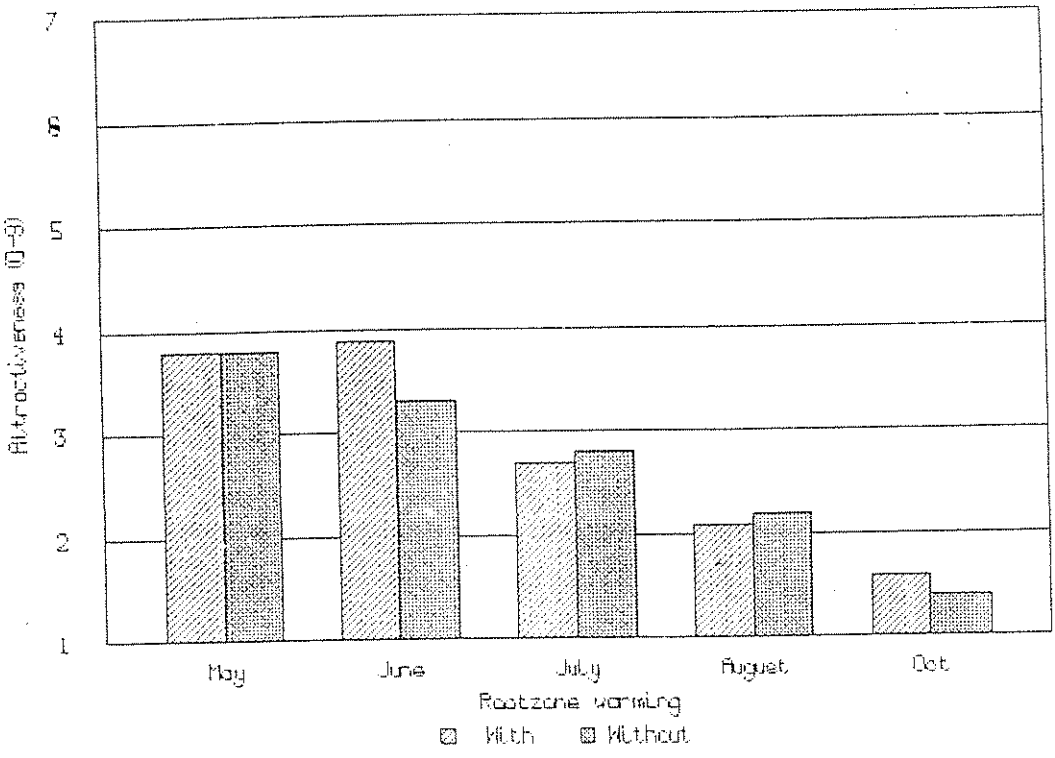


Figure 9: Overall Attractiveness (continued)

