VG217
Development of techniques to manipulate fibre development in ginger

Garth Sanewski
Queensland Department of Primary Industries

Know-how for Horticulture™

VG217

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FIBRE DEVELOPMENT IN EARLY HARVEST GINGER

HRDC PROJECT VG 217

G. M. Sanewski

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INDUSTRY SUMMARY

1. Germination Studies

The main contributor to poor and uneven germination particularly in the period up to mid-August, is rhizome dormancy. This dormancy was shown to be substantially diminished by mild pre-plant drying of planting material for 7 days. However, although this treatment improves germination it does not increase yield but rather has the potential to decrease knob size, shoot growth and possibly yield. Severe dessication as might be caused by leaving bins of planting material unprotected for long periods could in itself be a major cause of poor germination or uneven shoot growth.

Ethrel treatment also improves germination but decreases knob size without increasing yield making it an unsuitable practice.

Recommendations are;

- Attempt to plant even-sized planting material, preferably of a larger size (70+ g),
- Avoid severe dessication of planting material, particularly in the September period.

2. Time of Planting Studies

The decline in % choice grade rhizome is strongly influenced by daylength. Earlier planting dates than the traditional mid September should increase yield due to a lengthening of the growing season.

Recommendations are;

- Mid to late August planting is best. It is recommended that growers who usually plant in mid September should trial planting a percentage of their crop in mid to late August (15 th - 31 st August). It is best that only a percentage of the crop be initially planted at this time. This will ensure problems do not arise from the change in routine. The date of 45% choice rhizome may occur 2-3 days earlier than with a mid September planting.

- Do not plant too early. Planting in early August will result in very poor germination and reduced yield. Early August planting will however produce the largest knobs.

3. Effect of Temperature

While temperature was shown to affect yield of choice grade rhizome substantially, it does not have a major affect on the decline of % choice grade rhizome.

A mean day/night temperature regime of 25°/15°C is the most for growth of choice grade rhizome. This temperature regime is close to that experienced towards the end of February.

Temperature should not normally have a substantial effect on the rate of decline of percentage choice grade rhizome assuming early harvest occurrs in the February to mid March period.

4. Effect of Water Stress.

Ginger is very sensitive to water stress. Ginger cannot tolerate water stress so it ceases growth to conserve water, even under mild water deficient conditions. Even mild water stress will reduce yield substantially. Water stress does not however appear to have a major affect on the rate of decline of % choice grade rhizome.

Severe water stress actually results in an increase in the percentage choice grade rhizome although the actual yield of choice grade rhizome decreases. This occurs because the weight of fibred rhizome is reduced more by water stress than that of choice rhizome.

Conclusion

The rate of decline of % choice grade rhizome tends to be more dependant on the rate of starch deposition in the fibred rhizome relative to the production of new knobs, rather than the rate of fibre development. Rhizome fibre content tends to follow a similar trend as total plant dry weight.

The trials conducted have suggested that growing conditions can have a large effect on the decline in % choice grade rhizome. It is possible therefore that there are some growers who could extend their growing season and/or increase yields by improvements to growing practices such as irrigation and fertilisation. It is also likely that there are some growers who, because of very good cultural practices, are at the limit of these influences and because of daylength and low temperature, will not be able to delay the decline of % choice grade rhizome. It is strongly recommended therefore that growers keep plants as vigorous as possible in the period close to early harvest. This can be done by ensuring adequate irrigation and fertilisation.

Investigation of techniques to slow the deposition of assimilate into the fibred portions of the rhizome prior to early harvest time may offer some potential for temporarily slowing the decline in % choice grade rhizome. Partial topping of plants at early harvest may be one such technique. This could be expected to reduce rhizome growth but, because of the high price paid for choice grade rhizome may still be a proposition worthy of investigation. Studies into cultural practices such as fertilisation in the period prior to early harvest are also worthwhile.

SECTION 2

Technical summary

FIBRE DEVELOPMENT IN EARLY HARVEST GINGER

HRDC PROJECT VG 217

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TECHNICAL SUMMARY

Rhizome fibres in ginger are vascular bundles with a surrounding sheath of essentially non-lignified sclerenchyma fibre cells. These fibres are initiated at the apical meristem of each rhizome segment. Fibre development, in a commercial context, is the thickening of the fibre cell walls through the addition of cellulose. Rhizome fibre content closely follows total plant dry weight.

The rate of decline of % choice grade rhizome tends to be more dependant on the rate of assimilate deposition in the fibred relative to the production of new knobs, rather than actual fibre development.

In addition the trials conducted have shown;

- Plant maturity and fibre development are strongly influenced by daylength. An earlier planting date than the traditional mid September will increase yields and is recommended.
- Water deficit does not increase fibre development.
- Low temperature does not have a major effect on fibre development.
- The relative growth rate of the plant has a large effect on the decline in % choice grade rhizome. A high growth rate will maintain a higher % of choice grade rhizome.
- Rhizome dormancy is the main cause of uneven shoot emergence. While shoot emergence can be easily improved by pre-plant treatment with Ethrel, knob size and possibly yield are reduced.

It is possible that there are some growers who could extend their growing season and hence increase yields by improvements to growing practices such as fertilisation immediately prior to early harvest. It is also likely that there are some growers who, because they achieve good growth rates, are at the limit of these influences and, because of daylength and temperature, will not be able to delay the decline of % choice grade rhizome.

Investigation of techniques to slow the deposition of assimilate into the fibred portions of the rhizome prior to early harvest time may offer some potential for temporarily slowing the decline in % choice grade rhizome. As an example, partial topping of plants immediately prior to early harvest may be one such technique. This could be expected to reduce rhizome growth but, because of the high price paid for

choice grade rhizome may still be a proposition worthy of investigation. Studies into cultural practices such as fertilisation in the period prior to early harvest are also worthwhile.

PUBLICATION SCHEDULE

1. A paper titled "Shoot emergenceof ginger as affected by dormancy, size and type of rhizome pieces"will be submitted to *Australian Journal of Experimental Agriculture* by October, 1995. See draft attached.

2. A paper titled "Effect of water deficit on potted ginger plants"will be submitted to *Australian Journal Agricultural Research* by December, 1995. See 2 attached draft papers on water deficit on ginger.

3. Work is continuing on this project with the intention of submission as a PhD thesis in 1997.

SECTION 3

Shoot emergence of ginger as affected by dormancy, size and type of rhizome pieces

SHOOT EMERGENCE OF GINGER AS AFFECTED BY DORMANCY, SIZE AND TYPE OF RHIZOME PIECES

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Summary. Endodormancy was shown to exist in ginger rhizome pieces dug in mid August but to be substantially diminished by early September in Southern Queensland. Endodormancy was broken earlier by 7-14 days storage on open trays. 7 days storage resulted in greater shoot number and shoot dry weight. Storage for periods of 14 days or longer was detrimental to the development of leaf area. Endodormancy lasted longer in younger rhizome pieces such as fourth order pieces, and the number of shoots produced was less in fourth and third order pieces than in second order pieces. Planting piece weight on the other hand had no effect on endodormancy but 20-30 g planting pieces produced fewer shoots than 40-50 g and 60-70 g pieces.

Introduction

The Australian ginger industry is centred in Yandina near Nambour in South East Queensland, latitude 26'36°S.

The most common time of planting is in the period from early to late September when temperatures are considered warm enough. The mean maximum and minimum temperatures for Nambour (< 15 km south of Yandina) for the years 1983 to 1994 inclusive are shown. Frosts can occur in low-lying areas in the winter months from June to August. Early plantings are sometimes made in mid-August.

Month	**Max temp (°C)**	**Min temp (°C)**
June	21.1	9.4
July	21.0	8.5
August	22.2	8.0
September	24.9	10.5
October	26.5	14.0
November	27.7	16.3

Shoot emergence in ginger fields in South East Queensland is usually slow and erratic often taking 4 weeks for the first shoots to appear with the majority emerging in the period 6-8 weeks from planting (Evenson et al., 1978). This slow emergence may be due to the status of the planting material or unfavourable environmental conditions or both. Failure to germinate due to unfavourable internal conditions is the traditional meaning of dormancy as it pertains to seed and underground organs. It is now more appropriately referred to as endodormancy (Dennis, 1994). Failure to germinate due to unfavourable external conditions is often referred to as quiescence or rest (Salisbury and Ross, 1985; Dennis, 1994).

Poor shoot emergence in ginger has been studied previously by other researchers. Evenson et al., (1978) found the optimum soil temperature to be 25-26°C and low soil

temperatures at planting slowed the production of new shoots. They also found a large variation in germination among rhizome pieces but did not indicate possible causal factors.

It appears that an endodormancy is present in ginger as exposure to 35°C for 24 hr or 250 ppm ethylene for 15 minutes increases the number of shoots and the number of roots (Islam et al., 1978).

The nature of rhizome endodormancy and its relationship to the lack of uniformity seen in germinating fields of ginger has not previously been studied. Good establishment in ginger is however important as rhizome yield is strongly correlated to shoot number (Furutani et al., 1985). This study was therefore initiated to examine shoot emergence in ginger. It examined the nature of rhizome endodormancy during winter and spring, and the effects of storage conditions, planting piece mass and planting piece type.

Materials and Methods

There were 4 trials to investigate endodormancy, storage of rhizome pieces, planting piece mass and planting piece type.

Dormancy

The experiment was a completely randomised design consisting of 5 replicates of 5 treatments on time of planting.

Mature rhizomes of the cultivar 'Queensland' were dug from a field at Nambour at 5 times, 1 July, 5 August, 3 September, 21 September, and 6 October, 1993 to examine dormancy status of the rhizomes at different times of planting. They were immediately

washed, cut into pieces weighing 50-70 g and dipped for 1 minute in a fungicide solution of 1 g/L Benlate (0.5 g/L benomyl a.i.). The treated pieces were air-dried for 1 day then planted in seedling trays in a temperature controlled glasshouse maintained at a maximum day and minimum night temperature regime of approximately 30°/18°C. The trays contained a potting mix consisting of sand, peat and sawdust in the ratio 2:1:1 and a dry fertiliser mix. A layer of pine sawdust was placed on top of the rhizome pieces after planting. The trays were kept moist with regular watering. Each tray contained 10 rhizome pieces of the same treatment, and this constituted a replicate. The trays were repositioned in the glasshouse periodically. Shoot number was recorded every 2-3 days for up to 80 days after planting.

Storage of rhizome pieces

Mature rhizomes of the cultivar 'Queensland' were dug on 12 August 1992. The rhizomes were prepared in the same manner as previously described. Treated pieces were air-dried for 1 day in a shaded location before the imposition of treatments. The treatments were designed to examine the breakdown of endodormancy.

The treatments consisted of storage for 1, 7, 14, 21 or 28 days, either in high density polyethylene bags to prevent desiccation or on open trays to allow desiccation. Including the control, which was the 1 day storage, there were 9 treatments. In addition there were 2 treatments for rhizomes dug on the 22 September, 1992; 1 day storage and 7 days storage on open trays.

The experiment was a completely randomised design with 5 replicates each replicate consisting of 10 rhizome pieces.

Storage was conducted in a shed at ambient temperatures. Ambient temperatures in the storage location were within a maximum of 31°C and a minimum of 12°C.

The temperature in the plastic bags and on the open trays was monitored during storage using maximum/minimum thermometers. The temperature in the bags reached a maximum 5°C higher than that on the trays on the day rhizomes were enclosed, but after that day it was never more than 1°C higher.

After storage the rhizome pieces were planted in moist sawdust in plastic seedling trays in a naturally-lit, temperature-controlled glasshouse under conditions similar to those described in the previous trial.

The number of shoots was counted every 2-3 days and the shoots were harvested 40 days after planting for determination of dry weight and leaf area. The total fresh weight of the rhizome pieces in each replication was recorded at the beginning and after storage.

For dry matter determinations an additional 50 rhizomes of 50-70 g were prepared as previously described. They were divided into 5 lots of 10 rhizomes and each set of 10 was then stored for 0, 7, 14, 21, or 28 days on open trays. Fresh weights were recorded before and after storage. After storage the rhizomes were cut into thin slices, dried in a fan forced oven at 60°C and dry weights recorded.

Planting piece mass

Mature rhizomes were dug on 26 August 1992 and treated as for the previous experiments. The experiment was a randomised block design composed of 3 replications of 3 treatments. The treatments included 3 weight ranges, viz, 20-30 g (26 g), 40-50 g (45 g) and 60-70 g (65 g). Each replicate was comprised of 50 rhizome pieces. The trial was planted in raised beds in the field as for commercial ginger production. Fertiliser and irrigation were applied as is normal for commercial ginger production.

Before planting, buds were counted on 100 rhizome pieces of each treatment. Large pieces (8.7 buds) had more buds than medium pieces (6.9 buds), and both had more than small rhizome pieces (4.9 buds).

The number of shoots was recorded every 2-3 days up to 13 weeks after planting.

Planting piece type

The experiment was a randomised block design consisting of 5 replications of 3 treatments. The treatments were second, third and fourth order rhizome pieces. First order pieces are produced on the first shoots to germinate from the original planting piece. Second order pieces arise from first order pieces and so on. Fourth order pieces will therefore be younger than third, second and first order pieces. First order pieces were not included in this trial because they constitute only a small proportion of rhizome pieces planted by growers and because they are generally of a smaller mass than other rhizome pieces.

Mature rhizomes were dug and treated as for the rhizome piece mass trial. Rhizome pieces of 50-70 g were used. Each replication consisted of 20 rhizome pieces.

Before planting, rhizome buds were counted on 100 planting pieces of each treatment. Second order pieces (5.4 buds) and third order pieces (6.0 buds) had significantly more buds/rhizome piece than fourth order pieces (6.5 buds).

The trial was field planted adjacent to the planting piece mass trial and was treated identically.

Shoot counts were conducted every 2-3 days and the shoots were harvested 11 weeks after planting for dry weight and leaf area measurements.

Results

Dormancy

Figure 1 shows that the rhizomes collected in spring emerged much faster than those collected in winter. Rhizomes collected on 1 July did not emerge for the first 40 days and also did not exhibit a definite plateau in shoot number. They had the slowest mean germination rate at 0.01 shoots/day over the 80 day period. Mean germination rate increased with delay in rhizome collection to 0.03 shoots/day for the 5 August collection to 0.05 shoots/day for the September plantings. The maximum number of first order shoots achieved was similar for all plantings from August onwards at 1.6-2.0 shoots/planting piece, but it took longer to achieve this in the August planting than in the September and October plantings.

Figure 1

Storage of rhizome pieces

Rhizome pieces stored on open trays lost more fresh weight during storage than those in plastic bags (Fig 2). Rhizome pieces stored in plastic bags lost a small amount of weight (1%) over the first week of storage but maintained weight from then to week 4. Rhizome pieces stored on open trays declined in weight substantially in the first 2 weeks but only slightly over weeks 3 and 4. Weight loss on a dry weight basis shows that it was small in the first 7 days, but was much greater when the storage period was increased to 14 days (Table 1). Rhizome pieces stored on open trays for 28 days incurred a 4% decline in moisture content and an 8% decline in dry weight.

Table 1

Figure 2

The trends in shoot appearance for storage treatments are shown in figure 3. Data for open trays for rhizomes dug in August are shown in figure 3A and that for plastic bags are shown in figure 3B. Data for rhizomes dug in September are shown in figure 3C.

Figure 3

Storage on open trays for 7 and 14 days in mid-August resulted in rapid shoot emergence and increased the total number of shoots at day 40 whereas storage for 21 and 28 days reduced early emergence. Storage on open trays for 7 days produced the largest number of shoots/planting piece (2.5).

Storage in plastic bags for 7 or 14 days did not affect shoot production compared to the control whereas storage for 21 and 28 days reduced shoot production.

Figure 4 shows the effect of storage time on harvest data 40 days after planting using rhizomes dug in August. Rhizome pieces stored for 7 days on open trays produced the

greatest number of shoots, the greatest total shoot dry weight and the largest total shoot leaf area but dry weight or leaf area/shoot was less than that of freshly planted rhizome pieces (control). Rhizome pieces stored for 14 days on open trays produced more shoots than the control but total shoot dry weight and total leaf area were similar for the two. Rhizomes stored on open trays for 21 and 28 days appeared shrivelled in comparison with those in bags. The buds on rhizome pieces stored in plastic bags for 28 days were showing white tips. The smallest shoots were produced if storage was 21 days or longer irrespective of whether they were bagged or not.

Figure 4

Rhizomes planted in late September with 7 days storage produced the greatest overall dry weight and leaf area and the largest shoots. Storage of rhizomes for 7 days in late September produced substantially fewer shoots than the same treatment in mid-August but dry weight production per shoot was similar.

Planting piece mass

The trend of shoot emergence for planting pieces of different mass is shown in figure 5A. Significant differences in shoot number between treatments were seen on days 34, 86 and 88. On day 34, small pieces had more shoots than medium and large pieces. On days 86 and 88, medium and large pieces had more shoots than small pieces. The shape of the curves in figure 5A indicate that the maximum number of first order shoots were produced by about day 65 (the plateau) followed by a rapid increase in second order shoots.

Planting piece type

The general trend was for second order pieces to produce shoots earlier than third and or fourth order pieces (Fig 5B). Significant difference between treatments was seen on days 32-53 inclusive and on days 74 and 75. The figure indicates that second order pieces produced a maximum of approximately 1 first order shoot per rhizome piece in 53 days. Fourth order pieces produced a similar maximum but required 60 days to reach this maximum. The straighter emergence slope for third and fourth order pieces also indicates an overlap of first and second order shoots. That is, some rhizome pieces were producing their second order shoots while others were still producing their first. The more definite plateau of the emergence slope for second order pieces indicates that most of these rhizome pieces germinated and produced their first order shoot together. Uniformity of development between plants could therefore be expected to be better in plants produced from second order rhizome pieces in comparison with those from third or fourth order pieces.

Table 2 shows harvest data for shoots from rhizome pieces of different type.

Table 2

While only stem number showed a significant difference the data suggests a trend with the second order pieces producing more vigorous shoots in a given time.

Discussion

Rhizome endodormancy was shown to exist in rhizome pieces dug from early July to mid-August. Despite favourable external conditions, rhizome pieces dug and planted at these times produced fewer shoots in the first 70 days after planting than rhizome pieces dug and planted in early September.

This endodormancy was related to type of rhizome with the younger fourth order rhizome pieces having a longer period of dormancy than the older second order pieces. It was not however related to rhizome mass.

Endodormancy was shown to be reduced by 7 days desiccation before planting. Longer periods of storage did not further reduce the dormancy period but reduced shoot growth. While 7 days storage on open trays increased the number of shoots, dry weight/shoot was lower for this treatment than rhizome pieces planted with no storage. This suggests the high shoot number was responsible for the smaller shoot size.

The positive effect of pre-plant desiccation of the planting material on shoot emergence in other species not new. Hall (1992) reports that shoot emergence in some varieties of sweet potato is accelerated by increased duration of curing. In potato, storage at warm temperatures results in an accelerated conversion of high molecular weight polysaccharides such as starch to labile carbohydrates such as fructose, glucose and sucrose (Burton, 1948; Charles-Edwards et al, 1986). These sugars are the immediate substrate for the developing shoots. Pre-plant storage which triggers this conversion could therefore be expected to result in a higher concentration of sugars for immediate use following planting. This could be expected to increase the rate of shoot emergence rather than increase the ultimate number of shoots. It is conceivable that storage for periods longer than 7 days may result in substantially lower starch and sugar levels due to excessive respiration.

Desiccation of rhizomes in mid-August for periods of 14-28 days does not appear to be detrimental to shoot emergence but reduces subsequent shoot growth substantially. Storage in plastic bags for 28 days was however detrimental to shoot emergence. Perhaps increased CO_2 inhibited growth as shown in the work by Emilsson and Lindlom in Ivins and Milthorpe (1963).

Desiccation of rhizome pieces by pre-plant storage for 7 days appears to be beneficial. This agrees with work by Hasanah et al (1989). They found that storage for 4 weeks gave twice as many shoots as storage for 1 week. Both gave more shoots than no storage.

Rhizome pieces of 20-30 g produced fewer shoots than larger pieces probably because they had fewer viable buds and less assimilate. While the difference in the number of first order shoots was small, the difference in shoot number was increasing with time. Rhizome yield has been shown to be strongly correlated to shoot number (Furutani et al, 1985) and so differences in planting piece mass could be expected to affect rhizome yield.

However, while planting piece mass may affect important early harvest yield components, it most likely contributes little if at all to uneven germination in the first 10 weeks after planting in commercial ginger production. Growers generally use planting pieces within the 40-70 g size range. Pieces within this range were shown to produce similar shoot numbers but there may be minor differences in actual shoot size.

If growers planted by tonnage rather than by rhizome spacing and were consistent with their size grading, then rhizome pieces of 20-30 g size should actually produce more shoots per hectare than either of the larger sizes. At a planting tonnage of 6 t/ha, 20-30 g pieces should produce around 62,300 shoots/ha at 10 weeks compared with 44,400 shoots/ha for 40-50 g pieces and 32,600 shoots/ha for 60-70 g pieces.

Conclusion

Poor and uneven germination and emergence in ginger has shown to be caused by several factors. Uneven size grading in planting material, the inherent differences between planting pieces from different parts of the rhizome and time of planting all contribute to a protracted shoot emergence. Endodormancy appears the main contributor particularly in the period to mid-August. This endodormancy is substantially diminished by dessication for 7 days.

Mild pre-plant dessication may be a means of improving the uniformity and speed of shoot emergence and hence yield and quality of early harvest ginger. Further field trials are being conducted to test this hypothesis.

Severe dessication as might be caused by a long period of storage or hot, drying conditions could be expected to reduce shoot growth. This in itself could be a contributor to poor shoot emergence or uneven shoot growth.

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Table 1. Break-down of weight loss data for rhizome pieces stored on open trays.

Data represents the mean of 10 rhizomes per treatment.

Treatment	Moisture content after storage (%)	Water loss (g/100 g dry wt)	Dry weight loss (g/100 g dry wt)
Nil storage	86	nil	nil
7 days	84	132	1
14 days	82	112	9
21 days	82	119	6
28 days	82	127	8

Table 2. Harvest data for shoots per 20 rhizome pieces 11 weeks after planting.[z]

Treatment	Leaf area (cm^2)	Leaf fresh wt (g)	Stem fresh wt (g)	Total dry wt (g)	No stems
Second	2,028[a]	55.4[a]	80.4[a]	14.7[a]	32.8[a]
Third	1,560[a]	43.4[a]	70.0[a]	11.6[a]	27.4[b]
Fourth	1,334[a]	37.0[a]	63.8[a]	10.0[a]	27.4[b]
SD	662.5	18.2	24.9	4.5	2.6
LSD (P=0.05)					3.7

[z] Means followed by a common letter are not significantly different (P=0.05).

Figure captions

Figure 1. Trend in shoot production for rhizome planting pieces dug at different times of the year and germinated in a temperature controlled glasshouse. Each data point represents the mean of 5 replicates of 10 rhizome planting pieces. Vertical bars represent the LSD (P=0.05).

Figure 2. Weight loss in ginger rhizomes stored on open trays or in plastic bags. Datum points are means for 10 rhizome planting pieces of 50-70 g each.

Figure 3. Trends in shoot production for rhizomes dug on 12 August and stored on open trays (graph A), in plastic bags (graph B), and on open trays but dug on 22 September (graph C). Datum points are means for 10 rhizome pieces. Each plot represents a trend for a different storage period. Vertical bars represent the LSD (P=0.05). LSD bars shown apply to graph A, B and C.

Figure 4. Effect of storage time on trends in shoot number (A), total shoot dry weight (B), total leaf area (C), dry weight per shoot (D), and leaf area per shoot (E) for rhizome pieces dug on 12 August and stored on open trays or in plastic bags before planting. All data are for 40 days after planting. Each datum point represents the mean for 10 rhizome planting pieces. LSD bars are shown (P=0.05).

Figure 5. Graph A shows the effect of planting piece size on germination. Graph B shows the effect of rhizome order on shoot emergence. Vertical bars represent the LSD (P=0.05).

