GROWTH AND DEVELOPMENT OF ONIONS IN A SUBTROPICAL ENVIRONMENT

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GROWTH AND DEVELOPMENT OF ONIONS IN A SUBTROPICAL ENVIRONMENT

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DECLARATION OF ORIGINALITY

This thesis reports the original work of the author, except where otherwise acknowledged and is presented to the best of the author's knowledge and belief. It has not been submitted previously, in part or in whole, for a degree at this or any other University.

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Alan Andrew Duff

Signature Redacted

DEDICATION

I dedicate this work to my wife Helen for her love, understanding and patience. Her support has enabled me to achieve this goal.

I also dedicate this work to my parents Andrew (Andy) Adams Wilson Duff and Jean Polson Duff who emigrated to Australia with their five children in tow in 1971. Their courage to embark on such an endeavour enabled myself and my brothers and sister to aspire to greater things in life, in particular a higher education. I am grateful to them for their support and encouragement.

ABSTRACT

Australia currently produces 210 000 tonnes of onions annually. The major production areas are in southern Australia where the predominant onion type is adapted to an intermediate long daylength. Queensland's annual production is stable at 10% (20 000 to 25 000 tonnes) of the national production. Ninety percent of the Queensland crop is grown in southern Queensland (Lockyer Valley and the Darling Downs). Small production areas can be found in central and tropical north Queensland. Consequently, onions in Queensland are grown under a predominantly subtropical environment. Crops are sown from late February to late June. An extensive range of cultivars is required to meet the changing environmental conditions that occur during this time period in order to achieve maximum economic crop yield. In the past, incorrect cultivar selection has resulted in high levels of doubling and bolting with a corresponding reduction in economic yield. This study conducted at Gatton Research Station in the Lockyer Valley investigated the growth and development of several cultivars currently available to growers in Queensland.

The effects of time of sowing on yield, doubling and bolting for several cultivars were investigated. The marketable yield within cultivars varied as a result of time of sowing. Onions sown early in the season (February, March and April) produced predominantly No. 1 Large Grade bulbs (> 70 mm diameter). As the sowing date progressed into the cooler winter days (May, June and July) the bulbs produced decreased in size with greater numbers of picklers (<40 mm) and No. 1 Grade bulbs (40-70 mm) than that recorded for the earlier sowings. It was determined that the decrease in bulb size can be attributed to a decrease in average daily temperatures as the sowing date progressed.

The bolt tolerant, open-pollinated cultivar Golden Brown was investigated in depth. Golden Brown has been developed over a number of decades by Lockyer Valley seedsmen. Years of selection within this cultivar has resulted in a cultivar that is adapted to an early sowing (late February to late April), is bolt tolerant and will bulb

irrespective of the time of sowing. During this study Golden Brown formed bulbs at all sowing dates from late February to mid-July. Temperature was confirmed to be the controlling factor in the proportion of bolting in an onion crop. Extended periods of low temperatures experienced by the onion plant at its most susceptible stage will result in seedhead production. Although Golden Brown was exposed to extensive periods of cold temperatures during the winter months bolting only occurred in three of the sowings with a maximum 17% of the bulbs bolting.

The development of double bulbs is undesirable and reduces economic returns to the producer. The mechanism responsible for doubling in onions is not completely understood. In general terms large numbers of double bulbs are produced as a result of the onion plant being 'shocked' eg extreme temperature changes, herbicide damage, mechanical damage (hail). Golden Brown is very susceptible to doubling, particularly when sown in February and March. A greater proportion (up to 70% of the total plant population) of doubles occurred in these sowings (February and March) than during the later sowings. Although all the factors that contribute to the formation of doubles are unknown a number of factors have been identified in this study as playing a role in their expression. Large numbers of doubles occurred predominantly as a result of sowing in the warmer months. This suggests that high temperatures are a contributing factor to the development of doubles. Larger bulbs produced as a result of larger plants developed into doubles more frequently than smaller bulbs. High temperatures contribute to the production of large plants through increased leaf production. Therefore, by contributing to the development of large plants, high temperatures have indirectly influenced the production of doubles. This study also found cultivar differences in the level of doubling. Golden Brown was found to be more susceptible to doubling than that of any other cultivar in an early sowing. Investigations concluded that temperature, plant size and genetics contributed to the higher levels of double in the early sowings.

Dry weight production (g) of the cultivar Golden Brown sown at monthly intervals from February to July was correlated (r^2 = 0.816 to 0.986) very strongly with cumulative intercepted radiation (MJ m^{-2}). The photothermal quotient (MJ m^{-2} $°C^{-1}$) also produced very highly significant ($p<0.001$) regressions with dry weight production but in most cases within a sowing date the results were not as strong as those produced by analysing radiation alone. Grouping the data across the sowing dates resulted in an improvement by the photothermal quotient over the cumulative intercepted radiation. Results indicated that as the sowing date progressed the radiation use efficiency for Golden Brown decreased.

In general terms, solar radiation and temperature were found to be the controlling factors in the growth of the onion in Queensland. High temperatures (Feb-April) were responsible for the high levels of poor quality onion bulbs (doubles).

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ACRONYMS AND SYMBOLS USED IN THIS THESIS

ANOVA	=	analysis of variance
BC	=	before Christ
BOL	=	Bolero
c.	=	approximately
Ca	=	calcium
CAV	=	Cavalier
CLI	=	cumulative intercepted radiation
CON	=	Contessa
CR	=	a measure of the radiation that has penetrated the leaf canopy
cv	=	cultivar
DEM	=	Rio Demon
DD	=	degree-days
E	=	emergence
ELB	=	Early Lockyer Brown
ELW	=	Early Lockyer White
eg	=	*exampli gratia* (for example)
et al	=	*et alii* (and others)
F	=	fungicide
g	=	gram
GENSTAT	=	Genstat statistical software
GLA	=	Gladiator
GOB	=	Golden Brown
GRS	=	Gatton Research Station
H	=	herbicide
h	=	hour
ha	=	hectare
I	=	insecticide
i.e.	=	*id est* (that is to say)
IR	=	intercepted radiation
K	=	potassium
kg	=	kilogram

L	=	litre
LSD	=	least significant difference
m	=	metre
Mg	=	magnesium
ML	=	megalitre
mm	=	millimetre
N	=	nitrogen
No. 1	=	number one grade
ns	=	not significant
OP	=	open pollinated
P	=	Phosphorous
p	=	probability
pers. comm.	=	personal communication
QDPI	=	Queensland Department of Primary Industries.
Red	=	Red Rojo
RUE	=	radiation use efficiency
S	=	sulphur
SOM	=	Sombrero
TSS	=	total soluble solids
WAB	=	Wallon White
µg	=	micro gram
°C	=	degree Celsius
$>$	=	greater than
$<$	=	less than
$\sum$	=	summation
®	=	registered

CHAPTER 1

1. INTRODUCTION

Onions (*Allium cepa* L.) are a member of the *Alliaceae* family that contains some 500 unique species, both wild and cultivated. They have been cultivated from approximately 3000 BC to the present day for both culinary and medicinal uses (Brewster 1994; Jones and Mann 1963). Varietal development has generally been locality based and this has resulted in the development of cultivars suited to a large range of environmental conditions. Consequently, they are now cultivated from subarctic regions of the world through to the humid tropics. Although cultivated in a number of diverse climatic regions they are best adapted to production in the temperate to sub-tropic regions (Brewster 1994). However, a high proportion of production also occurs in the tropics (Currah and Proctor 1990).

Onion production in Australia in 2002 was 210,000 tonnes. The largest proportion of Australian onion production is to be found in the temperate regions of the south, predominantly Tasmania and South Australia. Subtropical Queensland produces approximately 18% of the Australian onion crop (Salvestrin 1995) with 80% of this crop grown in the Lockyer Valley, south-east Queensland. There is potential for increased production in central and north Queensland if suitable cultivars can be identified. Cultivars grown in Queensland have short to intermediate photoperiod (11-14 h) requirements. This differs from southern Australia where the cultivars require intermediate to long photoperiods (14 - >16 h). In general cultivars grown in subtropical to tropical regions tend to be short-day types (Currah and Proctor 1990).

Onions grown in Queensland tend to be either open-pollinated cultivars that are planted early in the season (February to early April) or hybrids that are planted mid to late season (mid-April to late June). The open-pollinated cultivars have been developed over a number of years by local seed producers and are ideally suited to the ambient growing conditions. In general, commercial seed companies have developed a range of hybrids specifically for Queensland conditions. Such a large variety of cultivars and planting times has resulted in difficult decision making for producers given variability in environmental conditions. The production of excessive numbers of doubles (i.e., twin bulbs from the same plant) and bolting (i.e., flowering) in cultivars planted out of season has been a constant problem for Queensland growers. Unseasonable environmental conditions have often been blamed for the excessive numbers of doubles produced by some cultivars across years. This may have some part to play, but the selection of cultivars also has an important role.

The study reported in this thesis was undertaken to evaluate the growth and development of onion cultivars grown in a subtropical to tropical growing environment. This evaluation included investigations into the effects of sowing dates and varietal selection on the incidence of doubling and bolting. The study examined the growth stages of several cultivars utilised by Queensland growers. Additionally, investigations were undertaken to evaluate the relationships between light interception and dry matter production.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Origin

Edible alliums, of which onions (*Allium cepa* L) are a member, are historically some of man's most cultivated crops (Brewster 1994). Onions appear as carvings on pyramid walls and in tombs of Ancient Egypt dating from 2700 BC. Writings from India indicate that onions have been grown since the 6th century BC (Jones and Mann 1963). Very little is known, however, about the introduction of the onion into countries that now boast onions as a major crop. It is understood that onions did not become widespread in Europe (Hanelt 1990) until the Middle Ages. Onion was one of the first cultivated plants to be brought to the New World, the Americas, via the Old World.

A great deal of new information about the onion has been gathered since 1900. This has included such topics as disease control measures, adaptation, cultivar improvement and value adding (Jones and Mann 1963). Garner and Allard (1920, 1923) first investigated the effects of photoperiod on the development of the onion plant. Their results showed that the onion plant was day length sensitive and subsequently Magruder and Allard (1937) indicated that different cultivars required different daylengths to produce bulbs. This led to onions being termed short-day, intermediate-day or long-day types. These terms were coined by seedsmen and do not refer to the physiological response to photoperiod. Thompson and Smith (1938) reported the effects of temperature on the formation of bulbs. If temperatures were too low bulb initiation would not occur. An increase in temperature results in an increase in the rate of bulb development (Brewster 1990b) if photoperiod requirements (i.e. longer than a certain critical minimum) are satisfied. As a result it was determined that both temperature and daylength are important factors controlling the initiation and development of onion bulbs.

2.2. Onion Growth Cycle

In Australia, onions are grown mainly for their bulbs. Shallots (in Australia, whole plants without developed bulbs) and spring onions (whole plants with small under-developed bulbs) are also important crops grown from seed throughout Australia. Both crops are onion (*Allium cepa* L.) cultivars that are grown out of season to ensure growth of plants that are acceptable in the domestic market place. Shallots, as members of the Aggregatum group (Brewster 1994), are of little economic value in Australia.

Under these various guises, the growth of the onion plant is influenced by time of planting, planting material, weed control, the effects of pests and diseases, irrigation scheduling, fertiliser application and rates, and planting density (Currah and Proctor 1990). Doubling, bolting, and bulb size and shape are influenced by environmental and cultural practices (Brewster 1990b). The major contributing factors to the development of the onion plant are photoperiod and temperature. Under Queensland conditions, onions are termed 'short day types' in reference to the minimum length of the photoperiod that is required to initiate bulbing.

The growth of the onion plant from seed consists of three phases (Sinclair 1989), as illustrated in Figure 2.1 and listed below.

- Vegetative Phase -planting to bulb maturity
- Bulb Dormancy Phase -bulb maturity to beginning of regrowth
- Seed Production Phase -onset of new growth to seed production

The vegetative phase consists of three stages (Brewster 1990b):

- Planting to emergence
- Juvenile growth to bulb initiation
- Bulb swelling to bulb maturity

A complete understanding of the vegetative phase is essential for the development of a model to predict growth and yield. There are a number of factors that influence the development of the onion plant during the vegetative phase (Abdalla 1967; Brewster 1990b; Brewster 1994; Jones and Mann 1963). The critical factors that determine the ability of onion plants to grow satisfactorily at different locations are daylength (Call 1986; Darley 1985; Darley 1986) and temperature. Abdalla (1967) concluded that temperature influences bulbing more so than photoperiod in the tropics. The number of days to maturity (Brewster 1994; Currah and Proctor 1990) also influences crop growth and subsequently final yield.

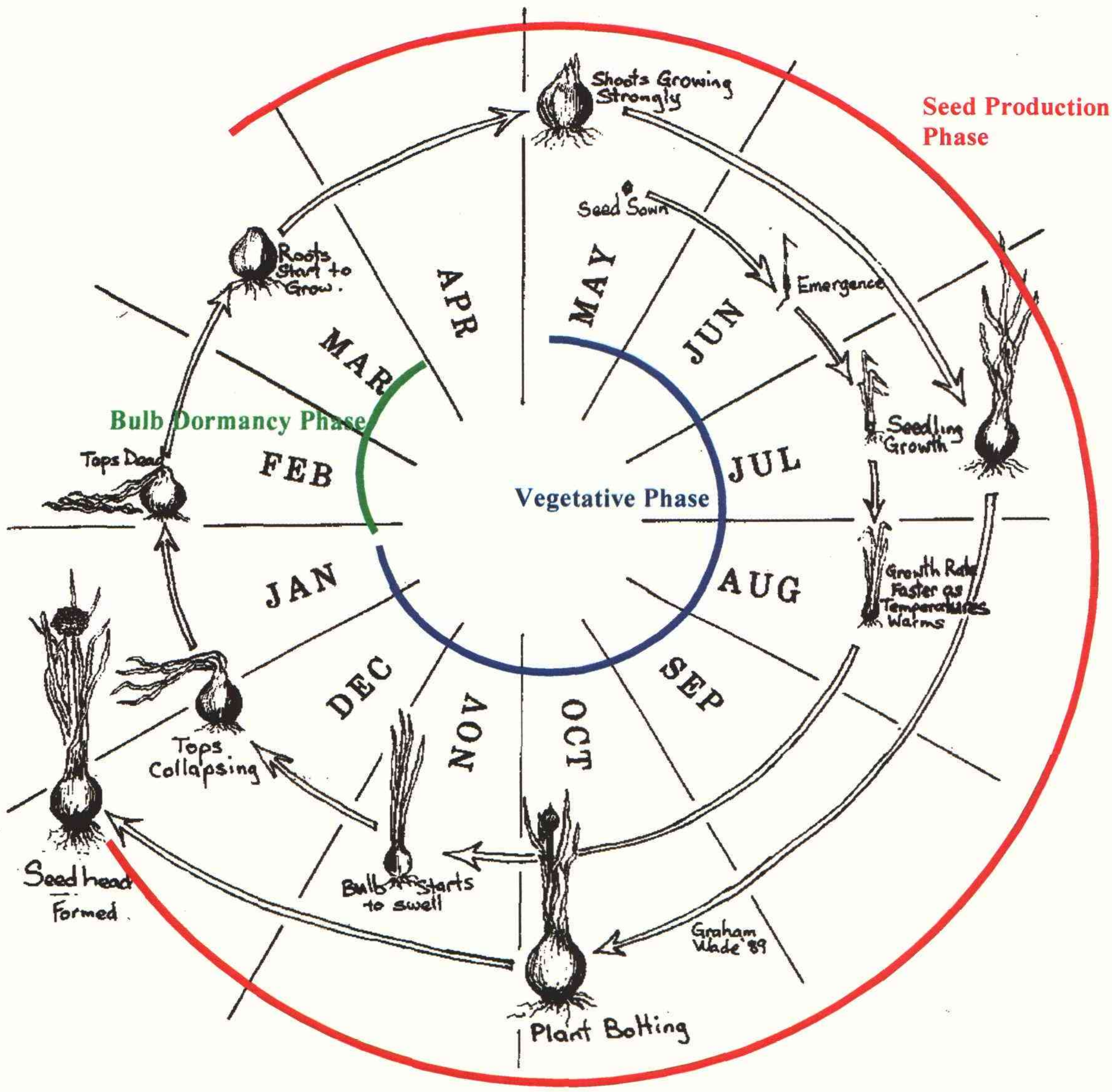

Figure 2.1. Life cycle of the Creamgold type onion grown in New South Wales, Australia. (Blue – Vegetative Phase; Green – Bulb Dormancy Phase; Red – Seed Production Phase). (Sinclair 1989).

2.2.1. Vegetative Phase

2.2.1.1 Stage I: Planting to Emergence

Seed quality is an important factor in the germination of seed and subsequent crop yields. High quality seed is achieved through optimising a number of factors including maturity of seed at harvest time, drying temperatures and moisture content of seed during storage (Brewster 1990b). Incorrect storage results in a rapid decrease in viability resulting in poor plant stands and ultimately reduced crop yields.

Seed size has an influence on the subsequent range of root/bulb size of vegetable crops including carrots (Benjamin 1982) and onions. Variable seed size would, therefore, result in variably-sized final bulbs and yields. Uniform seed size is therefore important to achieve uniform maximum crop yields.

Seed germination and consequently seedling emergence can determine the distribution of bulb grades and ultimately the total final yield of an onion crop (Finch-Savage and Phelps 1993). Final yield of an onion crop is predetermined by the choice of the size of bulbs required, and, therefore initially by ensuring optimum population density is achieved through an adequate germination percentage (Brewster 1990b).

Variations in seedling emergence can result from a lack of soil moisture at a critical period during seed germination (Finch-Savage and Phelps 1993). Adequate soil moisture levels are required to initiate germination (Taylor 1997). Consequently, onion beds should be of a fine tilth to maximise soil contact with the small onion seed. This ensures that adequate moisture levels are maintained around the seed and the subsequent emerging seedling. An adequate soil moisture level ensures that the rate of emergence is correlated with mean temperature (Finch-Savage 1986).

Optimum soil temperatures are required to ensure maximum seed germination. The optimum mean temperature range is 3-17 °C (Bierhuizen and Wagenvoort 1974). Decreasing and increasing temperatures particularly outside the optimum temperature range for prolonged periods results in reduced seedling emergence (Brewster 1990b). Therefore, planting when soil temperatures are ideal is essential to ensure maximum-programmed crop yield. Additionally, the rate of germination increases as ambient temperature increases (Finch-Savage and Phelps 1993). A uniform rate of emergence is necessary to ensure evenness of plant growth and consequently uniform bulb size at the final harvest.

Onions need a greater number of degree-days (heat sum above 5 °C) – 219 – for germination than most other temperate vegetables (Bierhuizen and Wagenvoort 1974) at a minimum germination temperature of 1.4 °C. This higher heat sum indicates slow germination. Subsequently, if this required heat sum for germination is achieved then maximum yield will be reached unless some other limiting factor occurs that constrains yield. Under Queensland growing conditions, this requirement is more likely to be met for early season crops (late Feb to early April sowings) when the soil temperatures are high, rather than for mid to late season crops (mid April to late June sowings).

2.2.1.2 Stage II: Juvenile Growth to Bulb Initiation

The growth of the onion plant from emergence to the onset of bulbing consists of the juvenile stage and the adult stage (Sowei 1997) (Figure 2.1). This commences with the 'hook' (loop) leaf and continues approximately to the seventh leaf and bulb initiation. Bulbing is considered to have commenced when the diameter of the bulb is twice that of the pseudostem (bulbing ratio of 2.0) (Brewster 1990b). This bulbing ratio is not definitive, as Lancaster (1986) and Abdalla (1967) have used bulbing ratios of 1.2 and 2.5 respectively. Bulb initiation corresponds with all the new leaves being of adult size and morphology (Brewster 1990b).

Once the first true leaf has emerged and is fully expanded, the adult vegetative stage commences and continues until the initiation of bulbing. The total number of leaves initiated during vegetative development varies greatly between cultivars (Regmi 1994; Regmi *et al.* 1992). This is particularly so when comparing long-day and short-day cultivars. Under temperate growing conditions, Brewster (1990b) reports that the plant will produce seven visible leaves prior to the initiation of bulbing. The total number of leaves initiated is greater than the total number of leaves emerged at this stage (de Ruiter 1986).

Photoperiod and temperature and their interaction are the most important factors affecting this pre-bulbing plant growth stage (Jones and Mann 1963). The interaction of both daylength and temperature (accumulated thermal time) influence the initiation of bulbing (Abdalla 1967; Lancaster *et al.* 1996). Under conditions with little variation in the photoperiod, temperature is the more important factor for bulb initiation (Abdalla 1967). This is of particular interest when investigating the growth of the onion plant under subtropical to tropical conditions. In contrast, the interaction of both photoperiod and temperature is critical in temperate regions (Heath 1945).

In temperate regions where photoperiod is the major contributing factor to bulb initiation (Heath 1945) the bulbing trigger coincides with the cessation of new leaf initiation (de Ruiter 1986) but previously initiated leaves may still emerge. Under tropical conditions where temperature is the major factor contributing to bulb initiation this cessation of new leaf initiation does not seem to occur (Abdalla 1967).

Thermal time (degree-days) is also considered an important tool in the quantification of the commencement of bulbing, and consequently in the development of an onion growth model (Lancaster *et al.* 1996). A measurement of thermal time (Equation 1) can be used to relate to the number of leaves initiated up to and including last leaf appearance (de Ruiter 1986). This tends to suggest that temperature has the greatest influence on plant growth (vegetative stage) prior to the initiation of bulbing.

$$\text{Degree day sum} = \sum_{i=1}^{n}[(Tmax_i + Tmin_i)/2 - T_b]$$

where mean > T_b, T_b for onion is reported to be 5 °C Equation (1)

Brewster (1982) suggested that bulbing occurs when the leaf initials switch to bulb scale formation rather than the production of new leaf blades. The bulb scale is a scale leaf with an expanded base and an aborted leaf blade. This may not be visible to the eye until a pronounced bulb swelling takes place, as indicated by a bulbing ratio of >2.0. Once bulbing has commenced Stage III of the Vegetative Phase commences. This stage involves bulb growth until top down i.e. the commencement of the Bulb Dormancy Phase.

2.2.1.3 Stage III: Bulb Swelling to Bulb Maturity

Bulb development in the onion plant has two main morphological features (Butt 1968). These features are (i) swelling of the base of the pseudostem (leaf sheaths) and (ii) conversion of leaf initials at the stem apex into scales.

Once bulbing has commenced the continued growth of the bulb occurs as a result of the plant switching from leaf production to bulb scale production and swelling (Brewster 1994; Jones and Mann 1963). This stage is critical to the final bulb size and a number of factors can affect this final size. Scully (1945) found that differing rates of nitrogen affect the development of the bulb. Excess nitrogen can delay final maturity therefore resulting in an increased bulb size. Alternatively, a nitrogen deficiency can result in a shortened maturity and a smaller bulb size. Scully (1945) also reports that the interaction of nitrogen and photoperiod can influence the development of the bulb under the critical photoperiods for certain onion cultivars.

