CARROTS: PRE-HARVEST TREATMENTS TO REDUCE DAMAGE DURING HARVESTING OPERATIONS

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PRACTICAL SECTION FOR GROWERS

In this 4-year project, a range of irrigation, defoliation, undercutting or salt treatments was applied to carrot crops in the month before harvest to identify factors which could help to reduce the level of breakage damage which occurs during commercial harvesting. Separate reports for years 1990, 1991 and 1992 of the project have been produced previously. This final report summarises the main findings from all four years.

The varieties used were Narbonne (NIAB rating 8) and Narman (rating 9), both relatively resistant to breakage damage, and Panther (rating 5) and Tamino (rating estimate of 2), both relatively susceptible.

Crop were drilled in April or May and harvested during the period from September to November in 1990 to 1993.

In 1990, the carrots were defoliated and a range of undercutting treatments was used. In 1991, in addition to these treatments, carrots were irrigated before harvest to test the effect of supplementary water on root turgidity and subsequent breakage during the harvest process. Also, concentrated salt treatments were applied to try to reduce splitting and breakage. In 1992 and 1993, carrots were irrigated and undercut before harvest.

At all harvests, the roots were subjected to standard breakage tests to simulate dropping either en masse 1.5 m from a trailer or individually 1.0 m off a conveyor belt.

Key findings

Variety

Choice of variety was the most important factor in reducing the amount of breakage damage in the trials. Panther and Tamino suffered many more damaged roots than either Narbonne or Narman. In one year Narman had less breakage than Narbonne. Most damage recorded was horizontal breakage, with very few vertical splits.

Irrigation

Applying irrigation within 4 weeks of harvest had a tendency to increase the number of broken carrots; this was particularly noticeable when treatments were applied in the rather wetter year of 1992.

Defoliation

Defoliation of carrots 24 hours before harvest increased breakage, but there was no problem when this was done 2 hours before lifting, (standard commercial practice).

Salt Application

Although salt applications just before harvest showed some reduction of subsequent damage, this wasn't felt to be sufficiently promising to continue working on.

Undercutting

In 3 out or 4 years, some of the undercutting treatments led to a reduction in damage. This caused some wilting of foliage, but it is thought not sufficient to cause a problem with top-lifting.

In 1990, damage was reduced in 3 or the 4 varieties used at the early, but not at a later, harvest. In 1991 and 1992, unirrigated treatments were more likely to benefit from undercutting.

Incorporating an undercutting treatment in a harvesting system could lead to overall benefits in damage reduction.

INTRODUCTION

Carrots roots are prone to mechanical damage and breakage during harvesting and transporting to the packhouse. The damage can be one of two major types; horizontal breakage of the root into two or more pieces or longitudinal splitting. Other less visible damage can be tip damage, gouging or surface abrasion. All of these reduce the quality of the root and can lead to loss of marketable yields and reductions of shelf life.

Studies were carried out at Silsoe college in the early 1980's in MAFF-funded projects looking at root breakage. The work carried out by Millington (1985) studied the influence of some physical properties of carrots on their damage characteristics. Smooth carrots proved more resistant to injury than 'notched' roots. Varieties differed significantly in their mechanical properties and response to impact damage. Kokkoras (1989) showed that the mechanical properties of carrot tissue were significantly affected by their temperature and water status.

This HDC study was started in 1990 using four varieties, Panther, Tamino, Narman and Narbonne. Several cultural techniques were applied in the month before harvest, which aimed to reduce the roots turgidity to a small degree but sufficient to render them less brittle and susceptible to damage, but still meeting market requirements. The varieties differed in their susceptibility to damage and followed the pattern of their NIAB rating for damage susceptibility: Panther and Tamino proving more susceptible than either Narman or Narbonne.

These cultural techniques examined included applying irrigation as a means of achieving moist soils at field capacity as occurs in late autumn in most seasons. As a comparison, irrigation was also withheld prior to harvest to test whether reduced soil moisture would lead to reduced turgidity of the carrots, hence to reduced levels of crop damage. Another technique was to undercut the main taproot severing it from the fibrous roots and leading to a reduction in turgidity of the carrots. In one season, a concentrated salt solution was applied with the aim of increasing surrounding soil osmotic potential leading to a reduction in root turgidity. The effect of defoliation, which is practised typically about 2 hours before harvest, on increasing root turgor was also investigated in one season.

OBJECTIVE

To assess the effect of irrigation and other cultural treatments carried out prior to harvesting on carrot root breakage and splitting.

OUTLINE OF MATERIALS AND METHODS

Site

The experiments were done at ADAS Arthur Rickwood Research Centre on peaty loam soils (24-33% organic matter) over fen clay of the Adventurers' Shallow Series.