Figure 1

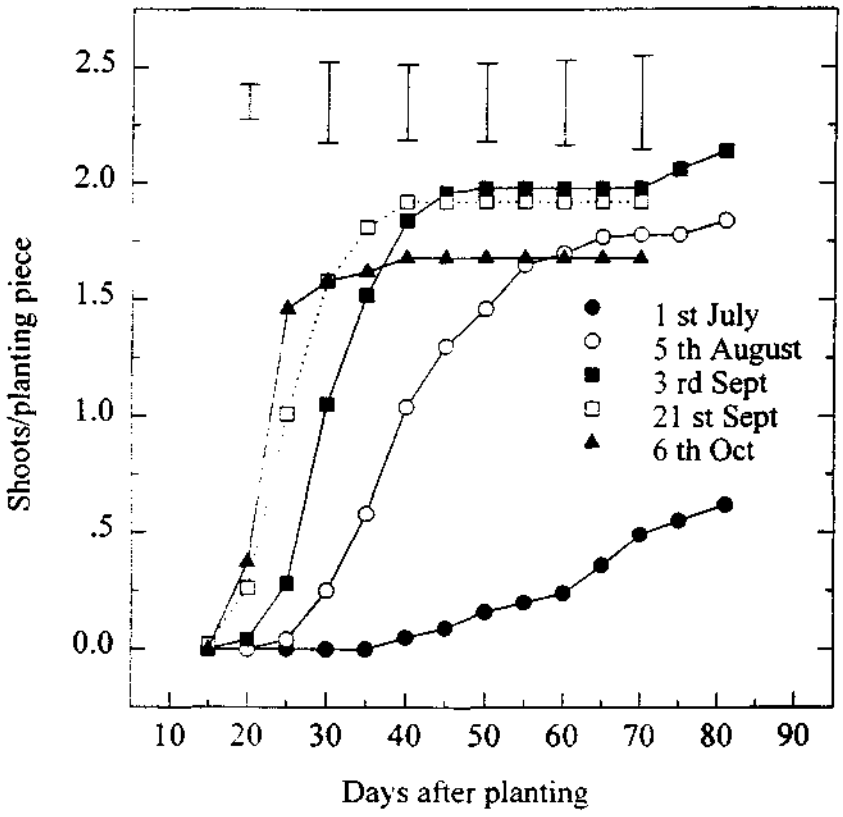

Shoots/planting piece
2.5
2.0
1.5
1.0
.5
0.0
10
20
30
40
50
60
70
80
90
Days after planting
1 st July
5 th August
3 rd Sept
21 st Sept
6 th Oct

Figure 2

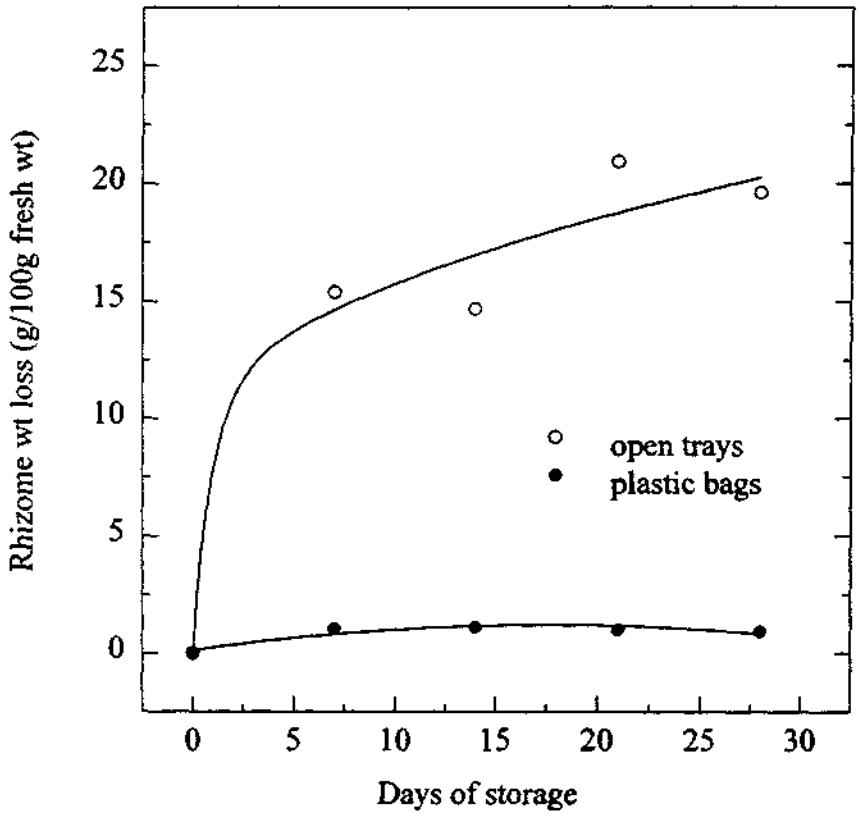

Rhizome wt loss (g/100g fresh wt)
25
20
15
10
5
0
0
5
10
15
20
25
30
Days of storage
open trays
plastic bags

Figure 3

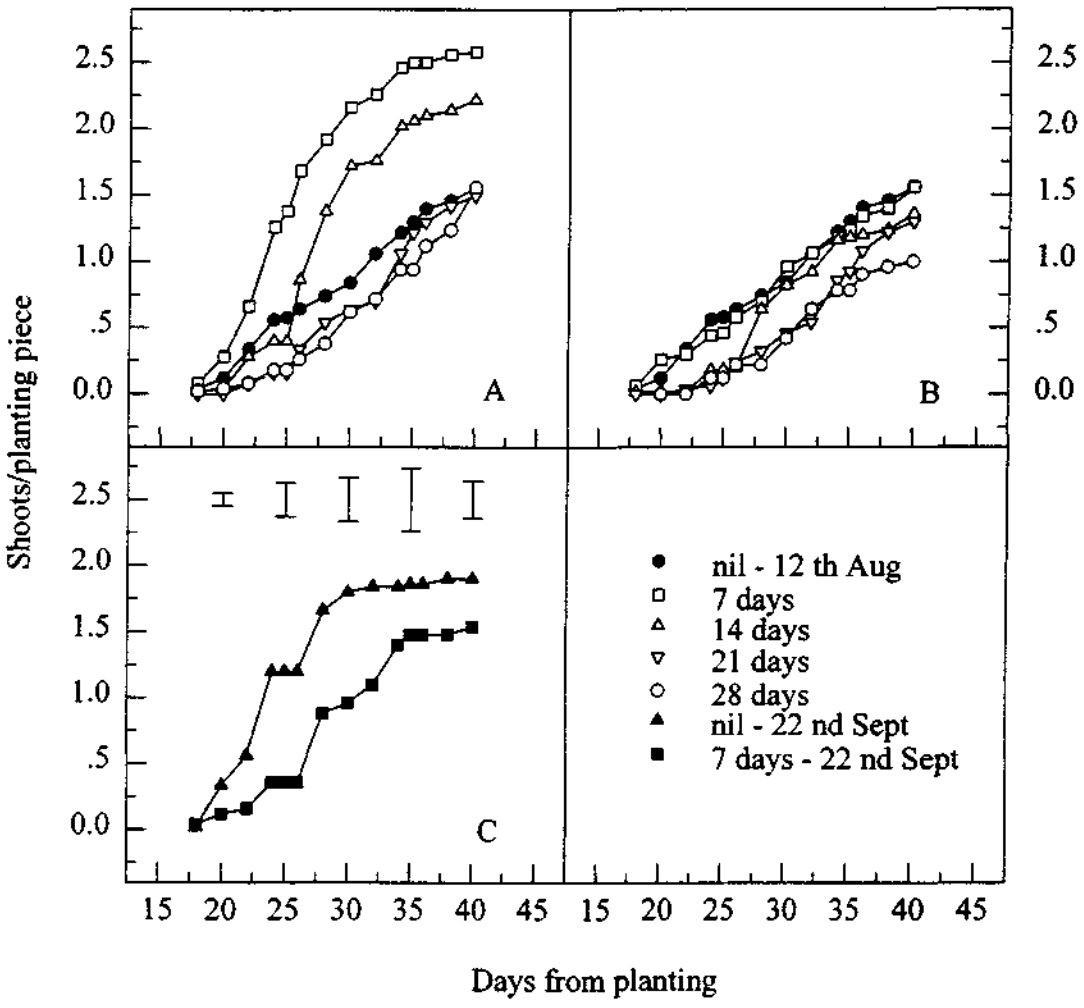

Shoots/planting piece
2.5
2.0
1.5
1.0
.5
0.0
A
B
C
nil - 12 th Aug
7 days
14 days
21 days
28 days
nil - 22 nd Sept
7 days - 22 nd Sept
15 20 25 30 35 40 45
Days from planting

Figure 4

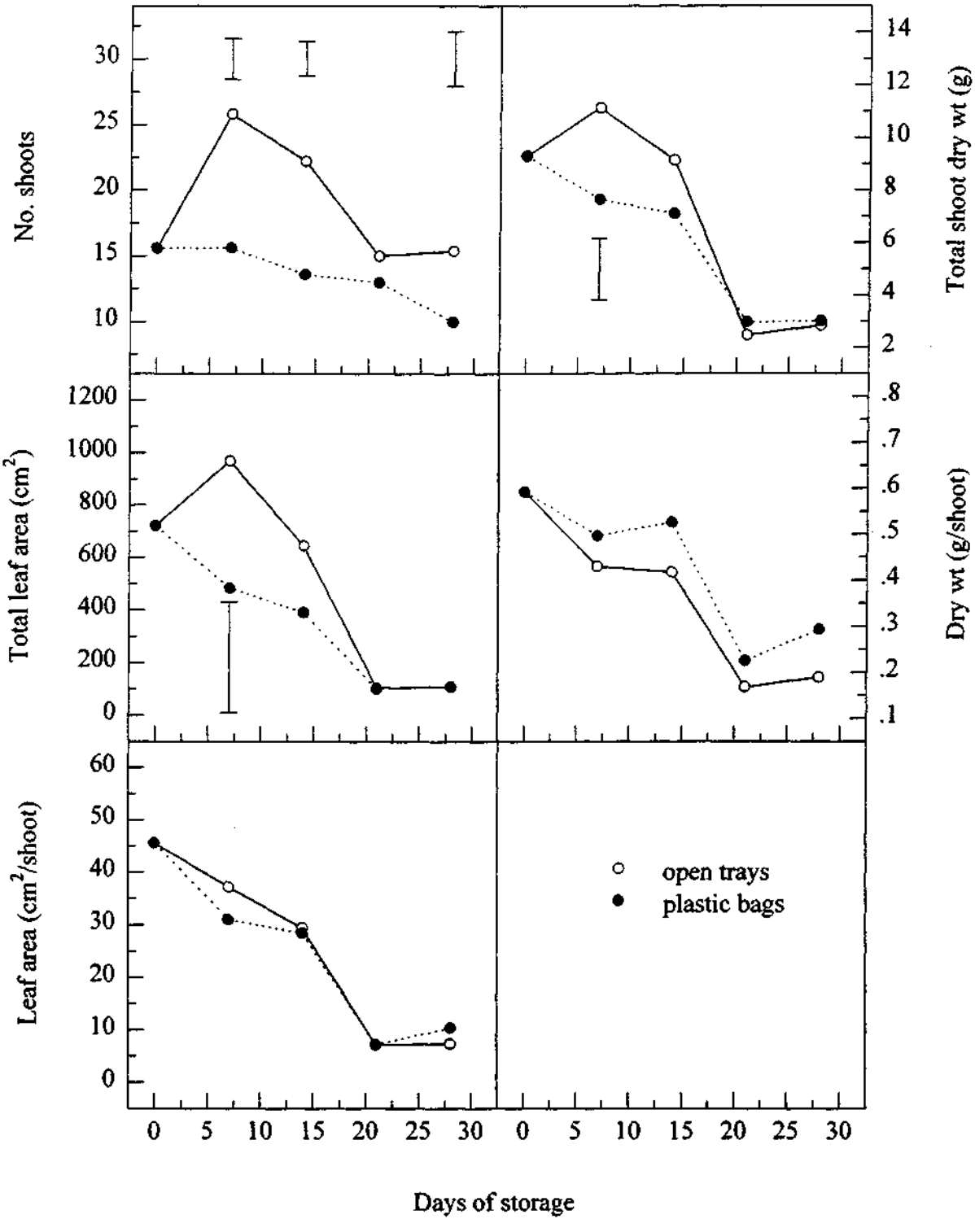
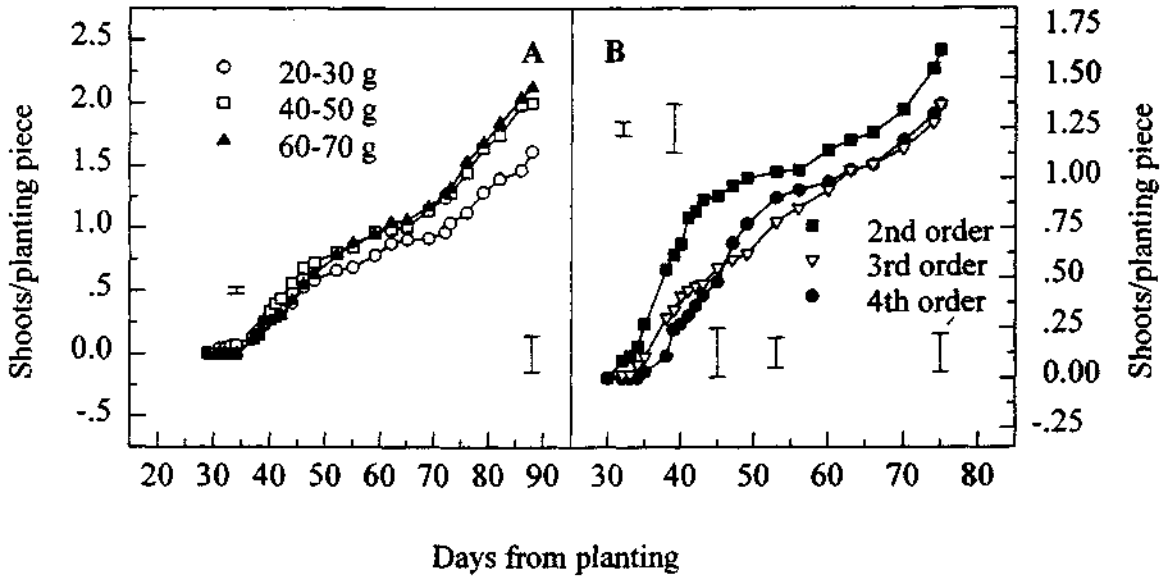

No. shoots
Total shoot dry wt (g)
Total leaf area (cm²)
Dry wt (g/shoot)
Leaf area (cm²/shoot)
open trays
plastic bags
Days of storage

Figure 5


Shoots/planting piece
2.5
2.0
1.5
1.0
.5
0.0
-.5
A
20-30 g
40-50 g
60-70 g
20 30 40 50 60 70 80 90
B
2nd order
3rd order
4th order
30 40 50 60 70 80
1.75
1.50
1.25
1.00
.75
.50
.25
0.00
-.25
Shoots/planting piece
Days from planting

SECTION 4

The effect of time of planting and germination on early harvest ginger

THE EFFECT OF TIME OF PLANTING AND GERMINATION ON EARLY HARVEST GINGER

G. M. Sanewski

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Summary. Despite up to 8 weeks difference in planting date, all treatments matured within 7 days of each other. This suggests a strong effect of photoperiod on plant ontogeny. It should therefore be feasible to lengthen the growing season and increase yields by planting earlier than is usual. The earliest time of planting in this study (17 August) produced the greatest yield.

Germination achieved in mid August to mid October plantings should be satisfactory in most situations even though it may appear sporadic. Treatment of planting pieces with Ethrel® can improve germination but reduces knob size without increasing yield. Desiccation of planting pieces for only 1 week can also improve germination but will reduce yield.

Introduction

The Australian ginger industry is based predominantly on the production of early harvest ginger. This ginger, due to its immaturity, is relatively low in fibre and consequently suitable for processing into confectionary products.

Early harvest usually commences around late February when the rhizome has declined to 45% choice grade as determined by the blunt knife technique (Whiley, 1980). The date of commencement of early harvest varies from year to year and has been associated with time of planting, mulching, soil conditions and weather patterns (Leverington, 1969) but there have been no in-depth studies.

Because ginger is a quantitative short day plant (Adaniya et al., 1988), it is reasonable to expect that early plantings will produce higher rhizome yield due to the longer growing season. A major objective of this study was to compare different planting dates.

Previous studies by the author (unpublished data) indicated that planting material lifted early in the season exhibited poor germination even at favourable temperatures. However, desiccation of planting pieces for seven days improved germination. Work by others (Islam, 1978; and Furutani et al., 1985) demonstrated the beneficial effects of a pre-plant treatment with Ethrel (R) on germination. Consequently, treatments to improve germination were included at each time of planting.

This study examines the effect of time of planting and germination on yield and fibre development of early harvest ginger in South East Queensland.

Material and method

Different time of plantings were combined with treatments to improve germination. The experiment was a randomised complete block design with 5 repetitions of 8 treatments.

Treatments are shown in table 1.

Table 1

Mature rhizomes of the cultivar `Queensland' were used. The rhizomes were washed, cut into pieces weighing 50-70 g and dipped for one minute in a solution of 1 g/L Benlate R (0.5 g/L benomyl). Nil pre-plant treatment and Ethrel dip pieces were air-dried for 1 day in open styrofoam trays in a shaded location. 8 days desiccation pieces were air-dried for 8 days. Ethrel treatment pieces were dipped in a solution of 1 ml/L Ethrel (480 g/L ethephon) and 0.1 ml/L Agral (a non-ionic wetter) for 1 minute and allowed to air-dry for about 1-2 hours before planting.

Pieces were planted in 3 rows on raised beds with 1.8m between bed centres and 0.15m between pieces along the row. Each plot was 3m long and 2 beds wide.

The experimental planting was in a field of commercially grown ginger and was treated identically. The block was fertilised and irrigated as required. Nemacur 10 G (100 g/kg fenaminophos) was applied at 110 kg/Ha on 25 November.

Climatic data was recorded using an Environdata ® automatic weather station.

Harvesting

At each harvest, 0.45m of the centre row and 0.45m of an inside row was harvested at approximately 2 weekly intervals. 1 plant was left along the row between consecutive harvests.

The harvesting sequence is shown in figure 1.

Figure 1

The rhizomes were washed of soil and the roots removed. The plants were then divided into shoots and rhizomes.

Shoot number was recorded before a sub-sample was taken, weighed and placed in a fan-forced dehydrator at 60°C. The rhizomes were weighed and knob number recorded before separating into choice and fibred portions using the blunt knife technique (Whiley, 1980).

The data was analysed using the statistical software program `Statistix'. Two way analysis of variance was used to determine the significance of treatment effects. Germination treatments were analysed separately from time of planting treatments.

Results

Germination

Germination data is shown in figure 2. Data for each planting date is graphed separately for ease of interpretation. Both Ethrel and desiccation treatments improved germination on all planting dates. The earlier the planting date, the straighter the germination response. The first asymptote on each curve represents the number of first order shoots (and hence first order knobs). The second asymptote represents the number of second order shoots. The maximum number of first order shoots for each treatment as taken from figure 2 are shown in table 2.

Figure 2

Table 2

Similar planting material lifted at various times and germinated in a heated glasshouse at 30/20°C achieved a maximum of 2 first order shoots per planting piece. This is equivalent to 22.2 shoots/m^2.

Harvest data

Harvest data for untreated planting pieces planted on different planting dates is shown in figures 3 and 4. Figures 5, 6, 7 and 8 contain harvest data for germination treatments.

Figure 3

Figure 4

Figure 5

Percentage choice

From figure 3, if we use 45% choice as the commencement of early harvest, then the mid August and mid September plantings matured on day 67, whereas the mid October planting matured on day 74, 7 days later.

Because of the difficulty of obtaining data for each treatment on the exact day of 45% choice, day 74 will be used as the early harvest date for all treatments.

Progressively later planting resulted in a higher percentage choice up to day 60. At day 60, all treatments declined quickly and there were no significant differences at day 74 although the general trend was for the mid October planting to be slightly higher at most times.

Shoot growth

There were no significant differences in shoot number or shoot dry weight up to or on day 74. In the 22 days after day 74, the mid August planting continued to produce shoots whereas the other treatments ceased.

Flower shoots

On day 74 , the mid August planting had 11.8 flower shoots/M^2, the mid September planting had 14.1/M^2 and the mid October planting had 10/M^2. These values were equivalent to 5.6%, 7.1% and 4.7% respectively of total shoot number. There were no significant differences.

Rhizome growth

The earlier the planting date, the greater the rhizome fresh weight over the period to day 74 although the differences were not significant on day 74.

The general trend was for the mid August rhizome to continue growth at a constant rate over the full experimental harvest period from day 39 to day 196. This was associated with a decline in choice rhizome growth from day 74 to 96 but an increase in the rate of growth of fibred rhizome.

Rhizome growth for mid September slowed considerably after day 53. This was associated with a decline in choice rhizome growth but a steady increase in fibred rhizome.

Rhizome growth for the mid October planting exhibited a double sigmoidal growth pattern over the period day 39 to day 96. This trend was also shown in fibred rhizome growth and knob number development.

Figure 6

Mid August germination treatments

From figure 6 both Ethrel and desiccation treatments increased the number of shoots in the period to day 74. Ethrel treatment produced the most number of shoots.

Ethrel and desiccation treatments also produced greater shoot dry weight than the control although the differences were small. Ethrel treatments also produced more but smaller knobs than the control and the desiccation treatments.

The control produced a greater rhizome fresh weight than the Ethrel and desiccation treatments.

Figure 5

Mid September germination treatments

From figure 7 the Ethrel treatment produced more shoots than the control and desiccation treatments although there were no differences in shoot dry weight.

Figure 8

Mid October germination treatments

From figure 6, the trend was for Ethrel treatment to produce more shoots but a similar shoot dry weight.

There were no differences in most rhizome parameters except the ethrel treatment produced slightly smaller knobs.

The growth curve for fresh rhizome, knob number and fibred rhizome all exhibited a definite double sigmoidal pattern over the harvest period. Both treatments were well synchronised.

Climatic data

Climatic data for the entire harvest period is shown in figure 9.

Figure 9

Discussion

Despite up to 8 weeks difference in planting date, all treatments matured within 7 days of each other. This suggests a strong effect of photoperiod on plant ontogeny. This has 2 ramifications. Firstly, it may be feasible to slow down fibre development by artificially extending daylength in the February to March period. Secondly it should be feasible to lengthen the growing season and hence increase yields by earlier planting dates. The

earliest date used here (17 August) produced the greatest yield. It is evident however that as the planting date is progressively earlier, germination is progressively less. Very early planting dates may therefore suffer reduced yields unless Ethrel treatment is applied to the planting material. This has not however been demonstrated.

Germination achieved in mid August to mid October plantings should be satisfactory in most situations even though it often appears sporadic. Germination can easily be improved by a pre-plant dip in Ethrel but there is not likely to be any benefit in yield. Instead, knob size will most likely be reduced.

Desiccation of planting pieces for at least 1 week can reduce yield even though the planting pieces will germinate better. It is thought the starch reserves are depleted during storage resulting in a lower growth potential for the ensuing crop.

According to Leverington (1969), early harvest can vary by +/- 2 weeks from year to year. The variation in commencement of early harvest for the 18 year period from 1973 to 1990 indicates +/- 3 weeks is possible and is probably attributable to differences in temperature and cultural operations such as fertilisation and irrigation (unpublished data).

The differences seen in the growth curves for rhizome and shoots are characteristically different for early and late planting dates. Early plantings (mid August) generally have straight lines whereas plantings later than about late August exhibit a definite sigmoidal pattern which is repeated with each new flush of knobs and shoots. This latter

developmental pattern appears characteristic of plantings with rapid, synchronised germination. It is evident that where all planting pieces germinate simultaneously and quickly, all first order shoots and hence first order knobs develop together. As they mature and slow in growth a plateau in the growth rate is seen. The second order shoots are then produced. This pattern is repeated for every series of shoots and/or knobs produced. In early plantings this pattern is not seen because the development of different orders of shoots and/or knobs is overlapped.

What is unclear from the data is how plantings on different dates become synchronised in their growth patterns as is seen in the mid September and mid October curves for knob number. While it is expected that the production of knobs and shoots are influenced by photoperiod and temperature, these factors were not responsible for the trends seen here as the mid August planting remained unsynchronised.

Marked changes in the ontogeny of the ginger plant were seen around day 60 (March 1). Production of new rhizome (new knobs, choice rhizome) slowed at this time. Shoot growth also slowed at this point. The growth of fibred rhizome remained unchanged or actually increased. It is known from previous studies (Whiley, 1980) that the rhizome is only about 60% grown at this time. Continued growth must therefore occur as a bulking of already established rhizome. It is hypothesised that this bulking occurs as a deposition of starch in the already established rhizome and is stimulated by short days. This is the point where the percentage of choice grade rhizome declines sharply.

Acknowledgments

Thanks to John Templeton for allowing the conduct of this trial on his farm and general care and maintenance of the trial block.

Financial assistance for this work was provided by the Australian Ginger Growers Association, Buderim Ginger Ltd and the Horticultural Research and Development Corporation. The assistance provided by these organisations is greatly appreciated.

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Leverington, R.E. (1969). Ginger processing investigations. 3. Improving the quality of processed ginger. *Qld J Agric Anim Sciences.* **26**:263-270.

Whiley, A.W. (1980). Growth and fibre development of ginger (*Zingiber officinale* Rosc.) in South East Queensland. *Aust J Exp Agric Anim Husb.* **20**:608-612.

Table 1. Treatment schedule

Time of Planting	Pre-plant treatment
17-8-93	Nil
17-8-93	1000 ppm Ethrel dip
17-8-93	8 days desiccation
15-9-93	nil
15-9-93	1000 ppm Ethrel dip
15-9-93	8 days desiccation
14-10-93	Nil
14-10-93	1000 ppm Ethrel dip

Table 2. Maximum number of first order shoots for each treatment. All data extrapolated from figures 2A, 2B and 2C.