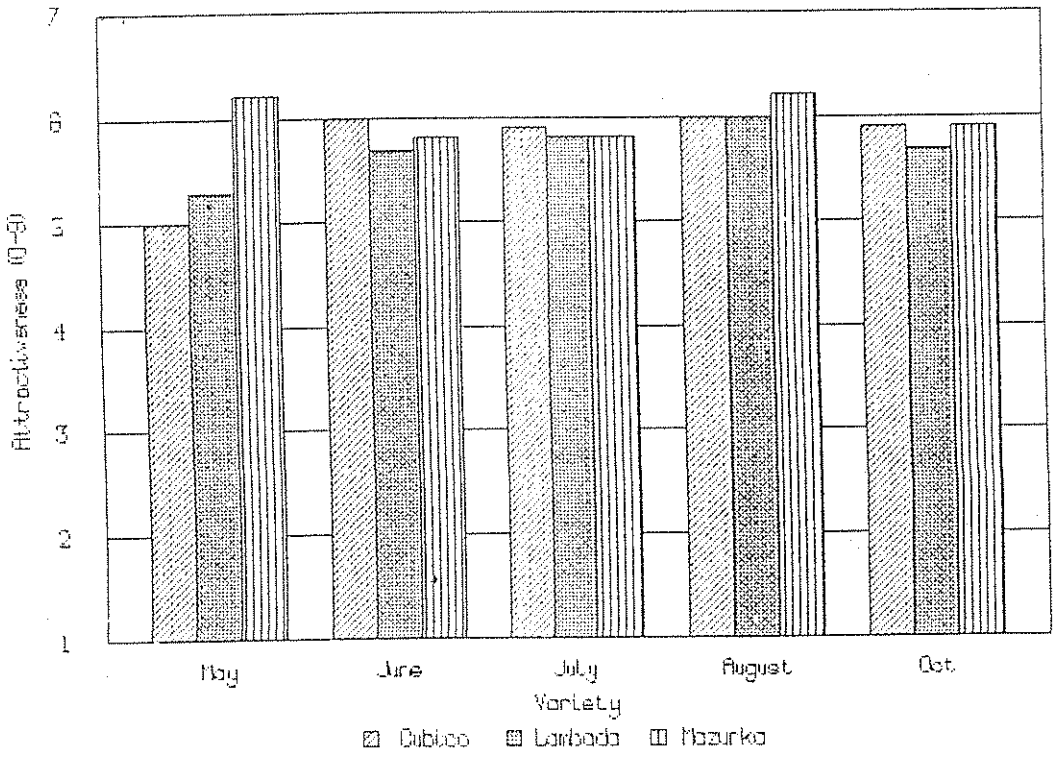


Assessment 1

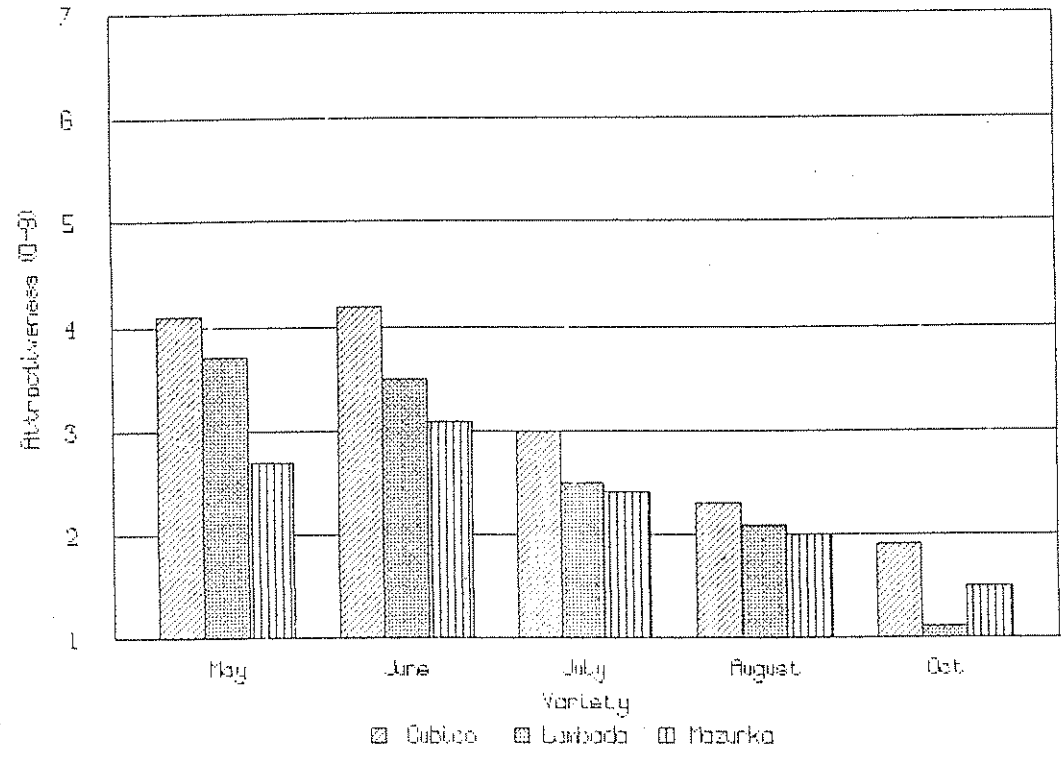


Assessment 3

Figure 9: Overall Attractiveness (continued)