Treatments

1. Varieties

a. Narbonne (BJO) highly resistant to breakage (NIAB rating 8)
b. Narman (BJO) highly resistant to breakage (NIAB rating 9)
c. Panther (BSL/SEG) relatively susceptible to breakage (NIAB rating 5)
d. Tamino (RS) very susceptible to breakage (NIAB rating estimate at 2)

2. Irrigation

a. None prior to harvest
b. Repeated application prior to harvest
   1990 - None because of NRA irrigation ban imposed from July
   1991 - Four times before each harvest (4 x 25 mm)
   1992 - Twice before first harvest (2 x 25 mm)
   Once before second harvest (1 x 25 mm)
   1993 - No irrigation treatments

3. Pre-harvest undercutting treatments

a. Not undercut
b. Undercut 2 hours before harvest (1990 only)
c. Undercut 24 hours before harvest (1990, 1991, 1992, 1993)
d. Undercut 48 hours before harvest (1991, 1992)
e. Undercut 72 hours before harvest (1991, 1992, 1993)
f. Undercut 118 hours (7 days) before harvest (1993 only)

4. Pre-harvest defoliation treatments (1990 only)

a. Not defoliated
b. Defoliated 2 hours before harvest to a height of about 15 cm
c. Defoliated 24 hours before harvest to a height of about 15 cm

5. Pre-harvest application of concentrated salt solution (1991 only)

a. Salt at 24 hours before harvest
b. Salt at 48 hours before harvest

The salt solution comprised 125 kg/ha PPDV Dendritic salt in 330 l/ha water and was applied using an Oxford Precision sprayer at 2 bar (200 kPa) pressure with Teejet 8003 nozzles.

Husbandry

The trials were drilled and harvested as shown in Table 1. The aim was to achieve a population of 160 plants/m² to give a good proportion of 25-32 mm sized carrots for the breakage tests.

Each trial had the same bed width of 1.7 m except in 1993 when 1.8 m was used. There were four rows per bed.

The crops were grown using standard husbandry inputs (Appendix I). Where appropriate, carrots were defoliated using shears (1990 only). For undercutting (1990-1993), a garden fork was used in 1990-1991 and a tractor-mounted undercutting bar was used in 1992 and 1993.

Assessments

Damage tests 1990-1993

Test 1 Simulate loading onto a trailer

At harvest, 50 plants at random per plot were lifted by hand, tops removed, and carefully placed into nets and dropped from a height of 1.5 m onto a pile of carrots with roots of the same size. The number and weight of broken and split carrots and root fragments were recorded.

Test 2 Simulate dropping off conveyor belt

At harvest in October, 50 roots of a similar size (within 25-44 mm size grade) were placed into a plastic bag, carried to the grading line, and there removed from the plastic bag and laid onto a roller conveyor belt. They were dropped once from a height on 1.0 m off this conveyor belt onto carrots of the same variety. The number and weight of damaged carrots were recorded.

Turgidity tests 1991 and 1992

20 roots per plot of pre-packed size grade were placed into plastic bags, carried indoors where they were washed and weighed, then placed into water for 96 hours, (in 1990, only for 24 hours) then surface dried and re-weighed. This test recorded any loss or gain in turgidity from the treatments applied to the roots prior to harvest.

Shelf life tests 1993

50 roots per plot of selected treatments of cv. Narman were placed in shelf life conditions at the National Institute of Agricultural Botany (NIAB). The treatments comprised all combinations of either irrigating or not prior to harvest and either undercutting 72 hours before harvest or not undercutting.

Two tests were done which comprised assessing the carrots placed in polythene bags to simulate pre-packing, and unpackaged to simulate 'loose fill'. The samples were weighed every 24 hours to determine percentage weight loss. After 7 days the samples were also assessed for quality. A 1-9 scoring systems (9 being good) was used to assess turgidity and skin texture. Disease was also assessed by recording percentage of root area affected.

Field storage 1993

Some plots were undercut in November, then subsequently field stored under 40 t/ha straw. This was to test whether undercutting to reduce levels of damage prior to field storage would affect root quality.

Foliage wilting 1993

After undercutting 24 or 72 hours before harvest, the foliage wilted slightly. An assessment of this degree of wilting was made on a scale of 1-10 where 1 = severe wilting and 10 = no wilting. This wilting could hinder smooth passage of the top lifting machine, and the potential effects were recorded on a 1-3 scale where 1 = would be difficult to lift, 2 = possible to lift and 3= easily lifted with top lifting harvester.

Designs and statistical analyses

In 1990, the trial design was a split plot with varieties and defoliation treatments on main plots, with the three under-cutting treatments at the sub-plot level. There were three replicates, half of each allocated to a harvest date. These data were analysed at HRI Wellesbourne.

In 1991 and 1992 the trials were split-split plot designs, with irrigation treatments at the main plot level, which were split for varieties, and split again for the undercutting (and salt) treatments. There were three replicates. In 1993 the trial was a randomised block with three replicates.

The data were analysed statistically, and transformed where appropriate.

Table 1. Treatments and crop schedules 1990-1993.

Year	Variety	Drilled	Harvested	Water regime (mm) 4 weeks before harvest		Other pre-harvest treatments
				Rainfall (mm)	Irrigation (mm)	
1990	Narbonne Narman	9 May	26-28 September	27.4	-	Defoliated 2 and 24 hours before harvest
	Panther Tamino		13-15 November	69.1	-	Undercut 2 and 24 hours before harvest
1991	Narbonne Narman	10 April	30 September - 2 October	43.1	100 (4x25)	Undercut 24, 48 and 72 hours before harvest
	Panther Tamino	24 May	30 October - 2 November	56.4	100 (4x25)	Salt 24 and 48 hours before harvest
1992	Narman	24 April	15 October	97.1	50 (2x25)	Undercut 24, 48 and 72 hours before harvest
	Panther		19 November	94.7	25 (1x25)	
1993	Narbonne Narman	7 May	5 November	68.6	-	Undercut 24, 72 and 118 hours before harvest

RESULTS

In each season, the crops established well with approximately 160, 150, 120 and 110 plants/m² on average in 1990, 1991, 1992 and 1993 respectively. The crops were grown to a good commercial standard.