Treatment	Maximum number of first order shoots/m^2
1	11.4
2	16.4
3	16.4
4	14.5
5	17.6
6	15.4
7	21.5
8	27.1

Figure captions

Figure 1. An example of a harvesting sequence fo a single plot. Each plot contains 2, 3-row beds.

Figure 2. Trends in shoots/M^2 for plantings made in mid August (graph A), mid September (graph B) and mid October (graph C). LSD bars are shown for days 299, 323, 337 and 348 ($P<0.05$). Graph D shows 5 day mean temperatures for air and soil (10 cm depth).

Figure 3. Trends in percent choice rhizome (A), total fresh rhizome wt (B), knob number (C), shoot number (D), fibred rhizome fresh wt (E) and choice rhizome fresh wt (F) for the period from 8 February to 5 April, 1994 for 3 planting dates. The 3 plantings were 17 Aug (mid Aug), 15 Sept (mid Sept) and 14 October (mid Oct). Each data point represents the mean of 5 repetitions of 0.9 m of row which was then converted into values per M^2. LSD bars are shown ($P<0.05$).

Figure 4. Trends in average knob weight (A) and shoot dry weight (B) for plantings made on 17 August (mid Aug), 15 September (mid Sept) and 14 October (mid Oct). Each data point represents the mean of 5 repetitions of 0.9 m of row which was then converted into values per M^2. LSD bars are shown ($P<0.05$).

Figure 5. Trends in percent choice rhizome (A), total fresh rhizome (B), knob number (C), shoot number (D), fibred rhizome fresh wt (E) and choice rhizome

fresh wt (F) for a mid August planting with nil preplant treatment of planting pieces, Ethrel dip or desiccation for 7 days. Each data point represents the mean of 5 repetitions of 0.9 m of row which was then converted into values per M^2. LSD bars are shown ($P<0.05$).

Figure 6. Trends in percent choice rhizome (A), total fresh rhizome (B), knob number (C), shoot number (D), fibred rhizome fresh wt (E) and choice rhizome fresh wt (F) for mid September planting with either nil preplant treatment of planting pieces, Ethrel dip or desiccation for 7 days. Each data point represents the mean of 5 repetitions of 0.9 m of row which was then converted into values per M^2. LSD bars are shown ($P<0.05$).

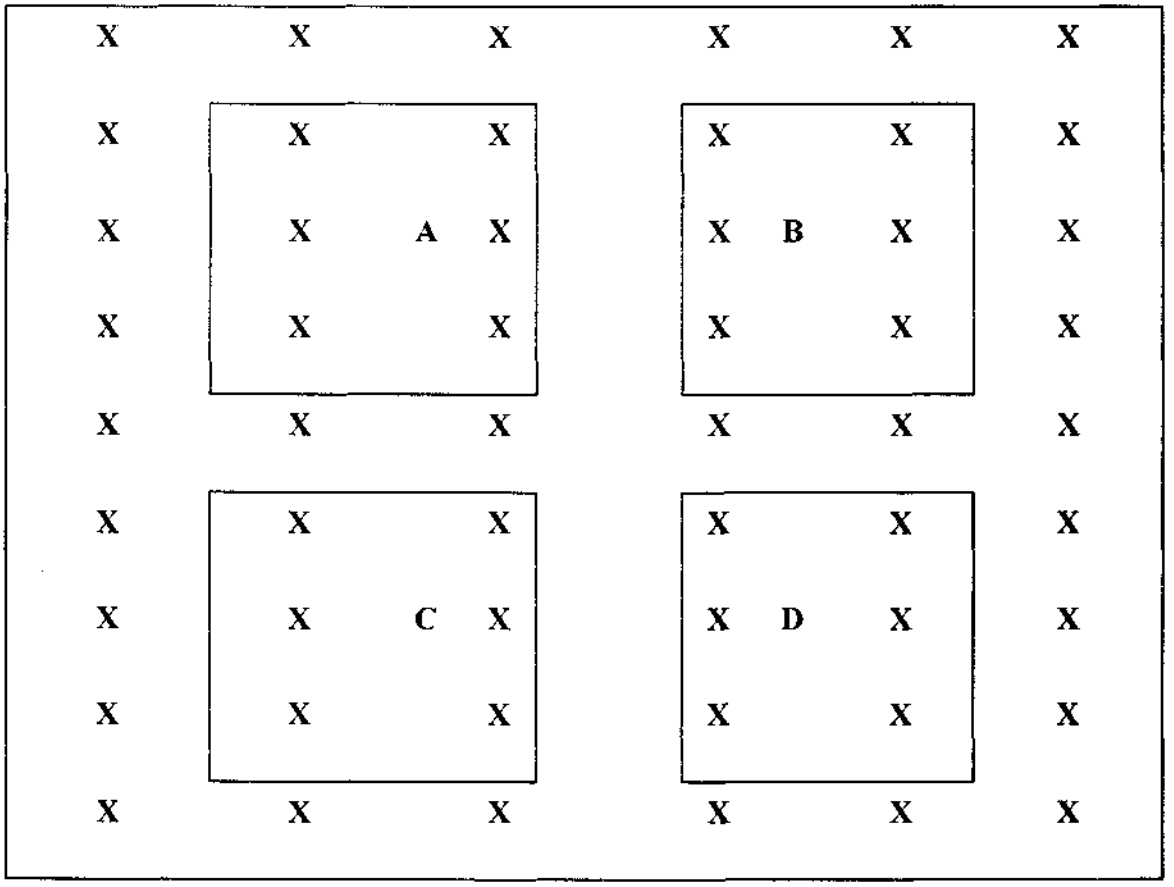
Figure 7. Trends in percent choice rhizome (A), total fresh rhizome (B), knob number (C), shoot number (D), fibred rhizome fresh wt (E) and choice rhizome fresh wt (F) for a mid October planting with either nil preplant treatment of planting pieces or Ethrel dip. Each data point represents 5 repetitions of 0.9 m of row which was then converted into values per M^2. LSD bas are shown ($P<0.05$).

Figure 8. Trends in average knob weight (A) and shoot dry weight (B) for a mid August planting with nil preplant treatment, Ethrel dip or 7 days desiccation; a mid September planting (C and D) with nil preplant treatment, Ethrel dip or 7 days desiccation; and a mid October planting (E and F) with nil preplant treatment or

Ethrel dip. Each data point represents the mean of 5 repetitions of 0.9 m of row which was then converted into values per M^2. LSD bars are shown ($P<0.05$).

Figure 9. Trends in ambient temperature, soil temperature, irradience and rainfall for the trial planting harvest period. All data was collected within the trial planting.

FIGURE 1



A. Harvest 1.

B. Harvest 2.

C. Harvest 3.

D. Harvest 4.

FIGURE 2

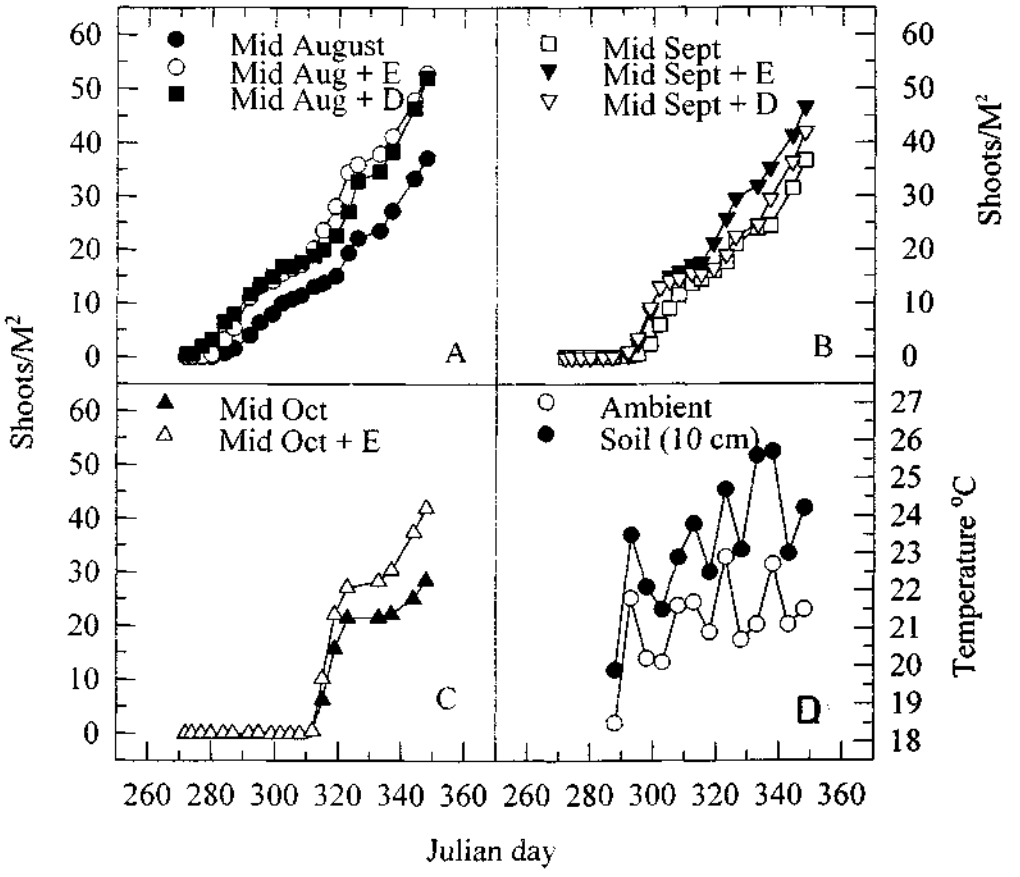

Mid August
Mid Aug + E
Mid Aug + D
Mid Sept
Mid Sept + E
Mid Sept + D
Mid Oct
Mid Oct + E
Ambient
Soil (10 cm)
A
B
C
D
Shoots/M²
Shoots/M²
Temperature °C
Julian day
0
10
20
30
40
50
60
18
19
20
21
22
23
24
25
26
27
260
280
300
320
340
360

FIGURE 3

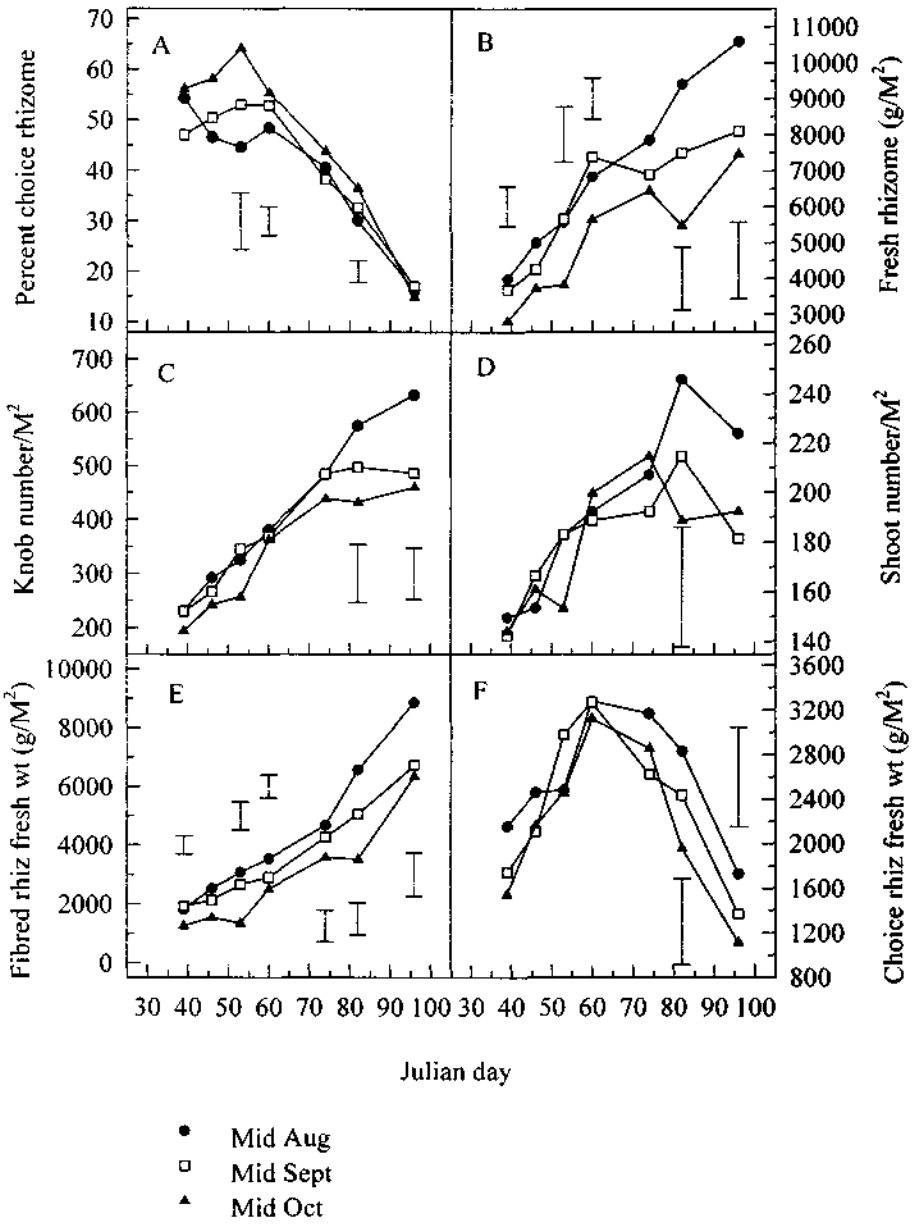

A
B
C
D
E
F
Percent choice rhizome
Fresh rhizome (g/M²)
Knob number/M²
Shoot number/M²
Fibred rhiz fresh wt (g/M²)
Choice rhiz fresh wt (g/M²)
Julian day
Mid Aug
Mid Sept
Mid Oct

FIGURE 4

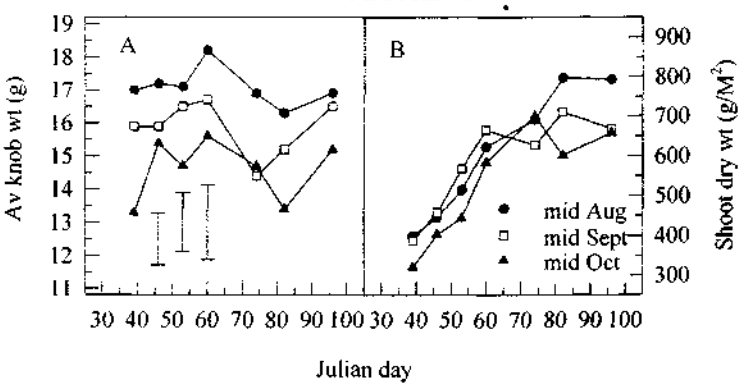

A
B
Av knob wt (g)
Shoot dry wt (g/M²)
mid Aug
mid Sept
mid Oct
Julian day

FIGURE 5

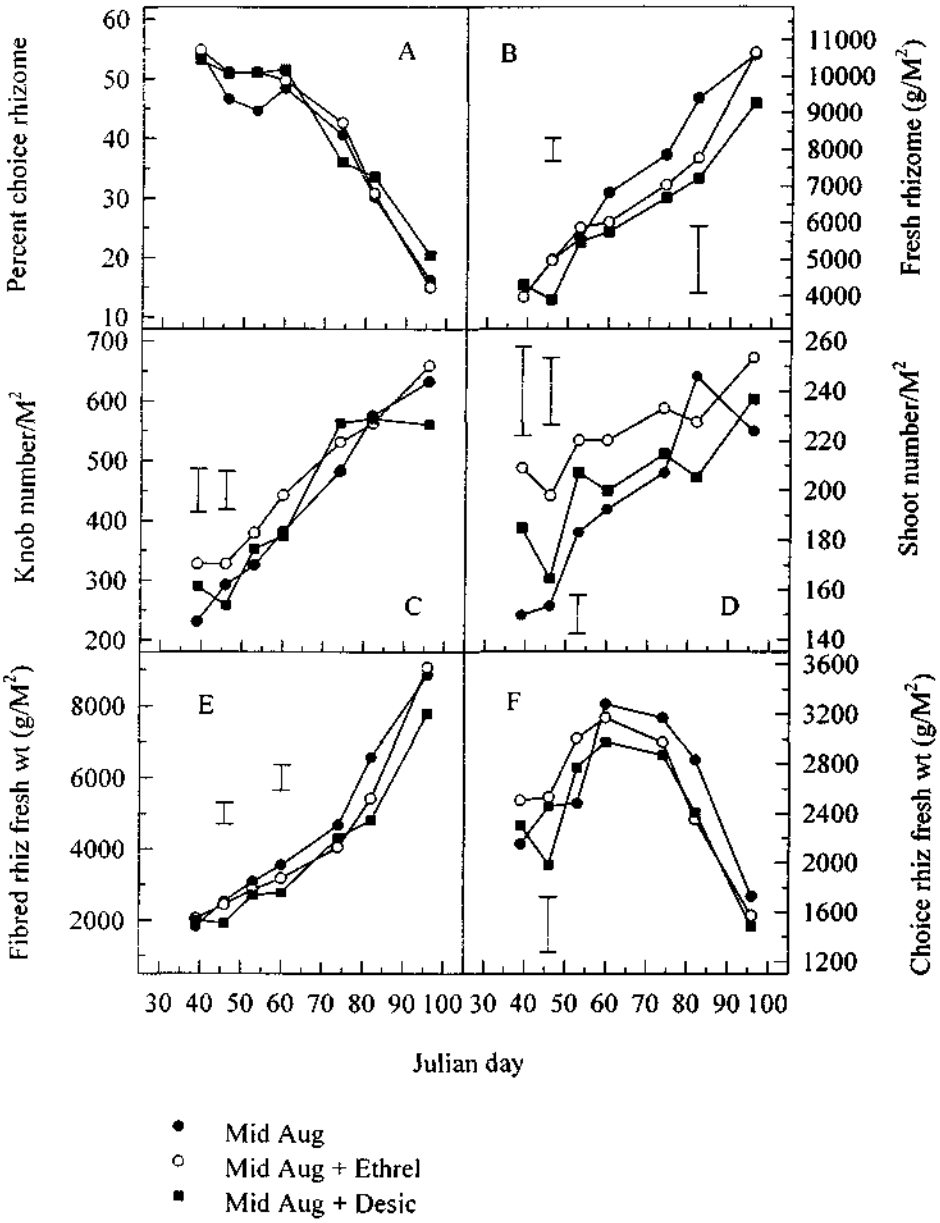

Percent choice rhizome
Fresh rhizome (g/M²)
Knob number/M²
Shoot number/M²
Fibred rhiz fresh wt (g/M²)
Choice rhiz fresh wt (g/M²)
A
B
C
D
E
F
Julian day
Mid Aug
Mid Aug + Ethrel
Mid Aug + Desic

FIGURE 6

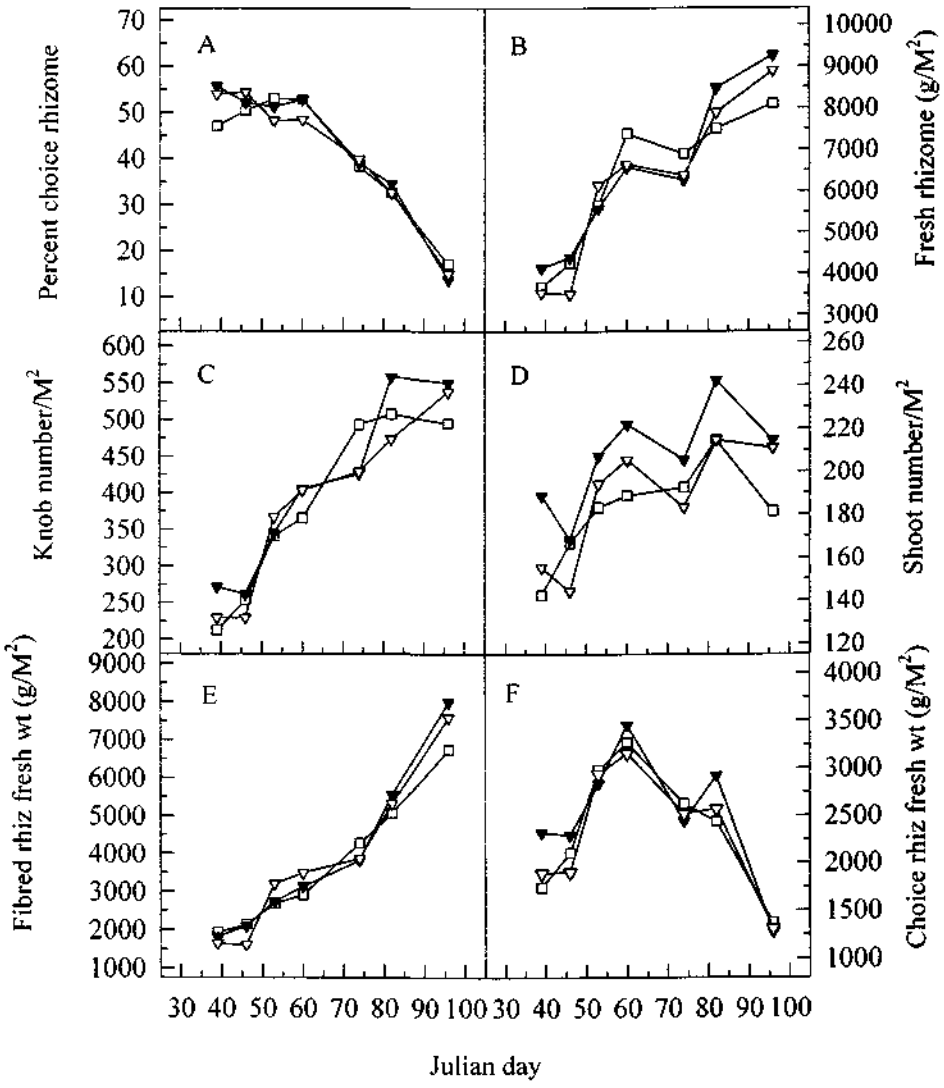

A
B
C
D
E
F
Percent choice rhizome
Fresh rhizome (g/M²)
Knob number/M²
Shoot number/M²
Fibred rhiz fresh wt (g/M²)
Choice rhiz fresh wt (g/M²)
Julian day
Mid Sept
Mid Sept + Ethrel
Mid Sept + Desic

FIGURE 7

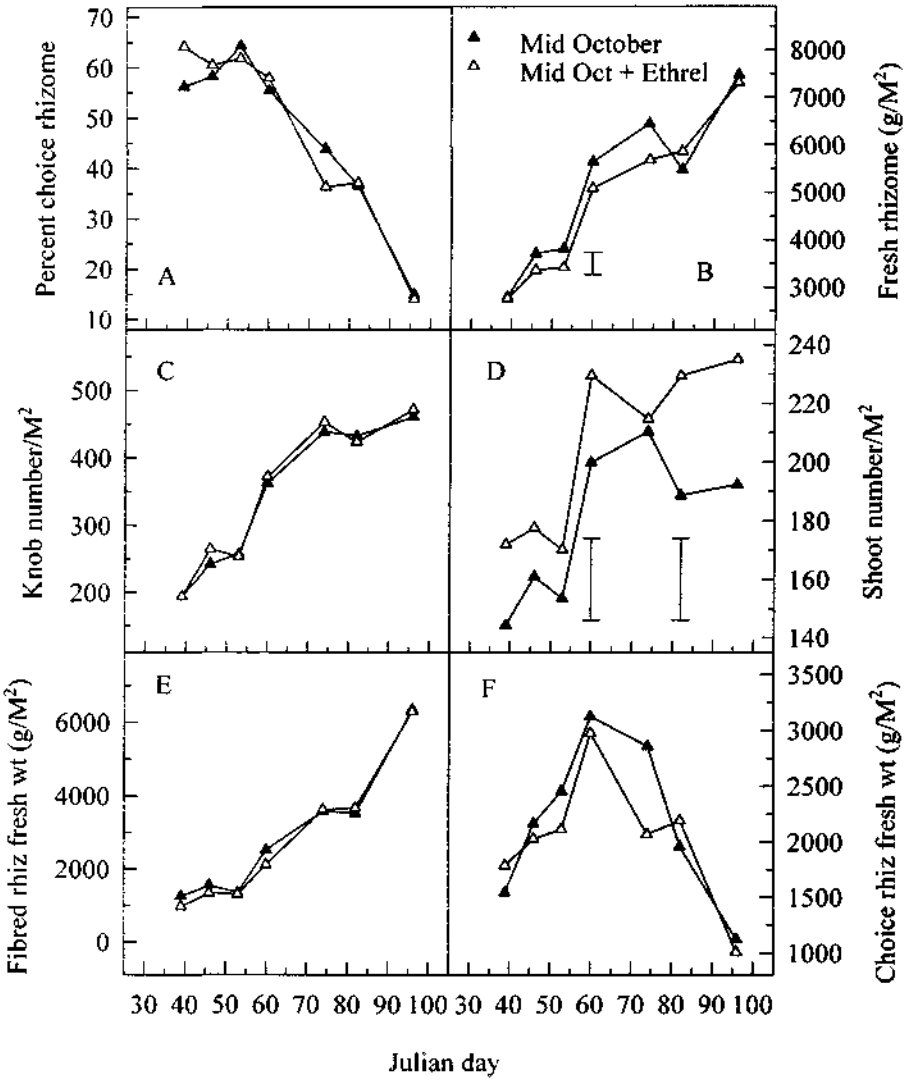

Mid October
Mid Oct + Ethrel
Percent choice rhizome
Fresh rhizome (g/M²)
Knob number/M²
Shoot number/M²
Fibred rhiz fresh wt (g/M²)
Choice rhiz fresh wt (g/M²)
A
B
C
D
E
F
Julian day