Final bulb yield is also determined by other factors including interception of solar radiation during the bulb swelling to maturity phase (Brewster 1982). Consequently, factors that affect leaf area duration throughout this phase are important in the determination of a final marketable yield. Both photoperiod and temperature affect final yield of short day onions by influencing the leaf area duration (Wiles 1994). High temperature hastens maturity by promoting leaf senescence and subsequently decreasing leaf area duration and thereby final marketable yield (Robinson 1971; Wiles 1994). Photoperiod determines whether developing leaf initials follow the bulb-scale formation path or, if the photoperiod is shorter than a certain minimum, revert back to bladed leaf production (Wiles 1994). If the plant reverts back to leaf blade production then final yield is dramatically reduced.

Although temperature and photoperiod are the main controllers of bulb development, plant density is also important in governing the onset of bulbing and the further development of the onion bulb (Mondal *et al.* 1986a).

As the bulb develops the absence of new leaf growth leads to a hollow pseudostem (Brewster 1994). The neck tissues begin to lose their turgidity and soften resulting in the collapse of the foliage under its own weight. This top collapse marks the completion of bulb maturity (Sinclair 1989). When 50-80% of an onion crop is at this stage it is considered ready for harvest (Robinson 1973) for sale as fresh product or to be stored. After the tops have been removed, mechanically or as a result of natural senescence, the outer scales dry out and the bulb progresses to ripen.

2.2.2. Bulb Dormancy Phase

The bulb dormancy phase commences once the bulb has ripened. This occurs when the outer skins have dried and the foliage has senesced and is totally desiccated (Brewster 1994; Sinclair 1989). The onion enters this stage as a survival mechanism to endure conditions that are unfavourable for growth (Currah and Proctor 1990).

The bulb is the storage organ (Currah and Proctor 1990) of the plant and its contents are utilised when the bulb breaks dormancy and sprouting commences. This is generally after a prolonged cool period (Brewster 1994).

Once conditions are favourable for the growth of the bulb, sprouting occurs and the plant progresses on to the seed production phase.

2.2.3. Seed Production Phase

Floral initiation occurs as a response to a prolonged period of low temperatures (Heath 1942; Heath 1943; Jones and Mann 1963) during the dormancy phase. This period of cool temperatures vernalises the plant and induces flowers to initiate (Brewster 1990b). Brewster (1990) points out that the temperature response of vernalisation depends on the cultivar. Tropical cultivars can be induced to flower (Rabinowitch 1990) in warmer conditions compared to temperate types.

After floral initiation the spathe develops and envelopes the inflorescence (Brewster 1994). The process of floral initiation and spathe development occurs within the bulb at the onion shoot apex. Scapes (stalks) topped by the spathe then develop to a length of one to two metres. Individual bulbs may produce between one and twenty inflorescences but three to six (Rabinowitch 1990) are more likely. The spathe then opens revealing a spherical umbel that possesses up to 2000 individual flowers (Brewster 1994). Once pollinated each flower can produce three to four seeds in a good season (Currah and Proctor 1990). Seed yields vary greatly depending on environmental conditions and cultivar. Seed crops of between 100-500 kg ha^{-1} are possible (P. Ryan, May and Ryan Seeds, pers comm.).

Once seed has been produced the life cycle commences again. This cycle takes two seasons (*c.* 20 months) from beginning to end.

Bolting is the undesirable trait whereby unwanted flower initiation results in seedhead production during the growth of a commercial onion crop. This unwanted seedhead production renders the bulb unmarketable.

2.3. Factors Affecting Onion Growth

Onions in Queensland are grown under subtropical to tropical conditions. Consequently the rate of growth and final yield will vary significantly in comparison to onion crops grown in temperate climates (Squire 1990). Under tropical conditions the overall effect of the environmental factors and their interaction varies in comparison to crops grown under temperate conditions (Abdalla 1967). The main environmental factors to consider are photoperiod and temperature and their effect individually and in combination during the growth stages of the plant (Jones and Mann 1963). Other factors, including plant density, and their correlation with percentage light interception by the crop canopy (Brewster 1994) can have a dramatic effect on the yield potential of bulb onions. Time of planting (Brewster 1990b; Hiron and Symonds 1985) affects maturity and subsequently final yield. Under tropical conditions, sowings delayed two weeks or more past their optimal planting time can result in reduced yields (Sowei 1997). Nutrition is also an important factor in the maximisation of crop yield in onions (Brewster 1994). High levels of N, P and K (eg. N:P:K = 150:30:100 kg ha^{-1}) are required in the soil to ensure that the crop will attain its maximum yield. The shallow root system and lack of root hairs result in the need for the high levels of nutrients in the upper level of the soil. These high levels are required to ensure that plant requirements are met.

2.3.1. Daylength

In general, the common onion is a long-day plant type (Jones and Mann 1963). The plant will initiate bulbing in response to an increasing daylength (Call 1986). The daylength required to trigger bulbing is cultivar specific (Jones and Mann 1963). This critical daylength varies from 12 hours for tropical cultivars (Currah and Proctor 1990), known as short-day types to 16 hours for long-day types (Darley 1985) grown in temperate regions. The minimum daylength required for bulbing can be as low as 10½ hours (Kedar *et al.* 1975; Magruder and Allard 1937); Brewster (1994) states that short day types require a minimum of 11-12 h.

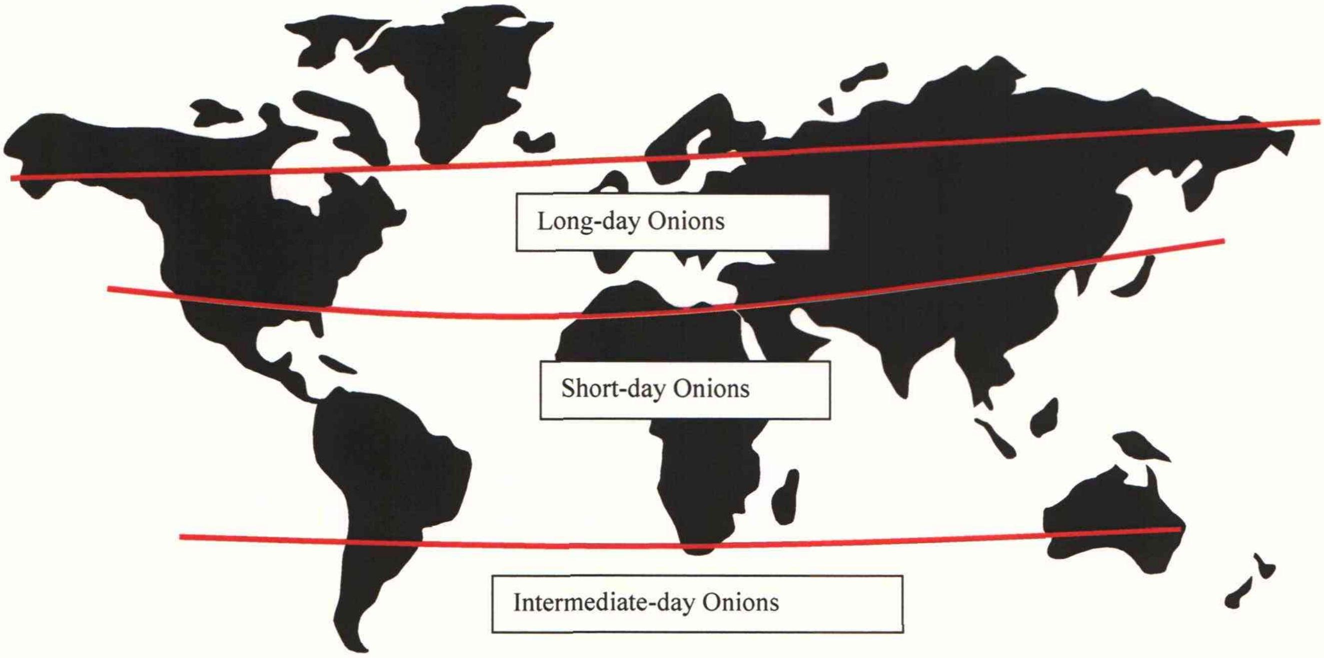

Figure 2.2. Response of onions to daylength in different regions.

Daylength (photoperiod) is a function of distance from the equator and the time of the year (Jones and Mann 1963) (Figure 2.2). In the Southern Hemisphere daylength reaches its maximum during December (early summer) and drops to its minimum in mid-June. Variation in daylength within the tropics is minimal (12 ± 1 hour) throughout the year (Abdalla 1967). Consequently, photoperiod variation may be less critical in the bulbing response for cultivars grown under these conditions. In the subtropics, onions are normally grown as a winter crop, while in temperate regions onions are a summer crop.

Tarakanov (1993) highlighted that tropical onion cultivars remain long-day plants in regard to their physiological response to daylength (i.e. they require daylength greater than a critical minimum to bulb) but are termed short-day types in reference to bulb production under short-day conditions. Previous research (Butt 1968; Magruder and Allard 1937; Mettananda and Fordham 1997; Steer 1980a; Wiles 1994) indicated that tropical onion cultivars bulb earlier under long day conditions (16 h) than under their adapted short day (12 h) conditions. Consequently, the plant will take longer to bulb under tropical conditions due to a later switch to bulb initiation i.e. conversion from bladed leaf to bulb scale production. Based on investigations with four long-day cultivars, Austin (1972) concluded that, although bulbing occurred earlier under longer days, the sequence in which cultivars bulbed remained similar amongst the cultivars.

In general, short-day onions can be grouped together into a class of their own; that is grown in and adapted to the tropics (Currah and Astley 1996). In Australia, onions are grown from latitude 41°S (Tasmania) to 12°S (Northern Territory) using intermediate-day and short-day types respectively (Coombs 1995). The Lockyer Valley (27°S) is termed a short-day environment (10–13 hours during growing period) (Hammer, QDPI, pers. comm.). This latitude is generally recognised as the limit for the growth of short-day onions in the Southern Hemisphere while in the Northern Hemisphere short-day types are limited to the southern states in the USA, Israel and subtropical parts of Japan. Under these circumstances selection of the correct cultivar is critical if a crop is to be produced. This selection is further complicated due to the fact that more genetic variation for bulbing response to photoperiod can be found in the short-day gene pool than among the suite of long-day cultivars (Bark and Havey 1995). The Australian cultivar Creamgold requires a longer daylength than cultivars such as the Queensland cultivar Golden Brown to bulb satisfactorily. The cultivar Creamgold will not bulb under Queensland conditions.

The interaction of daylength with temperature (Steer 1980a) makes the determination of a critical daylength for bulbing difficult particularly under the subtropical to tropical conditions in Queensland. Under Australian field conditions in spring, Steer (1980a) found it is likely to be low temperature and not short daylength that is the major constraint to bulbing, supporting the conclusions of Abdalla (1967) and Robinson (1971).

Although daylength has a profound effect on the onset/initiation of bulbing in onions it also affects other stages of the onion plant growth and development. Several authors have reported that inflorescence development subsequent to initiation is positively correlated to photoperiod. Long photoperiods and high temperatures (Brewster 1982; Brewster 1983; Heath and Holdsworth 1943; Scully *et al.* 1945; Woodbury and Ridley 1969), accelerated inflorescence development. Brewster (1983) also reported that inflorescence initiation is accelerated by long photoperiods at 9 °C. As photoperiod and temperature increase, the promotive effect on inflorescence development will at some stage be outweighed by the detrimental effect of bulbing on inflorescence growth (Brewster 1983). The combination of these responses varies with cultivar.

Photoperiod also affects the rate of sprouting in stored onion bulbs. (Bertaud 1990) found that for the cultivar Gladalan Brown sprouting occurred at a higher rate under short days than under long days.

2.3.2. Temperature

Extensive research has been documented on the role of temperature in the growth and development of the onion plant (Abdalla 1967; Brewster 1990b; Heath 1942; Heath 1943; Heath 1945; Robinson 1973). As indicated earlier, the effect of temperature on the growth of the onion plant first comes into effect at sowing. The rate of seedling emergence under optimal soil moisture conditions is correlated with mean temperature (Finch-Savage 1986). In general, a decrease in temperature will result in a corresponding decrease in germination percentage (Bierhuizen and Wagenvoort 1974). Ultimately this decrease in germination percentage will result in a decrease in potential yield due to decreased plant populations. Although constant temperatures greatly influence onion germination, there is evidence (Wagenvoort and Bierhuizen 1977) to suggest that varying soil temperatures may enhance germination rate as well as the germination percentage.

Temperature, in combination with photoperiod, contributes to the onset of bulbing but temperature is more important than photoperiod during the stage prior to bulbing. Higher temperatures combined with short days result in an increase in the rate of progress towards the onset of bulbing (Daymond *et al.* 1997) resulting in bulbing that commences sooner (Butt 1968). Subsequently, the duration of onion crop growth is shortened and yield is depressed (Daymond *et al.* 1997). This can be related to the fact that onions are a determinate crop and that increases in temperature decrease leaf canopy duration of determinate species (Wurr *et al.* 1998).

A number of investigations have been carried out into the influence of temperature on bulbing of the onion plant (Abdalla 1967; Brewster and Butler 1989b; Butt 1968; de Ruiter 1986; Steer 1980b). The majority of studies into the effects of temperature have been carried out under temperate growing conditions with varying photoperiods and temperatures generally below 30 °C. It is accepted that in these temperate regions temperature plays a minor role and only enhances or delays bulbing (Butt 1968; Thompson and Smith 1938). Abdalla (1967) considered the role of temperature in bulb formation to be catalytic in nature. Under tropical conditions Abdalla (1967) and Robinson (1973) determined that temperature has considerable influence on bulbing where variations in photoperiod were small. High day temperature (45 °C) (Abdalla 1967) combined with low night temperature (17 °C), under short days, retarded bulbing (Abdalla 1967; Steer 1980b). Abdalla (1967) found that the plant continued to develop emergent leaves but these leaves were much smaller than those produced under lower daytime temperatures. This meant that higher temperatures resulted in the elongation of the inner leaf blades at the expense of cell enlargement at the leaf bases. Cell enlargement at the leaf base leads to bulbing. Subsequently bulbing was retarded.

Once bulbing has commenced, high temperatures accelerate bulb development (Brewster and Butler 1989b; Daymond *et al.* 1997) and low temperatures delay the development of the bulb and promote seedstalk development. Under long day conditions there is a race between scape elongation and bulb formation (Heath 1943; Thompson and Smith 1938). If the temperature is high then bulb formation dominates while seedstalk development dominates under low temperatures. Although low temperatures do not necessarily prevent bulbing, and there may be some signs of bulbing, the plants may then proceed to bolting (Butt 1968). Studies by Steer (1980b) highlighted the importance of the influence of night temperatures on bulbing and the rate of bulb development. The number of days from sowing to the start of bulbing decreased with increasing night temperatures. The rate of bulbing after initiation increased as the night temperature increased.

It has been suggested that high daytime temperatures influence the production of doubles or bulb splitting in the onion bulb. While Robinson (1971) reported bulb 'splitting' to be more common at high rather than low temperatures in the Rhodesian Lowveld, Yamaguchi *et al* (1975) found no effect of soil temperature on lateral bud formation in three onion cultivars but one cultivar produced significantly more doubles than the other two.

Temperature is also important in the next stage of growth, namely flower initiation. Initiation of flowers will occur under low temperatures (Butt 1968; de Ruiter 1986). The optimum temperature for flower initiation is thought to be 9 °C (Brewster 1982). The duration and extent of low temperatures required for bolting differs between cultivars (Call 1986). High temperatures will prevent flower initiation (Butt 1968; Heath 1942; Heath 1943).

2.3.3. Light

Light is an important factor in the growth and development of the onion plant. The quantity and quality of solar radiation intercepted by the plant canopy determines the ultimate yield (Squire 1990). The efficiency with which a plant captures the incoming radiation determines dry matter production and subsequently final yield (Tei *et al.* 1996) The physiological factors that will influence this efficiency include the dimensions, configuration and longevity of the canopy (Squire 1990). The onion's poor leaf shape and arrangement (Currah and Proctor 1990) result in an inefficient plant for the interception of incoming radiation (Brewster 1982). Consequently there is a need to ensure maximum leaf development and length of growing season to maximise total light interception. Thus it is essential to achieve a large canopy as the onion plant partitions three-quarters of its dry matter into a harvestable bulb (harvest index 70-80%) (Brewster 1990b). Early planted cultivars in Queensland (late February to late March) will produce larger leaf areas and consequently higher yields than cultivars planted later in the season (mid April to late June) (Duff and Jackson 1997). This is the result of greater light interception leading to high bulb yields (Brewster 1990b).

Apart from influencing the quantity of light intercepted by the onion plant, the leaf area of the plant also affects the proportion of the red:far-red spectrum penetrating the canopy (Mondal *et al.* 1986c). The red:far-red ratio in daylight decreases as red light is preferentially absorbed by leaves as light filters through a leaf canopy (Brewster *et al.* 1986; Mondal *et al.* 1986c). Consequently, the average red:far-red ratio in the radiation intercepted by the leaves will decrease as the leaf area index increases (Mondal *et al.* 1986c). The red:far-red ratio, through the effects it has on the phytochrome of the onion plant, influences bulb development. Bulb development accelerates as the red:far-red ratio decreases. Individual plants growing in a situation where they receive radiation of lower red:far-red ratio than that of other plants i.e. grown adjacent to other plants rather than in isolation from other plants will experience an accelerated bulb scale initiation (Brewster 1990b; Terabun 1978). This leads to a shortened vegetative stage and subsequently reduced bulb yields.

2.3.4. Nutrition

Levels of macro and micronutrients can have varying effects on the growth of the onion plant. The role of the macronutrients nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) is well documented (Brewster 1994; Jones and Mann 1963). The onion plant requires greater quantities of nitrogen and potassium than phosphorous, calcium and magnesium. Nutrient availability among soils varies considerably. Corgan and Kedar (1990) reported that, in general, subtropical soils are deficient in nitrogen and available phosphorous. Most soils in the Lockyer Valley are deficient in nitrogen but possess high levels of phosphorous and adequate levels of potassium. As a consequence of this little or no response to the addition of P and K for the Lockyer Valley soils is evident (Schrodter 1975)

The shallow root system, low root densities and the lack of root hairs of the onion plant demands that high levels of nitrogen, phosphorous and potassium be present in the soil at planting (Brewster 1994). This is to ensure that the concentration of these nutrients is in a sufficiently high enough concentration to meet the demands of crop growth. Inadequate nutrient supplies will result in decreased crop yields.

2.3.5. Irrigation

Irrigation plays an important part in the growth of the onion crop. The onion plant is shallow rooted, therefore access to adequate soil moisture is essential, firstly, for the survival of the plant and secondly, the production of good yields (van Eeden and Myburgh 1971). Increasing levels of irrigation in an onion crop resulted in higher yields (Henderson and Webber 1995) and delayed maturity (Mondal *et al.* 1986c). Low levels of irrigation result in advanced maturity (Mondal *et al.* 1986c) and subsequently reduced yields by influencing the size grade distribution (Chung 1989).

The lack of, or low levels of, irrigation affects the bulb dry matter but generally not the pungency (MacGillivray 1950). Under such circumstances the dry matter is increased slightly.

2.3.6. Other Cultural Practices

The growth of the onion plant is also affected by a number of additional cultural factors. These factors include effects of diseases and pests, time of planting, population density and type and quality of planting material (Currah and Proctor 1990).

Sowing date in combination with cultivar selection has a profound effect on the growth of the onion plant (Grevsen 1989). Incorrect cultivar selection for a specific sowing date can result in the excessive production of doubles and bolting (Lydon, Terranova Seeds, pers. comm.). In temperate regions the earlier the crop is planted the earlier it matures due to a higher light interception (Brewster 1990b; Mondal *et al.* 1986c). Under subtropical conditions in the Lockyer Valley, Duff and Jackson (1997) found that early plantings took longer to mature than later plantings.

Plant spacing is an important factor in the growth of an onion crop. Plant density is influenced by both inter-row and intra-row spacing. Optimum density tends to occur when the individual plants are equidistant from each other (Bleasdale 1966). There is an optimum plant density to maximise yield (Bleasdale 1966; Frappell and Cox 1973) within a location, and once reached there will be no more significant increase in yield. With an increased plant density above an optimum there is a reduction in yield (Frappell 1973; Rickard and Wickens 1979).

2.4. Bolting

Bolting is the undesirable trait of the onion plant coming into flowering at the incorrect time. The term is used for biennial flowering species that occasionally flower in their first year of growth. Bolting results in a decrease in yield and poor onion bulb quality. Such an effect can have an important impact on grower income and an understanding of the factors that cause bolting is called for. The main factor affecting bolting is cool temperatures with total cold requirement being cultivar dependant (Call 1986; Jones and Mann 1963). In general, plants that experience temperatures of 9-13 °C (Kretschmer and Strohm 1988; Sinclair 1989) for a long enough period will tend to bolt. The plant must also be of a minimum size (Jones and Mann 1963) to be susceptible to the cold treatment for bolting to occur. The vernalisation studies of Thompson and Smith (1938) found that 100% bolting occurred with bulbs exposed to temperatures of 18-22 °C whereas those exposed to temperatures of 25-29 °C did not bolt. Heath (1945) reported that both exposure to long photoperiods (16 h) and high temperatures also suppressed bolting. Brewster (1983) reported that bolting could be accelerated by very long photoperiods (20 h)

Onion sets exposed to cold temperatures (5-10 °C) during storage (Sinclair 1989) will tend to bolt. This treatment can prove to be useful in breeding programs where maximum flower head production is required. Small sets are less likely to be susceptible to bolting (Jones and Mann 1963). Bolting can therefore be suppressed by storing bulbs at high temperatures.

In the southern hemisphere bolting tends to be a problem for early[1] (de Ruiter 1986) to mid[2] season sowings (Duff and Jackson 1997) as there is a greater likelihood of plants being large enough to respond to the cold temperatures required for inflorescence initiation. To avoid bolting at these sowings it may be necessary to select the sowing date to ensure the onion plant is sufficiently small to be unaffected by the cold temperatures (Sinclair 1989), to select a cultivar that requires a long exposure to cold to commence inflorescence initiation (Sinclair 1989) or to plant at a higher population density thereby reducing potential bulb size.

[1] for a May sowing at Palmerston North, New Zealand; latitude 40° 12′S

[2] for an April sowing at Gatton , Australia; latitude 27° 33′S

2.5. Doubling

Doubling is a defect in onions that causes serious loss of marketable yield and downgrading of quality. Doubling or "pregnant bulbs" (Plate 6.1) to a lesser degree is the result of the formation and visual expression of additional growing points. Due to its different levels of manifestation, doubles can be undetectable until the onion bulb is cut (multi-centred), or it can result in a poorly shaped bulb or a cloved or split bulb (Lydon 1996).

Little research into doubling has been undertaken, and there is very little available in the way of published results into this problem. Large stored bulbs have shown increased splitting when compared to smaller bulbs (Thompson and Smith 1938). There is evidence that increased plant spacings (lower populations) (Wilson 1934) will result in a greater percentage of split bulbs. Wilson (1934) reported that increasing the plant spacing from 5 cm to 25 cm by increments of 5 cm resulted in increased percentages in the number of split bulbs produced.