Irrigation

This factor was not tested in 1990 or 1993.

In 1991 a total of 100 mm of irrigation was applied prior to each harvest in addition to 34 or 28 mm of rainfall for the September and October lift respectively. Irrigation did not affect splitting or breakage and there were no interactions with other factors.

In 1992, a wet autumn, it was difficult to apply irrigation, but 50 and 25 mm were applied before the first and second harvests respectively. Irrigation increased the numbers of split carrots from 2.2 to 3.8% after dropping roots 1.5 m (mean over both harvest dates). Irrigation also affected the total number of damaged carrots but in a complex way, interacting with variety and undercutting treatments. These are referred to in the section on undercutting.

Variety

In 1990, at the first harvest taken from 26 to 28 September when the carrots were slightly immature, there were very large ($P<0.001$) differences between varieties at all breakage tests (Table 2). These differences showed throughout the four years of the experiment.

Table 2. Percentage number of broken carrots when dropped off a conveyor or in a net following harvest in September 1990 (data angularly transformed).

Variety	NIAB rating	Conveyor (Test 2) 1.0 m drop	Net (Test 1) 1.5 m drop
Narbonne	8	7.5	27.6
Narman	9	5.8	24.8
Panther	5	14.8	43.9
Tamino	(2)	17.5	43.4
S.E.D. (22 df)		1.30	1.68

Defoliation

Defoliating the carrots 24 hours before harvest increased (P<0.05) damage for all varieties in 1990 (Table 3).

Table 3. Percentage number of (broken and split) damaged carrots when dropped off a conveyor or in a net following defoliation before harvest in September 1990 (data angularly transformed).

Defoliation treatment	% damaged	
	Conveyor (Test 2) 1.0 m drop	Net (Test 1) 1.5 m drop
Nil	10.3	32.6
2 hours before harvest	10.6	35.5
24 hours before harvest	13.4	36.6
S.E.D. (22 df)	1.13	1.45

There did not appear to be any benefit from defoliating 24 hours before harvest (Table 3) and this treatment was not evaluated in later seasons. Defoliating the crop two hours before harvest, which is standard commercial practice , did not significantly increase damage levels.

Undercutting

The effects of undercutting in 1990 are shown in Tables 4 and 5. There were no significant interactions with either variety or defoliation treatment.

Table 4. Percentage number of damaged (broken and split) carrots when dropped 1.0 m off a conveyor after undercutting the crop before harvest in September 1990 (data angularly transformed).

Variety	% damaged (1.0 m drop)		
	Not undercut	Undercut 2 hours	Undercut 24 hours
Narbonne	7.5	7.8	7.3
Narman	5.7	6.9	4.9
Panther	17.0	15.4	12.0
Tamino	19.3	19.0	14.3
Mean	12.4	12.3	9.6

S.E.D. (48 df) between undercutting means	1.13
between undercutting means for each variety	2.26

Table 5. Percentage number of damaged (broken and split) carrots when dropped 1.5 m in a net after undercutting the crop before harvest in September 1990 (data angularly transformed).

Variety	% damaged (1.5 m drop)		
	Not undercut	Undercut 2 hours	Undercut 24 hours
Narbonne	30.3	27.6	24.9
Narman	24.4	26.3	23.6
Panther	46.2	44.4	41.2
Tamino	44.6	43.9	41.8
Mean	36.4	35.6	32.9

S.E.D. (48 df) between undercutting means 1.26
between undercutting means for each variety 2.52

Undercutting 24 hours before harvest reduced ($P<0.05$) the overall levels of damage when averaged over all varieties (Tables 4 and 5). Although there was no interaction between variety and undercutting factors, it appears that the varieties responded slightly differently which is of commercial importance. At the 1.0 m drop (Table 4) Narman and Narbonne had similar damage levels whether undercut or not. When dropped 1.5m (Table 5), the levels of damage in Narbonne were lower after undercutting.

At the second harvest in November 1990, when the roots were mature, undercutting did not reduce damage at either the 1.0 m or 1.5 m drop test. This effect was the same for all four varieties.

In 1991, at the first drilling/harvest date (April/September), there were no overall effects from undercutting. There were slight tendencies towards a reduction of damage when undercutting 72 hours before harvest. This effect was more apparent where the crop had received no additional irrigation (Table 6).

Table 6. Percentage number of damaged (broken and split) carrots after being dropped 1.0 m following harvest in September 1991 (data angularly transformed).