FIGURE 8

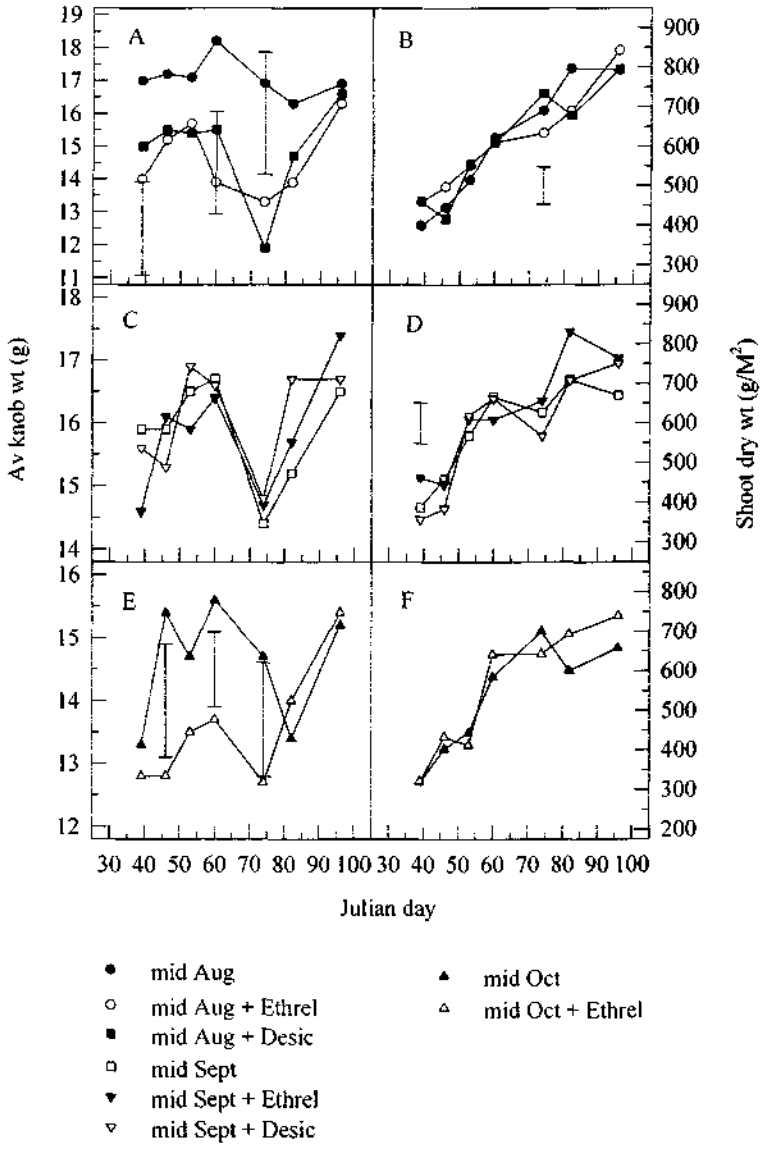
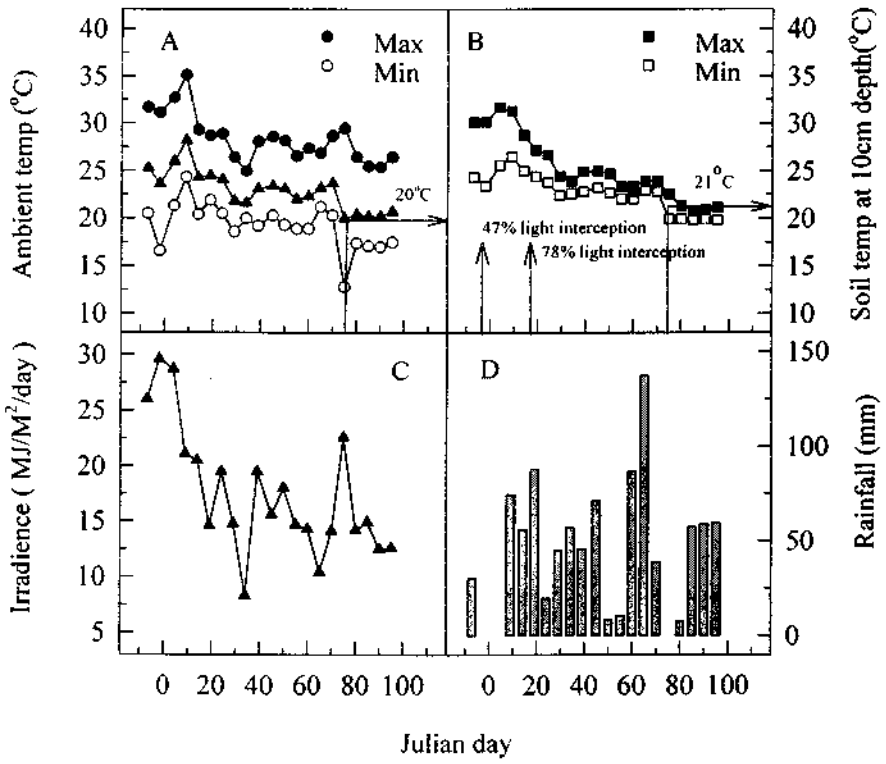

A
B
C
D
E
F
Av knob wt (g)
Shoot dry wt (g/M²)
Julian day
mid Aug
mid Aug + Ethrel
mid Aug + Desic
mid Sept
mid Sept + Ethrel
mid Sept + Desic
mid Oct
mid Oct + Ethrel

FIGURE 9


A
Max
Min
20°C
B
Max
Min
21°C
47% light interception
78% light interception
C
D
Ambient temp (°C)
Soil temp at 10cm depth(°C)
Irradience (MJ/M²/day)
Rainfall (mm)
Julian day

SECTION 5

The effect of temperature on growth and fibre development in potted ginger plants

THE EFFECT OF TEMPERATURE ON GROWTH AND FIBRE DEVELOPMENT IN POTTED GINGER PLANTS (*Zingiber officinale.* Rosc)

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Summary. 25°/15°C was the most favourable temperature regime for growth of ginger plants. Both shoot and rhizome growth were greatest at these temperatures.

Ginger plants appear very sensitive to changes in temperature. Temperature regimes of 20°/10°C and 30°/20°C decreased growth substantially despite being only 5°C lower and higher respectively.

25°/15°C was the best temperature for the production of choice grade rhizome although temperature appeared to have only a minor effect. Very high temperature (35°/25°C) appeared the most detrimental through a relatively greater depression in the growth rate of fresh weight choice rhizome compared to fibred rhizome.

Rhizome fibre content followed a similar trend as total plant dry weight.

Temperature did not have a substantial effect on the rate of decline of percentage choice grade rhizome.

Introduction

The Australian ginger industry produces over 5,500 tonnes of ginger annually. Over 60% of this is used in processing with the highest demand being for ginger with a low fibre content. Ginger of this quality is called choice grade ginger. To be suitable, 45% to 35% of the fresh rhizome should be free of fibre as indicated by the blunt knife technique (Whiley, 1980).

The ginger rhizome is approximately 60% grown when it reaches 45% choice grade. This is when harvesting commences. Fibred rhizome usually increases faster than new rhizome in this period so the percentage of choice grade rhizome declines. It declines from 45% to 35% choice grade over approximately 10-14 days. To achieve maximum yield of choice grade rhizome, growers must therefore harvest their entire crop within this 10-14 day period.

A greater understanding of the development of fibred rhizome with a view to its prediction or control would be of great advantage to the industry.

Temperature has been shown to have a strong effect on ginger plant growth. Anderson et al., (1990) demonstrated a cumulative yield increase of 25% over two seasons where maximum leaf temperature was reduced from 35° to 28°C.

Haque (1974) found 25°/20°C as the optimum temperature regime for ginger growth. In Haque's study, higher temperatures (30°/25°C) favoured shoot growth over rhizome growth. An even higher temperature (35°C) was shown to cause permanent leaf damage which lasted over an extended period. Similarly, exposure to low temperature (10°C for 10 hours) caused a temporary, but extended, reduction in photosynthesis. Temperatures higher than the optimum are more likely to occur around early harvest time than lower temperatures. It is more likely therefore that high temperatures around early harvest could limit yield development. However, Whiley (1980) in his study of growth of ginger suggested that low temperature reduced choice grade recovery. Also, there is no mention in any of these previous studies on the effect of temperature on fibre development.

This study was designed to examine the response of rhizome fibre development in particular in potted ginger plants subjected to either of four different ambient temperature regimes.

Materials and Methods

Mature rhizomes of the ginger cultivar 'Queensland' were harvested in early July 1993. The rhizomes were washed, cut into pieces weighing 50-70g and dipped for 1 minute in a solution of 1 g/L Bavistin R (0.5 g/L benomyl). Treated pieces were air-dried for 7-10 days before planting in styrofoam trays in a temperature controlled, naturally-lit glasshouse. The maximum day and minimum night temperatures were maintained at 30°/20°C. Relative humidity fluctuated between 60% and 100%. At the onset of germination the most uniform plants were selected and planted, 1 each, into 5 L plastic pots containing a sand, sawdust and peat potting mix in the ratio 2:1:1 and a mixture of solid fertiliser.

At 110 days after planting (DAP) 9 plants were harvested and 24 plants were placed in each of 4 temperature control rooms set at 30°/20°C. Over a period of 10 days these temperatures were gradually changed to the treatment temperatures (acclimatisation period). The treatment temperatures of 35°/25°C, 30°/20°C, 25°/15°C and 20°/10°C were then maintained for 33 days (treatment period). 6 plants were harvested from each room after 12 days (122 DAP), 22 days (132 DAP) and 33 days (143 DAP).

At each harvest plants were divided into leaf, stem, rhizome, seed-piece and roots. Fresh weights for each plant component (except roots), leaf area, flower stalk number, rhizome knob number and percentage choice grade rhizome were determined before samples were dried in a forced draft oven at 60°C.

Percentage choice grade rhizome was determined using the method described by Whiley (1980).

The dried fibred and choice grade rhizome samples were bulked, ground to a particle size of < 1 mm and the fibre content determined according to the neutral detergent fibre (NDF) method of Nahm (1993).

The experiment was a completely randomised design with 6 replicates of 4 treatments. All data was analysed in the statistical software program 'Statistix'. One way analysis of variance was used to determine the significance of treatment effects.

Results

The trends in dry weight for each plant component are shown in figure 1. Figure 2 shows the trend in total dry matter (TDM) and various indicators of rhizome development.

Figure 1

Figure 2

All treatments increased in TDM over the 33 day experimental period. 25°/15°C produced significantly more TDM than all other treatments. While there were no additional significant differences between treatments with respect to TDM, there was a general trend with 20°/10°C producing the least TDM.

Shoot growth

At day 143, 25°/15°C had produced more total shoot dry weight than all other treatments. This was comprised of a greater stem dry weight and a greater leaf dry weight. There were no differences between treatments in the percentage of shoot dry weight apportioned between leaf and stem.

35°/25°C produced leaves with a slightly higher specific leaf area (253 g/cm^2) than those at 25°/15°C (224 g/cm^2)).

Rhizome growth

25°/15°C produced a greater rhizome dry weight than all other treatments. There was also a significant difference between treatments in the way rhizome dry weight was apportioned to choice and fibred portions.

25°/15°C produced greater choice rhizome dry weight than all other treatments. All other treatments made only small gains in choice rhizome dry weight over the experimental period.

25°/15°C produced a greater fibred rhizome dry weight than 30°/20°C only. 30°/20°C had produced the least fibred rhizome dry weight increase of all the treatments. All treatments produced more fibred rhizome than choice rhizome.

The trend in percentage choice rhizome was slightly different for different treatments. There was an increase in percentage choice rhizome for all treatments over the first 12 days in which plants acclimatised. It then declined sharply for all treatments. 35°/25°C exhibited the greatest decline and 25°/15°C exhibited the least decline at day 132.

At day 132, 25°/15°C had produced more knobs than 20°/10°C. By day 143, there were no significant differences between treatments.

The moisture contents for fibred and choice grade rhizome are shown in figures 3A and 3B.

Figure 3

Rhizome fibre content

Neutral detergent fibre analysis for whole rhizomes are shown in figure 4A in g/plant and in 4B as a % of rhizome dry weight.

Figure 4

Root growth

25°/15°C produced a greater root dry weight at day 143 than 20°/10°C.

The root:shoot ratio was similar for all treatments at day 113. There was a general trend over the 33 day experimental period for the ratio of roots:shoots to increase.

Discussion

Acclimatisation period

Some different trends are evident in the acclimatisation period as that in the period after the final treatment temperatures were reached. The optimum temperature (25°/15°C) produced a steady increase in all plant components throughout the acclimatisation period and treatment period. Other treatments grew better in the acclimatisation period than during the treatment period. The 2 warmest temperature regimes tended to produce the fastest fibre development (and rhizome dry weight) in the acclimatisation period.

Treatment period

Rhizome fibre development responded to temperature as did total plant dry weight. Fibre development is therefore a function of total plant assimilate production. 25°/15°C was the most favourable temperature regime for fibre development but also favoured choice rhizome production. In general these results agreed with that of Haque (1974) although he used slightly different maximum and minimum temperature combinations.

Percentage fibre exhibited a decrease over the period to day 132, even though fibre growth continued. While not measured this can only be because accumulation of other rhizome dry matter components was greater than fibre. The likely predominant component is starch.

Starch usually comprises 20-30% of the rhizome dry weight around early harvest and is increasing (Ratnambal et al, 1987).

Plants in the 2 warmer treatments increased in % fibre over the final 11 days. This is probably also due to a decrease in starch and not because of a sudden increase in fibre growth. Supporting evidence is seen in the trend for moisture content of fibred rhizome. The % moisture content of fibred rhizome of 35°/25°C plants increased over the last 11 days. This can also be due to a decrease in starch content rather than a real increase in moisture. For the same reason 30°/20°C plants tended to have a higher fibred rhizome moisture content over the majority of the experimental period.

Temperatures cooler than the optimum resulted in a lower percentage of choice grade rhizome (on a dry weight basis) because new rhizome growth was more sensitive to temperature than growth of the fibred portion. Fibred rhizome growth at low temperature is thought to be mainly the result of assimilate deposition possibly by translocation from other areas and not enhanced fibre development.

Rhizome dry weight was less affected by low temperature than shoot dry weight. This is to be expected. In field grown ginger, rhizome bulking continues well into the winter period long after shoot production has ceased and senescence has commenced (Whiley, 1980; Ihara, 1957). This rhizome bulking is not growth of new rhizome but rather assimilate deposition probably translocated from the senescing shoots. The switch from growth of new rhizome to

bulking of old rhizome is most likely influenced by several environmental factors particularly daylength.

Conclusion

While temperature was shown to affect yield of choice grade rhizome substantially, it does not appear to have a major affect on the decline of percentage choice grade rhizome. The rate of decline in % choice grade rhizome tends to be more dependant on the rate of starch deposition in the fibred rhizome relative to the production of new knobs rather than the rate of fibre development.

The average maximum and minimum temperatures for Nambour in February and March for the 40 years from 1955 to 1995 were 29°/21°C and 28°/18°C respectively. More specifically, the maximum and minimum temperatures at early harvest towards the end of February are generally around 27°/19°C. These temperatures are very close to the optimum for ginger. It is more likely to encounter temperatures higher than the optimum rather than lower than the optimum at this time of the year. Low temperature around early harvest is not therefore thought to influence the rate of decline of % choice grade rhizome. It could however reduce the yield of choice grade rhizome as could high temperature. Also, even at temperatures favourable for new rhizome growth, a decline in % choice grade rhizome still occurs, probably through the influence of daylength.

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Figure captions

Figure 1. Trends in leaf dry weight (A), stem dry weight (B), total rhizome dry weight (C), root dry weight (D), fibred rhizome dry weight (E), and choice rhizome dry weight (F) over the period from 110 to 143 days after planting. Each data point represents the mean of 6 plants. LSD bars are shown ($P < 0.05$).

Figure 2. Trends in knob number (A), % choice rhizome on a fresh weight basis (B), fibred rhizome fresh weight (C), choice rhizome fresh weight (D), and total plant dry weight (E) over the period from 110 to 143 days after planting for plants grown at 4 different temperature regimes. Each data point represents the mean of 6 plants. LSD bars are shown ($P < 0.05$).

Figure 3. Trends in fibred rhizome moisture content (A) and choice rhizome moisture content (B) over the period from 110 to 143 days after planting for plants grown at 4 different temperature regimes. Each data point represents the mean of 6 plants. LSD bars are shown ($P < 0.05$).

Figure 4. Trends in total rhizome fibre in grams (A) and as a % of total rhizome dry weight (B) over the period from 110 to 143 days after planting for plants grown at 4 different temperature regimes.

Figure 1

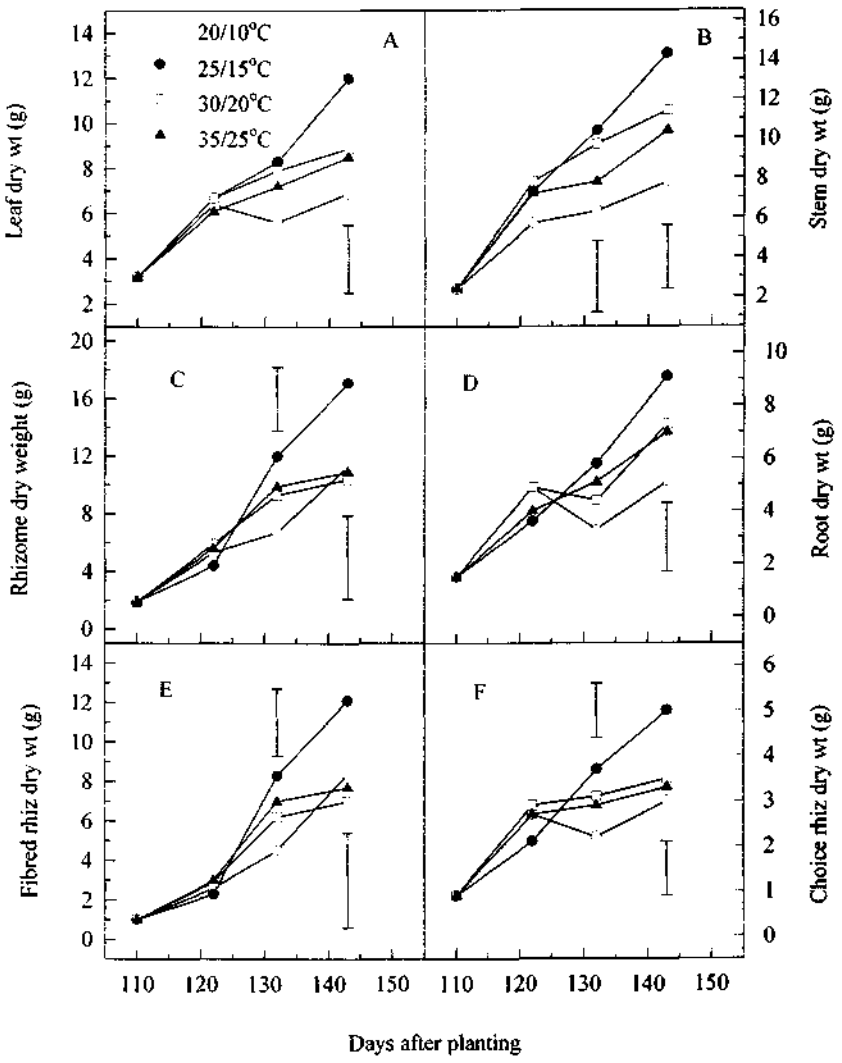

20/10°C
25/15°C
30/20°C
35/25°C
A
B
C
D
E
F
Leaf dry wt (g)
Stem dry wt (g)
Rhizome dry weight (g)
Root dry wt (g)
Fibred rhiz dry wt (g)
Choice rhiz dry wt (g)
Days after planting

Figure 2

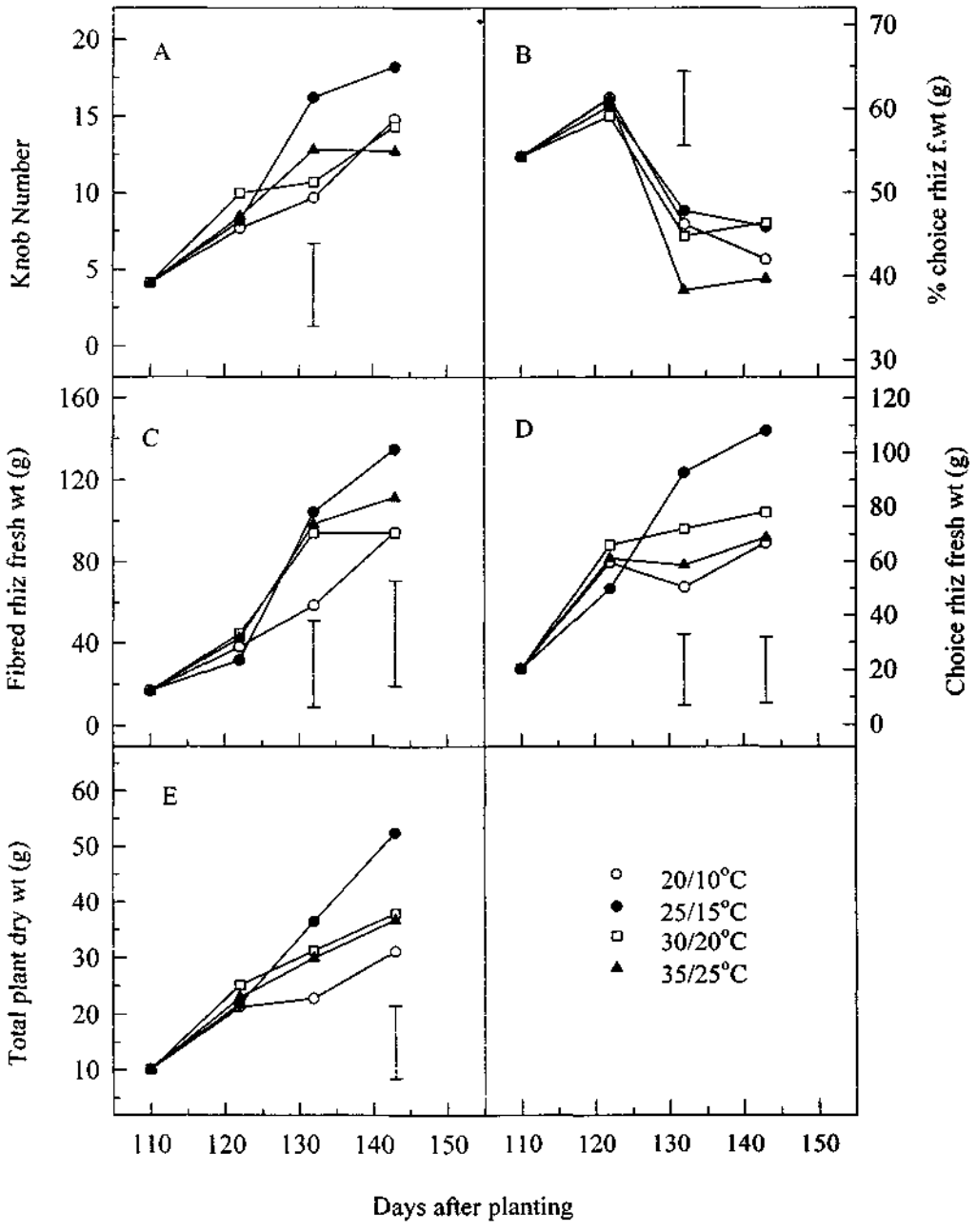

A
B
C
D
E
Knob Number
% choice rhiz f.wt (g)
Fibred rhiz fresh wt (g)
Choice rhiz fresh wt (g)
Total plant dry wt (g)
20/10°C
25/15°C
30/20°C
35/25°C
Days after planting

Figure 3

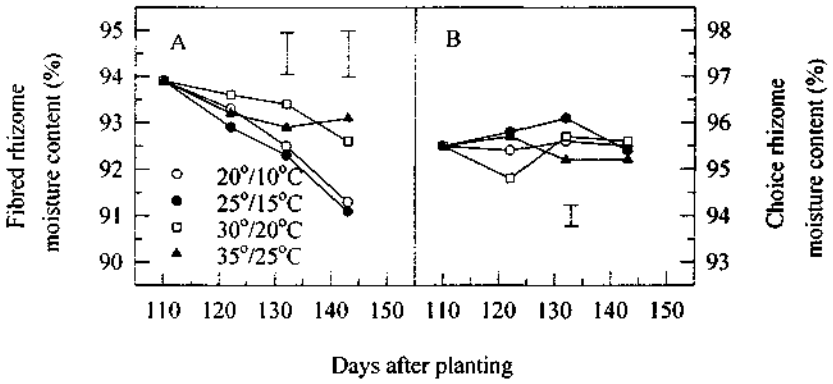
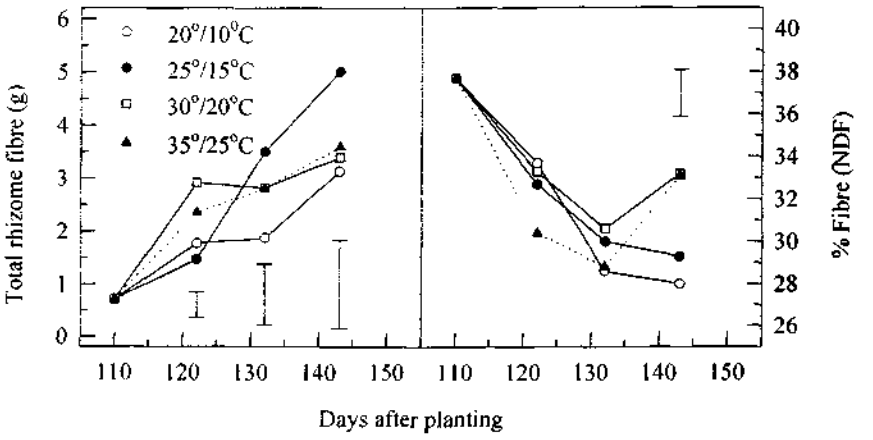

A
B
95
94
93
92
91
90
98
97
96
95
94
93
20°/10°C
25°/15°C
30°/20°C
35°/25°C
110
120
130
140
150
Fibred rhizome moisture content (%)
Choice rhizome moisture content (%)
Days after planting

Figure 4.