The cause of doubling in onions is unclear. A common view is that doubling occurs as a result of some type of shock to the plant that damages or stimulates the growing point (Lydon 1996). This shock may be in the form of unseasonal temperature fluctuations (high or low), excess nutrition or other type of external influence. All these factors may be seen to interrupt regular growth stages, thereby causing a reaction that result in the initiation of additional growing points. Once bulbing has commenced an external shock may cause the bulbs to revert to an earlier growth stage; leaf initiation as opposed to leaf swelling (bulbing) (Lydon 1996). The end result of this may be delayed bulbing and a high number of doubled or split bulbs.

2.6. Conclusions

It is recommended that controlled environment studies will need to be undertaken to investigate the effects of daylength and temperature on the growth and development of Australian cultivars currently grown under subtropical conditions in Queensland.

The evaluation of the relationships between photoperiod, thermal time and the 'onset of bulbing is desirable in order to provide a clearer understanding of the growth of the onion plant under the subtropical conditions of Queensland. Thermal time has been used to predict the 'onset of bulbing' in onions (Lancaster *et al.* 1996; Wiles 1989). Further investigation regarding the consistency or otherwise of these models may provide an insight into the production of doubles.

Additional field studies in conjunction with the controlled environment studies are required to investigate the effects of the environment on bulbing, double formation and bolting to further unravel the effects of the growing environments on marketable harvest for growers. Studies reported in this thesis were designed to do that.

CHAPTER 3

3. GENERAL MATERIALS AND METHODS

3.1. Location

The Queensland Department of Primary Industries (QDPI), Centre for Vegetable Crops, Gatton Research Station (GRS) was the site for all field trials (1999 and 2000) conducted for and reported in this thesis. The station is located in the Lockyer Valley, Queensland, Australia at 27° 33' South, 152° 20' East at an altitude of 95 m.

3.2. Climatic Data

The Lockyer Valley has a subtropical climate with a relatively high summer humidity (85-90%). The summers are long and hot followed by short cool winters with the occasional frost.

The annual rainfall (Figure 3.1) for the years 1999 and 2000 was 947.2 and 459.4 mm respectively (compared to the long term average of 780.8 mm). Rainfall during 2000 was only 60% of the mean annual rainfall. This resulted in a very dry growing season (nine months) during which a total rainfall of 198.2 mm was recorded.

The average monthly maximum and minimum (Figure 3.2.) temperatures ranged, respectively, from 20.4 to 30.1 °C and 7.7 to 19.6 °C in 1999, and 20.0 to 31.9 °C and 5.2 to 18.2 °C in 2000. Five frosts were recorded in 1999 whereas eleven were recorded in 2000. There was no recorded damage to the onion plants as a result of these frosts.

The onion season in the Lockyer Valley is accepted as a short to intermediate (13-14 h) growing environment (Figure 3.3). Short winter days (Hammer 1980) occur during the growth, particularly bulbing time, of early season onions sown from late February to late April. Onions sown in May and June are influenced by intermediate daylengths. Minimum daylength at the trial site is 10 h 36 min (Figure 3.3).

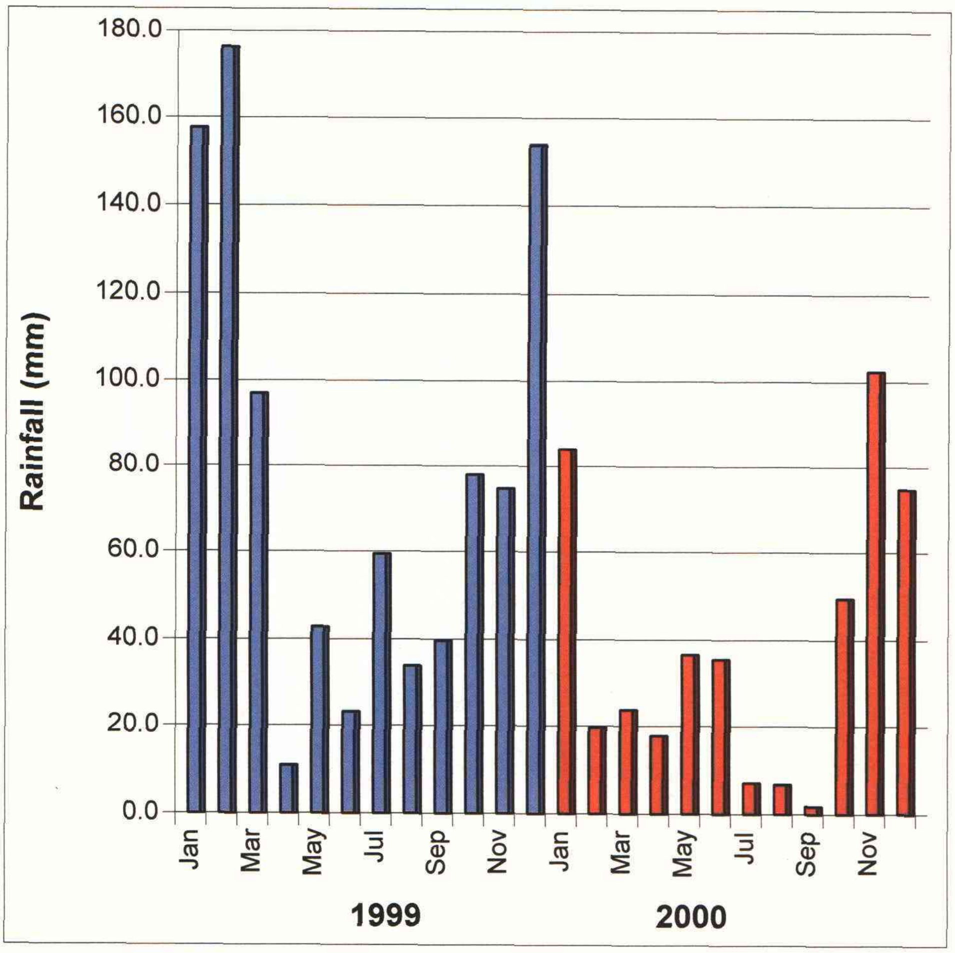

Figure 3.1. Total monthly rainfall (mm) for the years 1999 and 2000 at Gatton Research Station.

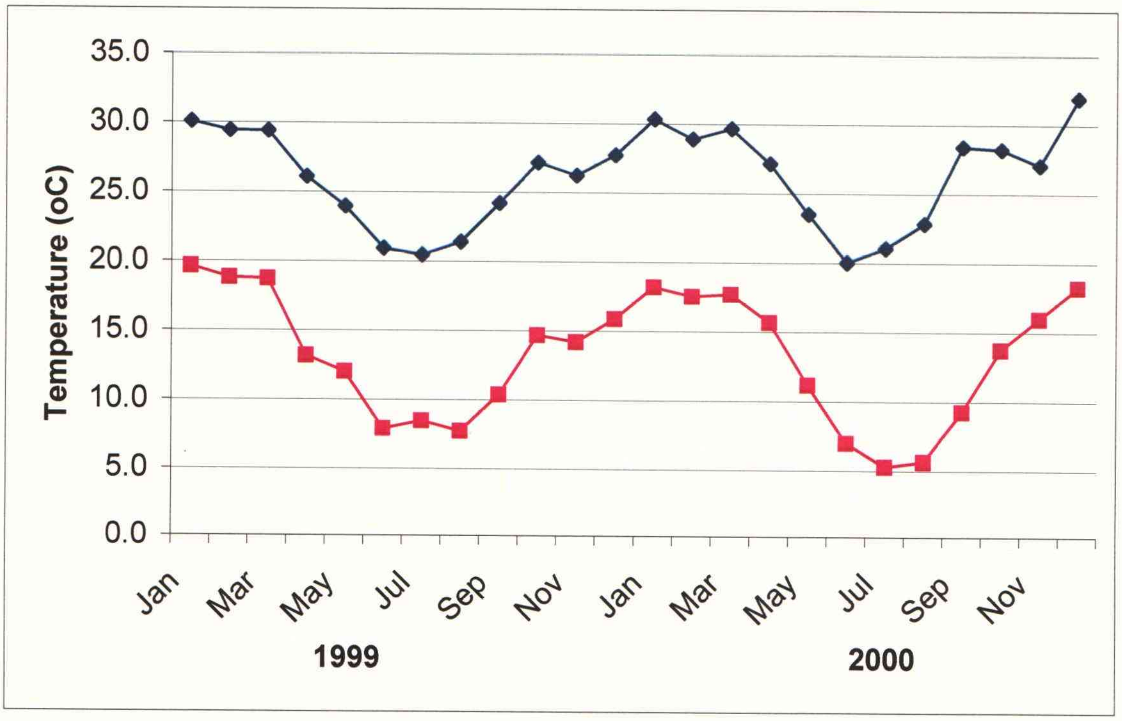

Figure 3.2. Average monthly maximum (-♦-) and minimum (-■-) temperature (°C) for the years 1999 and 2000 at Gatton Research Station.

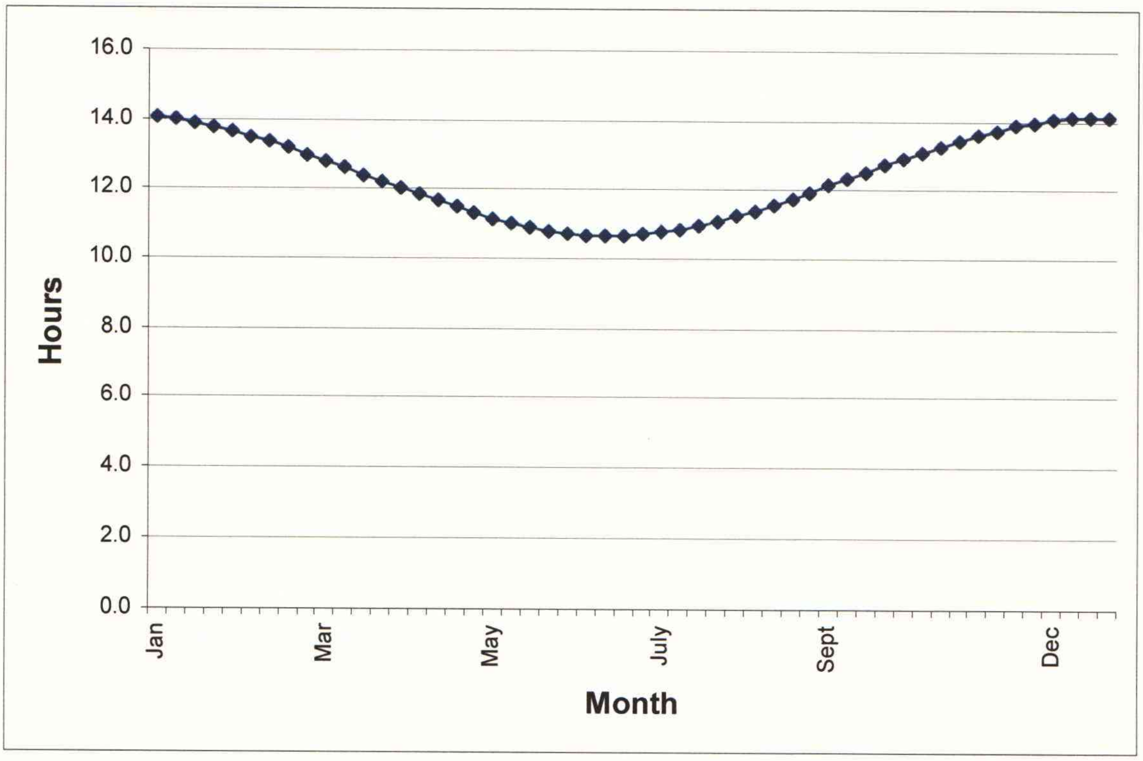

Figure 3.3. Average weekly daylength (h) for Gatton Research Station (27° 33' South, 152° 20') in the Lockyer Valley.

3.3. Soil type

Powell (1982) undertook a detailed soil survey of Gatton Research Station. All experiments were carried out on light clay loam soils with a pH of 7.5. Soil tests prior to the conduct of the experiments confirmed the following nutrient levels in the soil: low total N (0.13-0.15%), high to very high P (0.13-0.17% total P, >100 $\mu g\ g^{-1}$ extractable P) and K (1.1-1.4% total K, 0.86-1.7 milliequivalent 100 g^{-1} extractable K); and medium organic C (1.5-1.8%), Cu (1.2-1.7 $\mu g\ g^{-1}$), Mn (6-15 $\mu g\ g^{-1}$) and Zn (1.2.4 $\mu g\ g^{-1}$).

3.4. Experiment Design

Experiments were conducted in 1999 and 2000. Initial plans were to conduct trials only in 1999. As a result of severe damage caused to experiments by a hailstorm in April 1999 resulting in the loss of data collection opportunities and gaps in the data set it was decided to repeat the complete set of experiments in 2000. This enabled the generation of a complete data set during the 2000 season. This decision proved to be fortuitous as the 2000 growing season was perfect with no major experiment losses. Subsequently a complete data set was formed. The data collected from experiments conducted in 2000 forms the basis of this thesis.

3.4.1. Growth Study

A number of cultivars were evaluated at six sowing dates in each of the two years of experiments. A complete list of sowing dates and the cultivars evaluated is presented in Table 3.1. Each sowing consisted of the cultivars that were most suited to that particular sowing date. There are very few cultivars (Duff and Jackson 1997) to choose from for the early sowing dates (February, March and April) whereas there is a much larger range of hybrid cultivars for the mid to late season sowings (May, June and July). The cultivars were chosen to ensure a good cross-section of red, white and brown cultivars grown by local Queensland producers. Seed companies were canvassed for their input into the selection and suitability of the cultivars selected.

Sowing dates were treated as separate trials due to the fact that there are insufficient numbers of cultivars that can be commercially sown at any more than one sowing date. In Queensland, individual cultivars are generally very specifically adapted to sowing within a specific time slot spanning 2-3 weeks.

Table 3.1. Onion cultivars evaluated for the 1999 and 2000 Growth Study trials at Gatton Research Station (QDPI).

Sowing Date	1999	2000
February	Golden Brown Early Lockyer Brown Early Lockyer White	Golden Brown Early Lockyer Brown Early Lockyer White
March	Golden Brown Early Lockyer White Cavalier	Golden Brown Early Lockyer Brown Early Lockyer White Cavalier
April	Golden Brown Cavalier Wallon Brown	Golden Brown Cavalier Wallon Brown
May	Golden Brown Wallon Brown White Diamond Gladalan White Lefroy 1367	Golden Brown Cavalier Wallon Brown Bolero Sombrero Rio Demon
June	Golden Brown Gladiator Rio Xena White Diamond Red Rojo Lefroy 1367	Golden Brown Bolero Sombrero Gladiator Red Rojo
July	Golden Brown Gladiator Rio Xena	Golden Brown Gladiator Sombrero

All trials consisted of two replicates. The physical and practical constraints of these large field trials, including the collection of large quantities of raw data, resulted in fewer replicates than would otherwise have been necessary. For all cultivars, the plot consisted of three 10 m x 1.5 m beds each containing four rows 0.33 m apart and 10 m long. A sowing rate of 40 seed m^{-2} was used. Two of the three beds were used as the sampling plots and the third was reserved to measure light interception during the growing season. Each of the sampling beds had nine subplots (18 subplots per plot) 1 m in length marked out within the bed. These subplots consisted of only the two centre rows. This resulted in a subplot size of 0.66 m^2. The subplots were randomised throughout the two beds and numbered one to eighteen (Figure 3.4). This corresponded to the sampling order of each of the subplots. Destructive sampling occurred at fortnightly intervals commencing at approximately the 1-2 true-leaf stage. At each sampling date, five plants were removed at random from the designated subplots within each plot. Datum plants were removed from the centre (0.3 m in length) of the rows within each subplot resulting in a sampled area of 0.198 m^2. This ensured a buffer zone of 0.6 m (up to 8 plants) between each sampled area within the subplots. Only one sample was taken from each subplot.

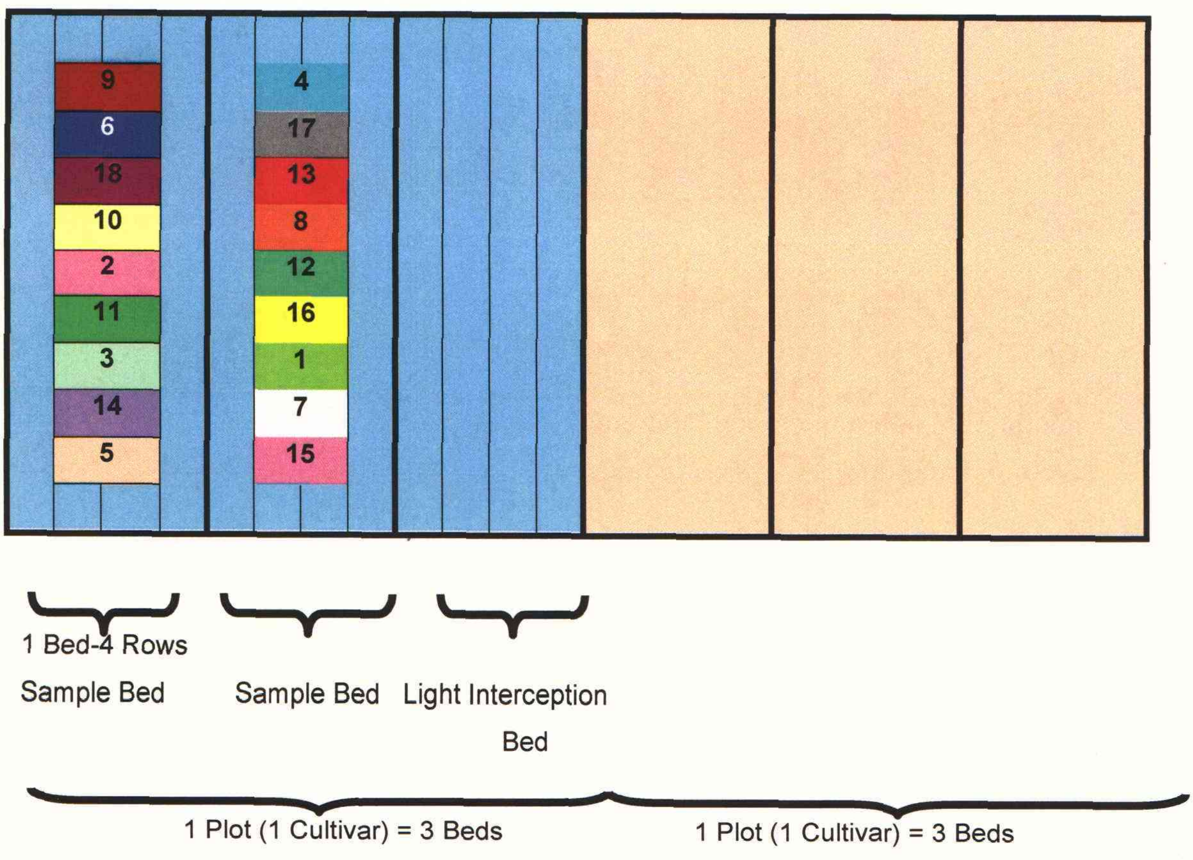

Figure 3.4. Plot layout for growth study experiments undertaken at Gatton Research Station (QDPI) during 1999 and 2000.

After careful removal, the individual plants were washed and excess moisture removed and air-dried. Data collected from the individual plants included: number of green leaves, plant height (defined as height from soil level to the tip of the longest leaf), minimum stem diameter, maximum bulb diameter, fresh and dry weights of the individual plant components, individual plant leaf area (planar impression), soluble solids (% brix), bulb dry matter (%) determination, final yield, number of centres per bulb (single centeredness), incidence of doubling and incidence of bolting. Fresh weights, dry weights and leaf areas of the plants were achieved by dissecting the individual plants into their various components (e.g. Plate 3.1) (roots, bulbs, leaves, pseudostems, flower stem). Prior to plant dissection pictorial records (Plate 3.2) of each of the cultivars at each of the sampling dates from each of the sowings were also made. The individual leaves were removed from the pseudostem at the point where they joined the leaf sheath (Robinson 1973). This is determined on the plant by a small paper-thin ligule type structure. In the early stages of plant growth (until there was a definite swelling of the plant base) the bulb was excised from the pseudostem at the soil line. At this point there is a marked lack of green pigment in the pseudostem. After the fresh weight of the individual green plant components was recorded, dry weights were determined after drying in a forced-air drying-oven at 45 °C for 48 to 72 hrs dependent on the sample size.

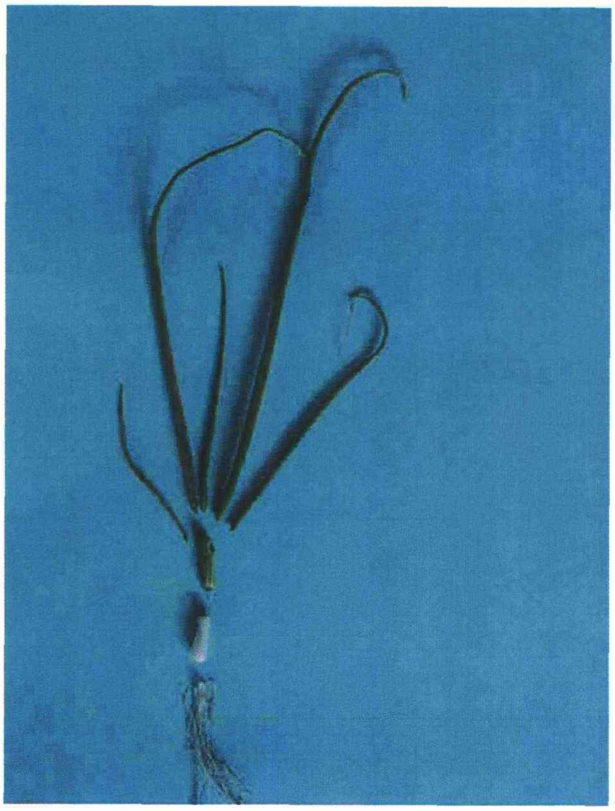

Plate 3.1. Dissected plant depicting the individual plant components used in the determination of the growth of the onion plant.

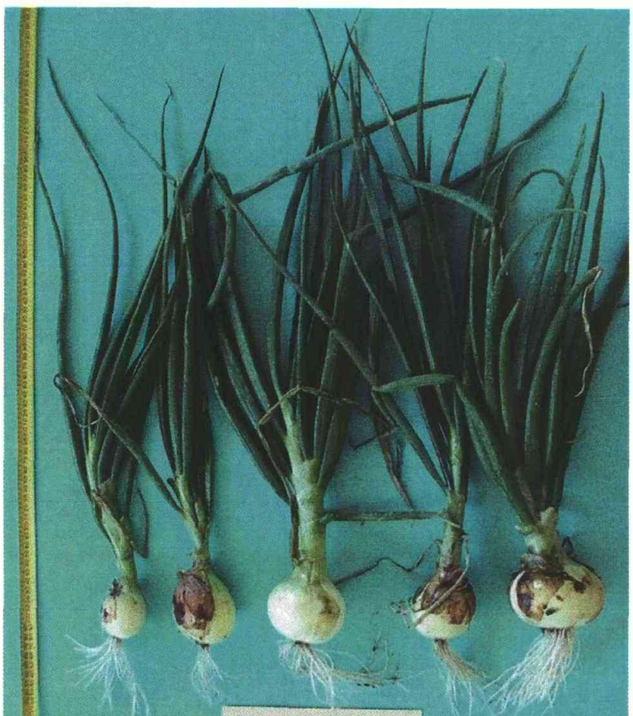

Plate 3.2. The cultivar Golden Brown sown 23rd Feb 2000 and sampled 18th July 2000 at Gatton Research Station (QDPI).