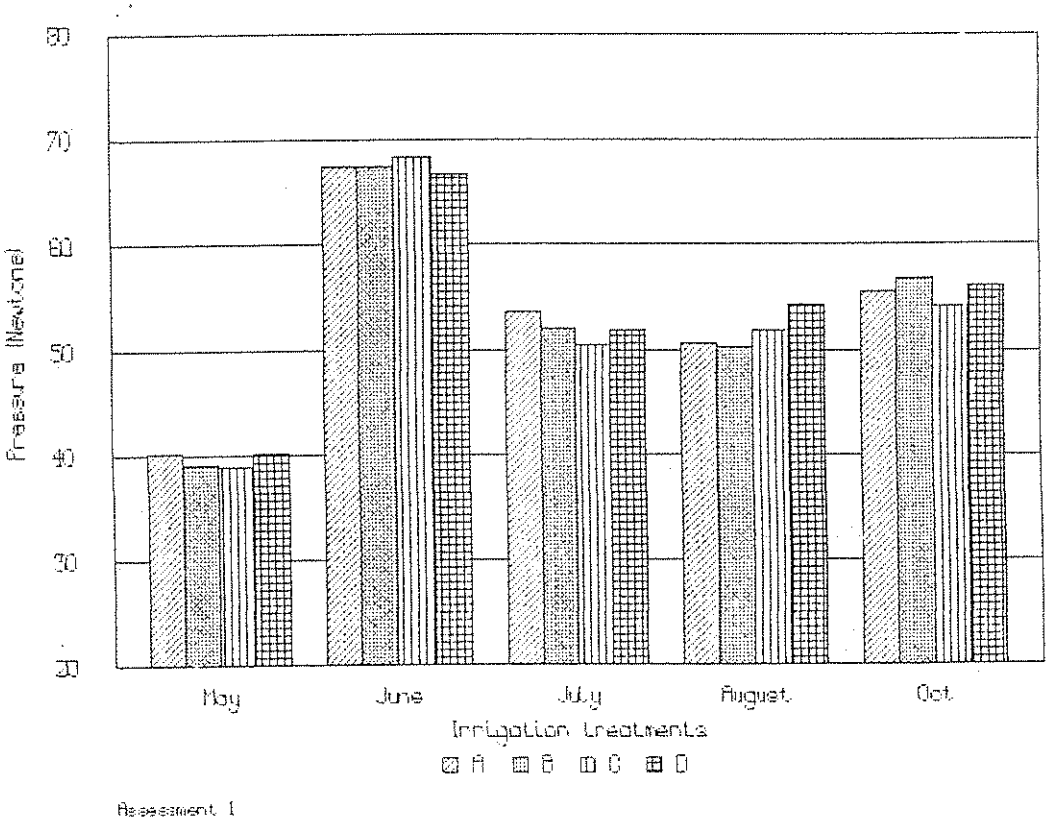


Assessment 1

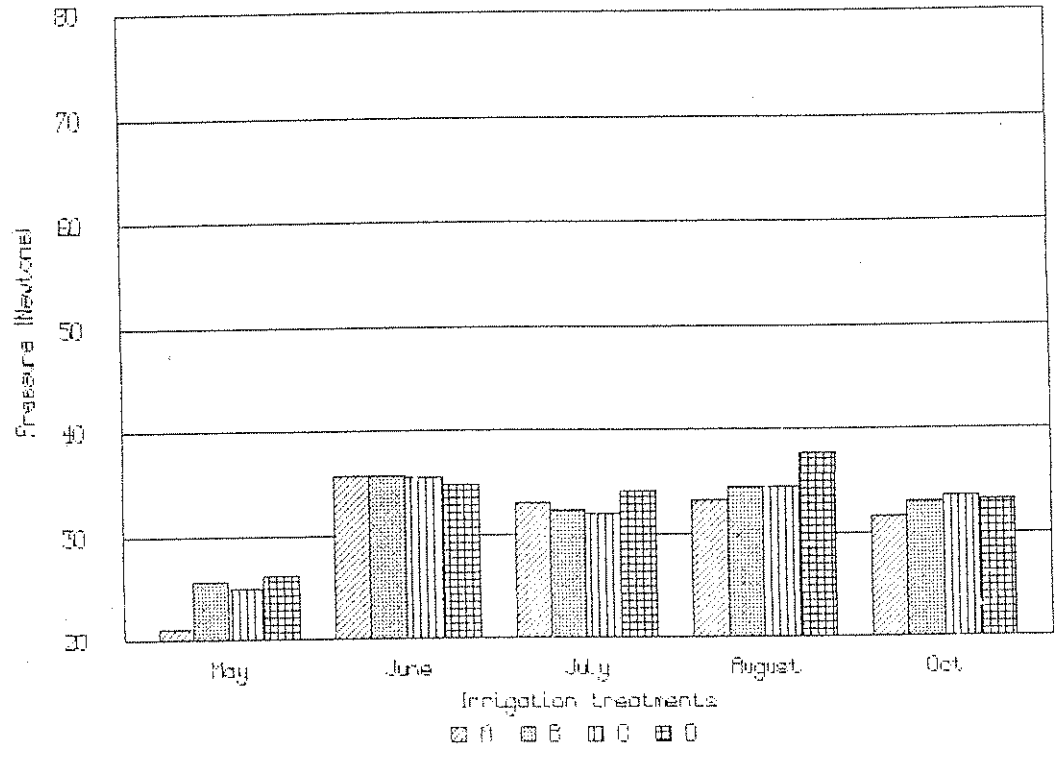


Assessment 3

Figure 10: Firmness - Whole Fruit

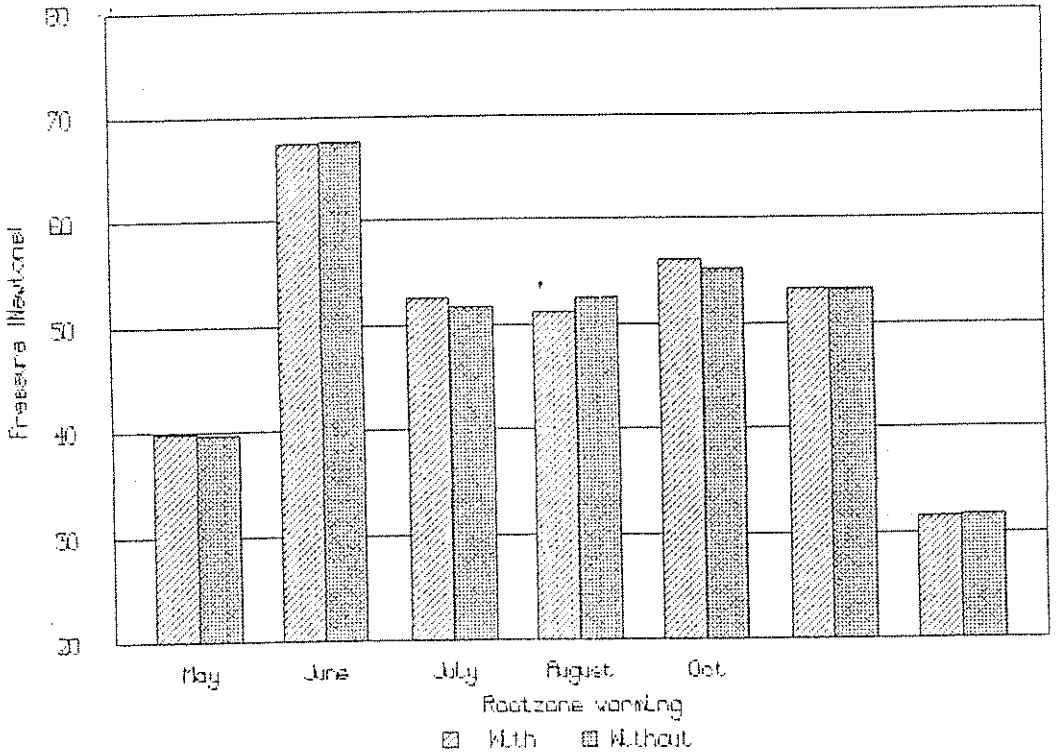


Assessment 1

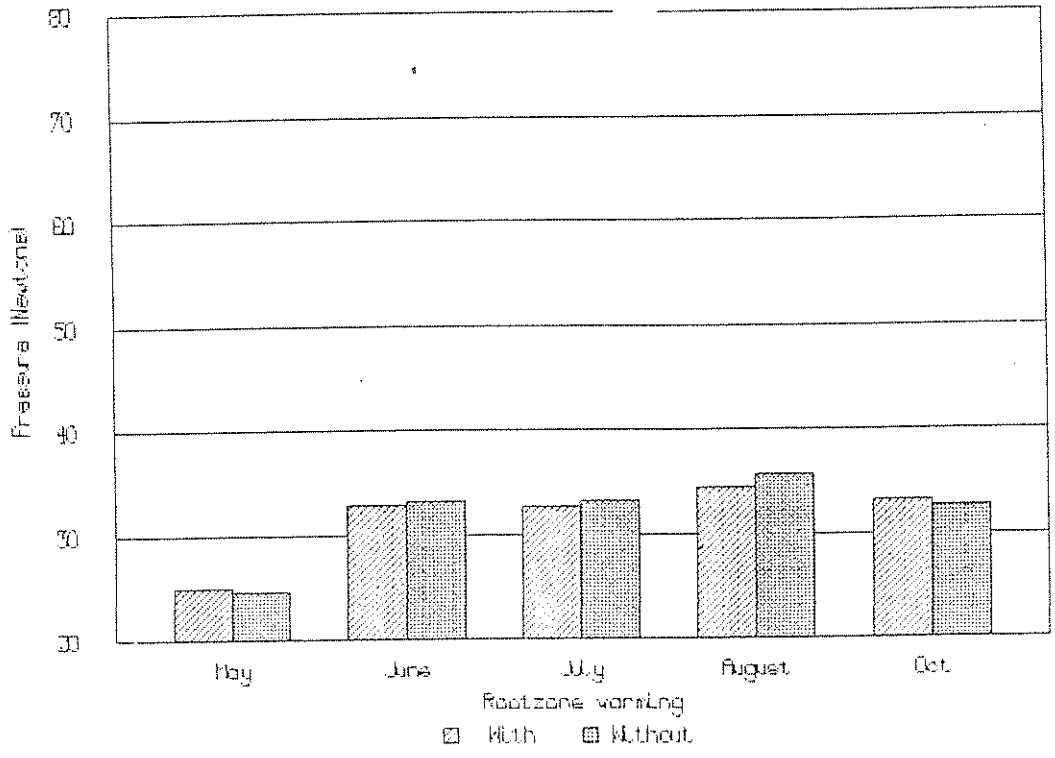


Assessment 2

Figure 10: Firmness - Whole Fruit (continued)