20°/10°C
25°/15°C
30°/20°C
35°/25°C
Total rhizome fibre (g)
% Fibre (NDF)
Days after planting
0
1
2
3
4
5
6
26
28
30
32
34
36
38
40
110
120
130
140
150

SECTION 6

Effect of mild water deficit on assimilate partitioning, fibre development and water relations of potted ginger plants

EFFECT OF MILD WATER DEFICIT ON ASSIMILATE PARTITIONING, FIBRE DEVELOPMENT AND WATER RELATIONS OF POTTED GINGER (*Zingiber officinale* Roscoe) PLANTS

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Summary. Mild water stress for a short duration did not affect fibre development relative to choice rhizome growth.

Despite a declining leaf water potential, water stressed plants developed osmotic adjustment in the roots. This was critical for continued water uptake by these plants. The experimental period was of insufficient duration to measure changes in dry matter partitioning as a consequence of the root osmotic adjustment.

It is proposed that root osmotic adjustment is a mechanism to help maintain rhizome moisture content. It is believed this is to protect the viability of the below-ground dormant meristems.

Introduction

The Australian ginger industry supplies the majority of the small but high value international markets for high quality confectionary products based on ginger. Quality of the ginger in terms of fibre content is important as is yield for profitability. It is desirable therefore to understand fibre development and how it responds to the environment and cultural operations. This paper examines the response of fibre development and plant water relations to mild water deficit.

Ginger is known to be very sensitive to water deficit (Haque, 1974). It is commonly considered within the ginger industry that water deficit leads to an increase in fibre development. The affect of severe water deficit on assimilate partitioning, fibre content and plant water relations was investigated by the author in a previous study. That study indicated that fibre development was impeded by severe water deficit. It was also demonstrated that assimilate partitioning to fibred and non-fibred portions of the rhizome had more effect on the percentage of choice grade rhizome than the development of fibre relative to rhizome growth. In addition to the above important findings, it also indicated the possible existence of osmotic adjustment in the roots.

Osmotic adjustment in plant roots is not a recent realisation but has been rarely investigated. Studies of plant water relations are more often concerned with the response of the leaf rather than the roots. It is usually assumed that leaf water relations are of more significance to plant survival or productivity or that if osmotic adjustment exists in the leaf, it exists in the roots as

well. There are of course fundamental differences between the physiological effect of osmotic adjustment in the root and in the leaf.

Osmotic adjustment in the leaf maintains leaf turgor and allows shoot growth to continue (Wilson et al, 1980; Santamaria et al, 1990; Hsiao et al, 1976). Leaf osmotic adjustment in sorghum cultivars has been shown to increase grain number and grain yield where water deficit occurred before anthesis. This resulted from a higher distribution index (DI). More specifically the osmotic adjustment increased root length density and allowed panicle exsertion which in turn reduced spikelet abortion (Santamaria et al, 1990). Where water deficit occurred after anthesis, leaf osmotic adjustment increased grain size through a higher DI (Ludlow et al, 1990). Tangpremsri et al (1990) indicated that leaf osmotic adjustment in sorghum is also related to a higher root length density and a high dehydration tolerance to give a longer sustained green leaf area. Sustained green leaf area allowed the plant to translocate assimilates which were fixed before the water deficit.

In some tropical grass forage species, leaf osmotic adjustment enables stomata to stay open and photosynthetic activity to continue. This increases productivity in the early stages of water deficit but gives rise to greater water deficits. It does not therefore necessarily improve leaf survival (Wilson et al, 1980). Osmotic adjustment in roots usually leads to a shift in the ratio of roots to shoots (Hsiao et al, 1976).

Root osmotic adjustment has been shown to exist in *Artemisia tridenta* (Bassiri Rad and Caldwell, 1992), Cotton (Oosterhuis and Wullschleger, 1987), Maize (Voetberg and

Sharp, 1991; Sharp and Davies, 1979: Spollen and Sharp, 1991), Pea (Hsiao et al, 1976) and Lupins (Turner et al, 1987).

This study was initiated to determine if osmotic adjustment existed in the leaf and roots of ginger plants and to establish the plants response, in particular fibre development, to mild water deficit.

Materials and Methods

Mature rhizomes of the ginger cultivar 'Queensland' were harvested in early July 1992. The rhizomes were stored in a coolroom at approximately 4°C for 1 week to remove dormancy (Whiley, personal communication). The rhizomes were then cut into pieces weighing between 50 g and 70 g and dipped for 1 minute in a fungicide solution of 1 g/L 'Benlate' R (0.5 g/L benomyl). Treated pieces were air-dried for 1 day before planting in moist sawdust in a naturally-lit glasshouse.

The glasshouse day/night temperatures were maintained at 30°/18°C by thermostatically controlled evaporative coolers. Relative humidity fluctuated between 60% and 100%.

After 2 weeks, germinating rhizome pieces were planted 1 each into 8 L plastic pots containing 12 kg of air-dry potting mix in the ratio 1 sand:1 soil and a mixture of solid fertiliser. At field capacity each pot contained about 1800 ml of water. This was equivalent to 14.3% moisture content on an oven-dried basis and 10.2% on an air-dried basis.

The experiment was a completely randomised design with 8 replicates of 2 treatments. The treatment regime is shown in table 1.

Control plants were watered about every 2 days with sufficient water to bring the potting mix to field capacity.

All pots were contained in plastic bags which were loosely closed around the plant stems to reduce evaporative losses.

Measurements

Osmotic potential along root length

Preliminary investigations were conducted into the variation of osmotic potential along the root length. This was necessary to establish a site for subsequent sampling. 13 week old ginger plants grown in polystyrene trays in a heated glasshouse were used. Measurements were made at the root tip, mid-way along the root and at the base of the root. 16 samples were taken from each site. This study was completed before the commencement of the main trial.

Harvests

Harvests were conducted on day 1, 9 and 15. At each harvest, plants were divided into leaf, stem, rhizome, seed-piece and roots. Fresh weights for each plant component (except roots), leaf area, and percentage choice rhizome were determined before samples were dried in a forced draft oven at 60°C.

Leaf area was measured on a leaf sub-sample using a Li-Cor planimeter.

The moisture contents (%) of the choice and fibred rhizome and seed-piece were calculated from fresh weight and dry weight data.

Soil moisture was determined by weighing a sub-sample of potting mix before drying in an oven at 60°C for greater than 48 hours and re-weighing.

A soil moisture/pressure curve for the same potting mix was determined using pressure plate apparatus (figure 1).

Figure 1

The percentage of choice grade rhizome was obtained using the 'blunt knife' technique described by Whiley (1980). Dry weights for fibred and fibre-free portions were also determined.

Relative growth rate was calculated from the following equation (Milthorpe and Moorby, 1988).

$$RGR\ (d/day) = \frac{(\ln W_2 - \ln W_1)}{(t_2 - t_1)}$$

Daily water use

Daily evapotranspiration of ten C and ten S plants was determined by recording pot weight changes over 36 hour periods.

C plants were firstly watered to field capacity late in the evening. A weight was then recorded at 8.30 am the following day. This was considered field capacity and was used as the starting weight. A second weight was recorded at 8.30 am the following day. The second weight was subtracted from the first weight to give the daily evapotranspiration.

Evapotranspiration was recorded for S plants in the same way except pots were not watered.

Leaf relative water content % (RWC_L%)

RWC_L of C and S plants was measured every 3 to 4 days from the commencement of the treatment period on day 1 to final harvest on day 15.

Samples were taken from third or fourth leaves only. One small piece of leaf tissue, approximately 1 cm^2 square was cut from each plant and sealed immediately in a previously tared Epindorf tube. In most instances 2 samples were taken per plant and averaged before being used for statistical analysis. Fresh weight was recorded and the leaf pieces then floated on distilled water in petri dishes illuminated with 12 to 15 $\mu E/M^2/S^1$ of PAR for 4 hours. The pieces were then removed and dried by pressing between 2 paper tissues using a standard weight and time of 500 g for 30 seconds. The pieces were returned to the same Epindorf tubes as used previously and turgor weight (TW) was recorded. The samples were then dried

in the same Epindorf tubes for dry weight (DW) determination. Percent leaf relative water content (RWC_L%) was calculated using the equation,

$$RWC_L\ \% = \frac{FW - DW}{TW - DW} \times 100$$

Water potential

Leaf water potential (ψ_L) was calculated from measurements made using 15 Wescor C-52 sample chambers connected to a 15 channel automatic scanning Wescor HP-115 Hygrometer in the dew-point mode. Calibration curves were prepared for each chamber using standard osmolality solutions of 100, 300 and 1000 mmol/kg sodium chloride. Regressions on calibration data points all had an R^2 of 0.99 or 1.0.

All readings were taken in a controlled temperature room set at 24°C. 6 to 10 readings with an interval of 30 minutes were taken for each sample and the means calculated.

For the measurement of ψ_L , whole leaves were removed from the plant between 12.00pm and 1.00pm and immediately wrapped in plastic cling film and aluminium foil. In the laboratory 2 discs of 0.95 cm^2 were punched from each leaf and each placed in a sample chamber. Two hours were allowed for thermal and vapour equilibration before readings were commenced. These 2 readings per plant were then used to calculate a mean for each

plant sampled before statistical analysis was performed. Each treatment mean was therefore the result of 2 samples from each of 4 plants per treatment.

Osmotic potential

Samples for the measurement of π_L were taken at the same time as for $RWC_L\%$. Whole leaves were collected and wrapped as for ψ_L but were frozen immediately in liquid nitrogen. In the laboratory the samples were thawed and allowed to equilibrate to room temperature over about 30 minutes. Two 0.95 cm^2 discs of lamina were punched from each leaf just adjacent to the midrib. Each was sealed in a separate chamber. The practice of measuring π on thawed tissue rather than extracted sap follows the procedure of Morgan (1992). The sample chambers were allowed to equilibrate over approximately 2 hours before readings were commenced. Two measurements were taken on each of 4 to 7 plants per treatment. The means were calculated for each plant before the data was used for statistical analysis.

π_L of S plants was adjusted for $RWC_L\%$ using the following equation cited by Morgan (1984);

$$\text{Adjusted } \pi_L = \frac{RWC_L\% \text{ (C plants) X } \pi_L}{RWC_L\% \text{ (S plants)}}$$

The osmotic potential of roots (π_R) was also obtained at each harvest. The same basic technique was used as for leaves. Samples about 1 cm long were taken at each harvest from the tip of fleshy roots about 2 mm to five mm thick at their base. To avoid contamination

with solutes from the potting mix, the epidermis was scraped from the root with a scalpel before the sample was wrapped and frozen in liquid nitrogen. In some cases the samples were stored in a freezer for measurement at a later time. Two samples were taken from each of 7 plants per treatment. The 2 samples for each plant were averaged. Only means for each of the 7 plants per treatment were used for statistical analysis.

Rhizome samples for the measurement of osmotic potential (π_{RHIZ}) were taken at the same time as root samples. A small cube of tissue was excised from within the choice and fibred rhizome of each plant. The samples were wrapped and frozen as for roots.

Samples for the determination of root water volume were taken at the same time as those for π_R. Two samples from each plant were collected as for π_R and each placed in a separate and previously tared Epindorf tube. These samples were dried in an oven at 60^{O}C for 24 hrs.

Root osmotic adjustment

Root osmotic adjustment was calculated using the procedure of Bassiri Rad and Caldwell (1992). This approach used Van't Hoff's equation (Salisbury and Ross, 1985) and measurements of root tip water content to calculate root tip osmolality on a dry weight basis. The value for C plants was subtracted from that of S plants to give the osmotic adjustment in osmolality/Kg root dry mass.

Example

Root tip water volume

From a root tip sample fresh weight (FW) of 0.1275 g and a dry weight of 0.0068 g (DW).

Root tip water volume (cm^3H_2O/Kg DW) = $^1/_{DW}$ (FW-DW)

$= {}^1/_{0.0068}$ (0.1275 - 0.0068)

$= 17.75\ cm^3H_2O$/Kg DW

Root tip solute concentration (Van't Hoffs equation)

$-mi = {}^{\pi r}/_{RxTx100}$

-mi = root tip solute conc (moles of solutes/1000g H_2O)

π_r = osmotic potential of root tip (MPa)

R = gas constant (0.00831L/MPa/mol/K)

T = absolute temperature in K (degrees C + 273)

If π_r was measured at 1.2 MPa in an hygrometer sample chamber at a temperature of 24° C,

$$-mi = 1.2 / 0.00831 \times 297$$

$$= 0.4862 \text{ osmol}.1000 \text{ cm}^{-3}$$

Osmolality/Kg root dry mass = 17.75 cm^3H_2O/Kg DW x -0.4862 osmol/1000 cm^3

= -8.63 osmol/Kg root dry mass

Osmotic adjustment (osmol/Kg) = osmol/Kg for S plants - osmol/Kg for C plants

Statistical analysis

All data was analysed using the statistical software program *Statistix*. One way analysis of variance was used to determine the significance of treatment effects.

RESULTS

Dry weights

Dry weights for all plant components are shown in table 2. From table 2, leaf and choice rhizome dry weight of C plants decreased slightly over the 15 day experimental period but dry weight of all other plant components increased except seed dry weight. The greatest increases were in rhizome and roots. Roots and fibred rhizome also had the highest relative growth rates. Choice rhizome, leaf and seed-piece had the lowest relative growth rates. S plants had a similar growth pattern except shoot growth in particular was substantially greater although not statistically different. Roots and fibred rhizome had the highest relative growth rates in S plants.

The percentage choice fresh weight was similar for both treatments. Percentage choice declined at about 1.2% per day over the 15 day period. Despite the lack of significant difference in fresh weight percentage choice, there was a difference between treatments in percentage choice on a dry weight basis at day nine. S plants had a higher percentage of dry weight choice grade rhizome at this time because they produced less fibred rhizome.

Plant water relations

Leaf and root water relations measurements are shown in table 3.

Leaf

After 15 days ψ_L rose in C and S plants but there were no significant differences between treatments. This rise in ψ_L was accompanied by a decline in RWC_L%. In S plants it was

also accompanied by an increase in π_L at day 15. Adjusted π_L was lower in C plants compared to S plants at day 15.

Surprisingly, T_L and $RWC\%_L$ were marginally but significantly higher in S plants at day 4. As expected, T_L declined considerably in S plants at day 15.

π_R declined in both treatments over the experimental period with a trend to S plants having a slightly lower value (not significant).

Rhizome and root

π_{RHIZ} for both C and S plants was generally lower in fibred rhizome compared to choice rhizome. π_{RHIZ} in S plants increased in choice rhizome but did not change in fibred rhizome.

Measurements of osmotic potential along the root length showed a decreasing gradient from the base of the root to its tip. The results are shown in table 4. The root tip was used for subsequent sampling.

Osmotic adjustment values for roots and rhizome are shown in table 5. From table 5 a root osmotic adjustment of -1.8 osmol/Kg root dry weight occurred after 15 days. There was no significant difference in osmolality values for choice or fibred rhizome although there was a trend for choice rhizome values in S plants to decline.

The moisture content (% on oven dry basis) for seed-piece, choice rhizome and fibred rhizome is shown in table 6.

There were no differences in moisture content between treatments in seed-piece, choice or fibred rhizome. The general trend was for the seed-piece moisture content to remain unchanged while choice rhizome moisture declined and fibred rhizome moisture increased slightly.

Soil moisture

The trend in soil moisture at several times over the 15 day treatment period is shown in table 7.

From table 7, the potting mix moisture content of S plants had decreased to 9 % after 8 days and 3 % after 15 days.

Pot evapotranspiration is shown in table 8.

Water use had declined slightly in C plants probably due to the decline in leaf growth. Evapotranspiration in S plants had declined significantly by day 4.

DISCUSSION

The trend in growth of each plant component has been documented previously (Whiley, 1980). The general trend in the period preceding early harvest is for the rhizome growth rate

to increase and shoot growth to cease and even decline. This general trend was observed over the experimental period in this study. However, while leaf growth ceased, stem dry weight increased slightly indicating it is less sensitive to mild water deficit than leaf growth. Fibred rhizome and roots had the highest relative growth rate.

Previous work (Sanewski, unpublished) demonstrated a decrease in dry weights of all plant components with severe water stress over the same phenological period. There were no significant differences in dry weight components between C and S plants at day 15 in this study. This indicated the level of stress imposed was relatively mild.

The percentage choice grade rhizome declined at a similar rate in C and S plants. Mild water stress does not therefore increase fibre development relative to choice rhizome growth as commonly thought by growers.

Water relations

Leaf

The higher T_L and RWC_L% values for S plants at day 4 suggests these plants had reduced their water loss and hence water deficit even at this early stage of stress. This agrees with earlier work (Sanewski, unpublished) which demonstrated an increase in stomatal resistance after only 2 days of withholding water. The difference in T_L gradually disappeared until day 15 when T_L in S plants was lower (not significant) than C plants. T_L was in fact probably lower in S plants at this time even though a significant difference was not shown. RWC_L at day 14 was similar for C and S plants. The decline in T_L that occurred was therefore a result

of the increase in π_L. This most likely occurred because leaf assimilate in S plants was used for respiration or translocated for use elsewhere in the plant. It was shown by the author in previous work that ginger maintains a high RWC_L by a high leaf resistance. Photosynthesis is therefore reduced and leaf assimilates depleted. In addition there is a natural decline in leaf assimilates in this period (around early harvest time). This appears to be regulated by endogenous factors and is accompanied by rapid rhizome growth.

Root

From table 7 and figure 1, field capacity occurred at a soil water content of about 12%. On day 15, S plants would have required a π_R of -1.0 to -1.5 MPa to extract soil moisture (figure one). π_R of S plants was measured at -1.14 MPa at this time. C plants had a π_R of only -0.94 MPa and would not have been able to extract water at that soil water content. The root osmotic adjustment observed (-1.8 osmol/Kg root dry weight) was therefore critical for continued water uptake by S plants.

Rhizome

There was no osmotic adjustment observed in choice rhizome but there was a small decline in π_{RHIZ} (-0.17 MPa) for choice rhizome in S plants after 15 days of stress. Choice rhizome represents the growing meristems of the rhizome and it is reasonable to expect osmotic adjustment to occur. It is possible that the water stress was insufficient after 14 days to result in osmotic adjustment in choice rhizome. Previous studies (Sanewski, unpublished) indicated up to 4 weeks stress in similar conditions may be necessary to induce this response. It is also

possible that these tissues would not have developed their suberised layer and so would be more prone to moisture loss than the other fibred portions.

CONCLUSION

No association was seen between root osmotic adjustment and the root:shoot ratio. It is expected that the short duration of the study did not allow sufficient time for changes to develop in dry weight components according to treatment. A cyclical stress over say 6 weeks may have been more effective to observe a change in assimilate partitioning. However, one of the primary objectives of this study was to investigate the existence of root osmotic adjustment and to that end was successful.

Percentage choice grade rhizome was also shown to be unaffected by a short duration of mild water stress (3% ADMC equals a soil water potential of about -1.5 MPa). It is expected however that even a mild water deficit will decrease the yield of choice grade rhizome if over a long period. Because ginger has very responsive stomata, even mild water deficits which could develop quickly in the field and persist over long periods, could easily reduce yields of choice grade rhizome.

It is likely that root osmotic adjustment in ginger is a mechanism to help maintain rhizome moisture content. Long term shoot survival is not necessary in ginger for survival of the plant from season to season. The below ground meristems are probably the most important organs for survival of the plant. Growth of the dormant meristems can resume when soil

moisture is favourable. This was demonstrated in a previous study (Sanewski, unpublished) where potted plants were stressed for 4 weeks then rewatered for a further 2 weeks.

It is hypothesised that when a prolonged plant water deficit develops the rhizome becomes the predominant sink for moisture. In this way the dormant meristems, which are all below the soil surface, are protected from desiccation. This behaviour would be fundamental to a plant which senesces during the winter only to persist as a dormant rhizome. Mature rhizomes of ginger which have undergone the winter in the field in South East Queensland with no irrigation have been shown to have a moisture content of about 86%. The mature rhizome has a suberised layer just below the epidermis (Paull et al, 1988) which functions to restrict moisture loss. The mature rhizome is 40-60% starch on a dry weight basis (Van Beek et al, 1987). It is also proposed that low osmotic potentials could quickly be developed in the mature rhizome by conversion of the large store of starch to sugars.

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Figure captions

Figure 1. The relationship between potting mix air-dried moisture content (%) and pressure (Mpa) as determined using pressure plate apparatus. The curve was fitted to the data points using the software program 'Tablecurve'.

Figure 1

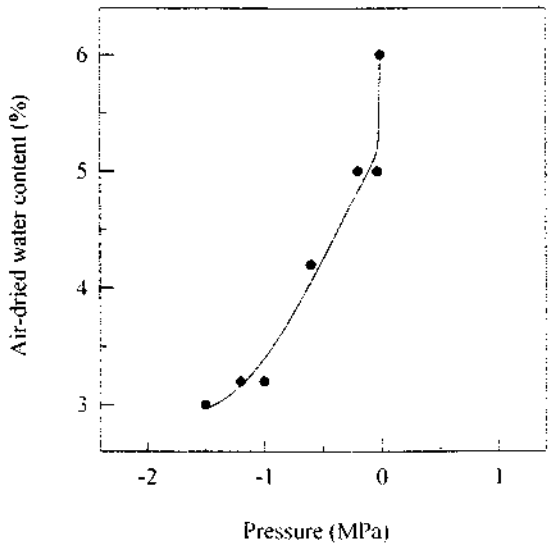

Table 1. Treatment regimes

Treatment	Watering regime
Control (C)	fully watered
Stress (S)	no water from 122 DAP (day 1) to 137 DAP (day 15)

Table 2. Dry weights of plant components at each harvest and growth parameters for 15 day experimental period.

Day	Treatment	Shoot				Rhizome			Roots	Seed	TDW	% choice (FW)
		Leaf	Stem	Total	Choice	Fibred	Total	% choice (DW)				
1	C	6.1	6.7	12.8	4.4	11.0	15.4	28	7.4	9.4	45	43
9	C	5.6^{NS}	7.6**	13.2^{NS}	2.6^{NS}	15.8^{NS}	18.4^{NS}	14*	7.6^{NS}	7.3^{NS}	46.5^{NS}	27^{NS}
	S	5.2	5.8	11.1	2.9	13.4	16.4	19	6.1	8.0	41.5	31
15	C	5.5^{NS}	7.7^{NS}	13.2^{NS}	2.8^{NS}	15.5^{NS}	18.3^{NS}	15^{NS}	9.5^{NS}	9.4^{NS}	50.4^{NS}	27^{NS}
	S	6.0	8.4	15.1	2.3	16.8	19.1	13	9.6	8.7	55.2	23
RGR ($g.day^{-1}$)	C	-0.007	0.009	0.002	-0.03	0.023	0.012	-	0.017	0	0.008	-
	S	-0.001	0.015	0.015	-0.04	0.028	0.014	-	0.017	-0.005	0.014	-
Wt change (g)	C	-0.6	1.0	0.4	-1.6	4.5	2.9	-	2.1	0	5.4	-
	S	-0.1	1.7	2.3	-2.1	5.8	3.7	-	2.2	-0.7	10.2	-

Table 3. Leaf and root water relations measurements. All potential values are in MPa.