Variety	% damaged Not undercut	 Undercut 72 hours
No irrigation		
Narbonne	3.9	2.7
Narman	7.4	2.7
Panther	11.5	7.4
Tamino	19.5	11.3
With irrigation		
Narbonne	8.2	6.6
Narman	2.7	2.7
Panther	4.7	9.3
Tamino	13.3	10.4

S.E.D. (94 df) between irrigation x undercutting means for one variety 2.40

When dropped 1.5 m, undercutting did not reduce levels of breakage damage in September 1991.

At the second drilling/harvest date (May/October) in 1991, undercutting 72 hours before harvest reduced the overall levels of breakage. This was the case for all varieties except Narbonne, but was only significant for Panther (Table 7). There were no irrigation effects.

Table 7. Percentage number of broken carrots after being dropped 1.0 m following harvest in November 1991 (data angularly transformed).

Variety	% damaged Not undercut	 Undercut 72 hours before harvest
Narbonne	3.3	3.3
Narman	5.2	2.7
Panther	15.8	7.9
Tamino	16.2	10.1

S.E.D. (94 df) between undercutting means within a variety 3.07

When dropped 1.5 m, breakage increased but with no overall benefit from undercutting.

In 1992, there were complex interactions between treatment factors. In the absence of irrigation, undercutting Narman reduced ($P<0.05$) the levels of damage. With irrigation, undercutting Narman did not significantly reduce the number of damaged roots (Table 8).

Table 8. Total numbers of damaged (broken and split) carrots after being dropped 1.5 m in 1992 (meaned over both harvests).

Variety	Irrigation	% damaged Not undercut	Undercut 24 hrs	Undercut 72 hrs
Narman	without	23.7	16.3	14.7
	with	21.7	15.3	19.3
Panther	without	33.0	42.7	43.3
	with	48.0	40.3	41.0

S.E.D. (48 d.f.) for irrigation x undercutting means for one variety 3.26

For Panther, undercutting the crop before harvest increased ($P<0.05$) levels of damage in the absence of irrigation. With irrigation, undercutting did not affect the levels of damage (Table 8).

When meaned over both varieties and irrigation treatments, the pre-harvest undercutting treatments gave a reduction ($P<0.05$) in damage at the second harvest but not at the first (Table 9).

Table 9. Total numbers of damaged (broken and split) carrots after being dropped 1.5 m (mean over both varieties and irrigation treatments).

Harvest	% damaged Not undercut	Undercut 24 hr	Undercut 72 hr
15 October	26.8	25.2	30.8
19 November	36.3	32.2	28.3

S.E.D. (48 d.f.) between harvest x undercutting means 3.26

After being dropped 1.0 m off a conveyor (Test 2), damage levels of broken and split carrots were lower at 13.2% and 0.5% respectively in 1992.

There was a highly significant ($P<0.001$) interaction between irrigation and variety treatments (Table 10). Applying irrigation before harvest increased the total number of damaged carrots for Narman, but reduced it for Panther. There were no other significant treatment effects or interactions.

Table 10. Total numbers of damaged (broken and split) carrots after being dropped 1.0 m when meaned over both harvest dates and all undercutting treatments (data angularly transformed).

Irrigation	% damaged Narman	Panther
Without	11.6	28.0
With	16.8	23.5

S.E.D. (48 d.f.) between irrigation x variety means 1.84

In 1993, Narbonne and Narman were undercut 24, 72 and 118 hours before harvest. There were differences between the varieties when subjected to the 1.0 m drop test off a conveyor; Narman was damaged least (Table 11). There were no overall significant differences between the undercutting treatments, but for Narbonne, there was a trend towards reduced damage, where undercut at least 72 hours before harvest.

Table 11. Percentage number of broken carrots following a drop of 1.0 m in 1993.

Actual data

Variety	% broken				
	Not undercut	Undercut 24 hr	Undercut 72 hr	Undercut 118 hr	Mean
Narbonne	11.7	11.0	8.3	8.3	9.8
Narman	2.0	3.3	5.3	4.0	3.7
Mean	6.8	7.2	6.8	6.2	6.8

Data angularly transformed for statistical analysis

Variety	% broken				
	Not undercut	Undercut 24 hr	Undercut 72 hr	Undercut 118 hr	Mean
Narbonne	20.0	19.2	16.4	16.4	18.0
Narman	8.0	10.5	13.2	11.5	10.8
Mean	14.0	14.9	14.8	13.9	14.4

S.E.D. (2 df) between variety means	0.42
S.E.D. (12 df) between undercutting means	1.78

Salt treatments in 1991

The effects of applying a concentrated salt solution were tested in one season only (1991). For the first drilling/harvest sequence (April/September), a reduction in damage was recorded where salt had been applied 48 hours before harvest (Table 12). This effect was observed in only the 1.0 m drop test, but not when the carrots were dropped 1.5 m, nor for the later drilling/harvest sequence. This technique was not pursued further.

Table 12. Total number of broken and split roots (%) when dropped off a conveyor belt at 1.0 m height - meaned for all varieties (angular transformation in brackets for statistical comparison) September 1991 harvest.