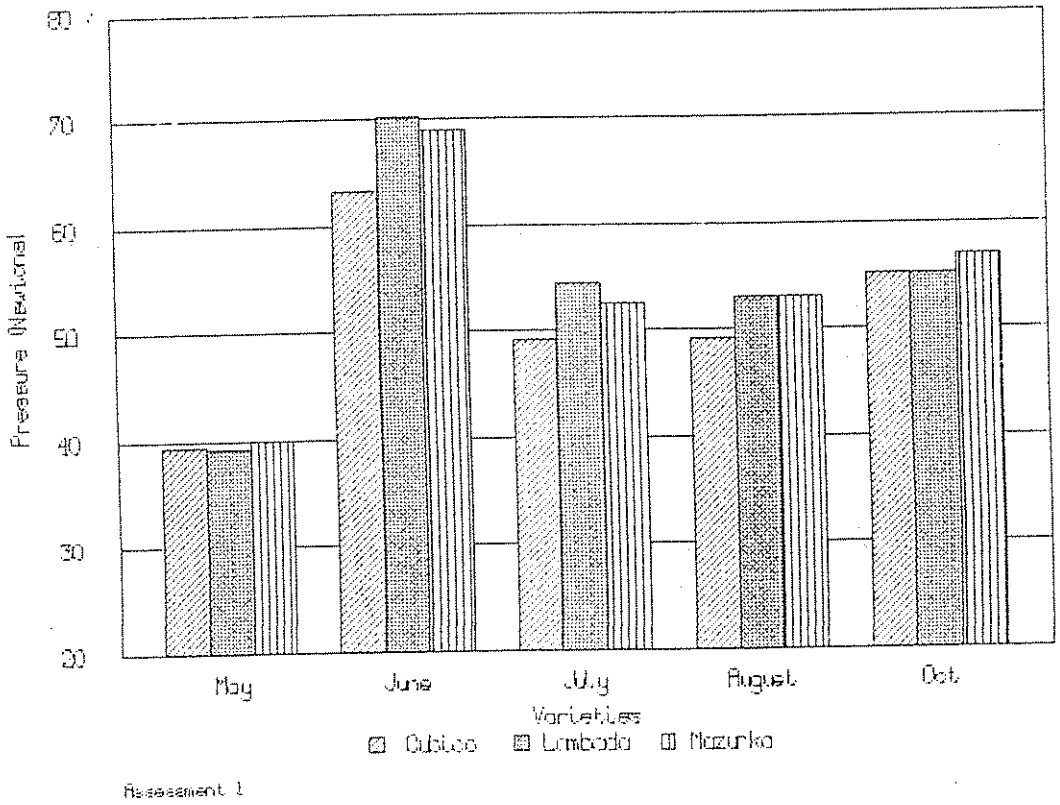


Assessment 1

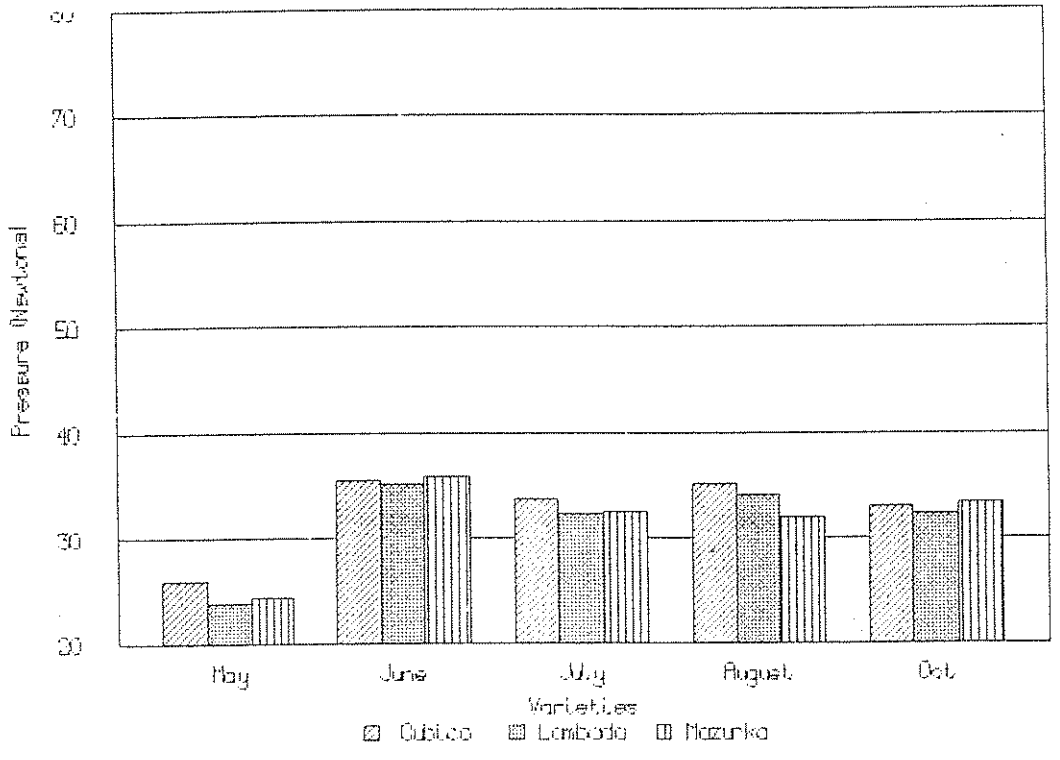


Assessment 2

Figure 10: Firmness - Whole Fruit (continued)



Assessment 1



Assessment 2

Figure 11: Relationship between pressure required to snap a piece of flesh and shrivelling