The leaf area (cm^2) of the plant was determined by assuming that the onion leaf is uniformly round. The individual leaves were then flattened and passed through a Licor® electronic leaf area meter. The actual leaf area of the plant was recorded as double the area determined by the leaf area meter as it is only recording one side of the flattened leaf.

Measurements of total soluble solids (TSS), bulb dry matter and single centeredness was only determined once the bulbs had reached a minimum fresh weight of 40 g. Each bulb was independently assessed for single centeredness and total soluble solids. The TSS was determined by removing a single 1 cm diameter core from the onion bulb at an angle of 45° from the top of the bulb through to the bottom of the bulb. Juice was extracted from the individual cores using a small garlic press and placed on the lens of an electronic refractometer (Kruss Optronic) from which a reading was taken and recorded. After the core was taken and assessed the bulb was sliced in half at the equator and assessed for single centeredness and any evidence of bolting. The bulbs were then blended in a Sunbeam Little Oscar® food processor from which two, 20 g samples were removed, weighed (fresh) and then dried in an air-forced drying-oven at 60 °C for 48 hrs. The bulb dry matter (%) was then determined.

Sampling continued until 80 % of the plants had their tops down. A final yield was determined by harvesting four, 1 m rows from each of the individual plots within the light interception plot (Figure 3.4) when the leaves were totally senesced. The bulbs were graded into their separate grade sizes (>40 mm, 40-70 mm, >70 mm, doubles and bolters), counted and then weighed.

At each general sampling date, percentage crop light interception was also recorded. This reading took place between 10 am and 2 pm on either the day of the sampling or the following day. Each bed had three permanent sites marked. These sites were used every time a reading was made. The sites were marked one in the centre of the bed and the others 2 m in from either end of the bed. The readings were measured using equipment manufactured by Monitor Sensors® (Plate 3.3). A single point light sensor was placed outside the crop to determine the total incident light on the crop. A 1 m wand with sensors along the length of it was placed inside the crop at ground level at an angle of 45^0 to the rows. Two readings were made at each of the three permanent sites: the point sensor and the sensor wand. Percentage light interception for the crop was then calculated from these data.

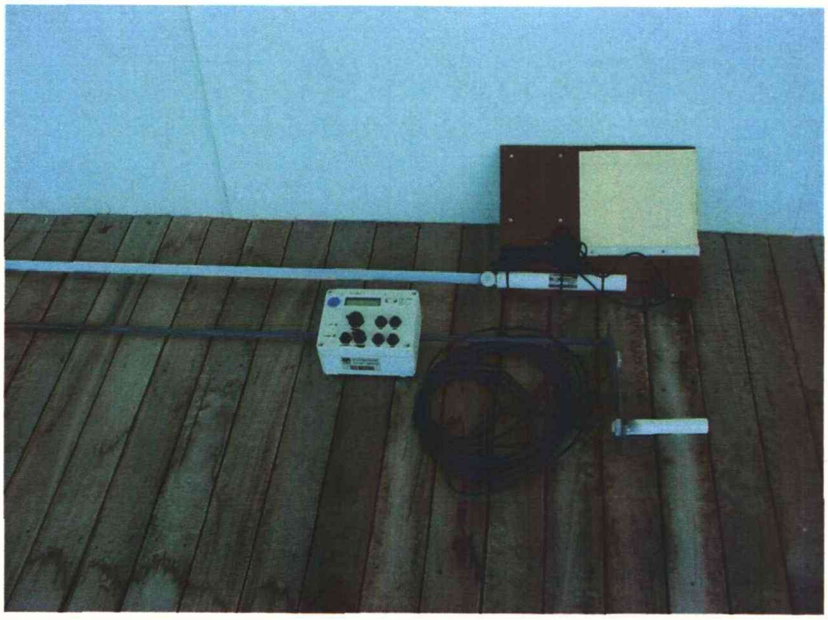

Plate 3.3. Monitor Sensors light interception equipment used to determine percentage light interception for growth study experiments at Gatton Research Station (QDPI).

3.4.2. Growth Development Study

Five cultivars (Table 3.2) were sown at fortnightly intervals commencing late February and concluding in late July during the 1999 and 2000 onion growing seasons. The aim of these trials was to determine the timing of plant growth stages and produce a chronology of when the various stages of the growth of the onion plant occurred, as affected by sowing date.

The experiments were all randomised block complete designs with four replicates. Each plot was 5 m long and contained four rows. Six plants within each plot were selected as the observation plants. These plants were selected at random from within the centre two rows of each plot and at least 0.5 m from the end of each plot. Individual plant observations commenced at emergence (hook leaf stage). Observations were recorded at 2-3 day intervals on the six individual plants to determine the following: number of green leaves; number of dead leaves; date of onset of bulbing; number of days to doubling; incidence of bolting; maturity and any other unusual occurrences (eg chimeras). Green leaves were counted as they emerged. A leaf was deemed as dead when all green colouring had disappeared. To keep track of the total number of leaves produced, every fifth leaf was tagged by placing a small bright green ribbon around the leaf. A plant was deemed to have commenced bulbing when the diameter of the bulb was twice that of the stem (Abdalla 1967). A plant was deemed to have bolted when the flower head was clearly evident. Plant maturity was determined when the top had fallen over irrespective of percentage of the top that was still green. Final bulb yield for each plant was also recorded to estimate crop yield.

Table 3.2. Cultivars and sowing dates for the growth development experiments at Gatton Research Station (QDPI).

	1999	2000
Cultivars	Golden Brown Wallon Brown Cavalier Contessa Gladiator	Golden Brown Wallon Brown Cavalier Contessa Gladiator
Sowing dates	25 February 11 March 25 march 6 April 22 April 6 May 20 May 3 June 17 June 1 July 15 July 29 July	23 February 8 March 22 March 4 April 19 April 4 May 17 May 31 May 14 June 29 June 13 July 26 July

3.5. Cultural Practices

Standard crop management practices were observed throughout the experiments and are outlined below.

3.5.1. Trial Equipment

A uniform seedbed was prepared well in advance of all experiments. This is essential to ensure maximum germination (Benjamin 1982; Finch-Savage 1986) of the seed once sown.

All experiments were sown with a small vacuum seeder (Plate 3.4) on loan from the University of Queensland, Gatton Campus horticultural field section. During the process of planting, beds were formed as a result of the imprints left in the soil by the tractor wheels (Plate 3.5).

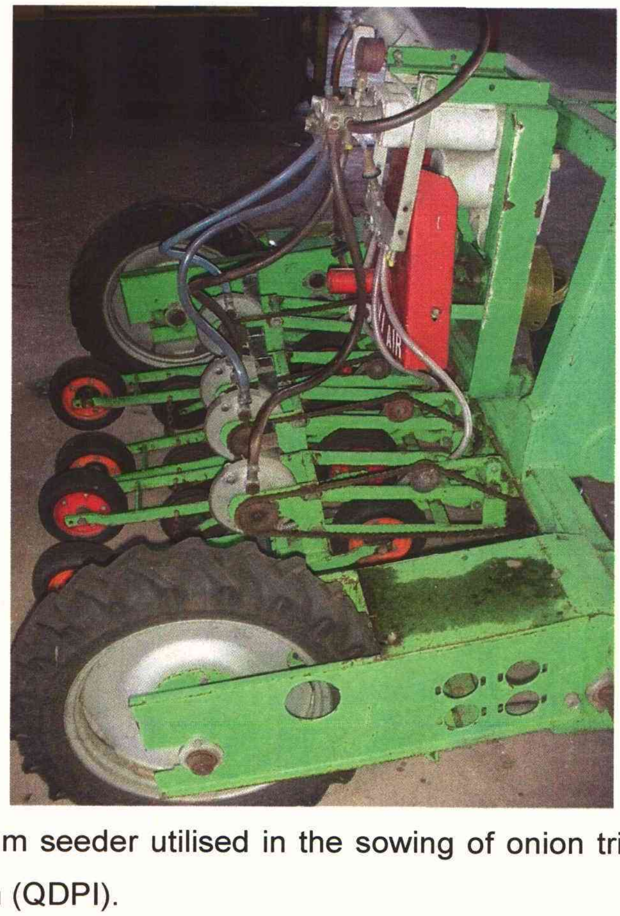

Plate 3.4. Vacuum seeder utilised in the sowing of onion trials at the Gatton Research Station (QDPI).

Plate 3.5. Onion bed formation after planting of growth and development trials at Gatton Research Station (QDPI) in 2000.

3.5.2. Irrigation

Irrigation was sourced from underground water. Underground water is the main supply of irrigation water in the Lockyer Valley. A solid set irrigation system (Plate 3.6) was used for all the onion experiments conducted during 1999 and 2000.

Plate 3.6. A solid set irrigation system similar to that used to irrigate experiments at Gatton Research Station (QDPI) during 1999 and 2000.

3.5.3. Fertiliser and Pesticide Application

Standard fertiliser and pesticide application practices were used during the management of experiments in 1999 and 2000. All experiments received a pre-plant application of Nitrophoska Blue® (N:P:K = 12.0:5.2:14.1) at a rate of 200 kg ha^{-1}. Nitrogen, as Urea (46% N), was applied at a rate of 120 kg N ha^{-1} in two subsequent applications each of 60 kg N ha^{-1}. These applications were applied as broadcast applications at six and nine weeks after sowing for all experiments during 1999 and 2000. The experiments were irrigated immediately following the nitrogen applications to ensure adequate N incorporation. Foliar zinc (Zinctrac) and boron (Bortrac) were applied at the rate of 1 L ha^{-1} and 2 L ha^{-1} respectively, at the 4-leaf stage in each experiment.

Table 3.3 outlines the applications of herbicides (H), insecticides (I) and fungicides (F) utilised to manage the various pests (if any) encountered during the experiments conducted during 1999 and 2000. During 1999 insecticides and fungicides were applied regardless of the presence of insects or fungi. Pesticides were applied in 2000 only when the level of pest infection warranted control.

Table 3.3. Pesticides utilised to control downy mildew, purple blotch, thrips and various weeds in all experiments during 1999 and 2000.

Pesticide	Rate	Number of Applications
1999		
Rogor (Dimethoate) (I)	750 ml ha^{-1}	4
Supracide (Suprathion 400) (I)	750 ml ha^{-1}	9
Dithane (Mancozeb) (F)	3 kg ha^{-1}	1
Acrobat (mancozeb+dimethomorph) (F)	2 kg ha^{-1}	9
Ridomil MZ (mancozeb+metalayxl) (F)	2.5 kg ha^{-1}	1
Fruvit (propineb+oxadixyl) (F)	2.5 kg ha^{-1}	2
Goal (Oxyfluorofen) (H)	100 ml ha^{-1}	1
2000		
Supracide (Suprathion 400) (I)	750 ml ha^{-1}	11
Rogor (Dimethoate) (I)	750 ml ha^{-1}	7
Dithane (Mancozeb) (F)	3 kg ha^{-1}	12
Goal (Oxyfluorofen) (H)	100 ml ha^{-1}	2
Roundup (Glyphosate) (H)	3 L ha^{-1}	1

3.6. Statistical Analysis

Genstat® 6 for Windows was used to carry out the analyses undertaken in this thesis.

SigmaPlot® 2001 Version 7.1 was used to plot all regression curves and other graphs used in the depiction of data collected and analysed.

CHAPTER 4

4. EFFECT OF TIME OF SOWING ON ONION GROWTH, YIELD AND YIELD COMPONENTS FOR TEN ONION (*Allium cepa* L.) CULTIVARS IN THE LOCKYER VALLEY

4.1. Introduction

Queensland onion production is centred in the Lockyer Valley and on the Darling Downs. Annual Queensland production varies between 20 000 and 25 000 tonnes, 80% of which is produced by the aforementioned regions. Producers commence sowing as early as late February, with their own maintained cultivars. Sowing continues until late June with hybrid germplasm only. In general, for the early sowing window (late February to Early April) the local germplasm (open pollinated) is particularly well adapted to the specific growing environments in the Lockyer Valley. Consequently, there are several local strains available. Selections of the local cultivars Early Lockyer White and Early Lockyer Brown are adapted to an early sowing (late Feb to late March). The cultivar Golden Brown is suited to an early to mid-season sowing window (late Feb to late April). There are two mid-season (late April to late May) local cultivars, namely, Wallon Brown and Wallon White. An extensive range of hybrids cultivars are available from commercial seed companies for sowing from early April through to late June.

Marketable yields vary according to the sowing window for a particular cultivar. An incorrect sowing date for a specific cultivar, even several days too early or too late, can result in a marketable yield reduction of as much as 50% (Duff and Jackson 1997) due to increased bolting or bulb doubling. However, Queensland growers also have access to several cultivars that produce very good marketable yields over an extended planting window (Jackson and Duff 1997).

In this chapter a number of cultivars was evaluated to determine their adaptability to sequential sowing dates. In addition, results and discussion are presented for a number of cultivars sown over a three-month period to evaluate the impact of an inappropriate sowing date on their marketable yield.

4.2. Materials and Methods

4.2.1. Treatments

Investigations were undertaken in 1999 and 2000 to evaluate time of sowing on biomass accumulation, yield and yield components of a number of cultivars at different sowing dates (Table 3.1). Only the results from the six trials carried out in 2000 are reported on. Hailstorms encountered during the 1999 season resulted in a loss of trials and, therefore, an incomplete data set. Cultivars evaluated and the sowing dates in 2000 are outlined in Table 4.1. The Queensland open-pollinated cultivar Golden Brown was evaluated in all six trials. The hybrid Cavalier was evaluated from March to May inclusive. The mid- to late-season hybrid Sombrero was evaluated in the final three sowings from May to July.

Table 4.1. Cultivars evaluated, and sowing, sampling and harvest dates for growth analysis trials during 2000.

Month	Cultivars	Sowing Date	First Sampling	Final Sampling	Final Harvest
February	Early Lockyer Brown Early Lockyer White Golden Brown	23/02/00	28/03/00	01/08/00	10/08/00
March	Cavalier Early Lockyer Brown Early Lockyer White Golden Brown	15/03/00	26/04/00	25/09/00	10/10/00
April	Cavalier Golden Brown Wallon Brown	19/04/00	06/06/00	10/10/00	25/10/00
May	Bolero Cavalier Demon Golden Brown Wallon Brown Sombrero	17/05/00	04/07/00	15/11/00	23/11/00
June	Bolero Gladiator Golden Brown Red Rojo Sombrero	20/06/00	17/08/00	27/11/00	6/12/00
July	Gladiator Golden Brown Sombrero	12/07/00	12/09/00	27/11/00	06/12/00

4.2.2. Experimental Design

Six trials were conducted in each of the 1999 and 2000 growing seasons. These trials consisted of growth evaluation trials sown at monthly intervals commencing in late February and concluding in mid-July. Trials were designed as randomised complete blocks consisting of the cultivars most suited to the particular sowing date. Individual trial design was as outlined previously in Chapter 3 (Section 3.4.1). In essence, each trial consisted of three to six cultivars with two replicates of each cultivar. Each plot consisted of two onion beds (1.5 m wide by 10 m long) with nine sub-plots per bed identified for sampling. The sub-plots were allocated at random throughout the two beds that designated each plot.

4.2.3. Yield Assessment

Data collected at fortnightly intervals included fresh weight and dry matter accumulation over time for the individual plant parts (leaves, pseudostems, bulbs, flower stems) on each sampling occasion. On each occasion 0.125 m^2 (5 plants) from each of the two replicates was harvested. The data presented are the means of ten plants for each of the sampling dates for each cultivar. At maturity, final bulb yield was also recorded for the individual plants. Two, 1 m by four-row (1.32 m^2) samples were taken from each replicate to determine final marketable yield. This resulted in two replicates per block per sowing date for final yield data analysis. These samples were taken approximately ten to twenty days after the final sampling date. This harvest occurred when all green leaf had completely senesced. The bulbs harvested were divided into their individual yield grade categories, namely, picklers (bulb < 40 mm diameter), No. 1 Grade (bulb 40-70 mm diameter), No. 1 Large (bulb > 70 mm diameter), doubles and bolters.

4.2.4. Bulb Soluble Solids Concentration (% brix)

Measurements of total soluble solids (TSS) were determined once the bulbs had reached an individual fresh weight of 40 g. The TSS was determined for each bulb by removing a single 1 cm diameter core from the bulb at an angle of 45° from the top of the bulb through to the bottom of the bulb. Juice was extracted from the individual cores using a small garlic press and placed on the lens of an electronic refractometer from which a reading was taken and recorded. This procedure was undertaken for all cultivars at each sampling from the designated start point.

4.2.5. Harvest Index

The harvest index (%) for each cultivar was determined utilising individual plant data collected at the final sampling date for each sowing. It was calculated from the measurements for bulb dry weight yield and the total plant dry weight yield (Charles-Edwards 1982) (excluding roots) as follows:

$$\frac{\text{Bulb Dry Weight}}{\text{(Green Leaf Dry Weight+Pseudostem Dry Weight+Bulb Dry Weight)}} \times 100$$

4.2.6. Data Analysis

Data for all treatments were subject to a one-way analysis of variance using Genstat for Windows Version 6.1 Statistical Software (Lawes Agricultural Trust). Means were separated using Fishers Protected LSD at $p<0.05$. As a result of the small number of replications (Section 3.4) the significance or otherwise of the results is not presented for any data in this chapter.

All graphs were created using SigmaPlot 2001 for Windows Version 7.101 (SPSS Inc).

4.3. Results

4.3.1. Dry Matter Accumulation

Dry matter accumulation for the individual plant parts for each sowing is shown in Figures 4.1 to 4.6. These data are the mean for each of the sampling dates for each cultivar (ten plants).

4.3.1.1. February

Bulb dry weight (Figure 4.1 C) continued to increase for all cultivars until the final harvest. The cultivar Early Lockyer White produced the highest final bulb dry matter (25.14 g). At each sampling the bulb dry weight per plant (Figure 4.1 C) of the cultivars Early Lockyer White and Brown was always greater than that of the cultivar Golden Brown. The cultivar Golden Brown produced a greater maximum green leaf (8.25 g) and pseudostem (3.85 g) dry weight per plant than either of the other cultivars.

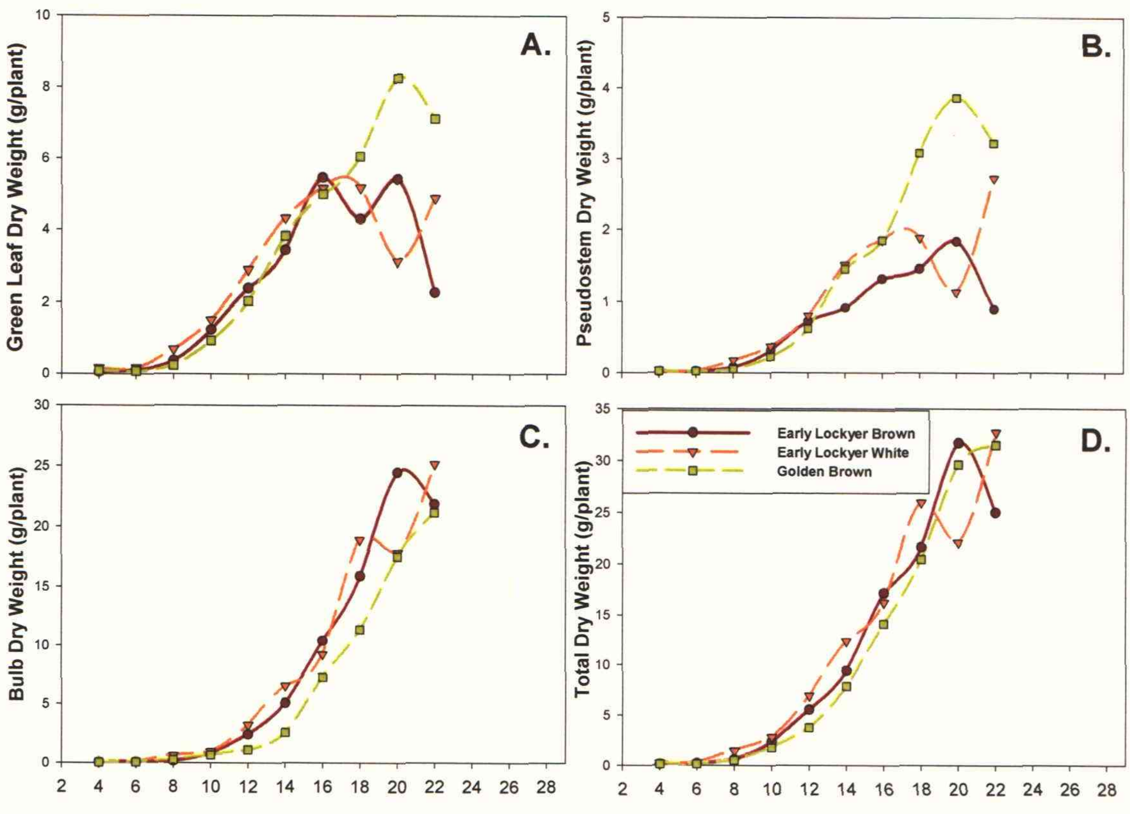

Figure 4.1. Dry weight (g plant^{-1}) accumulation of individual plant components and total for three cultivars sown on 23rd February 2000.

4.3.1.2. March

The three local open-pollinated cultivars matured four weeks earlier than the hybrid, Cavalier, a greater maximum green leaf dry matter per plant (16.36 g) than that of the other cultivars. The open-pollinated cultivars were mature at 24 weeks. At this time, Golden Brown produced a greater bulb dry weight per plant than that of Cavalier and Early Lockyer Brown. Cavalier produced a greater final bulb dry weight (47.22 g) than any of the other cultivars. The cultivar Cavalier produced a larger pseudostem (7.63 g) compared to the other cultivars. At 24 weeks, Cavalier and Golden Brown produced a greater total dry weight per plant than that of the other cultivars. Cavalier went on to produce a final total dry weight per plant greater than that of all the other cultivars.