Undercutting/salt treatment		Irrigation Nil		4 x 25 m		Mean	
Nil		4.8	(10.6)	2.8	(7.3)	3.8	(8.9)
Undercut	@ 72 hrs	2.0	(6.0)	2.2	(7.3)	2.1	(6.6)
	@ 48 hrs	2.2	(6.3)	3.3	(8.8)	2.8	(7.6)
	@ 24 hrs	5.7	(11.0)	3.3	(8.8)	4.5	(9.9)
Salt	@ 48 hrs	2.3	(5.6)	4.7	(11.6)	3.5	(8.6)
	@ 24 hrs	3.0	(7.3)	4.3	(9.3)	3.7	(8.3)
Mean		3.3	(7.8)	3.4	(8.8)	3.4	(8.3)

S.E.D. (92 df) for comparing irrigation treatment means	(0.98)
S.E.D. (92 df) for comparing undercutting/salt treatment means	(1.69)
S.E.D. (92 df) for comparing irrigation x undercutting treatment means	(2.40)

Splitting

In each season, natural growth splitting of carrots did not occur. Dropping the carrots did cause some longitudinal splitting, but this was at a very low level. Splitting was greatest for Tamino.

Foliage wilting and ease of lifting in 1992

There was a significant (P<0.05) interaction between harvest date and undercutting treatment (Table 13). At the first harvest, when the foliage was more upright than at the second harvest, there were large differences between the undercutting treatments; there were no differences at the second harvest. The 'ease of lifting' score was similar whether or not the plots were undercut. It is likely that top lifters would work satisfactorily even where the crop was undercut.

Table 13. Effect of harvest date and pre-harvest undercutting treatment on foliage habit, meaned across both varieties.

Harvest	Foliage habit score*		
	Not undercut	Undercut 24 hr	Undercut 72 hr
15 October	9.0	8.2	6.1
19 November	5.9	4.7	5.3

S.E.D. (48 d.f.) between harvest x undercutting means 0.54

* Foliage habit score 1 = severe wilted, foliage prone
10 = not wilted, foliage upright

Loss of root moisture by pre-harvest treatments

Following receiving the various pre-harvest treatments, the carrots were placed into sealed plastic bags of water to determine the degree to which they regained turgidity. From this 'water loss' attributable to each treatment technique was determined. When immersed for 24 hours, (1990) there were no significant differences in weight loss between the pre-harvest undercutting and defoliation treatments.

When immersed for 96 hours (1991 and 1992) there were large differences between treatments (P<0.001).

Withholding irrigation before harvest increased weight loss. In 1991, the mean percentage weight loss was 3.8% overall all treatments. Narbonne lost more weight than Panther and Tamino (Narman was in-between).

Undercutting the carrots 24-72 hours before harvest increased weight loss in 1991.

The salt treatments in 1991 did not cause weight loss of the carrot.

In 1992, the overall percentage weight loss was 2.36% with no difference between the two varieties. Carrots lost more of their turgidity after the second harvest than following the first harvest (Table 14). There were differences ($P<0.01$) between the pre-harvest undercutting treatments. There were no significant interactions.

Table 14. Effects of harvest and pre-harvest undercutting treatment on weight loss of carrots in 1992.

Harvest	% weight loss Undercutting treatment			
	Nil	24 hrs	72 hrs	Mean
15 October	1.55	1.82	2.62	2.00
19 November	2.41	2.93	2.81	2.72
Mean	1.98	2.38	2.71	2.36

S.E.D. (44 d.f.) between harvest means	0.186
between undercutting means	0.228

Diameter and length

The mean diameter and length for two varieties in 1992 is shown in Table 15.

Table 15. Mean diameter and length (cm).

NIAB rating	Diameter (mm)	Length (mm)	Ratio
Narman	38	168	1:4.4
Panther	31	156	1:5.0

Diameter and length were not affected by any factor other than variety. In all three seasons of the experiment, those varieties less susceptible to damage (high NIAB rating)had a lower ratio of diameter to length than those more susceptible to damage.

Shelf life in 1992

'Loose Fill'

- There were no significant differences between the four treatments tested for shelf life over a period of 7 days.

'Pre-pack'

- Pre-pack produce suffered from re-growth. This was significantly worse in roots that had been undercut 72 hours before harvest, and which had been irrigated prior to harvest.

The report from NIAB is available from ADAS Arthur Rickwood Research Centre.

Field storage in 1992

There were no effects in subsequent breakage or splitting between either the irrigation or pre-harvest undercutting treatments for Narman after four months of field storage.

DISCUSSION

The less severe damage test (1.0 m) reflected commercial handling and grading to a greater extent then the more severe test (1.5 m). After being dropped 1.5 m, there were very high levels of broken carrots but with few split roots. Panther and Tamino showed a much higher level of damage than Narbonne and Narman, which reflected the differences observed in standard tests by NIAB. The differences in these experiments could be attributed either to tissue strength or to natural maturity; Panther and Tamino being faster-maturing varieties. Those varieties less susceptible to damage had a lower ratio of diameter to length than those more susceptible to damage.

There were no effects of irrigation in 1991. However, in 1992 withholding irrigation prior to harvest reduced the numbers of split carrots in the severe damage test. The effect of irrigation on the levels of total damage in 1992 were complex. Irrigation interacted both with variety and with undercutting treatment. The experiment indicated some scope for both withholding irrigation to cv. Narman and then undercutting 72 hours before harvest in order to reduce subsequent damage. However, the apparent improvements gained from this combination of factors were not confirmed by the statistical analysis.