Day	Trt't	Leaf						Root		π_{RHIZ}	
		Ψ_L	π_L	Adj π_L	T_L	Ratio TW/DW	RWC_L%	π_R	DW_R%	CH	FB
1	C	-	-	-		4.6	96	-0.71	5.2	-1.04	-1.11
4	C	0.78^{NS}	-1.86^{NS}	-	1.12**	4.97	96**	-	-	-	-
	S	-0.71	-2.06	-2.1^{NS}	1.45	4.83	97	-	-	-	-
9	C	-0.91^{NS}	-1.88^{NS}	-	0.96^{NS}	4.74	-	-0.74*	4.8^{NS}	-1.10^{NS}	-1.18^{NS}
	S	-0.76	-1.82	-1.8^{NS}	1.15	5.12	-	-0.82	4.6	-1.03	-1.10
12	C	-0.86^{NS}	-1.82^{NS}	-	0.99^{NS}	4.59	95	-	-	-	-
	S	-0.62	-1.60	-1.6^{NS}	1.15	4.67	95	-	-	-	-
15	C	-0.41^{NS}	-1.72**	-	1.22^{NS}	7.01	59	-0.94*	5.0*	-0.95**	-1.16
	S	-0.58	-1.33	-1.3**	0.75	6.90	59	-1.18	5.7	-1.12	-1.06

Table 4. Osmotic potentials (MPa) for rhizome and roots of 13 week old plants

Rhizome	Root		
	Proximal	Mid	Distal
-0.88^{a}	-0.59^{c}	-0.68^{bc}	-0.78^{ab}

Table 5. Osmotic adjustment in roots and rhizome. All values are in osmol Kg $^{-1}$ root dry weight.

Day	Trt't	Root				Rhizome	
		Osmolality	osm adj	CH	FB	CH osm adj	FB osm adj
9	C	-6.36	-	-7.74	-4.14		
	S	-6.56	-0.2^{NS}	-7.37	-3.71	0.37^{NS}	0.43^{NS}
15	C	-6.64	-	-7.35	-3.95		
	S	-8.41	-1.8*	-7.67	-3.82	-0.32^{NS}	0.13^{NS}

Table 6. Moisture content (%) of seed-piece, choice rhizome and fibred rhizome.

Day	Treatment	Seed-piece	Choice rhiz	Fibred rhiz
1	C	86	94	88
9	C	87^{NS}	96	90^{NS}
	S	88	96	89
15	C	86	80^{NS}	93
	S	86	78	93

Table 7. Soil moisture (oven dry weight basis) over the experimental period

Treatment	Day 1	Day 9	Day 15
C	14%	11%**	12%**
S	_	9%	3%

Table 8. Pot evapotranspiration over the fifteen day experimental period.

Day	Evapotranspiration (mls / pot)	
	C	S
2	204	204
4	158*	107
6	196*	147
8	166*	69
12	179*	67
15	-	58

SECTION 7

Effect of water deficit on dry matter production, percentage choice grade rhizome and leaf water relations of potted ginger plants

EFFECT OF WATER DEFICIT ON DRY MATTER PRODUCTION, PERCENTAGE CHOICE GRADE RHIZOME AND LEAF WATER RELATIONS OF POTTED GINGER *(Zingiber officinale* Roscoe) PLANTS.

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Summary. Ginger plants were grown in a glasshouse for 21 weeks before being subjected to either of four regimes of water stress. Treatments were four weeks stress (SS), two weeks early stress (SC), two weeks late stress (CS). and fully watered (CC).

Yield was severely reduced in all treatments where water was withheld. There were however significant differences between treatments in the magnitude of the response and the changes in assimilate partitioning that occurred.

Percentage choice rhizome declined at the rate of 0.6% per day in CC plants. The decline in percentage choice rhizome either ceased or reversed when water was withheld. This occurred because fibred rhizome was adversely affected by water stress more than choice rhizome.

Root and seed-piece dry weight continued to increase in CS plants while all other plant components declined. It is likely assimilate was translocated from the fibred rhizome to the seed-piece and roots. Also, the leaf osmotic potential (π_L) increased in of CS plants. This was attributed to a decline in leaf assimilate levels.

SS plants were able to maintain leaf relative water content at the same value as CC plants for three weeks but a strong stomatal response was recorded two to six days after water was withheld. In addition, the osmotic potential of roots (π_R) decreased in all stressed plants. It is not clear whether this decline was due to osmotic adjustment or a direct result of moisture loss from the roots. This decline in π_R would enhance water uptake where soil water was limited.

The moisture content of the rhizome and seed-piece of all stressed plants was equal to or greater than that of CC plants. Rewatered stress plants (CS and SS) developed a greater moisture content in the rhizome and seed-piece than CC plants.

INTRODUCTION

Australia produces about 6,000 tonnes of ginger annually with about 3,600 tonnes used for processing. The processing industry has a strong demand for highly pungent, low fibre ginger. About 80% of the product processed is of this type. It is mainly used in the manufacture of high quality confectionary (J.Ruscoe, personal communication).

To produce choice grade ginger the rhizome is harvested when it is between 42% and 35% fibre-free by weight (fresh weight). The rhizome is 25 to 28 weeks old and about 60% fully grown (on a fresh weight basis) at this time (Whiley, 1980). Because rhizome yield is still increasing rapidly at this time, significant yields could be obtained if fibre development could be delayed. Even a short delay of one week would lead to a yield increase of up to 4.5 $t.ha^{-1}$. Despite the effect of fibre development on profitability, it has not been investigated in ginger to any extent.

Ginger rhizome fibres are actually vascular bundles with a surrounding sheath of fibre cells. Each fibrovascular bundle contains one or more tracheal elements and a single phloem strand (Tomlinson, 1969). The fibre sheaths that enclose the vascular bundles in herbaceous monocotyledons are usually made of sclerenchyma cells (Fahn, 1990). Paull et al. (1988) found no evidence of lignification in ginger rhizomes.

While no studies have been reported on the physiology of fibre development in ginger, several studies have been published on the response of fibre content of various pasture species to environmental variables. Wilson (1982) indicated that water stress in most pasture species

reduces fibre development. Water stressed plants, he explains, generally have less carbohydrate available for cell wall growth and lignin development. Crafts (1968) agrees that stressed cells have limited cellulose synthesis. Vaadia et al. (1961) adds that cellulose synthesis seems to be dependant on turgor pressure. Maturation of plant tissues, including fibre cells, is not therefore necessarily hastened by water deficit. However, Wilson (1982) reports that an increase in temperature usually leads to an increase in cell wall content and lignification. It could be that mild water deficit, and the associated reduced transpiration, may lead to an increase in plant temperature and hence an increase in fibre development whereas severe water deficit, because of the effect on assimilate production, might reduce fibre development. The effect on yield of fibre free ginger is however a more complex issue as production of assimilate and its relative partitioning to the fibred and non-fibred portions is also involved.

Hahn (1977) described the development of hard or fibrous tubers in sweet potato. Tubers became hard or fibrous when the primary cambium was less active but lignification of stele cells was increased. Factors which increased the percentage of hard or fibrous tubers included low potassium supply, high temperature, dry compact soil and waterlogged soil which is low in oxygen. Crafts (1968) reports that brassica crops may develop a higher fibre content if subject to water deficit during early growth and that fibre crops such as cotton benefit from water deficit during early growth.

It is commonly believed by people within the ginger industry that stress of any nature, particularly that associated with water deficit, will increase the rate of fibre development

relative to the growth of new rhizome thus reducing the percentage of choice grade rhizome. A major objective of this study was to test this hypothesis.

This study also aimed to make some preliminary observations on the physiological responses of the ginger plant to water deficit. Turner (1979) gives a good overview of the range of plant responses to water deficit. Each strategy is classified into either of three categories, drought avoidance, drought tolerance with low water potential or drought tolerance with high water potential. Avoidance mechanisms include developmental plasticity and rapid phenological development. Mechanisms of tolerance with low water potential have the effect of either maintaining cell turgor or enduring desiccation. The most well known of these mechanisms is leaf osmotic adjustment. Drought tolerance strategies that maintain high water potential either reduce water loss or maintain water uptake. Mechanisms in this category include increased stomatal and cuticular resistance, reduced radiation absorption and increased root density. This last strategy could also be considered as a stress avoidance strategy.

Root crops in general are characterised by shallow tuberous roots but in sweet potato and cassava at least, the roots responsible for water and ion uptake are usually deep thus conferring some tolerance to drought (Wilson, 1977).

Ginger is generally considered to be an under storey or shade loving plant and it is known to be sensitive to water deficit (Haque, 1974). There is little known however about the extent and nature of the drought response mechanisms inherit in the ginger plant. This study will

also attempt to identify the major drought adaption strategies inherit to the ginger plant. Mechanisms to be investigated are stomatal response, leaf folding, assimilate partitioning and osmotic adjustment.

MATERIALS AND METHODS

Mature ginger rhizomes of the cultivar `Queensland', were harvested in late June, 1991. These rhizomes were immediately washed, cut into pieces weighing 50 g to 70 g and dipped for one minute in a fungicide solution of 1 $g.l^{-1}$ `Spin' (0.5 l^{-1} benomyl). Treated pieces were air-dried for one day before planting in moist sawdust in a naturally lit glasshouse in the first week of July.

The glasshouse day/night temperatures were maintained at 30°/18°C by thermostatically controlled evaporative coolers. Relative humidity fluctuated between 60% and 100%.

As rhizome pieces germinated they were planted, one each, into seven litre plastic pots containing 4.5 kg of sand and peat potting mix in the ratio 2:1 and a mixture of solid fertiliser. At field capacity each pot contained about 880 ml of water. Early and late to germinate pieces were allocated evenly across treatments.

The experiment was a randomised block design with six replicates of four treatments. Treatments are shown in Table 1. Where a day number is mentioned this refers to the number of days after planting. The abbreviations in brackets will be used throughout this

report to refer to the treatments. Plants not subject to water deficit were watered about every two days. Sufficient water was applied to bring the potting mix to field capacity.

Harvests

Harvests were made of six plants from all treatments at days 148, 163, and 179. Only SS and CC plants were allowed to grow after day 179. SS plants were rewatered on day 180. An additional harvest of CC and rewatered SS plants was taken at day 193.

Harvests were structured over this period because it was judged to coincide with the period of rapid fibre development just prior to early harvest in commercial fields of ginger.

At each harvest, plants were divided into leaf, stem, rhizome and seed-piece. Fresh weights, knob number, leaf area and % choice rhizome were determined before each plant part was dried in a forced draft oven at 60°C. Dry weights were recorded for each plant part. Roots were also washed and dried and dry weight recorded. The moisture content (%) for each sample was calculated from fresh weight and dry weight data.

Leaf area was measured using a Li-cor planimeter. Folded leaves were placed in a plastic bag with a small quantity of water to induce leaves to unfold so leaf area could be measured more easily.

The percentage of choice grade rhizome was obtained using the 'blunt knife' technique described by Whiley (1980). The fresh rhizome was first cut into knobs and, using the back

of a knife, each knob was then cross-sectioned into 2 mm to 3 mm slices from the tip. As the older, more fibrous rhizome is encountered the rhizome knobs become more difficult to cut and the fibre is easily seen protruding from the cut surface. The fibred and fibre-free portions of each rhizome were weighed separately and the percentage fibre-free rhizome on a fresh weight basis (choice grade) calculated. Dry weights for fibred and fibre-free portions were also determined. The percentage fibre on a dry weight basis was not determined due to resource limitations.

Water Relations

Leaf relative water content % (RWC_L%)

RWC_L of CC and SS plants was initially measured about every four days from the commencement of the treatment period on day 148 then at about eight day intervals to final harvest on day 179. Measurements were also taken on SC and CS plants at day 179 and CC and SS plants at day 193.

Samples were taken from third or fourth leaves only on each of three plants per treatment. In some instances two samples were taken per plant and averaged before being used for statistical analysis.

One small piece of leaf tissue, approximately 1 cm^2 was cut from each plant and sealed immediately in a previously tared Epindorf tube. Fresh weight (FW) was recorded and the leaf pieces then floated on distilled water in petri dishes illuminated with 12 to 15 $\mu E\ m^{-2}\ s^{-1}$ of PAR for four hours. The pieces were then removed and dried by pressing between two

paper tissues using a standard weight and time of 500 g for 30 seconds. The pieces were returned to the same Epindorf tubes as used previously and turgid weight (TW) was recorded. The samples were then dried in the same Epindorf tubes for dry weight (DW) determination. Percent leaf relative water content (RWC_L) was calculated using the equation,

$$RWC_L\% = \frac{FW - DW}{TW - DW} \times 100$$

Water potential

Water potential (ψ_L) and its two components osmotic potential (π_L) and matric potential (T_L) were calculated from measurements made using 12 Wescor C-52 sample chambers connected to a 16 channel automatic scanning Wescor HP-115 Hygrometer in the dew-point mode. Calibration curves were prepared for each chamber using standard osmolality solutions of 100, 290 and 1000 mmol kg^{-1} sodium chloride. Regressions on calibration data points all had an R^2 of 1.0.

All readings were taken in a controlled temperature room set at 24°C. Six to ten readings with an interval of one hour were taken for each sample and the means calculated.

For the measurement of ψ_L, whole leaves were removed from the plant between 12.00 pm and 1.00 pm and immediately wrapped in plastic cling film and aluminium foil. In the laboratory two discs of 0.95 cm^2 were punched from each leaf just adjacent to the midrib and each placed in a separate sample chamber. Two hours were allowed for thermal and vapour

equilibration before readings were commenced. These two readings were then used to calculate a mean for each plant sampled before statistical analysis was performed. Each treatment mean was therefore the result of two samples from each of three plants per treatment.

An attempt was made to measure xylem water potential using the pressure chamber technique but accurate, reliable measurements were not possible. The petiole of ginger leaves is v-shaped and does not seal well in a rubber grommet with a round hole. An alternative approach was tried using a grommet with a slotted aperture and a strip of leaf lamina. It was found however that even after enclosing the strip of leaf lamina in a plastic sheath it was difficult to obtain a reading fast enough particularly with leaves from fully watered plants. Readings from fully watered plants often had a lower value than for stressed plants using this technique.

Samples for the measurement of π_L and T_L and the calculation of turgor potential (P_l) were taken at the same time as for RWC_L. Whole leaves were collected and wrapped in plastic cling film as for ψ_L but were frozen immediately in dry-ice. In the laboratory the samples were thawed and allowed to equilibrate to room temperature over about 30 minutes. For the determination of osmotic potential, a small portion of lamina was cut to include tissue from the leaf margin to next to the midrib. Sap was expressed from each sample using a 0.5 ml syringe. A drop of sap from each sample was placed on a 0.95 cm^2 filter paper disc in each of two sample chambers. The sample chambers were allowed to equilibrate over approximately two minutes before readings were commenced. Two measurements were

taken on each of six plants per treatment. The means were calculated for each plant before the data was used for statistical analysis.

π_L was adjusted for RWC using the following equation cited by Morgan (1984);

$$\text{Adjusted } \pi_L = \frac{RWC_L \text{ (CC plants)}}{RWC_L \text{ (stress plants)}} \times \pi_L$$

The osmotic potential of roots (π_R) was also obtained at each harvest. The same basic technique was used as for leaves. Samples were taken at each harvest from fleshy roots about 2 mm to 5 mm thick at a point on the root near its origin on the first order rhizome. To avoid contamination with solutes from the potting mix, the epidermis was scraped from the root with a scalpel before the sample was wrapped and frozen. In some cases the samples were stored in a freezer for measurement at a later time. Two samples were taken from each of six plants per treatment. The two samples for each plant were averaged. Only means for each of the six plants per treatment were used for statistical analysis.

For the calculation of T_L, samples were collected as for π_L. However, intact discs from thawed leaves were placed directly in the sample chambers. The readings obtained were a combination of π_L and T_L. T_L was calculated by subtracting the π_L value (not adjusted) for that same leaf sample from this value. T_L itself was not considered a useful measurement other than it was a necessary step in order to derive P_L.

Turgor potential (P_L) was calculated using the equation:

$$P_L = \psi_L - (\pi_L + T_L)$$

Leaf resistance and transpiration

Data was recorded using a Li-cor 1600 steady state porometer. All measurements were taken between 12.00 pm and 1.00 pm on third and fourth leaves on each of three plants per treatment. Diurnal patterns were recorded after eight days (day 156) and fourteen days (day 162) into the stress period for SS and CC plants and on day 173 for CC plants.

VPD was calculated on each occasion from wet and dry bulb measurements made using a sling psychrometer. Measurements were taken whenever leaf water relations or porometry measurements were taken. This was usually around midday or slightly later.

Leaf folding

The diurnal trend in leaf folding in CC plants on day 173 was quantified by measuring the distance from one edge of the lamina to the opposite edge at a point midway along the leaf. This distance was expressed as a percentage of the full width of the leaf at that point. Measurements were taken from third and fourth leaves on each of three plants per treatment.

Statistical analysis

All data was analysed using the statistical software program *Statistix*. Two way or one way analysis of variance ($P < 0.05$) was used to determine the significance of treatment effects. Where means were significantly different, least significant differences were calculated by pair-wise comparisons of the means. Multiple linear regression was used to determine the relationship between leaf folding and environmental or other physiological parameters.

RESULTS

Dry matter production

Trends in dry weight for plant components are shown in figure 1 and for rhizome components in figure 2.

From figure 1 total dry weight of CC plants increased almost linearly but leaf and stem growth slowed after day 179. There was also a moderate slowing in the growth rates of roots and to a lesser extent, the seed-piece. Rhizome growth rate increased with time. At day 179 the plants had lost vigour and, the first order shoots in particular, were pale in appearance with necrotic leaf margins. By day 193 many of the previously dormant buds on the seed-piece had germinated with most up to 2 cm long but some up to 5 cm long with new roots.

Total dry weight of SS plants remained virtually unchanged over the four week treatment period (day 149 to 179). However, individual plant components changed in mass as assimilate was lost or redistributed. Plant components that suffered a decline in dry weight were the seed-piece followed by the leaf. In comparison with CC plants, SS plants produced

105% less total dry weight over the four week treatment period. In absolute terms CC plants produced 28 g in this period whereas SS plants lost approx 1 g. In comparison with CC plants SS plants produced 138% less seed-piece 113% less leaf, 97% less root, 95% less rhizome and 92% less stem over the four week period. Water deficit for 31 days (day 179) resulted in a slightly higher root:shoot ratio (see Table 2). At this time the seed-piece was quite wrinkled in appearance. At day 195 when rewatered SS plants were finally harvested, the first order shoots were pale in appearance with necrotic leaf margins. Many of the lower leaves were dead and some shoots, particularly the first order shoots, had lodged. The terminal leaves of some plants had failed to unfold.

SC plants virtually ceased growth during the two weeks water was withheld. After rewatering total dry weight increased at about the same rate as in CC plants. Leaf dry weight did not however respond well. Rhizome and stem resumed growth at a rate approximate to that of CC plants two weeks previously. Growth of the seed-piece and roots was however, more closely aligned with that of CC plants for the same period. These plant components appeared to enter a phase of increased sink strength from about day 164. This occurred in CC, CS and SC plants. In comparison with CC plants, SC plants produced 56% less total dry weight over the four week treatment period. This was comprised of 60% less leaf, 60% less root, 58% less rhizome, 55% less stem and 46% less seed-piece.

CS plants were the most severely affected in terms of dry matter production within the period water was withheld. Plants actually suffered a 11% decline in total dry weight in the two weeks water was withheld. The rhizome declined the most followed by the leaf and

stem. Late stress for two weeks was just as detrimental to rhizome dry weight as four weeks of stress initiated earlier. However, seed-piece and root dry weight continued to increase in CS plants over the two week stress period. In comparison with CC plants, CS plants produced 76% less total dry weight over the four week treatment period. This was comprised of 92% less leaf, 90% less rhizome, 64% less seed-piece, 63% less stem and 62% less root.

Leaf area data over the period day 149 to 195 is shown in table 2. Leaf area increased only marginally in CC plants after day 179. All stress treatments up to day 179 gave a similar decline in leaf area. The leaf area of rewatered SS plants was still significantly less than for CC plants.

The ratio of plant parts to that of roots is shown in table 3. The sink strength of the shoots and rhizome had decreased relative to the roots in SS plants at day 164. Water stress for longer periods or at different times resulted in decreased sink strength in the roots relative to the shoot.

Knob number and weight

The trend in knob number and weight is shown in figures 2E and 2F. Knob number increased almost linearly in CC plants but the growth rate of individual knobs, as indicated by mean knob weight, progressively slowed and had reached its maximum by about day 179.

Knob number continued to increase over the last two weeks in SS plants despite a substantial decline in mean knob weight. While SS plants and CS plants ended with rhizome

knobs of a similar mean weight. rhizome knobs of CS plants, because they initially increased, suffered the greatest actual decline in weight.

Rhizome knob weight exhibited a marked response to changes in water availability across all treatments.

Choice grade rhizome

Changes in choice rhizome and fibred rhizome dry weights are shown in figures 2A and 2B. In CC plants growth of choice rhizome was slowing during the observation period while that of fibred rhizome was increasing rapidly. Stress affected each rhizome portion differently. For instance, SS plants produced 44% less choice rhizome and 71% less fibred rhizome compared with CC plants. The changes in partitioning of assimilate to fibred or non-fibred portions of the rhizome can be seen more clearly in table 4. Here the increase or decrease in fibred and non-fibred rhizome dry weight is expressed as a percentage of the increase or decrease in total rhizome dry weight. This procedure of course ignores any change in the rate of fibre development that may occur. It assumes fibre development continues at the same rate and it is only changes in assimilate partitioning to the fibred or non-fibred portions that occurs. So while it is a simplistic way of examining the data it is nevertheless relevant in that it is changes in relative weight of fibred and non-fibred portions that are commercially important. As will be explained in the discussion, the relative partitioning of assimilate is probably the major determinant of percentage choice grade ginger.

From table 4, the fibred rhizome increased more in dry weight relative to the non-fibred portion in CC plants in the second two week period. Water deficit in the first two week period (day 149 to 164 in SS and SC plants) resulted in a larger percentage of rhizome assimilate going to the fibred portion. In SS plants this was reversed slightly in the second two week period with slightly more of the rhizome assimilate going to the non-fibred portion although the difference was quite small. Over the course of the four week period, both SC and SS treatments resulted in a proportionally greater percentage of rhizome assimilate going to the non-fibred portion relative to the fibred portion. The values for CS plants for the period day 164 to 179 represents a decline.

Changes in the percentage choice grade rhizome on a fresh and dry weight basis are shown in figures 2C and 2D. The percentage of choice rhizome (fresh weight) declined in CC plants from 40% at day 179 to 31% at day 195. These respective percentages are roughly equivalent to the commencement and cessation of early harvest in commercial fields. The decline in percentage choice rhizome occurred much slower in SS plants. This was attributed to a general lack of growth in the rhizomes.

In SC plants the percentage of choice rhizome remained virtually unchanged after water was applied indicating growth of fibred and choice rhizome portions resumed at about the same rate.

The percentage of choice rhizome actually increased in CS plants when water was withheld. As with SS plants, fresh weight of fibred rhizome declined more than that of choice rhizome when water became deficient. This response was more severe in CS plants than in SS plants.

There was no indication that fibre development was stimulated in SS, CS or SC plants.

Water Relations

Water potentials

Leaf water potential (ψ_L) and its components, osmotic (π_L), matric (T_L) and turgor potential (P_L) recorded at about midday at the end of the treatment period are shown in table 5a. Similar measurements, taken from CC and rewatered SS plants at day 193 are shown in table 5b.

From table 5a, two weeks of late stress (CS plants) was sufficient to reduce ψ_L to as low as did four weeks of stress initiated earlier (SS plants). CS plants also had a higher π_L than SS plants. SC plants recovered after two weeks of rewatering in all except P_L. π_L of stressed plants was similar to CC plants or, as in the case of CS plants, significantly higher. The adjusted π_L values differed little from that of CC plants and consequently there is no evidence of osmotic adjustment. P_L declined in all stressed plants but was lowest in CS plants. Despite being rewatered for two weeks, P_L of SC plants was still significantly lower than that of CC plants.

Table 5b shows that despite being rewatered for two weeks, SS plants still had a lower P_L compared to CC plants. SS plants were also observed to have many permanently folded leaves particularly on the first order shoots.

Root osmotic potential

Data for root osmotic potential (π_R) is shown in table 6.

From table 6, π_R decreased substantially with water deficit. In SS and CS plants π_R decreased within 14 days of water being withheld (days 163 and 179 respectively). π_R increased to normal in SS plants and SC plants after rewatering for two weeks (days 193 and 179 respectively).

Moisture Content of plant components

Significant differences between treatments in the moisture content of leaf, rhizome and seed-piece were not seen until day 179. At that time differences were seen in the leaf, rhizome and seed-piece. At day 179, SC plants had a seed piece moisture content 4% higher than CC plants. The moisture content of the rhizome and seed-piece of rewatered SS plants at day 195 was also higher (8%) than CC plants.