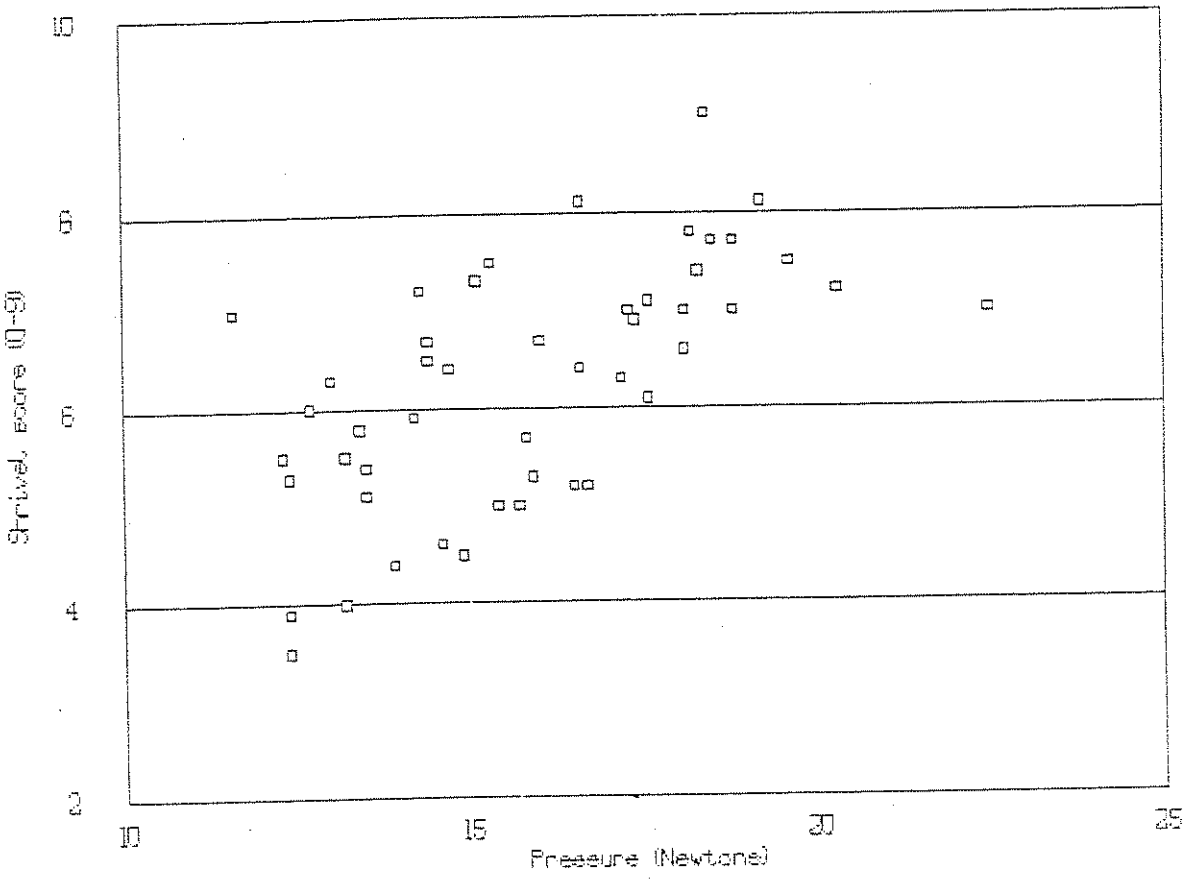
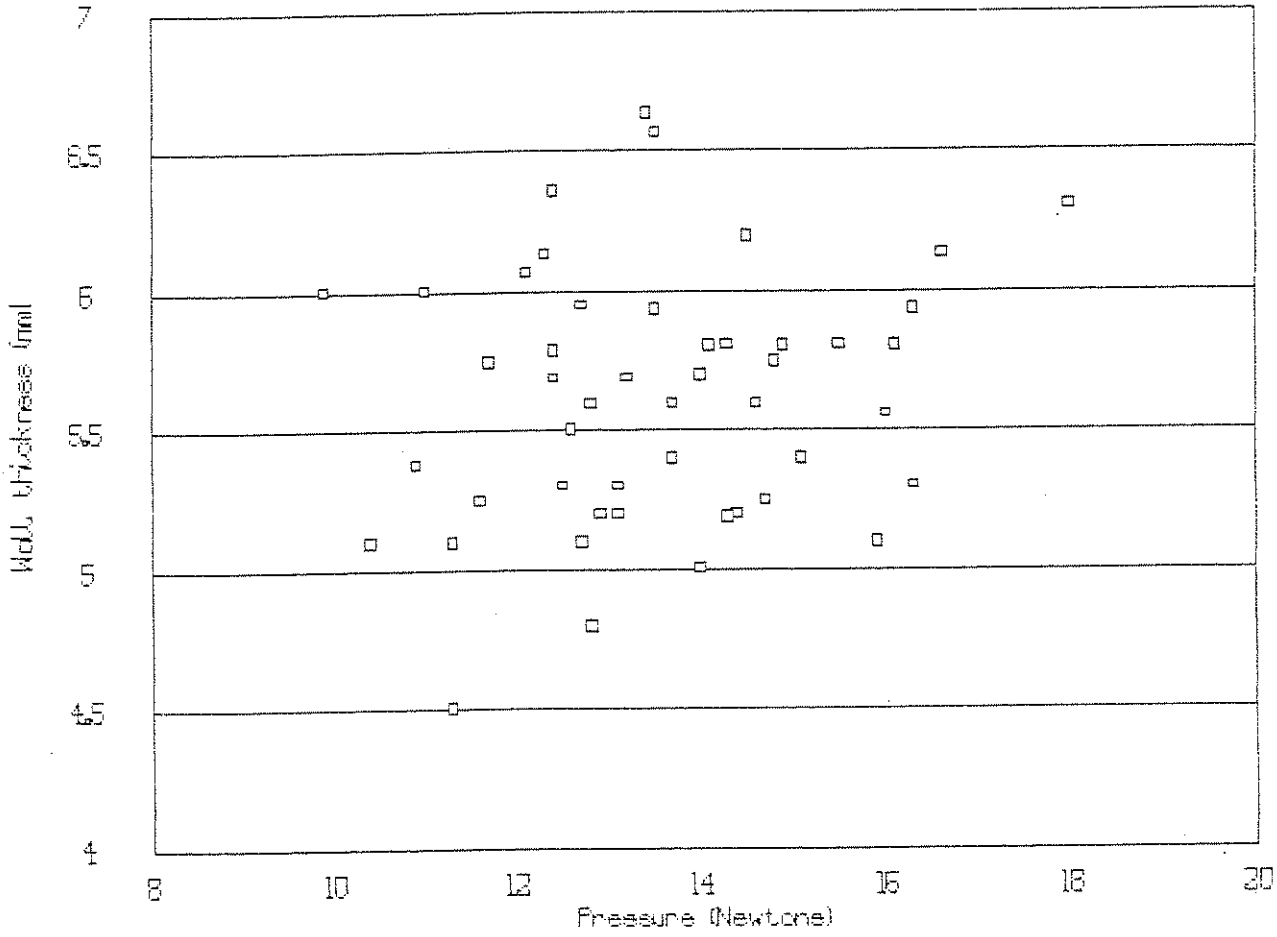