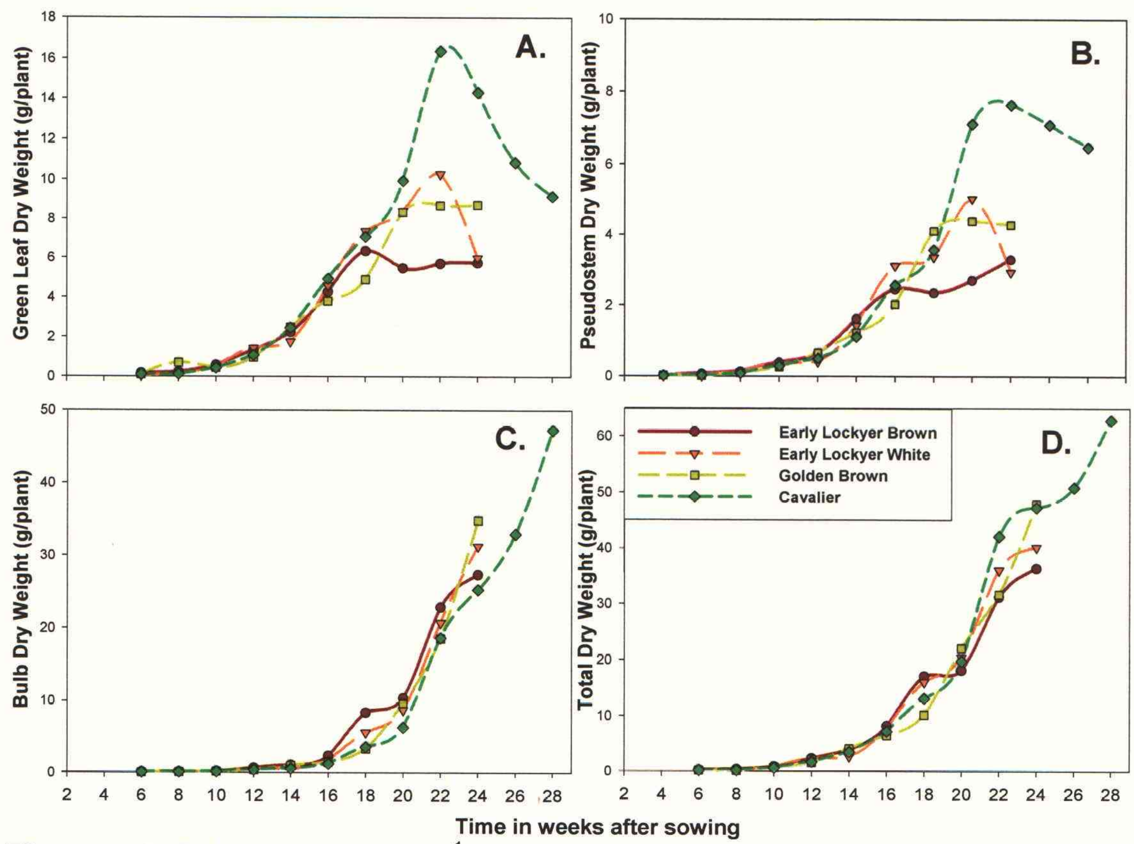

Figure 4.2. Dry weight (g plant^{-1}) accumulation of individual plant components and total for four cultivars sown on 15th March 2000.

4.3.1.3. April

The cultivars Cavalier and Wallon Brown produced greater maximum green leaf dry weights per plant than that of Golden Brown. The hybrid cultivar Cavalier (35.53 g) produced a higher dry weight per bulb than that of Wallon Brown and Golden Brown (22.8 g and 26.31 g respectively). Wallon Brown and Golden Brown produced bolters (seed stems) (Figure 4.3 D). Cavalier produced a greater pseudostem dry weight per plant than that of Golden Brown. There were differences between cultivars in total plant dry.

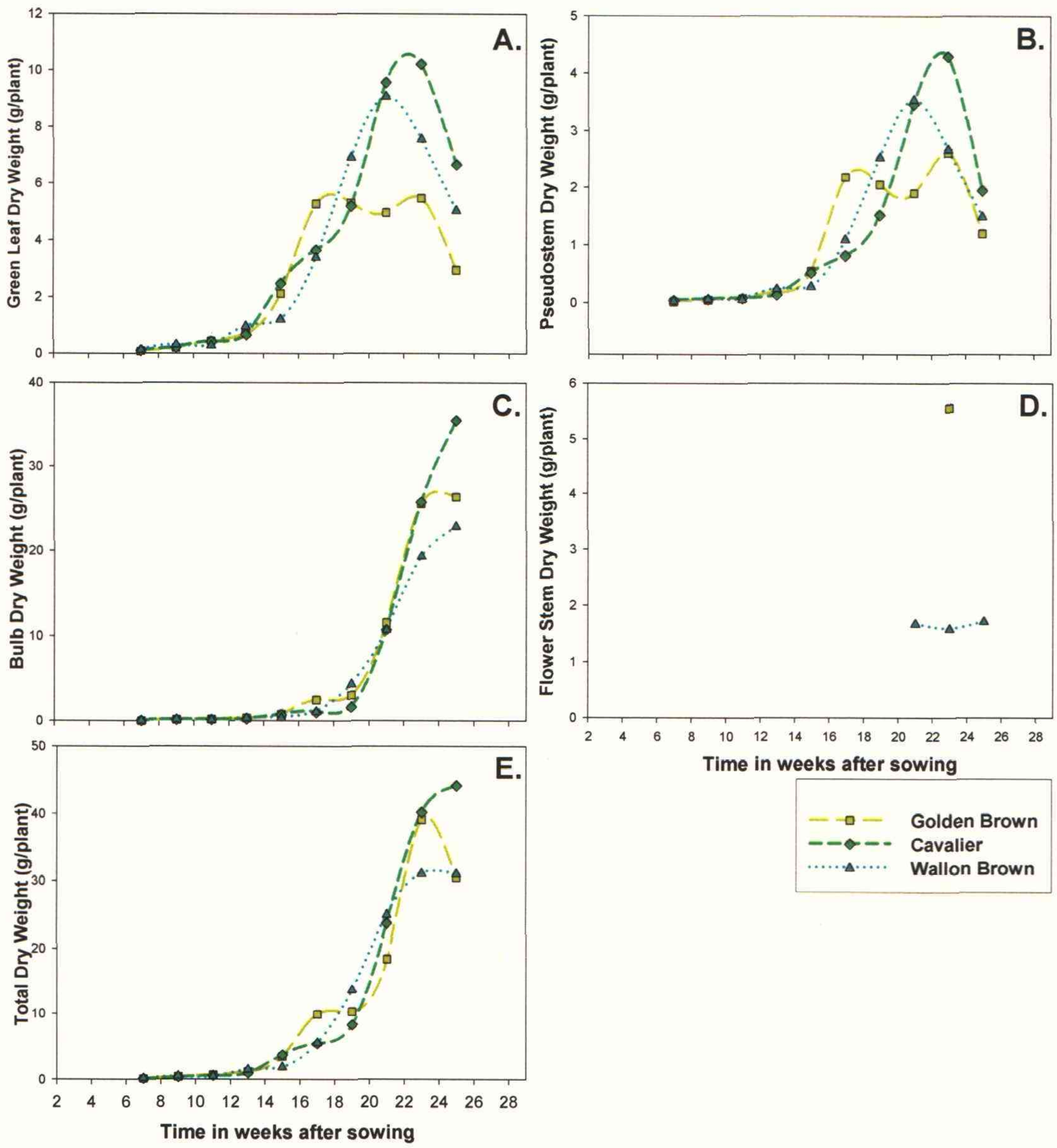

Figure 4.3. Dry weight (g plant^{-1}) accumulation of individual plant components and total for three cultivars sown on 19th April 2000

4.3.1.4. May

The F1 cultivars Demon and Sombrero matured four to five weeks later than the other cultivars. Demon produced a greater green leaf (8.60 g) and pseudostem (2.50 g) dry weight per plant than that of the other cultivars. At 19 weeks after sowing the cultivar Cavalier produced a greater bulb dry weight per plant than that of the other cultivars. Due to the late maturity of the cultivars Demon and Sombrero they produced the highest dry weight per bulb (27.49 g and 24.48 g respectively). This equated to a bulb dry weight per plant increase of 87% and 77% for Demon and Sombrero respectively compared to their bulb dry weight at the same time as the final sampling for the other four cultivars. At 21 weeks after sowing Demon produced a greater total dry weight per plant than that of all cultivars except Cavalier. An additional two weeks growth for Demon and Sombrero resulted in total dry weight increase of 32% and 39% respectively compared to the other four cultivars.

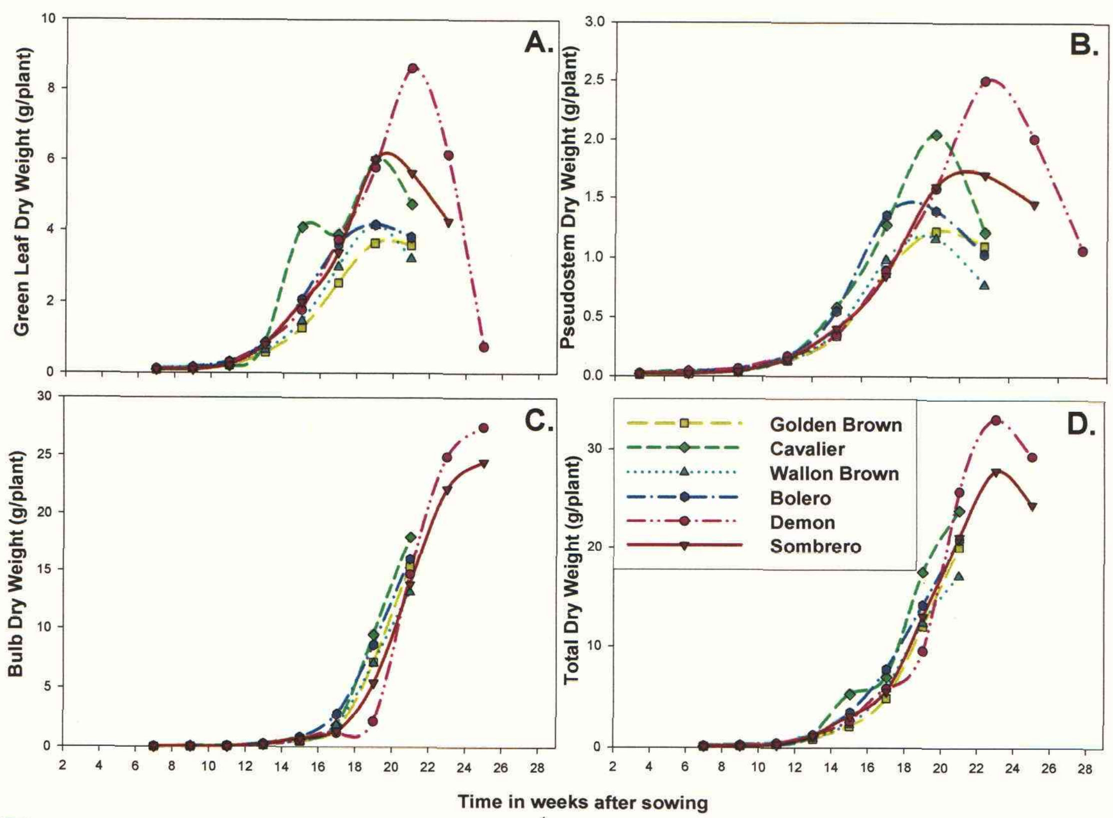

Figure 4.4. Dry weight (g plant^{-1}) accumulation of individual plant components and total for six cultivars sown on 17th May 2000.

4.3.1.5. *June*

The maturity of the cultivars varied. At 18 weeks Bolero and Sombrero were mature followed by Golden Brown at 20 weeks and Gladiator and Red Rojo at approximately 22 weeks (Figure 4.5 A). At 18 weeks all cultivars had produced their maximum green leaf dry weight. At this time Gladiator produced the maximum green leaf dry weight per plant (6.33 g). Pseudostems were quite small with a maximum dry weight per plant not exceeding 2.0 g for any cultivar. At 20 weeks after sowing Gladiator, Bolero and Red Rojo produced greater bulb dry weights per plant than Golden Brown and Sombrero. The maximum final bulb dry weight (22.79 g) per plant was produced by Gladiator.

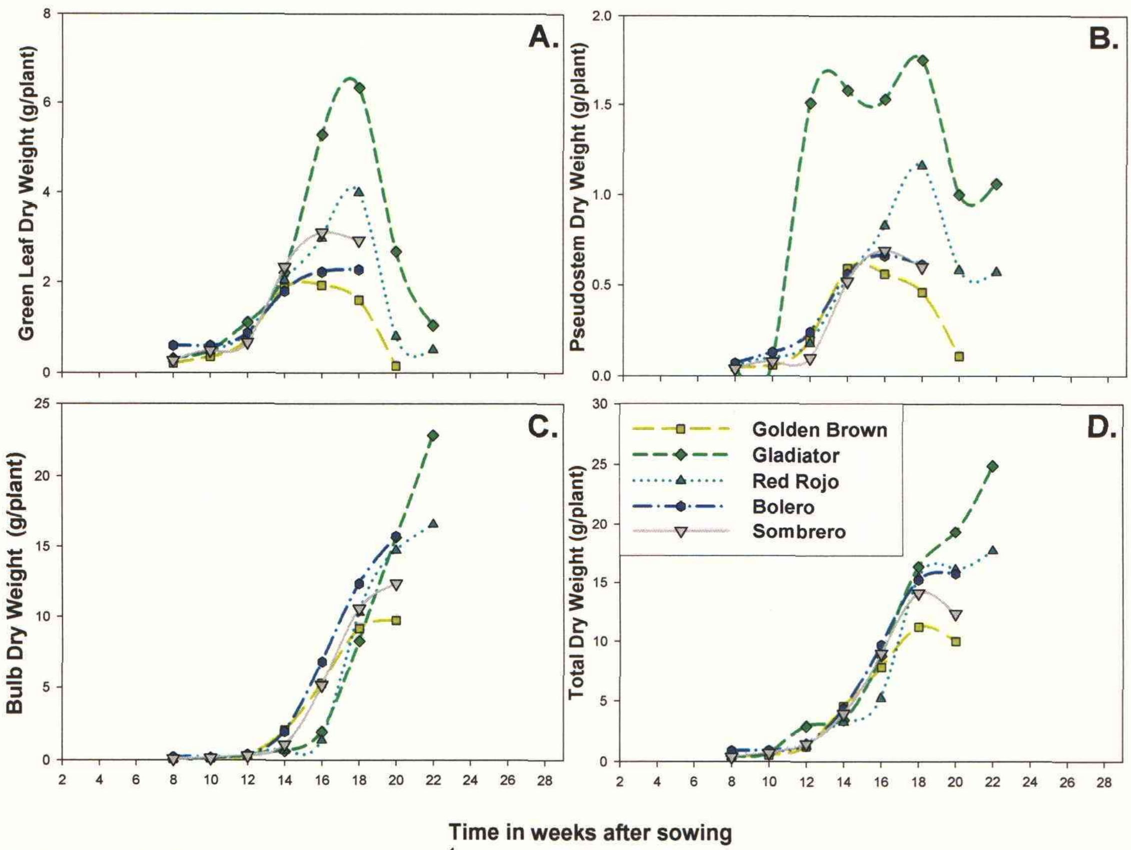

Figure 4.5. Dry weight (g plant^{-1}) accumulation of individual plant components and total for five cultivars sown on 20th June 2000.

4.3.1.6. July

Golden Brown and Sombrero produced small plants as indicated by their small dry weights for both green leaf and pseudostem. After reaching its maximum green leaf dry weight (Figure 4.6 A), the cultivar Sombrero, rapidly senesced. Gladiator produced a greater dry weight in each of the plant components than that of the other cultivars. Sombrero produced a greater green leaf and bulb dry weight per plant than that of Golden Brown. Total plant dry weight for all cultivars (Figure 4.6 D) continued to increase due to the continuous increase in bulb dry weight (Figure 4.6 C)

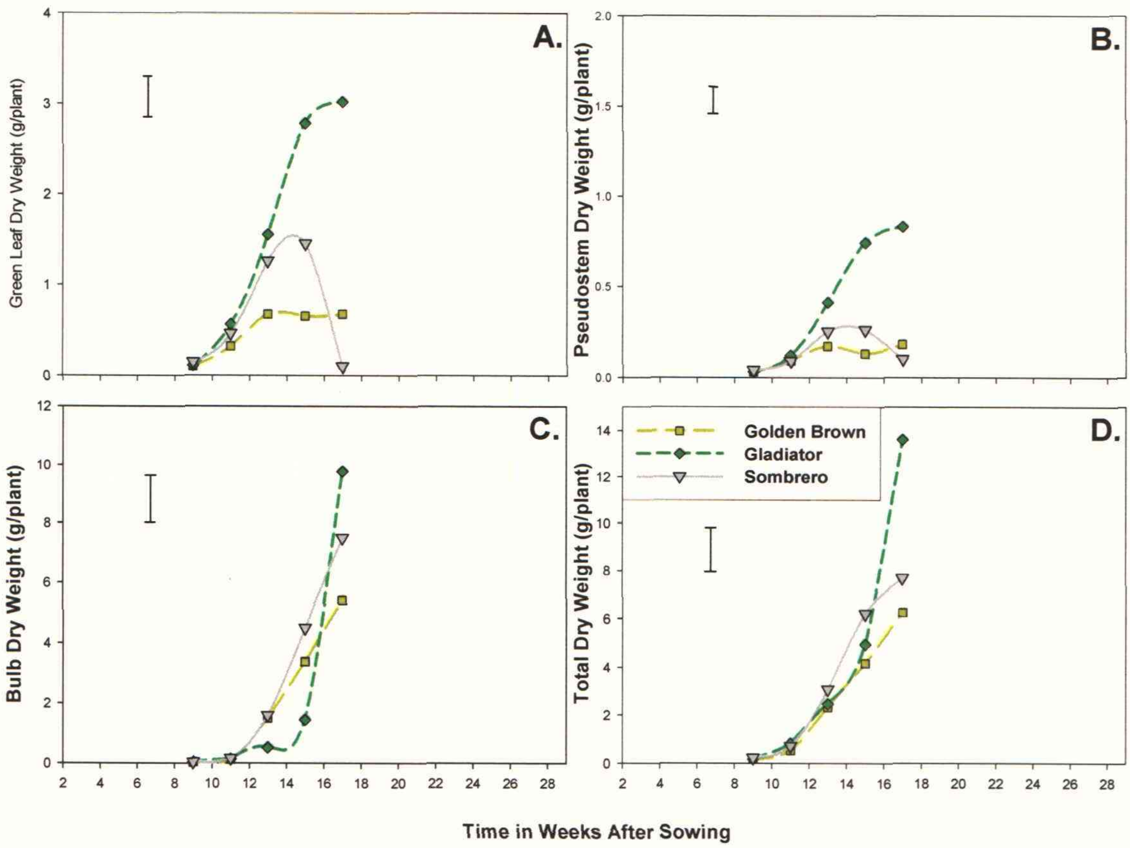

Figure 4.6. Dry weight (g plant^{-1}) accumulation of individual plant components and total for three cultivars sown on 12th July 2000.

4.3.2. Harvest Index

Data on harvest index (%) for all cultivars at each sowing date are presented in Figure 4.7. The harvest index varied between 67.2% for Golden Brown in February to 91.4% for Red Rojo in June. For the February sowing the cultivars had differing harvest indices with a greater maximum of 87.4% for Early Lockyer Brown than that of 67.2% for Golden Brown. The four cultivars in the March sowing all had very similar harvest indices (72.8 to 77.8%). The greatest harvest indices occurred in the June sowing when, with the exception of Sombrero, all cultivars achieved a harvest index of greater than 80%. Red Rojo produced a greater harvest index than that of all other cultivars in the June sowing.

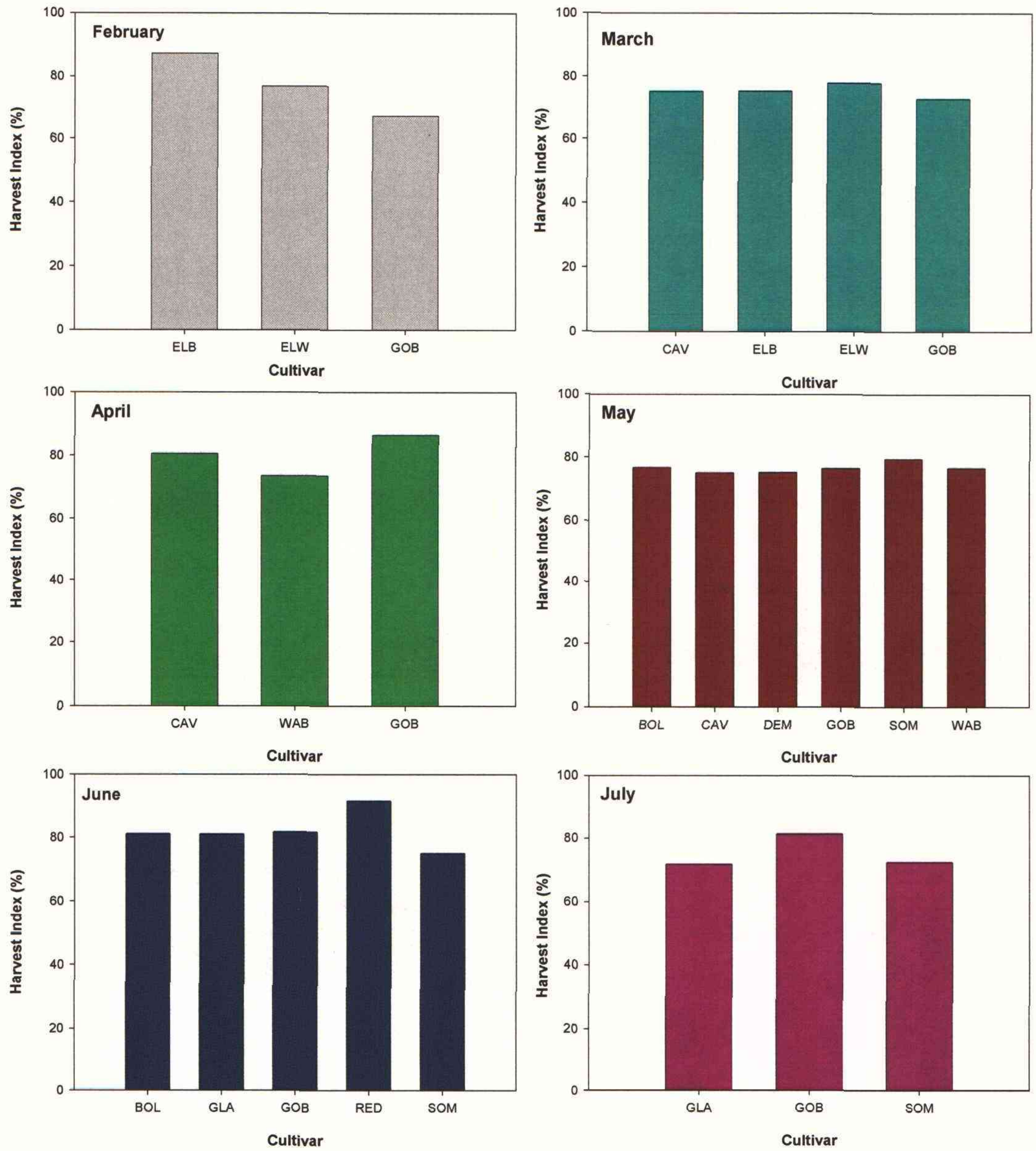

Figure 4.7. Harvest index of several cultivars sown at monthly intervals during 2000. (ELB – Early Lockyer Brown, ELW – Early Lockyer White, GOB – Golden Brown, CAV – Cavalier, WAB – Wallon Brown, COL – Bolero, DEM – Demon, SOM – Sombrero, GLA – Gladiator, Red – Red Rojo).