Leaf resistance and leaf relative water content

Figures 3A and 3B shows the midday stomatal response to water deficit over the period from 145 to 173 days after planting. Within [illegible] days of withholding water, midday leaf resistance (r_L) of SS plants had begun to increase and leaf transpiration (E_L) had begun to decline. Figure 3C shows the midday RWC_L trends over the period from day 148 to 193. Significant differences were not seen until day 17[illegible] After two weeks of rewatering RWC_L of SS pants was still lower than for CC plants. RWC_L of leaves of CC plants at midday declined from 96% on day 148 to 93% on day [illegible] The lowest RWC_L recorded over the treatment period was 86% for SS plants. Leaves of CS plants (not shown in figure 3C) declined to a similar RWC_L in two weeks as leaves for SS plants did in four weeks.

The diurnal trends in stomatal behaviour for CC and SS plants at day 156 and 162, eight and 16 days after water was withheld are shown in figures 4 and 5. The trend in RWC_L for SS and CC plants for the period from 6.00 am on day 162 to 6.00 pm on day 163 is shown in figure 5C.

From figure 4, r_L of SS plants decreased for a short period from 6.00 am to 8.00 am then increased but declined again from about 3.00 pm. E_t remained at a constant low level in SS plants throughout the day. From figure 5, r_L of SS plants increased from about 4.30 am to 8.30 am. Stomata remained fully closed in SS plants for the remainder of the diurnal period. RWC_L of SS plants was lower than CC plants at 7.00 am but remained constant over the day while that of CC plants declined. RWC_L of both treatments but particularly SS plants declined substantially overnight.

Additional plants, not part of the main experiment, were stressed until the lower leaves had senesced and the plants were near collapse and the lowest RWC_L recorded was 80%.

Leaf Folding

Leaf folding is a common response in irrigated field-grown ginger. In this study even CC plants displayed this behaviour in the hotter periods of the day. It was however more severe in water stressed plants and intensified as stress became more severe. SS plants were rewatered on day 180 but, after a further ten days of daily watering, still displayed permanent leaf folding in some shoots despite a rise in RWC close to that of CC plants.

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The diurnal trend in leaf folding, r_L, E_L and leaf temperature in CC plants and various other environmental parameters was recorded on day 173 and is shown in figure 6. The degree of leaf folding increased quickly up to about midday before declining.

There was a highly significant correlation ($R^2 < 0.88$; $P < 0.01$) between leaf width and E_L. The fitted equation was:

Leaf width = 100.9 - (.54 +/- 0.534) x E_L

Leaf folding also showed a close relationship with light levels and leaf temperature. It was explained by the regression:

Leaf width = 156.9 - (.7 (+/- 0.722) x leaf temperature - 0.026 (+/- 0.09) x light

($R^2 < 0.88$; $P < 0.01$)

It is also worth noting from figure 6 that r_L momentarily ceased rising while leaves folded to their maximum.

DISCUSSION

Dry matter productio

Generally speaking t treatments were probably too se re to induce subtle changes in assimilate partitioning . o, insufficient plants ere av ble to observe the ong-term effects of water deficit Nevertheless, some important observations were made.

At the time treatm were imposed (weeks 2 to 25) the centre of sink strength was changing from the ab -ground components to the below-ground components. This same general trend was sho by Whiley (1980 in weeks 29 to 32 in field grown ginger. The seed-piece gained cons able dry weight particularly in the period from day 164 to day 179. This was the period o mum increase in total dry weig nd it be reasonable to assume it was excess assimilat at was stored in the seed-piece. However the seed-piece continued to increase in dry wei after day 179 when most other plant components slowed in growth indicating competition assimilate. The seed-piece was therefore not just a storage site for excess assimilate but a sink in its own right. Dewen e al. (1987), using labelled CO_2, also found that assimi was moved both in and out of the eed-piece. In this study, root growth followed the s trend as seed-piece growt

Because CS plants e the greatest actual dec ine in t l dry weight during the period water was withheld it be considered the most severe treatment followed by SS and SC treatments. SS plants a smaller leaf area and r system than CS plants whe water was withheld and as a con ce, SS plants could be expected to have depleted the soil water slower than CS plants The water deficit imposed on SS plants was therefore more gradual

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than the sudden and more severe deficit experienced by CS plants. Stress earlier (SC) was less detrimental than stress later (CS) due to the smaller leaf area. This response was also seen in cassava by Bal et al.(1989).

Under conditions of gradual water deficit, as in SS plants, assimilate was withdrawn from the seed-piece yet the change in dry weight of other plant components was negligible. When soil water was depleted quickly as in CS plants, the rhizome suffered the greatest decline in dry weight while the seed-piece and roots continued to increase in dry weight. This increase in seed-piece and root dry weight was also seen in CC plants so may not have been a response to water deficit. The fact that it occurred despite severe water deficit is of interest. CS plants had a substantially lower π_R compared with CC plants but a similar seed-piece moisture content. In itself is not conclusive but it suggests there may have been some osmotic adjustment by the roots and seed-piece to maintain their water content and hence growth.

Another interesting response was seen in SS plants during their first two weeks of water deficit. During this period of relatively mild water deficit, knob number continued to increase despite mean knob weight decreasing. Because rhizome weight remained unchanged over this period, assimilate must have been taken from existing knobs to continue initiation of new knobs. Bartels (1987) reports that prolonged water stress at tuber setting in potato decreased average tuber weight but increased the number of tubers per plant slightly. The production of new knobs at the finger would initially appear a wasteful strategy. However, each new knob is a new growing point which is potentially a new shoot. An increase in knobs

therefore represents a increase in growth potential. At an esoteric level it could be compared with osmotic adjustment in grain sorghum which increases grain number or enables completion of grain development.

Also, gradual water stress as seen in SS plants up to day 164, results in a slight greater root:shoot ratio.

Choice grade rhizome

The rate of decline in percentage choice grade rhizome was determined more by the relative rate of deposition or removal of assimilate into or from fibred or choice rhizome portions rather than the rate of fibre development. When water was withheld assimilate deposition in the fibred rhizome was slowed or reversed more than that for choice rhizome, hence the rate of decline in percentage choice rhizome was slowed. In the case of SS plants rhizome growth stopped in the period from day 164 to day 179 and the decline in percentage choice grade rhizome also stopped. Although fibre development did not proceed independently of rhizome growth. Beyond this generalization, the direct effect of water stress on the actual development of fibre cells was not further quantified in this study.

It appears that there was a close relationship between increase in mean knob weight and the rate of decline in percentage choice rhizome during the phenological period investigated. The majority of assimilate translocated into rhizome knobs must therefore have been into the fibred portions thus increasing the weight of this portion relative to the non-fibred portion.

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Water relations

The lowest ψ_L of abo[illegible] MPa was recorded after four weeks of water deficit. This is a comparatively high [illegible] when compared with wha[illegible] has been recorded in other plants subject to water deficit. Fuku[illegible] nd Inthapan (1988), in a study of the response of various plants to water deficit, recorded [illegible]lues of -4.0 MPa in ri[illegible] -2.0 MPa in sorghum and [illegible] MPa in maize. Tengpremsri [illegible] (1991) recorded ψ_L va[illegible]es of -1.9 to -2.7 MPa in cultivars of sorghum subject to wa[illegible] deficit. Wilson et al. (19[illegible]) recorded minimum ψ_L values of -1.3 to -4.4 MPa in four s[illegible]es of tropical pasture gras[illegible] The highest midday ψ_L value recorded here in fully watered [illegible]ger plants was about -0.[illegible] MPa. This suggests mechanisms were operating in the ginge[illegible]ant to prevent large changes in ψ_L. This is another example of a drought tolerance mec[illegible]sm through maintenance [illegible] a high water potential.

As mentioned earlier [illegible]re was no evidence of osmotic adjustment in leaves. In fact, the π_L values actually increas[illegible] The CS treatment was probably the most severe in terms of plant response and yet it pr[illegible]ced the highest π_L. CS plants suffered the greatest decline in dry weight and in particul[illegible] of dry weight. Substantial quantities of assimilate had therefore been removed from t[illegible] leaves of CS plants thus resulting in an increase in π_L. A similar relationship was sho[illegible] by Tangpremsri et al. (199[illegible] in sorghum where osmotic adjustment was negatively correl[illegible] with grain number. That is, when there were many grain, the demand for assimil[illegible] was greater and there was therefore less available for maint[illegible]nce of a low π_L.

The P_L value for ... ...ed SS plants suggest ...at ginger may not recove... ...ell from prolonged water defic... This low P_L, despite two weeks of watering, arose from slightly higher π_L and T_L (... ...ficant). A low P_L sug...sts a low potential for leaf expansion. Begg and Turner (... ...dicate that growth in s...nflower and maize was sho... to cease when P_L declined to ... ...8 MPa. It is consiste... that these plants made only small gains in leaf area and leaf d... ...ght after rewatering. ... plants also had a low P_L ... because their RWC_L was si... ...C plants, it is more lik... their lower P_L was an accu...lation of error from adding ... ... and subtracting it from ...

Leaf relative water ...

The lowest midd... ... recorded in fully wa...ed plants was 92%. Gene...y it was between 97 and 92 ... are reasonably high ...ues and indicates a good ...trol over water loss. RWC_L ... ...ed throughout the day b... not to any great extent. ... day 162 (figure 5) RWC_L decli... from 99% at dawn to ab... 95% by 3.00 pm. Haque ... (74) also found RWC_L of gin... ...ated little throughout t... day. He recorded a decline ...m 98% at 8.00 am to 95% ... ...m which is consistent w... this data.

The closely relate... ...also has a high degree ... control over RWC_L. Turne... ...d Lahav (1983) recorded a ... ... 94 to 96% in bananas grown at a similar VPD as ... in this experiment.

The decline in RW... ...S plants was surprisingly slow and it was not until 3... ...ys after water was withhel... ...day RWC_L dec...ed to ...ow that of CC plants. H... ...e (1974)

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also studied the resp[illegible] of RWC_L in ginger to [illegible]ater deficit and in contras[illegible] results presented here, found [illegible]WC_L declined quickly dur[illegible] only 11 days of water deficit. The main difference be[illegible]n this study and this one w[illegible] that the measured RWC_L [illegible]8.00 am whereas in this stud[illegible]00 pm was used. Diurnal [illegible]WC_L data gathered on day [illegible]2 (figure 5) helps explain thi[illegible]d [illegible]rence. At 6.00 am there [illegible]as a large difference in RW[illegible] between CC and SS plants s[illegible]r to that seen by Hoque. [illegible]owever, by 12.00 pm the R[illegible]$_L$ of CC plants had declined [illegible]milar value as that of SS [illegible]lants. By measuring RWC_L [illegible] midday, no difference was see[illegible] day 178 but it appears [illegible]differences were present at [illegible]n much sooner after water w[illegible]held.

The diurnal trend [illegible]n figure 5 also sugge[illegible]hat [illegible]ater deficient ginge[illegible]lants can control water loss reas[illegible]bly well throughout the da[illegible] but in this instance suffered [illegible]decline in RWC_L overnight. Th[illegible]s[illegible]ct was not investigated [illegible]t it could be a consequenc[illegible] the fact that these plants w[illegible]e in a glasshouse wher[illegible]heated dry air was blown [illegible] night. Irrespective of this [illegible]ality, the data presented i[illegible]licates a considerable degre[illegible] control by the plant over wat[illegible]s and is another exampl[illegible] of thi[illegible] plant's ability to to[illegible]e water deficit. It also foll[illegible]s [illegible] midday RWC_L is not a g[illegible]d measure of water stress i[illegible]nger.

Moisture content of [illegible]components

It is tempting to s[illegible]e rhizome or seed-piec[illegible] may b[illegible] a source of water [illegible] the plant during times of soil [illegible]ficit. This strategy ex[illegible] in m[illegible]y plants where eit[illegible]he tuber or succulent fruit [illegible] substantial buffer to water d[illegible]t to the leaf (Milthorpe a[illegible] Moorby, 1988). This was n[illegible]e[illegible]er the case in ginger. [illegible]fact, CS and SS plants h[illegible] slightly

higher rhizome moist[illegible]ontent, and in SS plant[illegible] a higher seed-piece moist[illegible] content compared to CC pl[illegible] [illegible] 16 and 30 days [illegible] wat[illegible] deficit respectively. This [illegible]icates an increased ability for [illegible]se plants to store water [illegible]he rhizome and seed-piece. Also, in both rewatered SC an[illegible]S plants the rhizome and [illegible]d-piece had a higher mois[illegible] content than CC plants. Th[illegible]gests π of the rhizome [illegible]d seed-piece of stressed p[illegible]s before rewatering was low[illegible]e cell water volume in co[illegible]parison with CC plants. W[illegible]e π was not recorded for the [illegible]or seed-piece [illegible]as l[illegible]he fleshy roots. π_R of SS [illegible]nts was substantially lower [illegible]n CC plants. Also, th[illegible] fact that the moisture co[illegible]t of the rhizome and seed-pi[illegible] [illegible]ressed plants do[illegible]s not [illegible]cline below that of fully w[illegible]d plants suggests stressed pla[illegible] [illegible] have a regulatory mech[illegible]nism t[illegible] maintain water con[illegible] in these plant components. W[illegible] conclusive data is not p[illegible]sented here it is likely so[illegible] osmotic adjustment may be [illegible]g in the roots, rhizo[illegible] or seed-piece to enhance[illegible]l water extraction and retent[illegible] Osmotic adjustment in ro[illegible]s as a response to water d[illegible] it is not unknown. Turner [illegible] eports respons[illegible]n b[illegible]pea and maize plants. [illegible] ginger rhizome is composed [illegible]rally of starch (Pomlins[illegible], 196[illegible]). In field grown g[illegible]er about 150 days old, starch [illegible] only about 24% of rhiz[illegible]e dry weight. This increa[illegible] to about 43% at full maturit[illegible] [illegible]mbai et al. 19[illegible] Pr[illegible] 19[illegible]). According to V[illegible]ia et al. (1961), water defici[illegible] accelerate the conversio[illegible] of starch to sugars. Sugar[illegible] known to be a major osmoti[illegible]ponent of cell sap in mes[illegible]ytic plants (Morgan, 199[illegible] and hence their production was [illegible]nsistent with a decrease [illegible] π_R. Paull et al. (1988), i[illegible] study on compositional chang[illegible] ginger rhizomes f[illegible] a thr[illegible] starch content doubled [illegible] a seven month period wet the [illegible]ntent stayed co[illegible]nt.

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π_R of CS and SS pl[illegible] t day 179 was lower than [illegible]eir ψ_l especially in CS plants. Diurnal E_L in SS plants was [illegible]ril at this time [illegible] do[illegible]ced [illegible]ovement of water driven by a low π in the roots. a[illegible]s bly the rhizome and se[illegible]piece may have been initiated around this time. The retent[illegible] water in the rhizome a[illegible] seed-piece in preference to the shoot would constitute a [illegible]n survival mec[illegible]anism [illegible]damentally different to the tolerance mechanisms discussed [illegible]his point.

So, while the rhizom[illegible]d seed-piece do not act as [illegible]ater supply organs to buffer against and avoid stress, they may [illegible]en as water stor[illegible]g org[illegible] in a plant survival sense, when stress becomes very severe, [illegible]s to say water may be [illegible]nted to these organs when plants are close to death. When [illegible]ater availability improv[illegible] new shoots can then sprout from the rhizome or seed-piece [illegible] response was [illegible]bserve[illegible] six additional ginger plants, not part of the main experi[illegible] subject to water stre[illegible]ove[illegible] six weeks then rewatered. Comprehensive data w[illegible] collected on these plan[illegible] but new shoots were observed to arise principally from the e[illegible] seasons rhizome after [illegible]watering. This response also suggests that water deficit may [illegible] increased the ontogeny [illegible] these new seasons buds which would normally not commen[illegible]ith until the fol[illegible]g s[illegible].

It is possible that th[illegible] also a strong r[illegible]pres[illegible] wh[illegible]h enables temporary storage of water in the intercell[illegible]s[illegible]s, the leaf [illegible]he [illegible] RWC$_L$ (>100%, recorded on leaves with a water-so[illegible]ppearance suggest[illegible]this[illegible]y be the case. This phenomena is also seen in banana, and [illegible]crop is attribute[illegible] low PL[illegible]d a lower π_R compared to ψ of the surrounding soil[illegible]t crop, this resul[illegible] in [illegible]posi[illegible]e root pressure and temporary

storage of water in t intercellular spaces (D.T ner, personal communication). Root pressure is a well-kn phenomena in plants a frequently reaches -0.1 to -0.2 MPa (Slatyer, 1967). Salis nd Ross (1978) attribut oot pressure to active ion uptake from the soil to the apoplas ati the root stele such t thei is a buildup in concentration of solutes in the root apo greater level in surrounding soil. Storage of water in the intercellular spac is likely to be effective and significant in humid, low light environments. Haque 9?4) found that ginger g wn under shade maintained a higher RWC_L.

Leaf resistance

A stomatal response recorded as earl as tw six days after water was withheld. Also, r_L in SS plants r higher than tha for CC ants about 25 days before a difference in RWC_L was record There are two important thing sing from these observations. Firstly, the ginger plan very good stomatal cont and no doubt this is one of its drought tolerance mechanisms ondly, stomata appear be responding to signals in the water deficient plant other ast RWC although it expected there would be a strong association. Haque ( ) found increased shar once RWC_L, both measured at 8.00 am, declined to below . This is not inconsist with data presented in figure 5A and 5C. This response to does not however expl the ntinued rise in r_L throughout the day when RWC_L rema sistant.

In this study, change were measured in SS as well before changes in RWC_L were detected and it m stomata were ons at least initially anyway, to signals

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originating in the roots. Response to root signals is [illegible] suspected in banana but has not been demonstrated beyond doubt (Brun, 1965).

Leaf folding

Leaf folding is a common drought tolerance mechanism in many crops including the closely related banana. In banana, leaf folding is controlled by a band of pulvinar cells along either side of the midrib (Mi[illegible]n et al. 1989). Turner and Lahav (1983) associated leaf folding in banana with RWC at all times except under cool conditions (17^{o}C) where leaves folded despite high RWC. They also found folding was more pronounced on sunny days.

Leaf folding in ginger was closely associated with radiation and leaf temperature. It is not possible to say from the collected data whether the leaf was responding directly to light or other associated factors such as temperature. All these factors are interdependent on each other. Also, data on leaf RWC was not collected but no doubt there is a close relationship. The close relationship shown between leaf width and E_r indicates this may be the case, being that it is reasonable to expect that RWC may decline as E_r increases.

It is important to note that leaf folding can occur independently of stomatal response so they must therefore either have different levels of sensitivity or be influenced by a different set of stimuli.

A similar behaviour of leaf rolling is seen in rice which has been associated with ψ_L (Fukai and Inthapan, 1988). [illegible] their study, leaf rolling did not

commence until the w[illegible]as at least -2.0 MPa. Le[illegible]ld [illegible] in ginger appears to be much more sensitive than in e[illegible] it appears to take p[illegible]wer before any major water deficit occurs. The minimu[illegible]t day ψ[illegible] record[illegible]d [illegible]w[illegible]d [illegible]nger plants was -0.9 MPa. It should not therefore be [illegible]s a form of w[illegible]ng o[illegible]or turgor, which is a sign of stress, but rather a sensitive [illegible]chanism to avoid excess water loss, and possibly to a lesser extent, to allow photos[illegible]s to proceed under [illegible]ural circumstances.

CONCLUSION

Water deficit cons[illegible]ces reduced rhizome yi[illegible]. This was the result of the plant developing a high r[illegible]t and likely a low rate of pi[illegible]synthesis.

The decrease in perce[illegible]g choice grade rhizome [illegible]owed or reversed by water deficit. This occurred in seve[illegible]ressed plants because [illegible]hizome stopped growing, but in the case of more mild def[illegible]assimilate was withdraw[illegible]from the fibred rather than non-fibred portion, thus inc[illegible]sing the percentage choice[illegible]ue rhizome.

The various respons[illegible]water deficit identified [illegible]dy indicate ginger avoids water stress by maintaining [illegible]. Strategies to do t[illegible]clude very responsive stomata, leaf folding and possibly s[illegible]to root signal[illegible]and o[illegible]djustment in roots. During water deficit, assimilates i[illegible]withdraw[illegible]from the l[illegible]ster and rhizome but the seed-piece and roots continue g[illegible]

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Ginger does not pos[illegible] mechanisms to c[illegible]ntinue [illegible] growth under soil water deficit but rather it ceases growth [illegible]ce conserves water.

While osmotic adjus[illegible]t in the roots was not pr[illegible]s[illegible]eral factors point to its possibly existence. Firstly the [illegible]s of water deficien[illegible] plants [illegible]ve a [illegible]onsiderably lower π_R. Also, the same plants exhibited [illegible]gnificantly highe[illegible] root shoot [illegible]a[illegible] knob number increased despite rhizome weight declin[illegible]. In addition, the [illegible]ncentrat[illegible]ion of the rhizome of water deficient plants was similar to w[illegible]ell plants during s[illegible]tress bu[illegible]ghe[illegible] after rewatering. It may be that adjustment occurs by [illegible]onversion of starch to s[illegible]ugar[illegible]ing that starch is the principal component of the rhizo[illegible].

Investigation of tec[illegible]ue to s[illegible]ow the [illegible]epositi[illegible] of assimilate into the fibred portions relative to the non-fi[illegible]portions of the [illegible]rhizome [illegible]ear[illegible] harvest time may offer some potential for temporar[illegible]s[illegible]wing the decline in p[illegible]ra[illegible] choice grade rhizome. Partial topping of plants at e[illegible] harvest may be one such [illegible]chnique. This could be expected to reduce the rhizome gr[illegible]rate but because of the [illegible]prices paid for choice grade rhizome, it may still be an econ[illegible] proposition worthy of in[illegible]ga[illegible]n.

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I would like to ackn[illegible]e the guidance readily [illegible]ed by my supervisor Dr Shu Fukai throughout this study [illegible] wide [illegible]ranc[illegible] and [illegible]ible patience made it both an intellectually rewardi[illegible] enjoy[illegible] exp[illegible]ience [illegible] also like to thank A.W.Whiley

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Table 1. Schedule of treatment watering regimes

Treatment	Water relations
No stress(CC)	Watered
4 week stress(SS)	Water from day 149 to 179 Watered from day 179 to 193)
Early 2 week stress(SC)	Water from day 149 to 164
Late 2 week stress(CS)	Water from day 164 to 179

Table 2. Mean leaf area per plant (cm^2) on days 149, 164, 179 and 195 after planting.

Day (after planting)	Leaf area (cm^2)				LSD (P=0.05)
	CC	SS	CS	SC	
149	1487				
164	2359	1745			571
179	2930	1581	19	2053	717
195	3001	1917			978

Table 3. Dry weight ratios for each plant component in days 149, 164, 179 and 195 after planting. All plant components are expressed in relation to roots which is expressed as 1.0.

Treatment	Day	Root:Shoot	Rhizome:S[illegible]	ce Ratio
CC	149	1	[illegible]	2.5
	164	1	[illegible]	2.1
	179	1	[illegible]	1.7
	195	1	[illegible]	1.6
SS	164	1	[illegible]	2.2
	179	1	[illegible]	1.7
	195	1	[illegible]	2.3
CS	179	1	[illegible]	2
SC	[illegible]	1	[illegible]	2.1

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Table 4. Percentage of dry weight change in total rhizome partitioned to fibred and choice portions. Values for fibred and choice rhizome for each treatment in each period should add to 100%. The arrows indicate if the change represents an increase or decrease.

Treatment	Rhizome portion	Period (days)		
		49 - 164	64 - 179	149 - 179
CC	Fibred	72	79	76
	Choice	28	21	24
	Total rhizome change (g)	3.6	4.7	8.3
SS	Fibred	94	0	62
	Choice	6	0	38
	Total rhizome change (g)	0.5	0.0	0.5
CS	Fibred		79	50
	Choice		21	50
	Total rhizome change (g)		2.8	0.8
SC	Fibred		70	71
	Choice		30	29
	Total rhizome change (g)		3	3.5

Table 5a. Midday leaf potentials (MPa) a[t] day 179 [of] treatment period). SS plants had been stressed for four weeks. CS p[lan]nts had [been] stressed for two weeks and SC plants had been s[tr]essed for two weeks th[en] rewater[ed] for two weeks.

Treatment	Water potential	Osmo[tic] poten[tial]	Matric potential	Turgor potential
Fully watered (C[W])	-0.[0]1[b]	-1.2[ ]	-0.[ ]3[a]	0.98[a]
4 week stress (SS)	-1.[ ]3[a]	-[ ].26[a](-	-0.[ ]9[a]	0.35[b]
Early 2 week str[e]ss(SC)	-0.[ ]5[b]	-[ ].33[a](-	-0.[ ]9[a]	0.64[b]
Late 2 week stre[s]s(CS)	-1.[ ]4[a]	-0.89[b](-	-0.[ ]4[a]	0.08[c]
LSD ($P<0.05$)		-0.[ ]	NS (-0.24)	0.27

Table 5b. Leaf w[at]er potentials (MPa) a[t] [d]ay 193. [Plants] had [been] r[e]watered for two weeks.