Figure 12: Relationship between pressure require to snap a piece of flesh and wall thickness



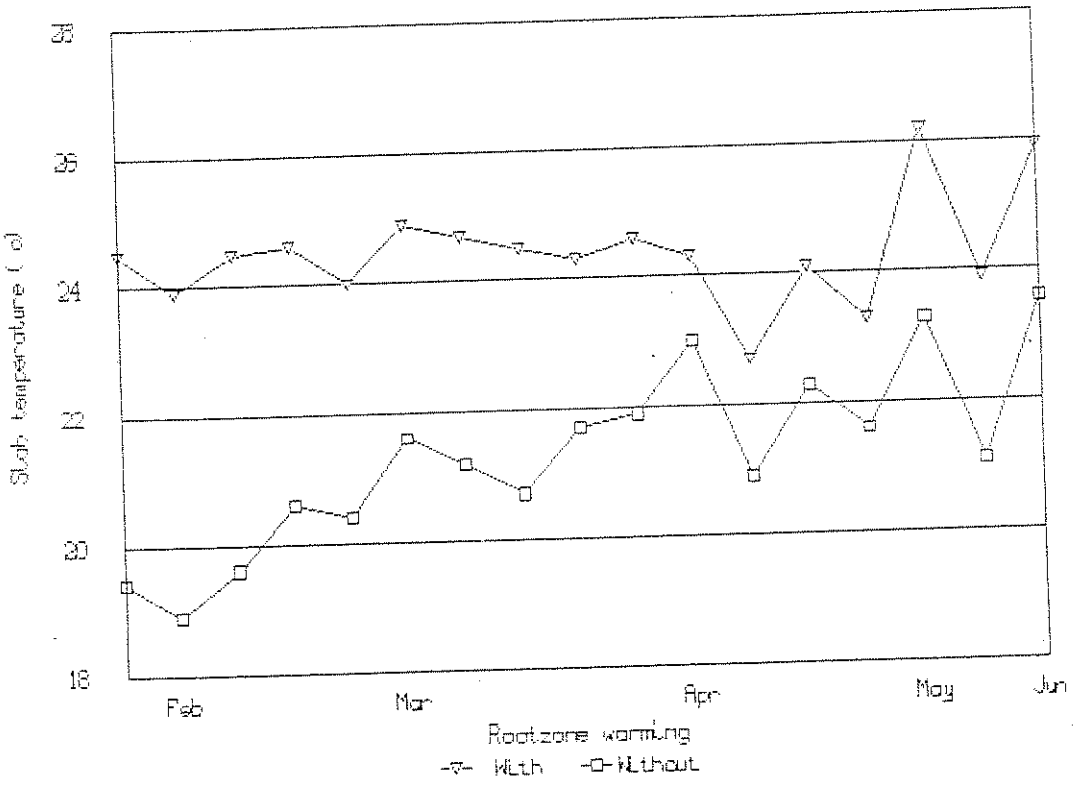
Root Zone Warming

Figure 13 demonstrates the differences in slab temperature between those treatments receiving root zone warming and those without.

Treatments with root zone warming maintained a fairly constant temperature until mid April when fluctuating environmental conditions began to have a significant effect.

Slabs without root zone warming were initially 5 °C cooler than those with root zone warming. The difference became smaller until April and from then on a difference of 1-2 °C was maintained.

Figure 13:



Discussion

Irrigation Treatments

The irrigation regimes influenced total marketable yield with both the day only treatment (A) and the day and night treatment (B) showing yield reductions compared with the reservoir system (D). Fruit size was not affected by the irrigation treatments.

The perlite reservoir showed the lowest Blossom-end rot levels in some months, and there was also a suggestion of some benefit from the day and night watering regime. This led to the slight improvement in Class I production from the reservoir system in September and October/November.

The reservoir system produced fruit with higher calcium levels, particularly at the blossom end and was therefore the optimum system for calcium uptake and distribution to the fruit.

The day only watering regime was the poorest overall when detailed fruit quality and shelf life was assessed. Over the 7 day shelf life period fruit lost most weight and showed more shrivelling and loss of shine. The fruit were the least attractive at the final assessment.

Fruit from the reservoir system (D) and the extra day irrigation system (C) showed less shrivelling and weight loss.

Irrigation treatments were started on 20 May and there were some initial problems calibrating the irrigation systems to give consistent differences between the treatments. Results for the early part of the season should therefore be interpreted with caution.

It should also be considered that the reservoir system used perlite as the substrate and this may have contributed to the advantages of the system.

Root Zone Warming

Slab temperature differences were highest until April but a small difference was maintained throughout the season.

In the early part of the season use of root zone warming improved production of Class I fruit and reduced waste. Blossom end rot was also reduced.

There was no overall yield benefit from use of root zone warming and early season differences were inconsistent. There was less very large fruit from plants in the treatments with root zone warming.

Use of root zone warming increased the level of calcium in the fruit. There was less fine net cracking on the fruit and better shine. Higher slab temperature seemed to promote calyx lifting but there was no consistent pattern of increased weight loss during shelf life.

Root zone warming reduced fine net cracking.

The results suggest that root zone warming could be beneficial in terms of enhancing calcium uptake and reducing Blossom-end rot. In this experiment differences in slab temperature were small when Blossom-end rot was most severe. It is unusual for Blossom-end rot to be a problem before April when there are greatest temperature benefits from root zone warming.