Defoliation of the roots in 1990 increased subsequent damage as expected. The removal of the foliage may have reduced the transpiration rate and lead to increased root turgor. (Differences in root turgor were not observed in the test used in that season).

Applying salt in 1991 slightly reduced damage indicating that the increased Osmotic pressure surrounding the root may have had an effect on the turgor within it. However, it was not considered worthwhile to pursue this.

Undercutting the roots reduced damage in each season except in 1993. The levels of reduction in damage were not usually high although for Narman in 1992 there was a 9% reduction in damage (1.5 m drop) when undercut 72 hours before harvest.

Undercutting appeared to be the most promising technique which could be included in an overall system to reduce damage at harvest.

There were complex relationships between time of harvest, irrigation, variety and undercutting making it difficult to give clear guidelines for damage reduction where all factors are involved. The susceptibility to damage is not always related to root turgor as measured by weight loss (which could be measured at harvest).

The data from these experiments could contribute towards developing a computer model to supply advice to growers on whether to withhold irrigation or undercut in a given situation.

REFERENCES

Kokkoras, I. (1989) The effect of temperature and water status on the susceptibility of carrots to damage. Cranfield Institute of Technology - Silsoe College. (Thesis for Doctor of Philosophy Degree).

Millington, S. (1985) The influence of some physical properties of carrots on their damage characteristics. Cranfield Institute of Technology - Silsoe College (Thesis for Doctor of Philosophy Degree).

Appendix I Management of trial site 1990-1993

Management of trial site in 1990

Previous cropping	1989 Sugar beet 1988 Winter wheat 1987 Winter wheat	
Cultivations	13 December	ploughed
	9 April	prepared the bed system
	9 May	drilled
Herbicides	9 May	0.8 kg/ha ai paraquat as 4 l/ha cp Power Paraquat in 400 l/ha water
	7 June	2.24 kg/ha ai pentanochlor as 5.6 1/ha cp Atlas Solan 40 in 500 l/ha water
	27 June	1.2 kg/ha ai pentanochlor as 3 l/ha cp Atlas Solan 40 + 1.5 kg/ha ai metoxuron as 3 l/ha cp Dosaflo in 500 l/ha water
	16 July	2.75 kg/ha ai metoxuron as 5.5 l/ha cp Dosaflo in 500 l/ha water
Insecticides	9 May	2.8 kg/ha ai phorate as 28 kg/ha cp BASF Phorate applied at drilling
	24 July + 20 August	2.4 kg/ha ai chlorfenvinphos as 10.0 l/ha cp Sapecron 240EC in 1000 l/ha water
	13 September + 24 October	1.05 kg/ha ai triazophos as 2.5 l/ha cp Hostathion in 1000 l/ha water
Fungicides	5 June	1.2 kg/ha ai metalaxyl and 5.76 kg/ha mancozeb as 12 kg/ha cp Fubol 58WP in 1000 l/ha water
Fertiliser	December	apply 50 kg/ha P and K
	May	apply kg/ha N
Trace elements	7 June	9 kg/ha $MnSO_4$ in 250 l/ha water
	27 June	as above
	11 July	as above
Irrigation	30 May	20 mm
	26 June	25 mm
	26 July	25 mm
	28 July	25 mm
Harvest/assessment	26, 27, 28 September 13, 14, 15 November	

Management of trial site in 1991

Previous cropping	1990 Sugar beet 1989 Wheat 1988 Wheat	
Cultivations	20 December	ploughed
	23 March	beds formed using Cultirateau
Fertiliser	4 December	80 kg/ha $P_2 0_5$ + 120 kg/ha $K_2 0$

Drill date 1

Drilled	10 April	
Herbicides	22 May	2.24 kg/ha ai pentanochlor as 5.6 l/ha cp Atlas Solan 40 in 500 l/ha water
	22 June	1.1 kg/ha ai linuron as 2.2 l/ha cp Linuron 50WP in 300 l/ha water
	3 July	2.75 kg/ha ai metoxuron + 0.63 kg/ha ai linuron as 5.5 l/ha cp Dosaflo + 1.4 l/ha cp Afalon in 400 l/ha water
Insecticides	10 April	2.8 ai phorate as 28 kg/ha cp BASF Phorate (at drilling)
	17 June, 2 July + 18 July	140 g/ha ai pirimicarb as 280 g/ha cp Aphox in 400 l/ha water
	26 July	0.239 kg/ha ai oxydemeton-methyl as 420 ml/ha cp Metasystox R in 400 l/ha water
	2 August	2.4 kg/ha ai chlorfenvinphos as 10 l/ha cp Sapecron 240 EC in 1000 l/ha water
	20 August	25 g/ha ai cypermethrin as 0.25 l/ha cp Ambush in 1000 l/ha water
Fungicides	29 May	5.76 kg/ha ai mancozeb + 1.2 kg/ha ai metalaxyl as 12 kg/ha cp Fubol 58WP in 1000 l/ha water
Trace elements	14 June	9 kg/ha $MnSO_4$ in 250 l/ha water
	28 June	as above
	17 July	as above
Irrigation	9 July	25 mm
	21 August	25 mm as appropriate
	28 August	25 mm as appropriate
	4 September	25 mm as appropriate
	11 September	25 mm as appropriate