Treatment	Water [p]otential	[O]smotic [p]otential	Matric potential	Turgor potential
Fully watered (C[W])	-0.[ ]1[a]	-1.[ ]1[a]	-0.44	1.05[a]
4 week stress-rewatered (SS)	-0.[ ]4[a]	-1.[ ]2[a] (-1.[ ]4)	-0.28	0.64[b]
LSD ($P<0.05$)	NS (-0.[ ]7)		NS (-0.2[ ])	0.38

Values with a different letter are significantly d[if]ferent ($P<0.05$). Values for each treatment may not fit exactly the equation $\psi_L = \pi_L + P_L$. A greater number of samples were used to generate the values for π_L, T_L and ψ_L. The adjusted π_L value for SS plants (adjusted for RWC) is shown in brackets

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Table 6. Osmotic potential of roots (MP. Day 16 sented two weeks of stress for SS plants. Day 179 represente four we s of stre S plant tw weeks of stress for SC plants and two weeks of ewaterin in SC pl day 193, S plants had been rewatered for two weeks.

Treatment	Day 16	79	Day 193
Fully tered(C	.8		-0.86[a]
4 week stress(SS	1		-0.84[a]
Early 2 week stress(SC)			
Late 2 week stress(CS)			
LSD (P<0.05)	.14		NS (-0.31)

Values with a diff rent letter are gni ican different 5).

Plant Part	Treatment	Days fr[illegible]nting			
		14[illegible]	164	[illegible]79	195
Stem	CC		93[illegible]	[illegible]1[a]	91[illegible]
	SS		92[illegible]	[illegible]2[a]	87[illegible]
	CS			[illegible]2[a]	
	SC			[illegible]1[a]	
Leaf	CC		84[illegible]	[illegible][ab]	81[illegible]
	SS		83[a]	[illegible][b]	79[b]
	CS			[illegible][a]	
	SC			[illegible][ab]	
Rhizome	CC	95	95[illegible]	[illegible]3[b]	93[b]
	SS		95[illegible]	[illegible]3[a]	94[illegible]
	CS			[illegible][a]	
	SC			[illegible][ab]	
Seed piece	CC	9[illegible]	90[illegible]	[illegible]4[b]	84[b]
	SS		89[a]	[illegible][ab]	92[illegible]
	CS			[illegible][ab]	
	SC			[illegible][a]	

Dat[illegible] table 7 [illegible] as derived fr[illegible] fr[illegible]sh [illegible]ht [illegible]nd [illegible] [illegible]t data. [illegible]g[illegible]ificantly different values ($P < 0.05$) [illegible]re represented [illegible]ith [illegible] d[illegible]ent letter

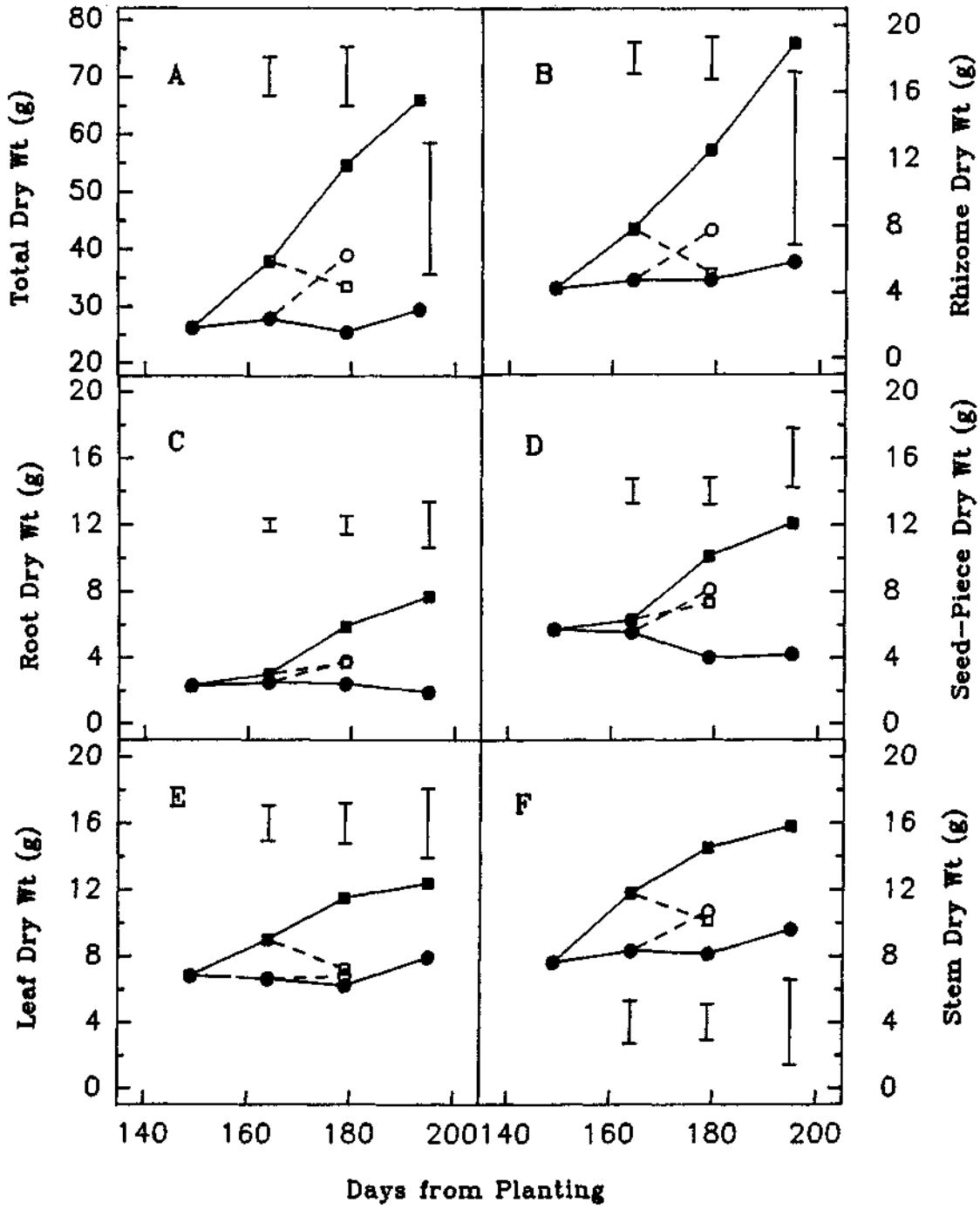

Figure 1. Trends in total (A), rhizome (B), root (C), seed-piece (D), leaf (E) and stem (F) dry weights over the period from 148 to 193 days after planting. Data is shown for CC plants (■), SS plants (●), CS plants (□) and SC plants (○). SS plants were rewatered late on day 179. LSD bars are shown ($P<0.05$).

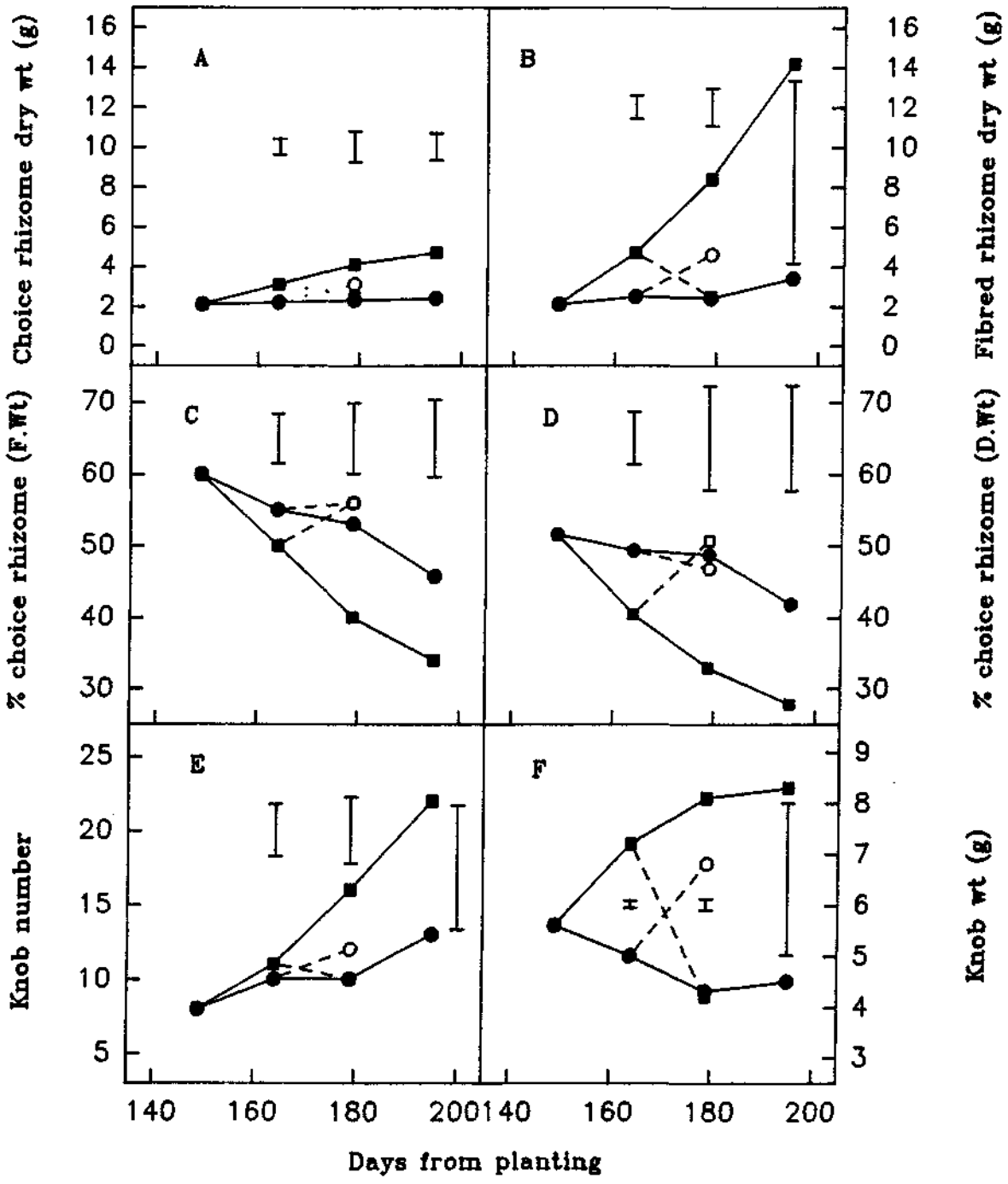

Figure 2. Trends in choice rhizome dry weight (A), fibred rhizome dry weight (B), % choice rhizome on a fresh weight basis (C), % choice rhizome on a dry weight basis (D), knob number (E) and knob weight (F) over the period from 148 to 193 days after planting. CC plants (■), SS plants (●), CS plants (□) and SC plants (○) are shown. SS plants were rewatered late on day 179. LSD bars are shown ($P<0.05$).

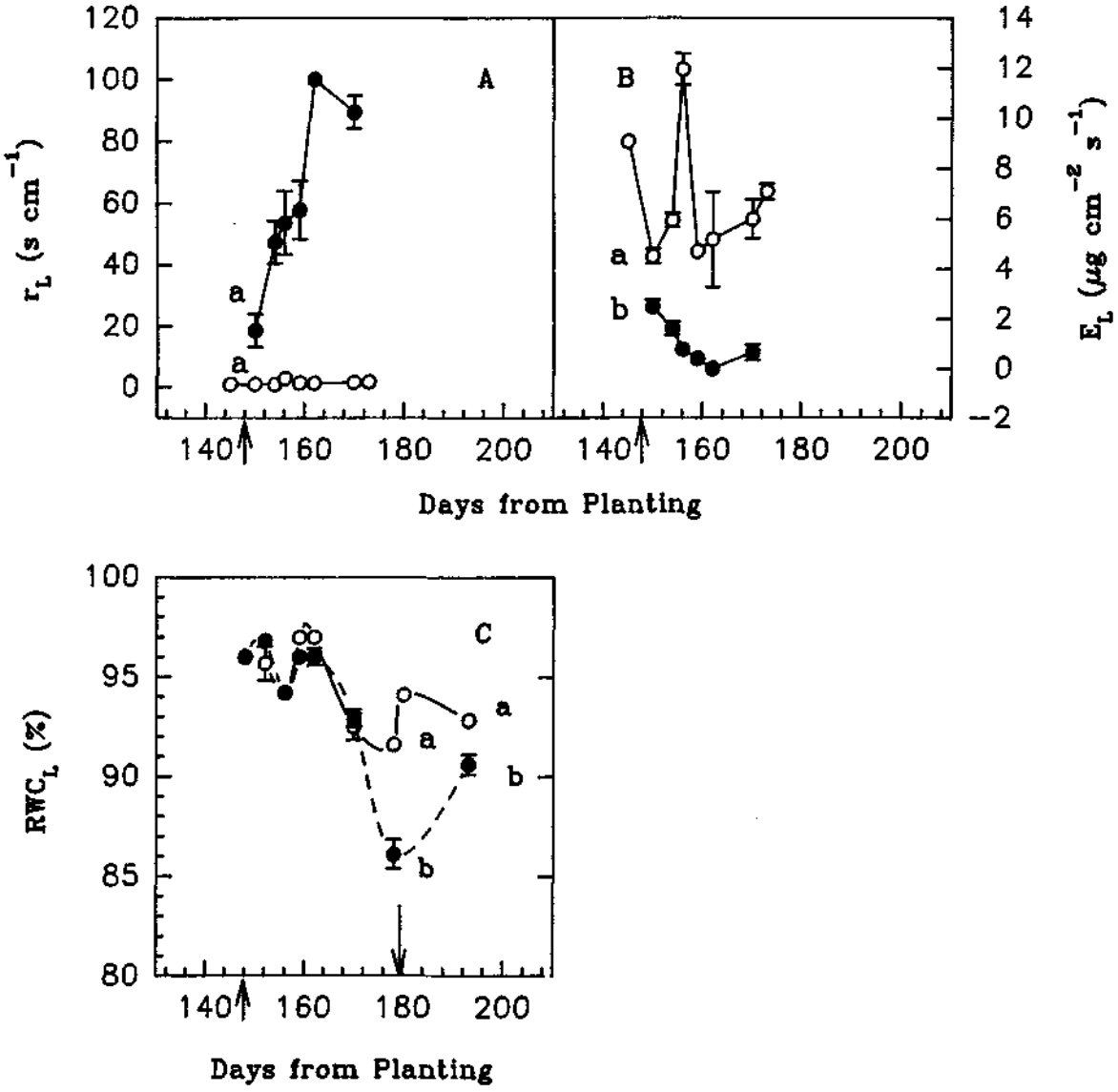

Figure 3. Trends in leaf resistamce (r_L) are shown in graph A, leaf transpiration (E_L) in graph B and leaf relative water content % (RWC_L) in graph C for the period from 142 to 193 days after planting for CC plants (o) and SS plants (●). Standard error bars are shown ($P<0.05$). Different letters indicate significant differences for selected data points. Upward arrows indicate day of last watering in SS plants. Downward arrows indicate day of rewatering in SS plants.

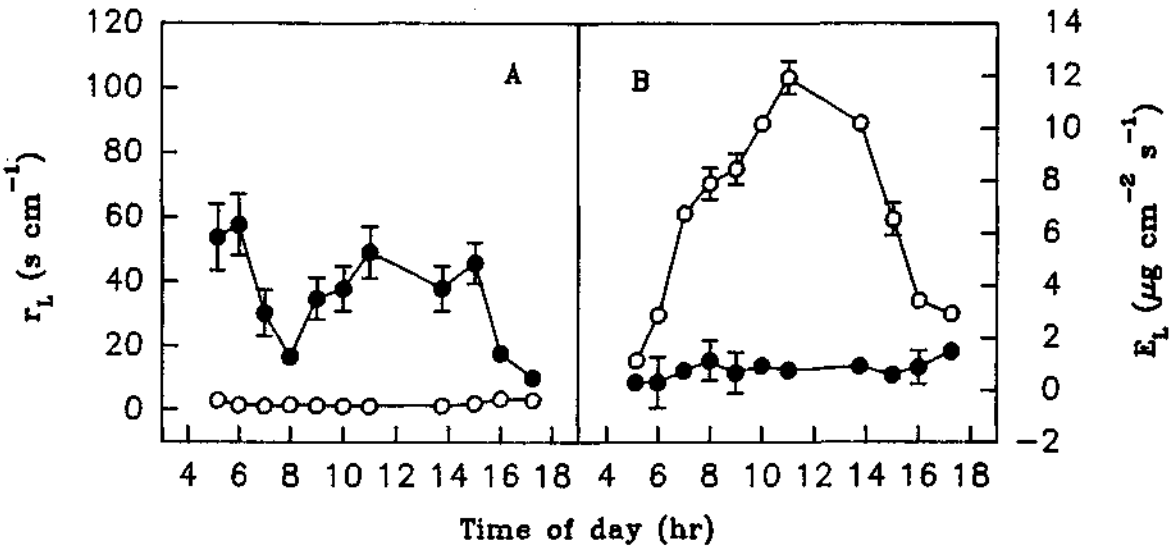

Figure 4. Trends in leaf resistance (r_L) are shown in graph A, and leaf transpiration (E_L)in graph B for CC plants (o) and SS plants (●) 156 days after planting. Standard error bars are shown ($P<0.05$).

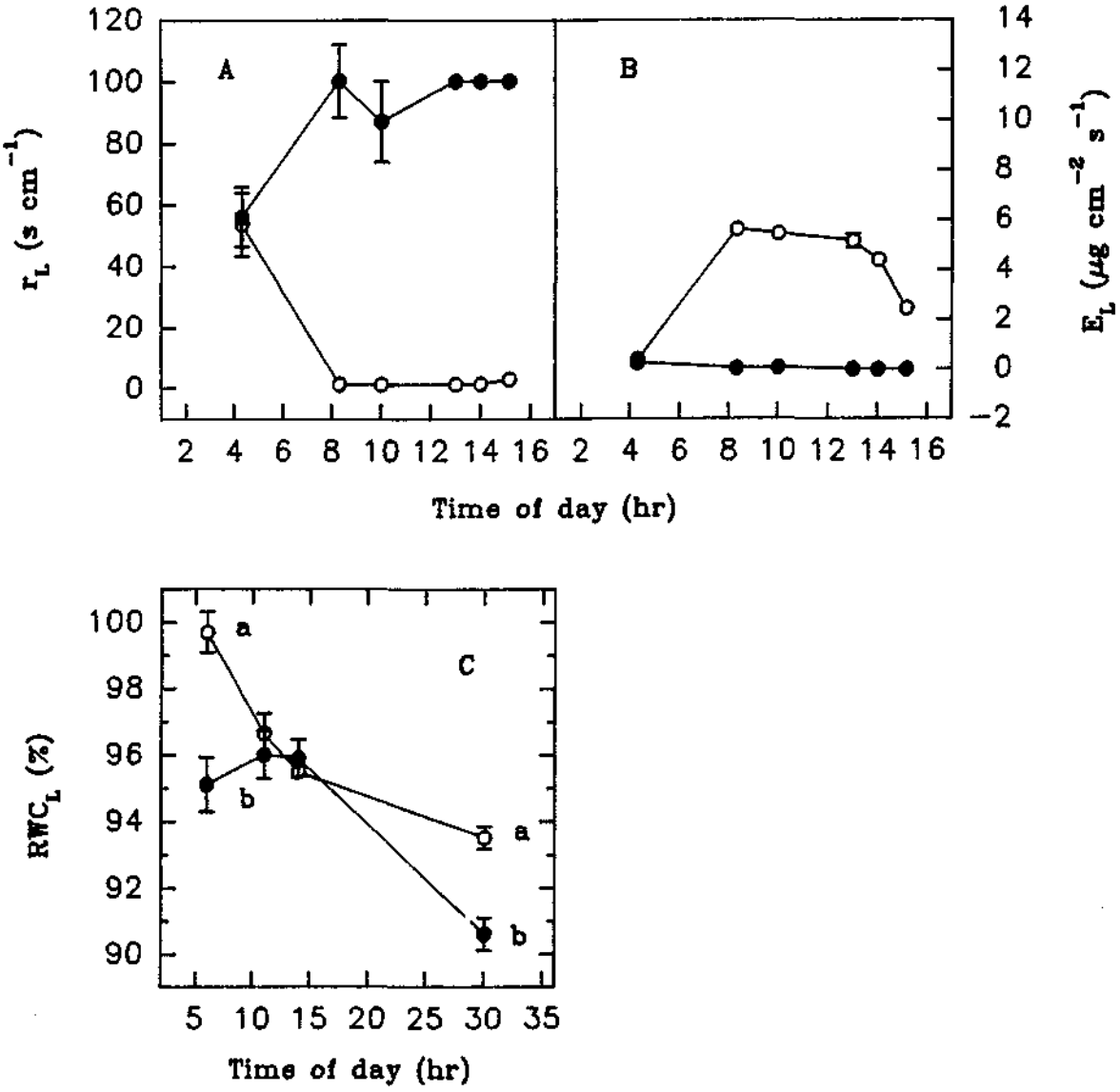

Figure 5. Diurnal trends in leaf resistance (r_L) is shown in graph A, leaf transpiration (E_L) is shown in graph B and leaf relative water content % (RWC_L) is shown in graph C for CC plants (o) and SS plants (●) 162 days after planting. Standard error bars are shown ($P<0.05$). Different letters indicate significant differences for selected data points.

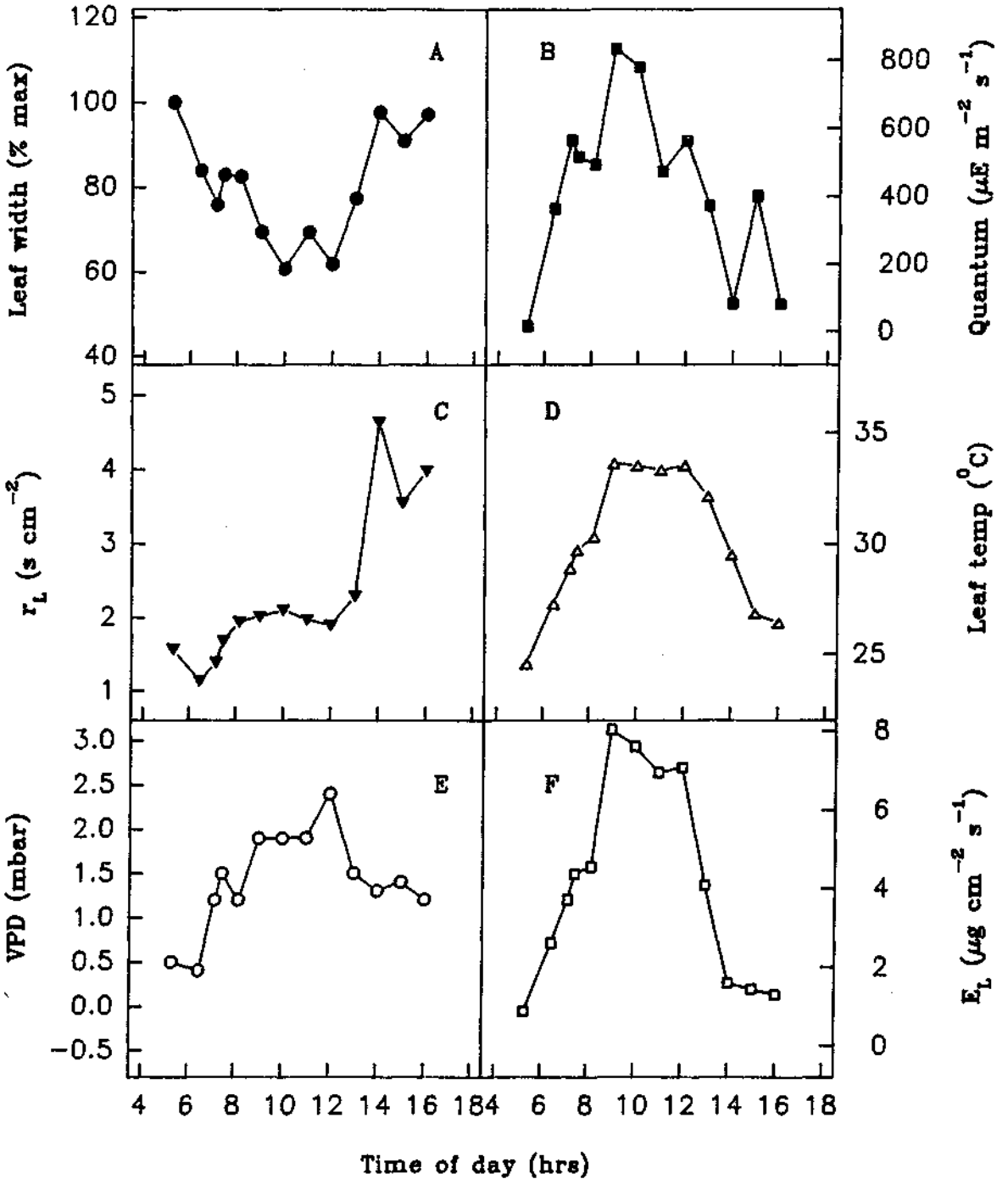

Figure 6. Trends in leaf width (folding) are shown in graph A, quantum levels in graph B, leaf resistance (r_L) in graph C, leaf temperature in graph D, VPD in graph E and leaf transpiration (E_L) in graph F in CC plants on day 173.