Varieties

Variety selection plays an important part in optimising crop yield and fruit quality.

In this trial Cubico produced high yields of very large fruit but a large percentage was downgraded into Class II, due mainly the poor shape.

Mazurka produced the second highest yield and the highest percentage of fruit in Class I.

Lambada gave the lowest yield and the most waste fruit. It was most susceptible to Blossom-end rot and had the lowest fruit calcium levels.

Cubico had the lowest percentage weight loss over the shelf life period and the least shrivelling but the most fine net cracking.

This suggests that fine net cracking may not be as important in determining how long a fruit remains marketable as other factors such as calyx lifting. Cubico showed very little calyx lifting, compared with Lambada and Mazurka.

Cubico was the most attractive variety after 7 days under shelf life conditions.

Conclusions

1. Yield was reduced by the standard day irrigation and the day and night irrigation treatments, compared with extra day and the reservoir system.

2. Blossom-end rot was reduced slightly by the use of root zone warming and there was a suggestion that the perlite reservoir system was the best of the irrigation treatments.

3. Fruit calcium levels were highest in the root zone warming and the perlite reservoir treatments.

4. Fruit from the standard day irrigation treatment had the poorest shelf life.

5. Of the 3 varieties Cubico produced the highest yields. Fruit was very large and shelf life was the best.

6. Fine net cracking was reduced by the use of root zone warming but there was no consistent relationship with irrigation regime.

7. The results of this experiment suggest that the optimum growing system to minimise fruit quality problems should include:

   i) root zone warming at least for the early part of the season.

   ii) daytime irrigation at a rate higher than the 'standard', either as addition volumes at set times or as a reservoir system.

   iii) the selection of a suitable variety eg Mazurka.

APPENDIX I: FRUIT QUALITY RESULTS

Table A: Flecking

Treatment	May	Jun	Jul	Aug	Oct
Cubico	7.7	1.2	8.5	5.4	2.7
Lambada	2.6	2.6	7.7	3.7	0.9
Mazurka	6.5	5.9	9.5	2.9	2.5
With RZW	4.1	4.2	8.7	3.3	1.0
Without RZW	7.2	2.3	8.5	4.7	2.8
A	6.3	7.6	11.3	3.7	1.9
B	6.0	2.7	10.0	4.0	1.2
C	7.3	0.9	7.3	3.9	1.6
D	4.5	1.7	5.7	4.3	2.8

Table B: Shrivelling (No shrivelling on first assessment)

Treatment	Jun	Jul	Aug	Oct
Second Assessment				
Cubico		1.6	2.3	2.4
Lambada		2.3	2.6	3.0
Mazurka		1.6	3.0	2.5
With RZW		2.2	2.5	2.7
Without RZW		1.6	2.7	2.6
A		2.0	3.6	3.1
B		2.0	2.6	2.3
C		1.9	2.0	2.5
D		1.6	2.2	2.6
Third Assessment				
Cubico	5.1	4.8	5.1	6.6
Lambada	6.1	5.4	5.6	7.6
Mazurka	5.8	6.0	5.5	7.1
With RZW	5.6	5.7	5.3	7.0
Without RZW	5.7	4.8	5.3	7.1
A	5.7	5.8	6.3	7.5
B	5.6	6.0	5.3	7.2
C	6.0	5.6	5.1	7.1
D	5.4	5.3	4.9	6.5

Table C: Calyx Lifting

Treatment	May	Jun	Jul	Aug	Oct
Cubico	0.8	1.7	1.7	1.3	2.5
Lambada	3.5	5.8	5.8	4.1	4.6
Mazurka	2.5	5.3	5.0	3.1	4.2
With RZW	2.3	4.7	4.2	2.7	3.7
Without RZW	2.2	3.8	3.9	2.9	3.9
A	1.9	4.0	4.3	2.9	2.9
B	2.2	4.3	4.4	3.1	4.0
C	2.4	4.4	4.1	2.7	4.3
D	1.9	4.4	3.5	2.6	4.0

Table D: Fine Net Cracking

Treatment	May	Jun	Jul	Aug	Oct
Cubico	3.9	3.3	3.6	4.3	3.7
Lambada	3.1	4.1	3.5	3.8	3.5
Mazurka	2.1	3.2	2.2	2.5	3.4
With RZW	2.6	3.3	2.9	2.9	3.4
Without RZW	3.4	3.7	3.2	3.6	3.9
A	3.0	3.2	3.3	4.0	3.2
B	2.8	3.6	3.1	3.5	3.8
C	3.0	3.6	2.9	3.3	3.9
D	3.2	3.6	2.9	3.2	3.6

Table E: Weight Loss

Treatment	May	Jun	Jul	Aug	Oct
Cubico	7.5	10.6	9.9	10.8	13.8
Lambada	10.7	12.1	12.4	12.1	13.9
Mazurka	10.5	12.4	11.2	11.6	13.8
With RZW	10.1	11.6	11.1	11.6	13.7
Without RZW	9.8	11.9	11.3	11.4	14.0
A	10.2	12.9	11.3	12.5	14.5
B	9.7	10.7	12.2	11.3	13.9
C	10.2	11.7	10.5	11.1	13.7
D	9.8	11.5	10.7	11.1	13.3

Table F: Sugar Content

Treatment	Jun	Jul	Aug	Oct
Cubico	7.6	7.4	7.1	7.3
Lambada	7.3	7.4	7.4	6.7
Mazurka	6.5	6.0	6.7	6.8
With RZW	7.1	7.0	7.1	6.9
Without RZW	7.2	7.3	7.0	6.9
A	7.0	6.9	7.4	7.1
B	7.2	7.6	7.1	6.6
C	7.2	6.8	7.1	7.0
D	7.1	7.4	6.7	7.1