The cultivar Golden Brown was included in all sowings. There was a trend for the harvest index to increase for this cultivar as the sowing date moved into the cooler months (Table 4.2). The growth and development of this cultivar will be investigated in greater detail in future chapters.

Table 4.2 The harvest index (%) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

Sowing Date	*February*	*March*	*April*	**May**	**June**	**July**
Harvest Index	67.2	72.8	86.4	76.6	81.6	81.3

There did not appear to be any trend over three successive sowings (May-July) for Cavalier but the harvest index for the cultivar Sombrero over March-May decreased from 79.6% to 72.4% as the sowing date progressed.

4.3.3. Yield

4.3.3.1. February

Individual marketable final yield components are presented in Figure 4.8. For the pickler and No. 1 Grade categories the yield produced was very small. Early Lockyer Brown produced a substantially greater No. 1 Large Grade yield (38.8 t ha^{-1}) than Golden Brown (20.7 t ha^{-1}). Early Lockyer Brown (41.7 t ha^{-1}) also produced a substantially greater total marketable yield than Golden Brown (23.3 t ha^{-1}).

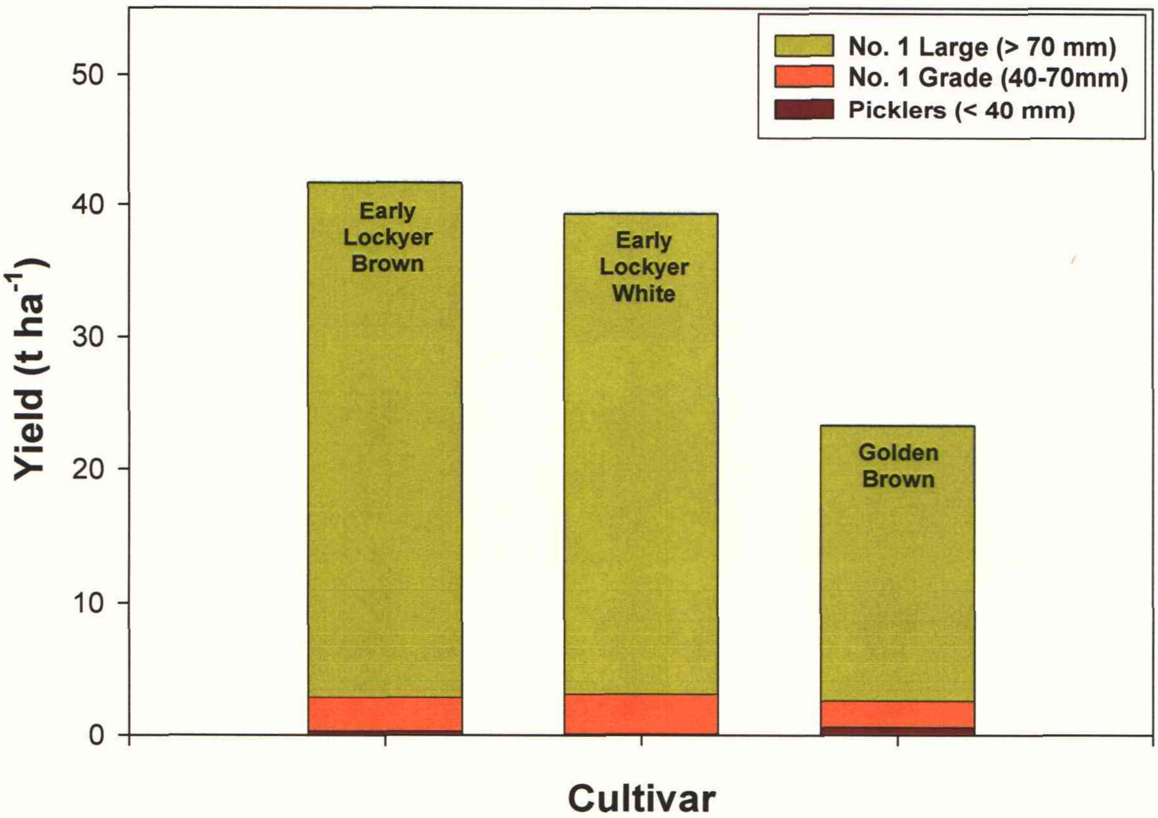

Figure 4.8. Final marketable yield (t ha^{-1}) for three cultivars sown on 23rd February 2000.

Sixty-eight percent of the total yield (Figure 4.9) of Golden Brown was double bulbs (50.6 t ha^{-1}). Forty-eight percent of the total yield of Early Lockyer White and 24% of the total yield of Early Lockyer Brown was unmarketable (double bulbs and bolters).

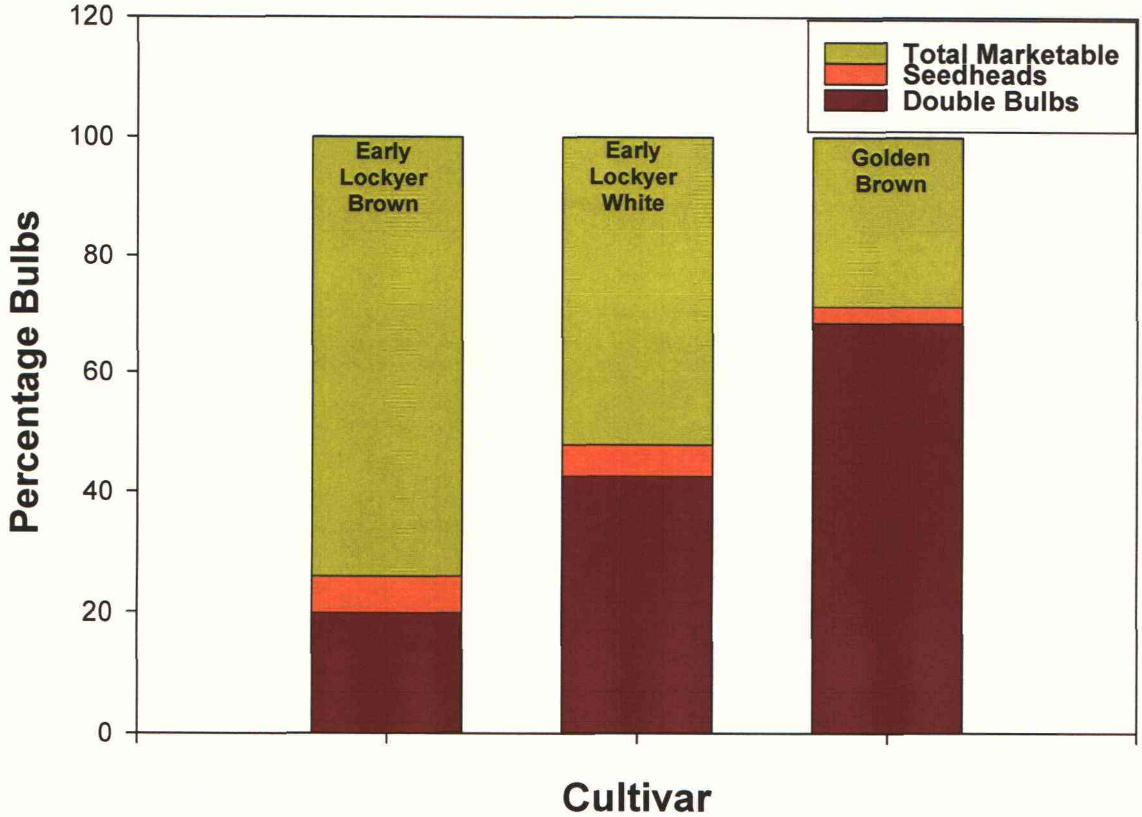

Figure 4.9. Distribution by weight of yield, marketable and unmarketable (double bulbs and bolters) for three cultivars sown on 23rd February 2000.

4.3.3.2. March

Individual final yield (marketable) components are presented in Figure 4.10. There were significant ($p<0.05$) effects of cultivar for the No. 1 Grade Large and total marketable yield. The cultivar Cavalier (78.4 t ha^{-1}) produced a greater No. 1 Large Grade than all other cultivars. Golden Brown (39.5 t ha^{-1}) produced a lower total marketable yield than all other cultivars.

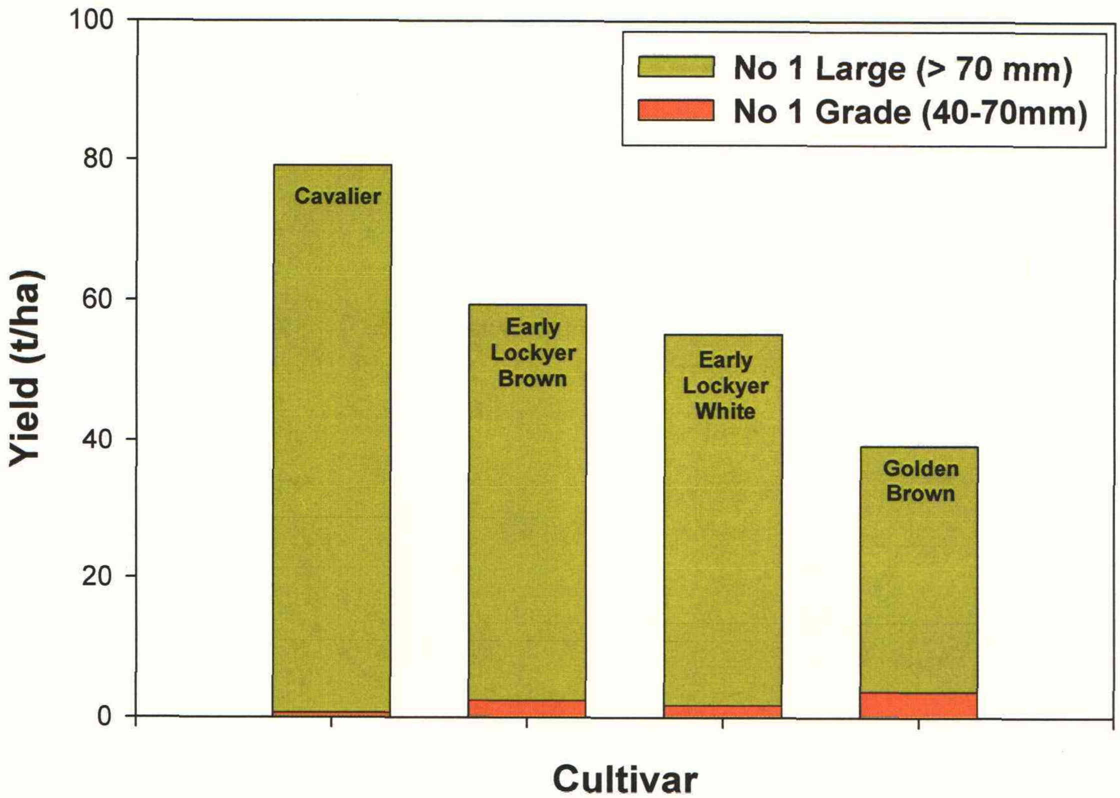

Figure 4.10. Final marketable yield (t ha^{-1}) for four cultivars sown on 15th March 2000.

There was an effect of cultivar on the proportion of bolters, doubles and total unmarketable bulbs (Figure 4.11). Golden Brown produced a higher proportion of doubles than the other cultivars. There was a difference between cultivars for the bolters and total unmarketable yield. Early Lockyer White and Early Lockyer Brown (22% and 20% respectively) produced a greater proportion of bolters than Cavalier (0.0%). Cavalier produced a lower total unmarketable yield than Golden Brown and Early Lockyer White.

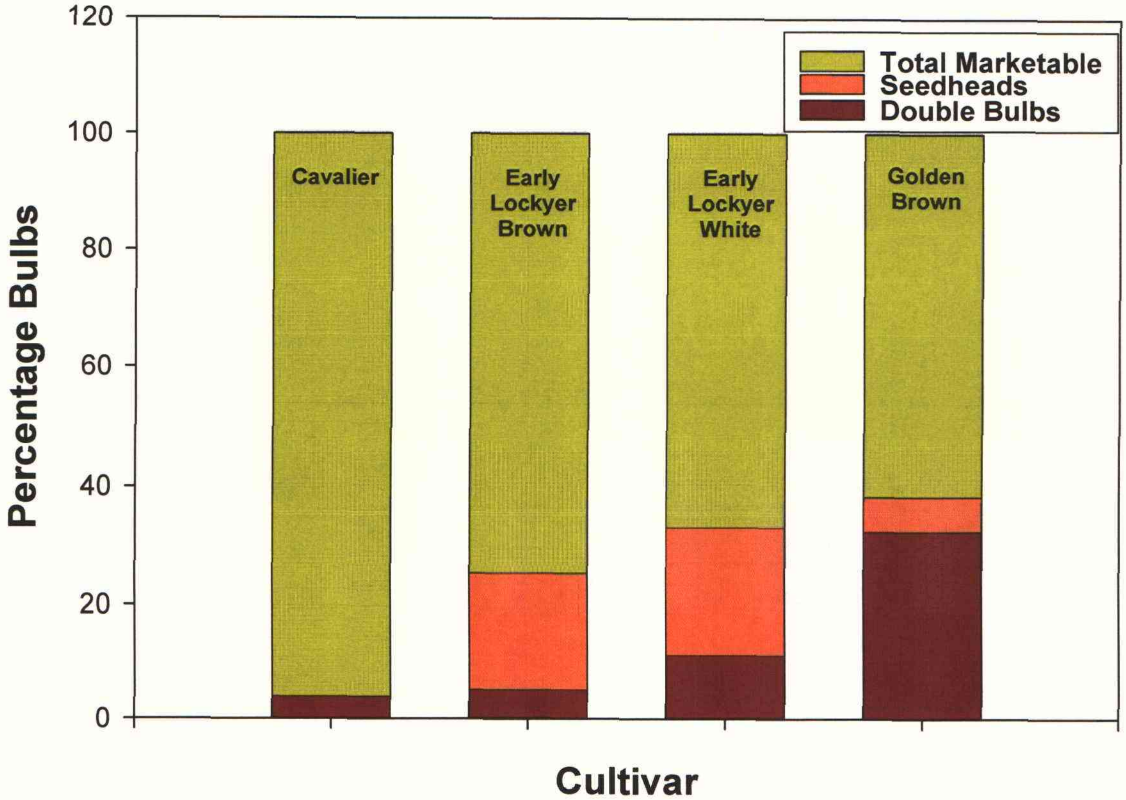

Figure 4.11. Distribution by weight of yield, marketable and unmarketable (double bulbs and bolters), for four cultivars sown on 15th March 2000.

4.3.3.3. April

Individual final marketable yield components are presented in Figure 4.12. Golden Brown produced a higher No. 1 Large Grade yield (75.7 t ha^{-1}) and total marketable yield (82.29 t ha^{-1}) than Cavalier (60.10 and 64.53 t ha^{-1} respectively) and Wallon Brown (60.90 t/ha and 69.82 t ha^{-1} respectively).

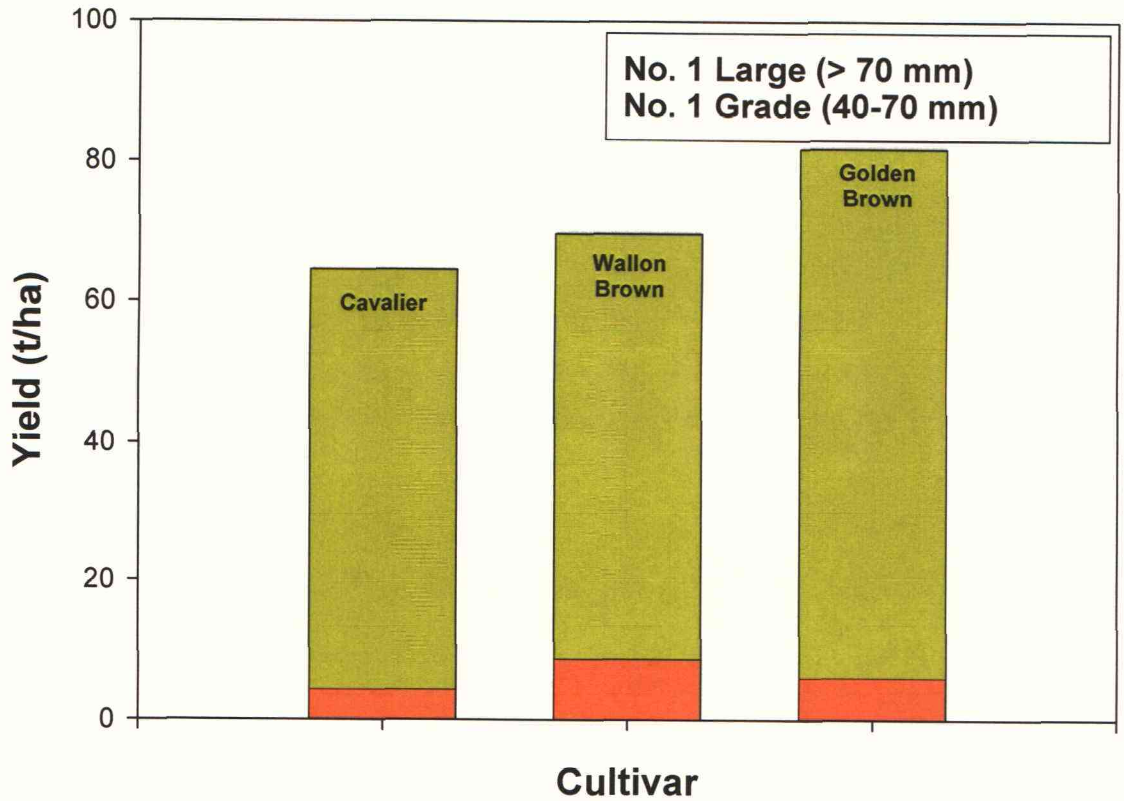

Figure 4.12. Final marketable yield (t ha^{-1}) for three cultivars sown on 19th April 2000.

Wallon Brown produced a considerably higher proportion of bolters (15%) than Cavalier (3%) and Golden Brown (4%). The production of double bulbs was low in all cultivars compared to previous sowings (Figure 4.13).

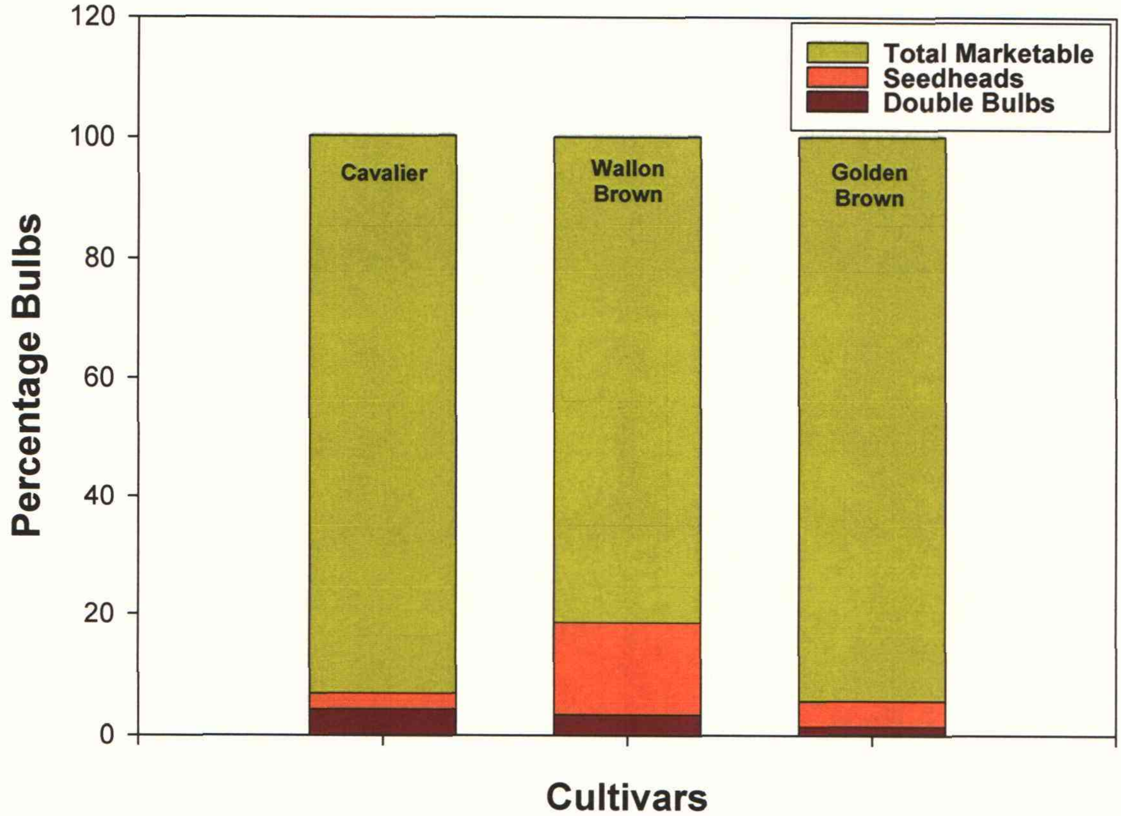

Figure 4.13. Distribution by weight of yield, marketable and unmarketable (double bulbs and bolters), for three cultivars sown on 19th April 2000.

4.3.3.4. May

Individual final marketable yield components are presented in Figure 4.14. Sombrero produced a higher No. 1 Grade Large and total yield (102.5 t ha^{-1} and 106.61 t ha^{-1} respectively) than all cultivars except Cavalier. Golden Brown (18.65 t ha^{-1}) produced a higher No. 1 Grade yield than the other three cultivars Demon (7.38 t ha^{-1}), Cavalier (6.00 t ha^{-1}) and Sombrero (3.8 t ha^{-1}).