Harvest/assessment	30 September	replicate 1
	1 October	replicate 2
	2 October	replicate 3

Drill date II

Drilled	24 May	
Herbicides	29 May	1.1 kg./ha ai linuron as 2.4 l/ha cp Linuron Flowable in 500 l/ha water
	10 July	1.1 kg/ha ai linuron as 2.4 l/ha cp Linuron Flowable in 300 l/ha water
	28 August	2.75 kg/ha ai metoxuron + 0.56 kg/ha ai linuron as 5.5 l/ha cp Dosaflo + 1.25 l/ha cp Afalon in 600 l/ha water
Insecticides	17 June + 2 July + 18 July	140 g/ha ai pirimicarb as 280 g/ha cp Aphox in 400 l/ha water
	26 July	0.239 kg/ha ai oxydemeton-methyl as 420 ml/ha cp Metasystox R in 400 l/ha water
	2 August + 25 September	2.4 kg/ha ai chlorfenvinphos as 10 l/ha cp Sapecron 240EC in 1000 l/ha water
	20 August	25 g/ha ai cypermethrin as 0.25 l/ha cp Ambush C in 1000 l/ha water
	12 September	0.75 kg/ha ai quinalphos as 3 l/ha cp Savall in 1000 l/ha water
Fungicide	29 May	5.76 kg/ha ai mancozeb + 1.2 kg/ha ai metalaxyl as 12 kg/ha cp Fubol 58WP in 1000 l/ha water
Trace elements	14 June	9 kg/ha $MnSO_4$ in 250 l/ha water
	28 June	as above
	17 July	as above
Irrigation	18 September	25 mm as appropriate
	25 September	25 mm as appropriate
	2 October	25 mm as appropriate
	9 October	25 mm as appropriate
	16 October	25 mm as appropriate
Harvest/assessment	30 October	replicate 1
	1 November	replicate 2
	2 November	replicate 3

Management of trial site 1992

Previous cropping	1991 Onions	
	1990 Sugar beet	
	1989 Winter wheat	
Cultivations	14 January	ploughed
	22 April	beds formed
	24 April	drilled
	12 August	hand weeded
	19 November	undercut and straw down appropriate areas
Herbicides	30 April	840 g/ha ai chlorpropham + 1.68 kg/ha ai pentanochlor as 5.6 l/ha cp Atlas Brown in 250 l/ha water
	22 May	2.24 kg/ha ai pentanochlor as 5.6 kg/ha cp Atlas Solan 40 in 250 l/ha water
	1 June	1.08 kg/ha ai linuron as Linuron Flo as 2.4 l/ha in 1000 l/ha water
	8 June	3.5 kg/ha ai metoxuron as 7 l/ha cp Dosaflo in 300 l/ha water
	29 June	3.0 kg/ha ai metoxuron as 6 l/ha cp Dosaflo in 300 l/ha water
Insecticides	24 April	2.8 kg ai phorate as 28 kg/ha cp Phorate granules
	23 June	25 ml/ha ai cypermethrin as 250 ml/ha cp Ambush C in 1000 l/ha water
	7 August	525 g/ha ai triazophos as 1.25 l/ha cp Hostathion in 1000 l/ha water
	21 August	525 g/ha ai triazophois as 1.25 l/ha cp Hostathion in 1000 l/ha water
	5 September	Hostathion as above
Fungicides	15 May	1.2 kg/ha ai metalaxyl + 5.8 kg/ha ai mancozeb as 12 kg/ha Fubol 58 WP
Fertiliser	13 January	50 kg/ha $P_2 0_5$, 50 kg/ha $K_2 0$
	3 June	60 kg/ha N
Trace elements	9 June	8 kg/ha $MnS0_4$ in 250 l/ha water
	7 July	as above

Irrigation	28 May	25 mm to whole trial
	12 September	25 mm to 'irrigated' plots
	19 September	25 mm to 'irrigated' plots
	29 October	25 mm to 'irrigated' plots
Harvest	15 October	
	19 November	
	8 February	(after field storage)

Management of trial site in 1993

Previous cropping	1992 Sugar beet 1991 Wheat 1990 Wheat	
Cultivations	14 February	plough and furrow press
	24 April	set up beds with Simon Cultirateau
	7 May	drill Narbonne and Narman
Herbicides	2 June	2.24 kg/ha ai pentanochlor as 5.6 l/ha cp Atlas Solan 40 in 250 l/ha water.
	17 June	1.08 kg/ha ai Linuron Flo as 2.4 l/ha in 250 l/ha water.
	6 July	2.8 kg/ha ai metoxuron + 0.47 kg/ha ai linuron as 5.5 l/ha cp Dosaflo + 3.5 l/ha cp Liquid Linuron in 3000 l/ha water.
Insecticides	6 July	25 ml/ ha ai cypermethrin as 250 ml/ha cp Ambush C in 100 l/ha water.
	5 August	525 g/ha ai triazophos as 1.25 l/ha cp Hostathion in 1000 l/ha water.
	19 August	525 g/ha ai triazophos as 1.25 l/ha cp Hostathion in 1000 l/ha water.
	17 September	525 g/ha ai triazophos as 1.25 l/ha cp Hostathion in 1000 l/ha water.
Fungicides	13 May	1.2 kg/ha ai metalaxyl + 5.8 kg/ha ai as 12 kg/ha Fubol 58 WP
Fertiliser	2 February	50 kg/ha P_2O_5 50 kg/ha K_2O
	10 May	40 kg/ha N
Trace elements	4 June	8 kg/250 l/ha manganese sulphate
	28 June	as above
	21 July	as above
Irrigation	9 July	25 mm
	12 August	25 mm
Harvest	5 November	

Appendix II Rainfall 1990-1993

Rainfall data recorded during the trial in 1990.