Table G: Fruit Shine

Treatment	May	Jun	Jul	Aug	Oct
First Assessment					
Cubico	6.5	6.9	6.7	6.6	6.6
Lambada	6.2	6.4	6.2	6.4	6.4
Mazurka	6.7	6.4	6.3	6.4	6.8
With RZW	6.6	6.6	6.4	6.6	6.8
Without RZW	6.3	6.6	6.2	6.3	6.4
A	6.7	6.6	6.4	6.4	6.3
B	6.7	6.7	6.5	6.5	6.9
C	6.1	6.5	6.3	6.4	6.6
D	6.6	6.6	6.2	6.6	6.5
Second Assessment					
Cubico	6.2	6.4	5.7	6.0	5.5
Lambada	5.7	6.0	5.3	5.7	5.3
Mazurka	5.7	5.9	5.8	5.7	5.9
With RZW	6.0	6.1	5.6	5.7	5.8
Without RZW	5.8	6.1	5.6	5.8	5.3
A	5.9	6.1	5.1	5.6	5.5
B	6.1	6.1	6.0	5.9	5.5
C	5.7	6.1	5.4	5.9	5.7
D	6.0	6.1	5.9	5.8	5.5
Third Assessment					
Cubico	5.1	5.4	4.7	3.7	3.7
Lambada	3.9	4.9	4.1	4.0	2.8
Mazurka	3.7	4.6	4.7	4.3	3.4
With RZW	4.5	5.2	4.4	4.2	3.5
Without RZW	4.7	4.7	4.5	3.3	3.0
A	4.6	4.2	4.3	3.4	3.1
B	4.3	5.4	4.7	4.0	3.8
C	4.4	5.5	4.3	4.5	3.3
D	4.9	4.8	4.6	4.5	3.2

Table H: Overall Attractiveness

Treatment	May	Jun	Jul	Aug	Oct
First Assessment					
Cubico	5.0	6.0	5.9	6.0	5.9
Lambada	5.3	5.7	5.8	6.0	5.7
Mazurka	6.2	5.8	5.8	6.2	5.9
With RZW	5.7	5.9	6.0	5.7	6.1
Without RZW	5.2	5.8	5.7	6.0	5.6
A	5.9	6.0	5.6	5.8	5.9
B	5.6	5.9	6.0	6.2	5.9
C	5.4	5.8	6.0	6.0	5.9
D	5.2	5.8	5.7	6.2	5.6
Second Assessment					
Cubico	4.6	5.7	5.2	5.2	4.9
Lambada	5.1	5.5	5.1	4.7	4.6
Mazurka	5.3	5.6	5.4	4.7	5.1
With RZW	5.2	5.6	5.3	4.5	5.0
Without RZW	4.8	5.6	5.4	4.7	4.7
A	5.0	5.6	5.3	4.4	4.6
B	5.2	5.7	5.4	4.9	5.0
C	5.0	5.5	4.8	5.1	5.1
D	4.9	5.6	5.3	4.9	5.0
Third Assessment					
Cubico	4.1	4.2	3.0	2.3	1.9
Lambada	3.7	3.5	2.5	2.1	1.1
Mazurka	2.7	3.1	2.4	2.0	1.5
With RZW	3.8	3.9	2.7	2.1	1.6
Without RZW	3.8	3.3	2.8	2.2	1.4
A	3.7	3.0	2.5	1.7	1.1
B	3.8	4.1	3.0	2.3	1.6
C	3.8	3.8	2.8	2.3	1.5
D	3.7	3.6	2.4	2.1	1.8

Table I: Wall Thickness (mm)

Treatment	Jun	Jul	Aug	Oct
First Assessment				
Cubico	6.4	6.7	5.9	6.0
Lambada	7.1	7.2	6.5	6.4
Mazurka	6.7	7.0	6.7	6.2
With RZW	6.8	6.9	6.3	6.3
Without RZW	6.5	6.9	6.4	6.1
A	6.7	7.0	6.3	6.0
B	6.7	6.8	6.4	6.2
C	6.5	6.8	6.2	6.2
D	6.8	7.0	6.6	6.4
Second Assessment				
Cubico	6.0	6.3	5.7	5.2
Lambada	6.8	6.5	5.7	5.2
Mazurka	6.6	6.3	6.0	5.4
With RZW	6.4	6.4	5.6	5.2
Without RZW	6.5	6.4	5.4	5.3
A	6.5	6.5	5.9	5.2
B	6.6	6.4	5.8	5.2
C	6.3	6.2	5.7	5.2
D	6.7	6.6	5.5	5.4

Table J: Firmness of Whole Fruit

Treatment	May	Jun	Jul	Aug	Oct
First Assessment					
Cubico	39.5	63.2	49.1	49.1	55.1
Lambada	39.3	70.3	54.5	53.1	55.1
Mazurka	40.0	69.0	52.6	53.2	57.1
With RZW	39.7	67.3	52.5	51.1	56.2
Without RZW	39.5	67.7	51.7	52.6	55.3
A	40.2	67.5	53.8	50.7	55.7
B	39.1	67.5	52.2	50.3	57.0
C	38.9	68.3	50.5	52.0	54.2
D	40.2	66.7	51.8	54.3	56.3
Second Assessment					
Cubico	26.1	35.6	33.6	35.1	32.9
Lambada	23.9	35.1	32.4	34.2	32.4
Mazurka	24.4	35.8	32.6	32.0	33.5
With RZW	24.9	32.9	32.7	34.5	33.1
Without RZW	24.7	33.1	33.1	35.6	32.7
A	21.2	35.7	33.0	33.3	31.7
B	25.7	35.8	32.3	34.5	33.0
C	24.9	35.5	32.0	34.5	33.7
D	26.4	34.8	34.2	37.8	33.3

Table K: Flesh Firmness

Treatment	Jun	Jul	Aug	Oct
First Assessment				
Cubico	11.7	11.3	9.2	8.8
Lambada	13.1	14.8	12.5	10.3
Mazurka	11.3	12.0	13.0	9.9
With RZW	12.4	12.4	11.1	10.6
Without RZW	11.7	12.2	12.1	8.8
A	12.3	13.9	10.6	8.8
B	13.9	11.7	12.3	10.8
C	10.2	12.9	11.6	8.9
D	11.6	13.8	11.9	10.1
Second Assessment				
Cubico	16.4	12.0	13.2	16.2
Lambada	20.1	13.2	15.8	18.2
Mazurka	18.0	10.5	14.3	17.4
With RZW	18.9	12.2	14.2	17.3
Without RZW	17.5	12.4	14.6	17.3
A	18.4	11.3	15.1	17.3
B	17.7	10.7	14.0	17.9
C	17.0	13.1	14.3	17.6
D	19.6	12.6	14.1	16.6