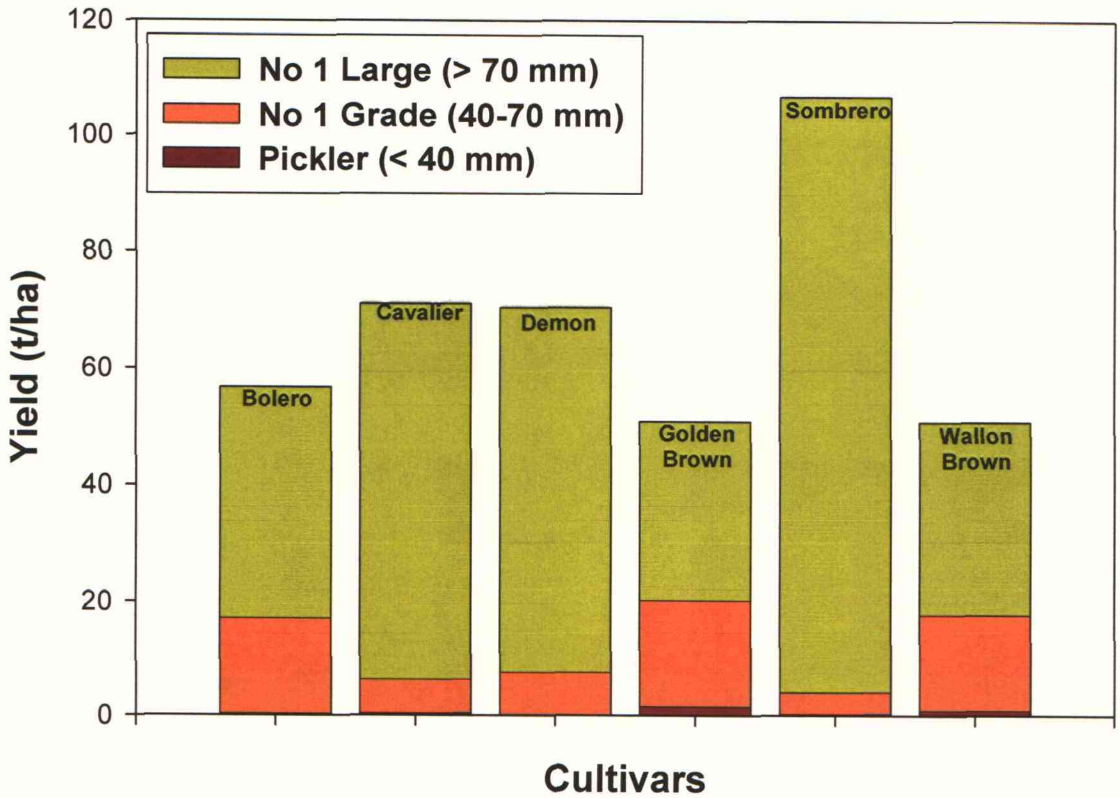

Figure 4.14. Final marketable yield (t ha^{-1}) for six cultivars sown on 17^{th} May 2000.

The production of unmarketable bulbs (doubles and bolters) was very low and considered insignificant for all cultivars in this planting. Demon produced the greatest yield of doubles bulbs and bolters (2.6 and 0.7 t ha^{-1} respectively).

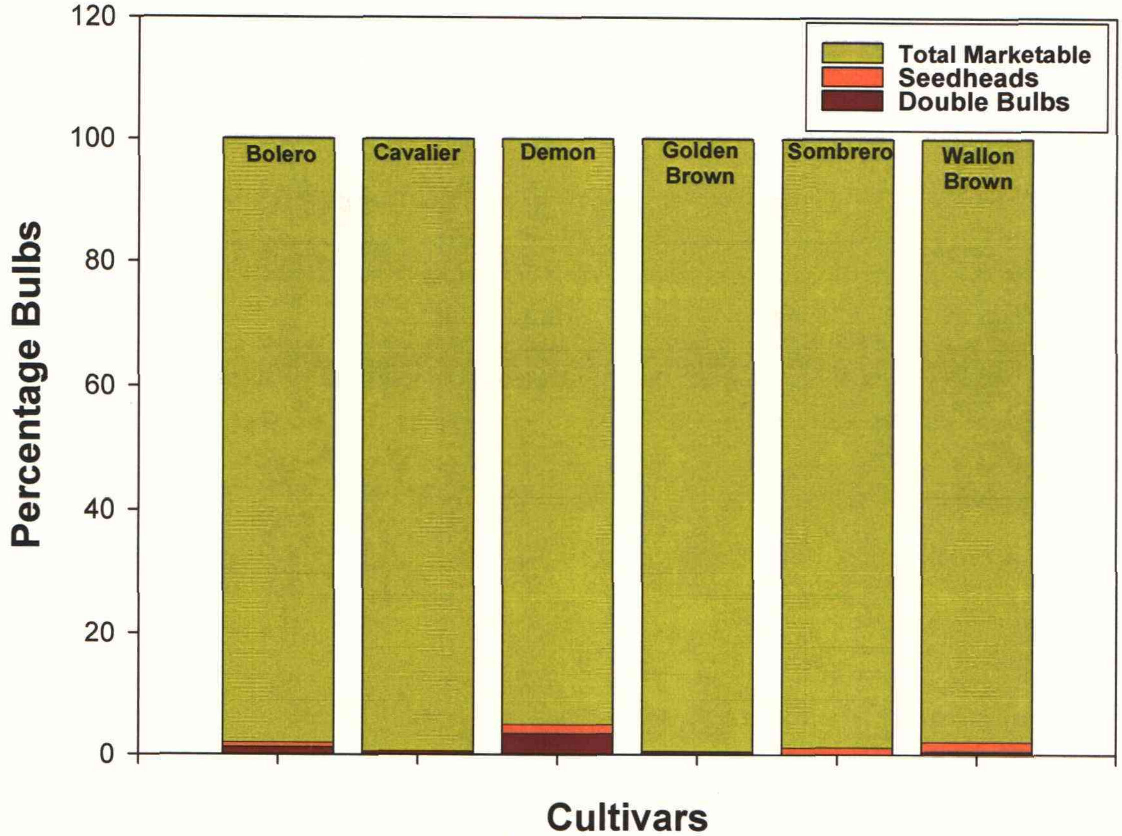

Figure 4.15. Distribution by weight of yield, marketable and unmarketable (double bulbs and bolters), for six cultivars sown on 17th May 2000.

4.3.3.5. June

Individual final marketable yield components are presented in Figure 4.16. The cultivars Bolero and Gladiator produced a greater No. 1 Grade yield than other cultivars. Sombrero produced a greater No. 1 Large Grade yield and a greater total marketable yield than all other cultivars.

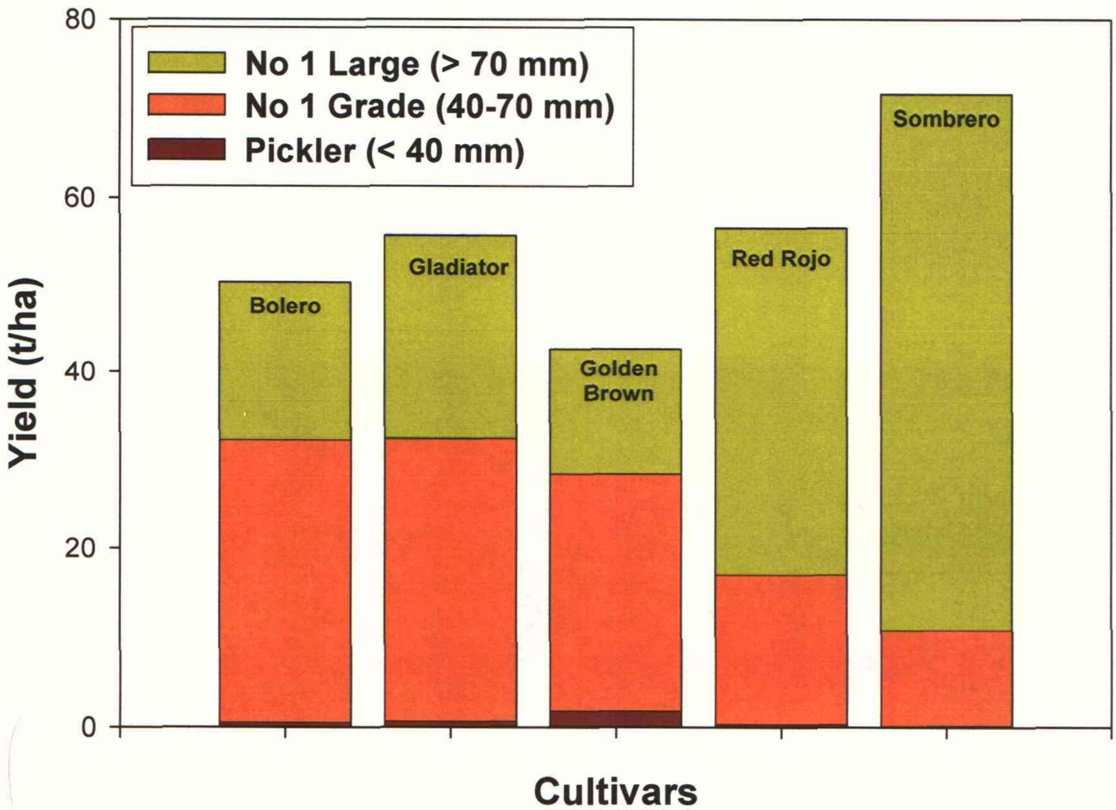

Figure 4.16. Final marketable yield (t ha^{-1}) for five cultivars sown on 10th June 2000.

Only three cultivars produced unmarketable bulbs (doubles only), namely, Gladiator, Golden Brown and Red Rojo (Figure 4.17). Gladiator (6%) produced a greater proportion of double bulbs than all other cultivars.

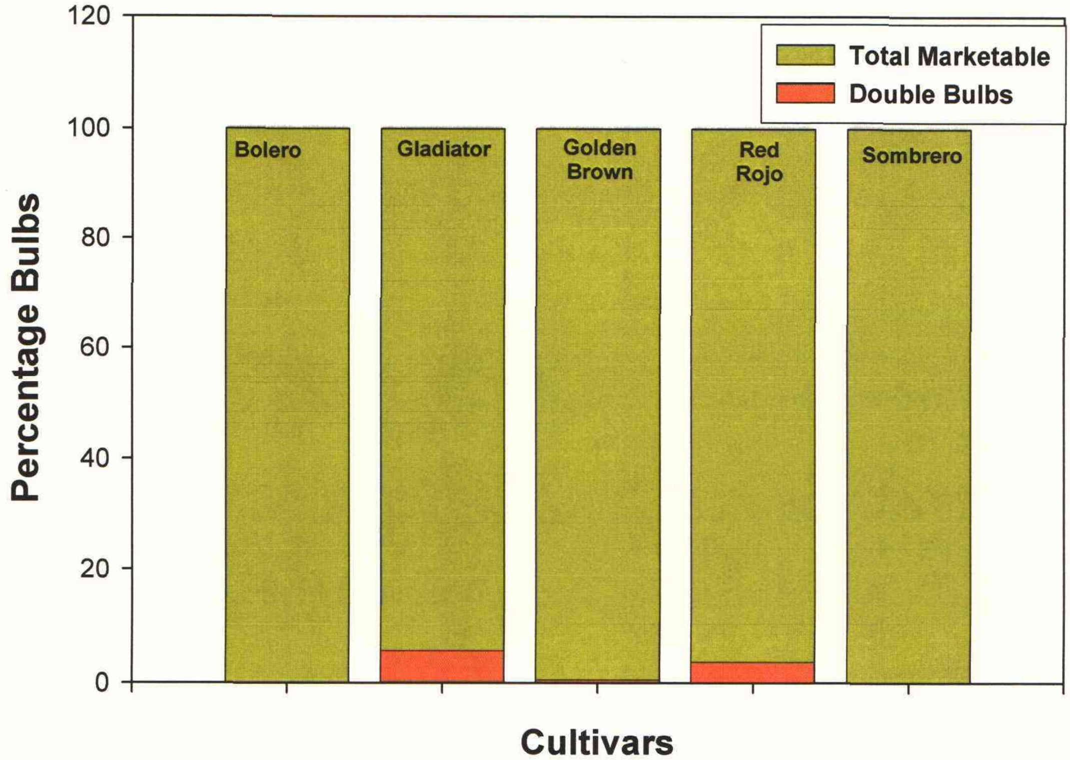

Figure 4.17. Distribution by weight of yield, marketable and unmarketable (double bulbs), for five cultivars sown on 10th June 2000.

4.3.3.6. July

Individual final yield (marketable and unmarketable) components are presented in Figure 4.18. Gladiator and Sombrero produced a greater total marketable yield than Golden Brown.

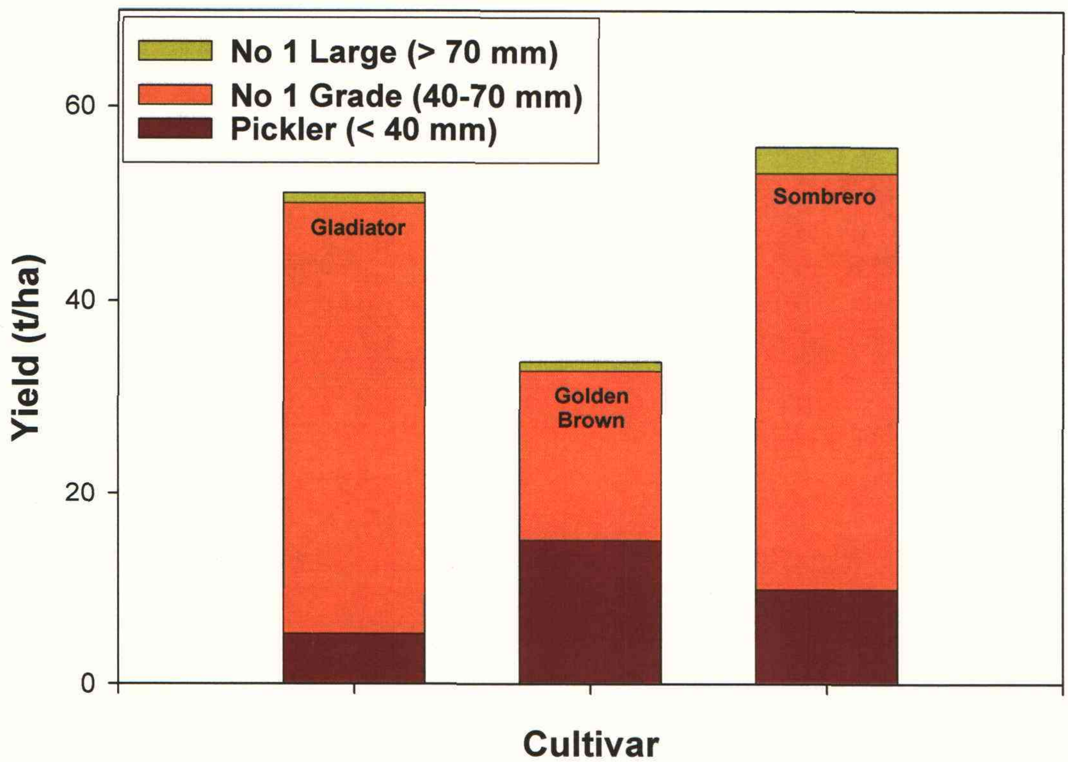

Figure 4.18. Final marketable yield (t ha^{-1}) for three cultivars sown on 12^{th} July 2000.

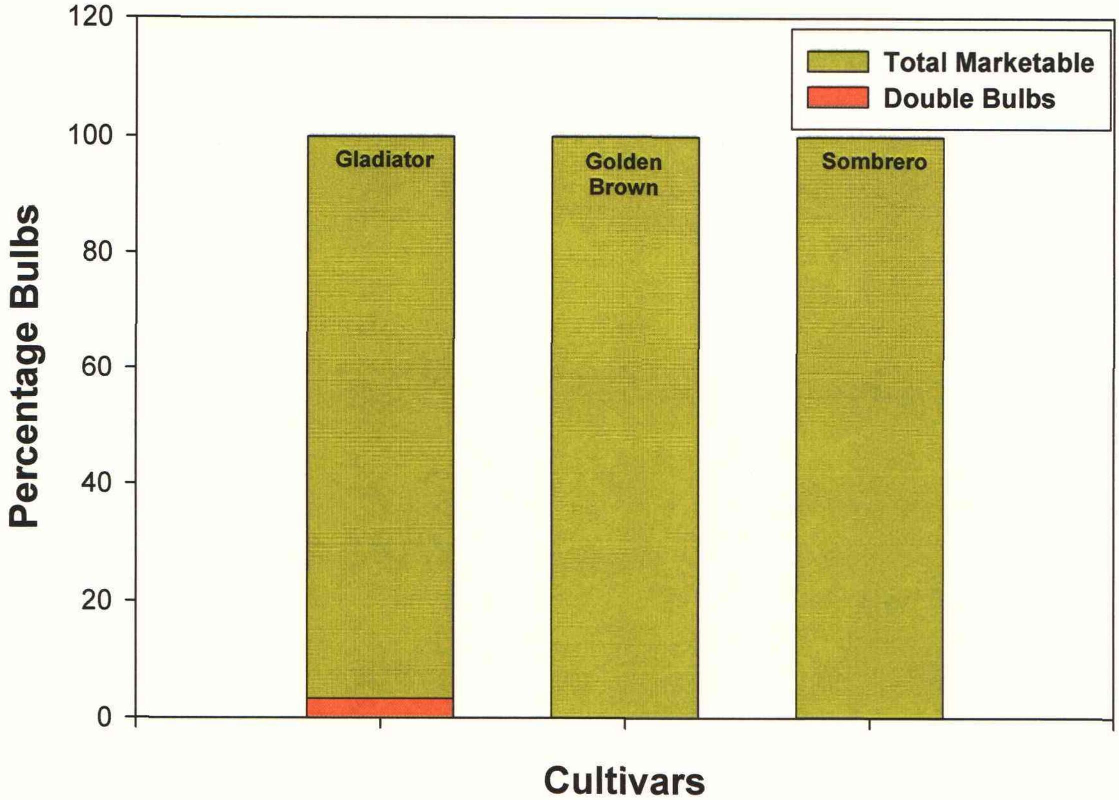

Figure 4.19. Distribution by weight of yield, marketable and unmarketable (double bulbs), for three cultivars sown on 12th July 2000.

All three cultivars produced minor quantities of unmarketable bulbs (doubles only) which ranged between 0.1 and 3.4 percent (Figure 4.19). Gladiator (3.4%) produced a greater proportion of double bulbs than the other cultivars (0.1% for Golden Brown and 0.2% for Sombrero).

4.3.4. Bulb Sugar Content (Brix (%))

Soluble solid content of bulbs from bulbing to harvest for the cultivars sown at monthly intervals from February to July is illustrated in Figures 4.20 to 4.25.

During the February sowing, the brix levels (%) of the cultivar Golden Brown (GOB) increased from 7.6% at 12 weeks after sowing to 9.7% at 20 weeks after sowing. With the exception of a sudden increase at 20 weeks for Early Lockyer Brown (ELB), the brix (%) levels of ELB and Early Lockyer White (ELW) rose very slightly as the bulbs matured. ELB produced a greater brix level at 20 weeks than at any other time during the growth of this cultivar.

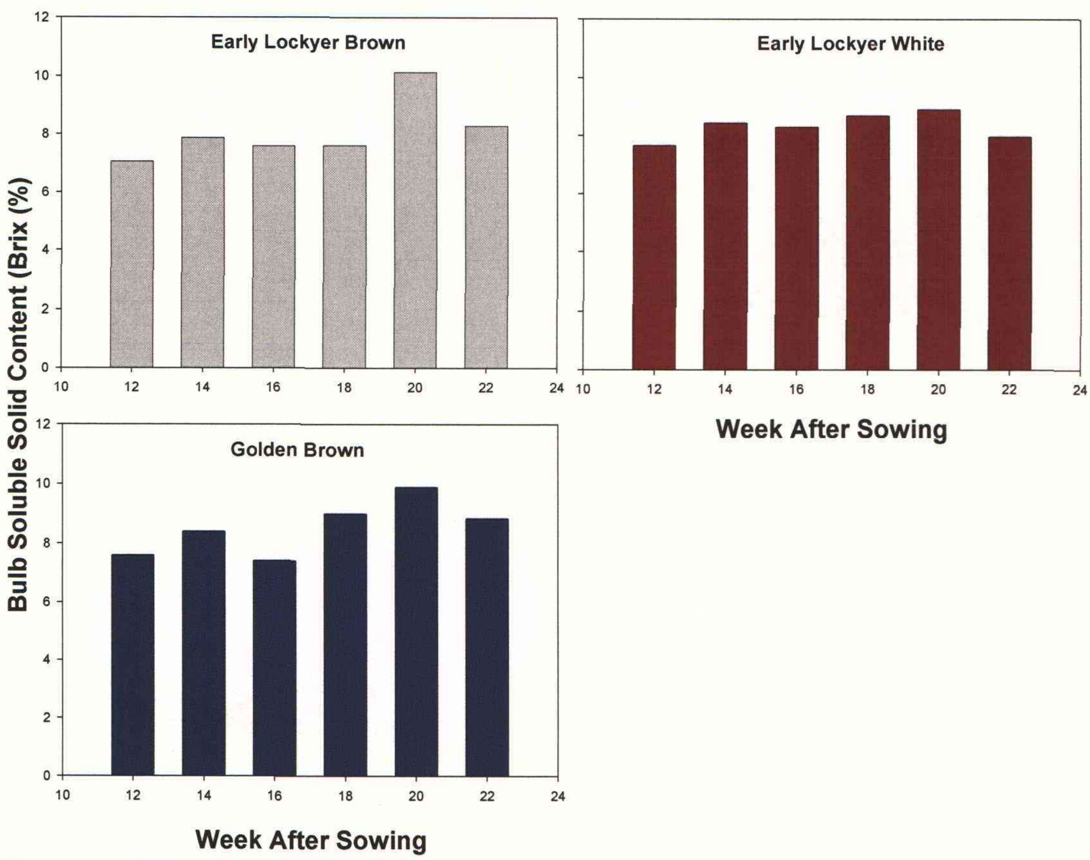

Figure 4.20. Bulb soluble solids content (brix - %) of three cultivars sown on 23rd February 2000.

All cultivars sown in March experienced a steady increase in brix (%) levels as the bulbs approached maturity. The three open-pollinated cultivars (ELB, ELW and GOB) reached their maximum brix (%) levels (9.89, 10.82 and 10.81 respectively) at 24 weeks (final assessment). The F1 hybrid Cavalier (CAV) reached its maximum brix (%) level (10.89) at 26 weeks, four weeks later than the other cultivars. The brix levels of all cultivars increased from their initial level to their final level.