Week commencing	Rainfall (mm)
7 May	16.1
14 May	0.2
21 May	0
28 May	5.9
4 June	12.0
11 June	0
18 June	15.9
25 June	8.1
2 July	13.8
9 July	0
16 July	0
23 July	10.0
30 July	0
6 August	0.5
13 August	10.5
20 August	0
27 August	3.9
3 September	4.1
10 September	0
17 September	6.6
24 September	12.8
1 October	8.1
8 October	0
15 October	12.3
22 October	15.1
29 October	10.0
5 November	8.4
12 November	23.3
Total	197.6

Rainfall data recorded during the trial in 1991.

Week commencing	Rainfall (mm)
8 April	0.0
15 April	12.0
22 April	1.9
29 April	26.0
6 May	1.3
13 May	4.5
20 May	0.7
27 May	0.4
3 June	14.5
10 June	14.0
17 June	18.4
24 June	39.2
1 July	1.3
8 July	0.0
15 July	6.9
22 July	18.5
29 July	3.0
5 August	8.8
12 August	0.1
19 August	8.9
26 August	0.0
2 September	0.0
9 September	3.0
16 September	3.8
23 September	27.4
30 September	0.8
7 October	0.0
14 October	0.6
21 October	2.2
28 October	25.4
Total	243.6

Rainfall (mm) during the growing period of crop until field storage 1992.

April		May		June		July		Aug		Sept		Oct		Nov	
24	0.2	2	1.3	3	2.3	1	3.7	2	0.3	1	0.4	2	30.3	1	2.3
25	0.3	3	0.1	4	7.3	2	1.3	5	0.2	2	0.8	3	1.7	2	3.5
26		4	1.1	5	1.8	3	4.7	7	1.0	3	2.0	7	0.5	8	0.4
27	5.1	5	0.5	9	4.6	5	6.0	8	5.0	6	0.5	9	0.1	9	5.1
28	1.3	8	1.6	19	8.6	7	1.0	9	0.4	12	2.6	10	0.5	10	14.7
29	0.5	9	15.6	29	0.2	8	0.1	10	0.6	13	5.5	11	0.1	14	9.5
30	4.1	10	2.7	30	1.4	9	11.3	11	1.1	14	0.1	18	0.5	15	1.0
		11	1.2			10	0.1	12	0.3	17	5.9	19	21.7	16	3.3
		14	0.7			11	1.5	13	7.2	18	0.2	20	11.6	17	0.2
		23	0.1			12	3.0	15	12.7	20	1.6	21	0.1	18	0.2
		28	1.7			13	21.2	20	6.6	21	16.2	22	0.4		
		29	9.0			16	4.0	22	1.7	22	27.2	23	0.3		
		30	2.7			20	26.2	23	7.1	23	4.6	24	16.0	Total	445.8
		31	10.3			23	1.3	24	4.5	24	3.4	25	2.0		
						26	2.1	26	1.9	25	2.8	26	0.2		
								27	0.1	29	2.5	27	1.8		
								28	0.1			29	0.4		
								29	14.5						
								30	2.0						

Rainfall (mm) during the growing period of crop until field storage 1993.

May		June		July		Aug		Sept		Oct	
2	0.2	2	3.9	8	16.2	4	5.4	3	0.9	1	3.6
8	1.4	10	19.6	9	6.7	9	1.3	7	3.5	2	1.0
9	0.1	11	2.5	10	3.2	10	1.2	8	2.6	3	3.0
11	0.1	12	0.7	11	0.6	11	9.5	12	11.9	4	3.3
14	2.0	13	6.5	12	0.9	12	5.3	13	0.5	5	0.2
17	7.2	14	2.7	13	8.0	15	0.8	14	4.3	6	2.4
18	0.9	15	3.4	14	1.9	21	25.4	15	0.5	7	2.2
20	8.9	16	3.4	15	2.9	22	0.1	16	22.3	10	4.4
21	0.1	17	4.9	16	1.3	25	0.6	19	0.4	11	8.6
26	21.5	22	0.2	18	1.3	26	0.2	20	10.6	12	36.8
27	6.3	23	0.6	19	1.7			26	7.9	13	8.8
28	0.1	25	1.2	23	6.3			27	12.7	14	1.9
29	2.8			24	2.4			28	0.4	20	10.0
				25	5.1			29	1.2	21	0.2
				26	2.8			30	3.3	25	0.9
				27	0.2			29	2.5	26	0.5
				28	1.3					27	0.7
				29	0.4						
				30	5.1					Total	393.3