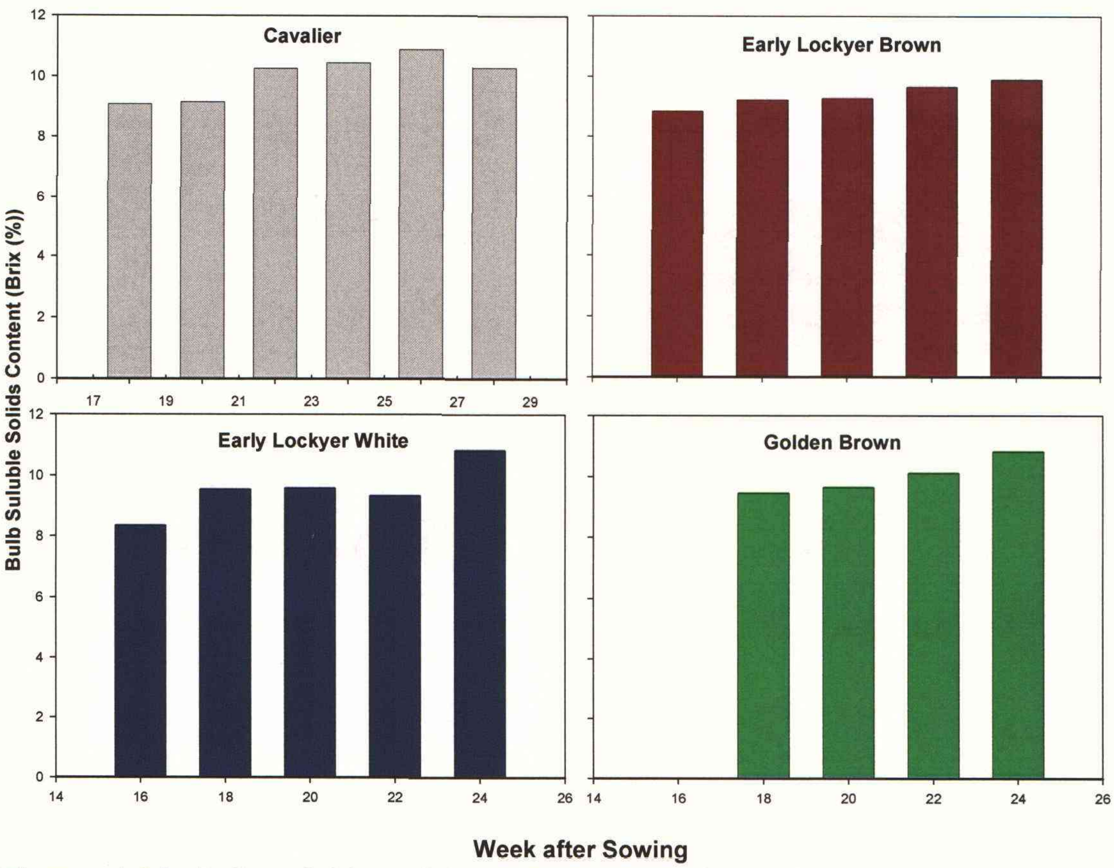

Figure 4.21. Bulb soluble solids content (brix - %) of four cultivars sown on 15th March 2000.

When sown in April, the brix levels of the cultivars did not vary greatly when evaluated from 15 to 25 weeks after sowing. The soluble solids level of GOB and WAB remained at between 8.6% to 9.8% while CAV produced slightly higher levels of between 9.2% and 10.2%. The brix level of Golden Brown decreased from week 17 to week 23.

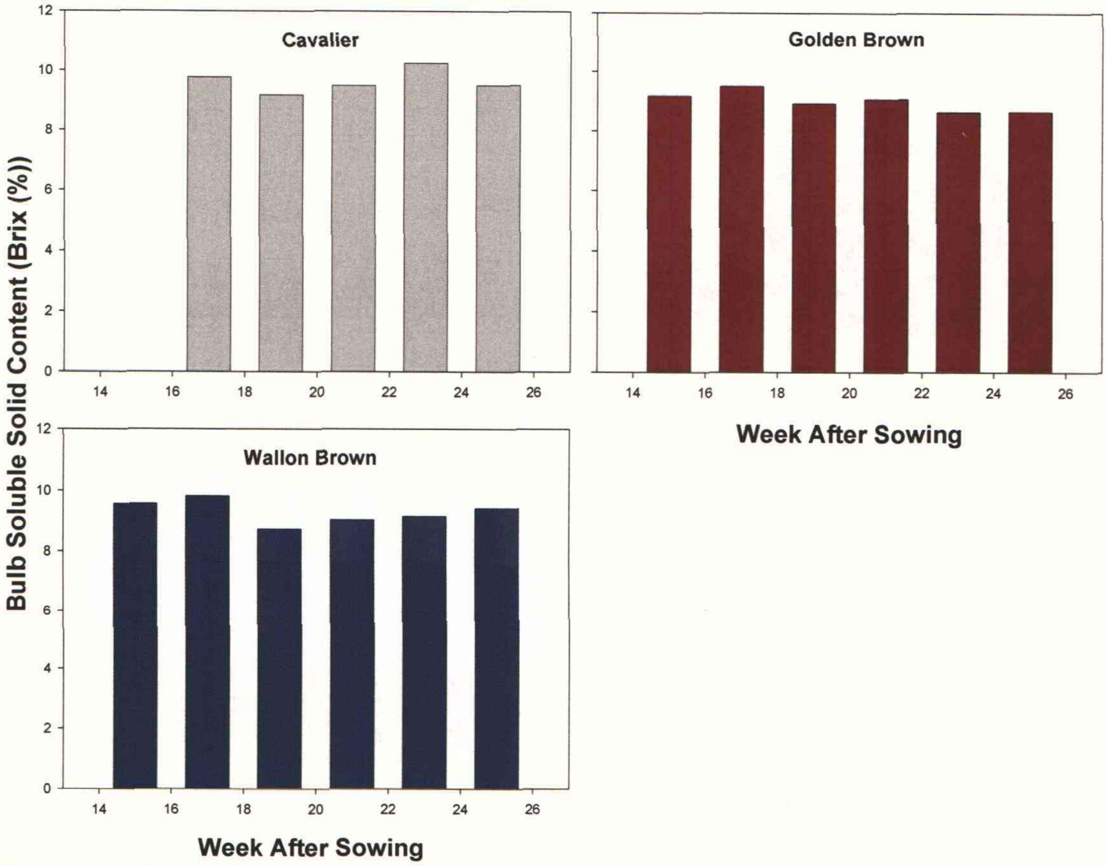

Figure 4.22. Bulb soluble solids content (brix - %) of three cultivars sown on 19th April 2000.

The cultivars sown in May varied considerably in bulb soluble solid content. The white cultivar Bolero had a steady increase in sugar levels to a maximum of 10.2% at week 21. The F1 hybrid Cavalier had a low sugar level (6.4%) at week 17 but then increased to plateau at a level of 9.1%. The red cultivar Demon commenced with a high sugar level (11.2%) at week 19 and slowly decreased to a level of 10.2%. The open pollinated cultivar Golden Brown maintained a constant sugar level of between 8.4% and 9.2%. The mild onion cultivar Sombrero produced the lowest sugar levels ranging from 5.9% to 8.6%. The brix levels of Sombrero increased from week 17 to week 21 then decreased from this time to week 25. The Queensland cultivar Wallon Brown produced a very consistent sugar level of 8.9% throughout this sowing.

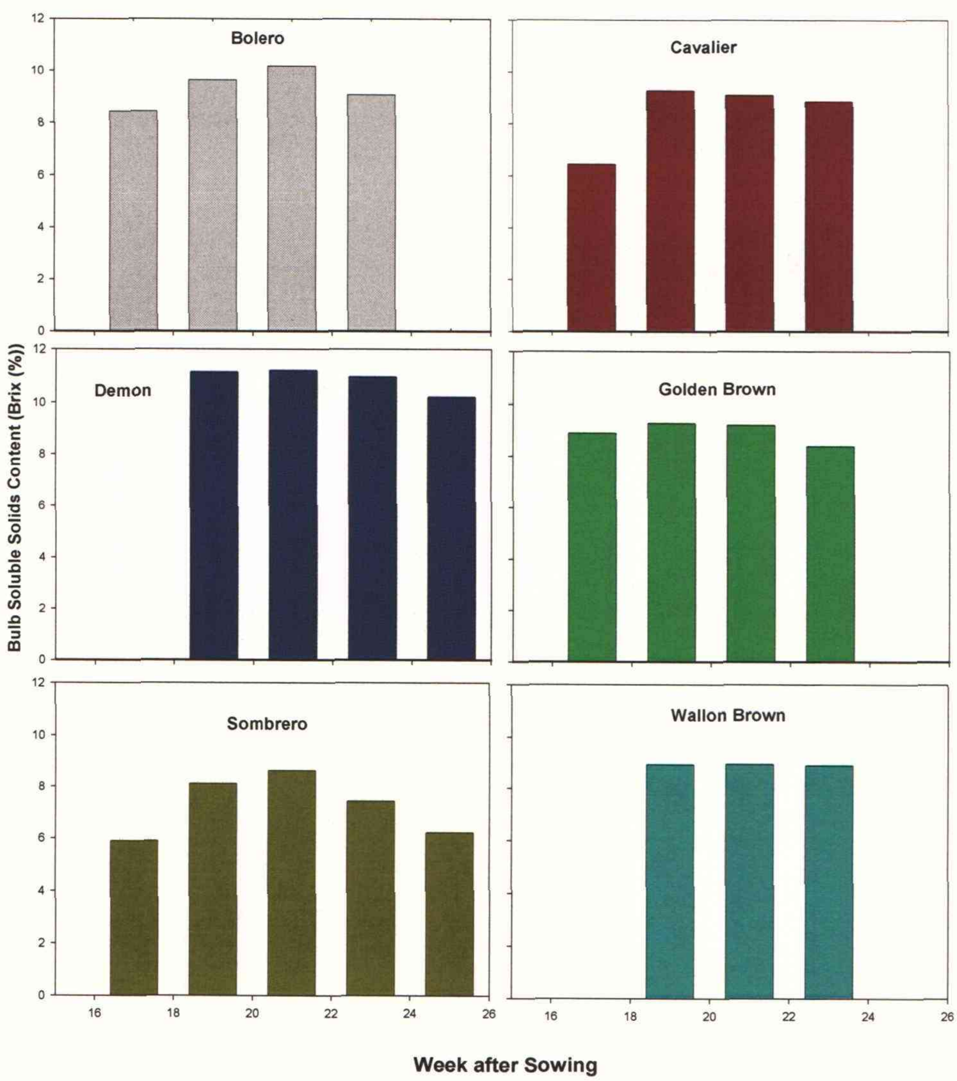

Figure 4.23. Bulb soluble solids content (brix - %) of six cultivars sown on 17th May 2000.

The five cultivars sown in June produced varying sugar levels. Bolero initially had a high sugar level (9.2%) but the level steadily declined as the bulbs matured. The sugar levels of the storage cultivar Gladiator steadily increased to a maximum of 11.1% in week 20. As the bulbs matured, the bulb sugar levels of the cultivar Golden Brown decreased to a low of 7.3%. The sugar levels of the red cultivar Red Rojo commenced at a high level of 10.0% but steadily decreased to a low of 8.0%. Sombrero produced low sugar levels dropping to a low of 6.4% in week 20. The brix levels for Golden Brown and Red Rojo decreased from week 16 to the final sampling of each cultivar.

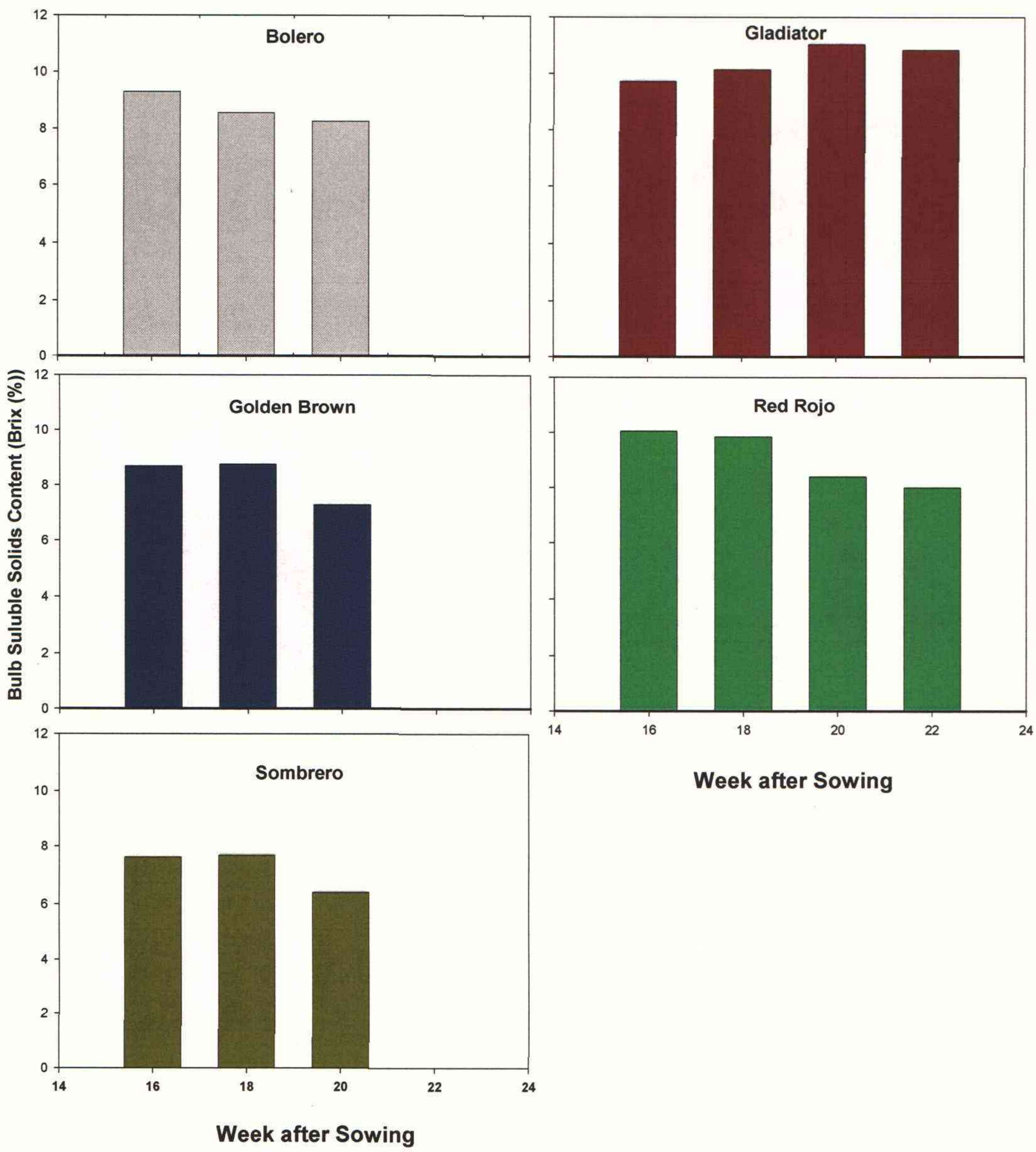

Figure 4.24. Bulb soluble solids content (brix - %) of five cultivars sown on 10th June 2000.

When sown in July the three cultivars matured very early therefore only two sampling dates yielded marketable-size bulbs for sugar content analysis. The sugar levels in the cultivar Gladiator were consistently above 10.0%. Sombrero produced the lowest bulb sugar level of 6.4% at 17 weeks. The sugar levels of all three cultivars decreased from the first to the second sampling.

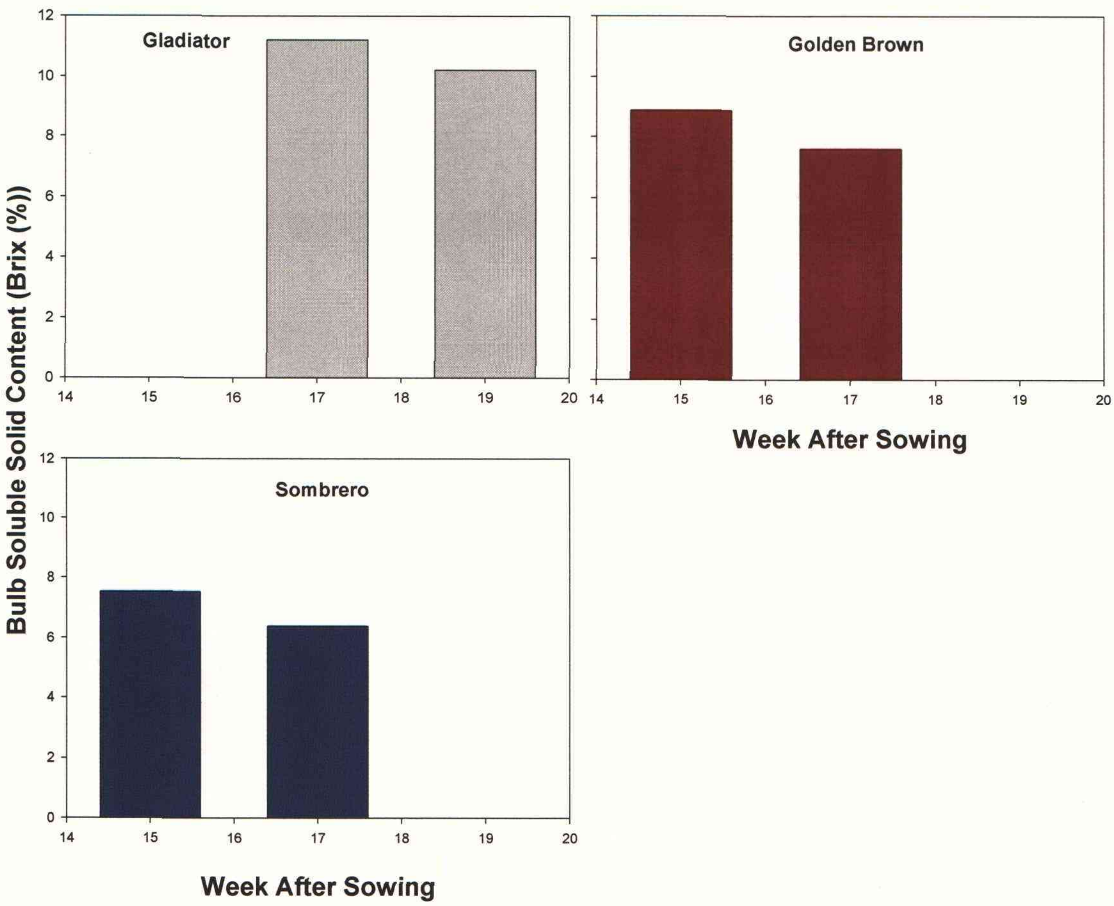

Figure 4.25. Bulb soluble solids content (brix - %) of three cultivars sown on 12th July 2000.

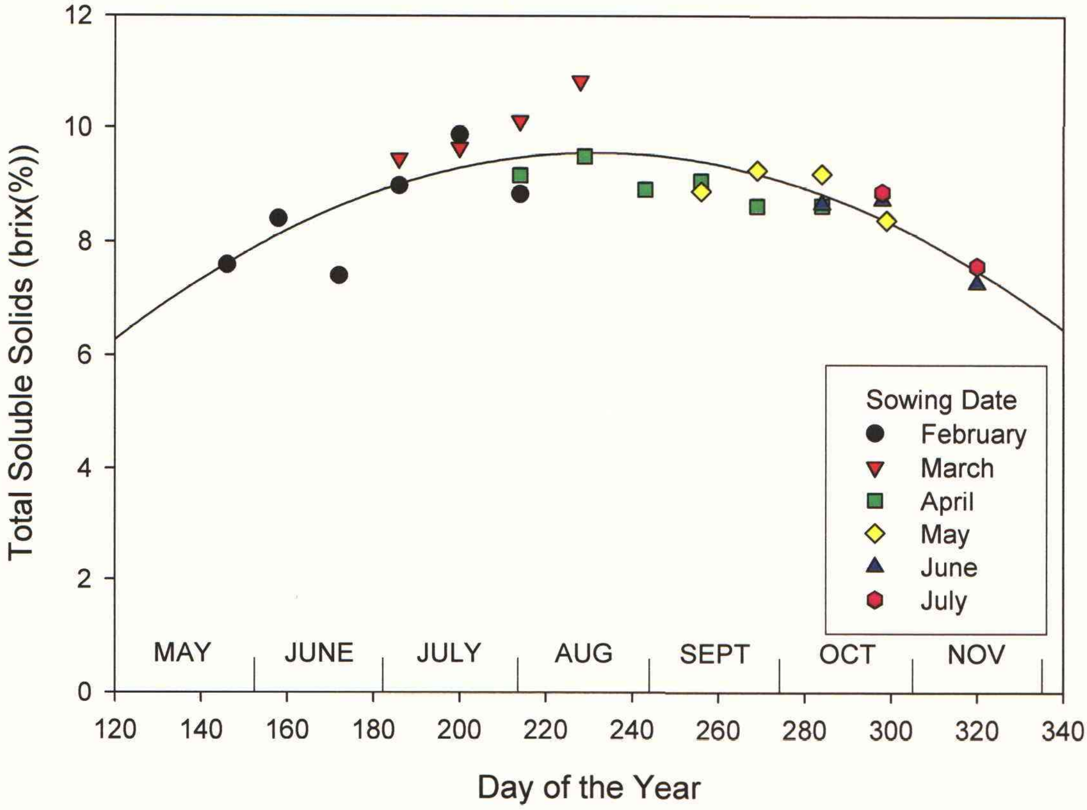

Figure 4.26. Bulb soluble solids content (brix - %) for the onion cultivar Golden Brown sown at monthly intervals for February to July 2000. Regression line (——) represents TSS versus day of the year for all sowings. Equation: $Y = -4.582 + 0.122*X - 0.0003*X^2$. $r^2 = 0.616$.

The TSS levels for the cultivar Golden Brown sown from February to July 2000 are depicted in Figure 4.26. For the February and March sowing the TSS levels steadily increased as the bulbs matured. For each of the four remaining sowings the TSS levels decreased as the bulb matured.

There was a highly significant ($p<0.01$) regression for all sowings dates for the TSS (% brix) versus day of the year.

4.4. Discussion

4.4.1. Dry Matter Accumulation

In general, for each sowing date cultivars did not differ in total dry weights, although in some instances i.e. May and June (Figures 4.4 A and 4.5 A) the final sampling for specific cultivars was 2-4 weeks later than that of other cultivars at the same sowing. Brewster (1977) found similar results in the northern hemisphere where the total dry matter produced across cultivars did not differ within successive sowing dates. In general, as the sowing date was delayed towards shorter cooler days, the total dry matter per cultivar decreased supporting the findings of Robinson (1973). The decrease in total dry weight of the cultivars in later sowings can be attributed to the prolonged cold period (Brewster *et al.* 1977; Steer 1980a) experienced by the crop during the early stages of development and growth (July and August). Cultivars sown in the early months (Feb to April) were exposed to greater mean monthly ambient temperatures and higher average daily solar radiation levels than those sown in later months. Mean monthly ambient temperatures (°C) and average daily solar radiation level (MJ m^{-2} day^{-1}) at Gatton Research Station during 2000 were as follows: February 23.2/19.36, March 23.7/19.01, April 21.4/14.48, May 17.3/11.91, June 13.4/11.74, July 13.1/12.70, August 14.2/15.78, September 18.8/20.51, October 20.9/21.52 and November 21.5/18.60.

The effect of low temperatures on the growth of the crop (Mettananda and Fordham 1999) is evident in the time taken for plants sown in June and July to be of a sufficient size to warrant sampling of bulbs compared to early sown cultivars. For cultivars sown in June and July the first samples were not taken until weeks 8 and 9 of growth after planting respectively. In comparison, the plants reached sampling size at four and six weeks after planting for the February and March sowings, respectively. The onion is a poor interceptor of light in the early growth stages (Tei *et al.* 1996). This combined with the higher levels of solar radiation during the early sown trials than that of the later sown trials helps to explain the difference in time taken to reach the first sampling date. These results support several studies (Brewster 1982; de Ruiter 1986; Mettananda and Fordham 1999; Steer 1980a; Tei *et al.* 1996) highlighting the combined effects of temperature and solar radiation differences on growth rate of the onion plant at different sowing dates.

For early sown cultivars, this temperature effect resulted in the production of a large plant that, once the required photoperiod for bulb initiation occurred, produced a large bulb resulting in a high crop yield. Conversely, the late sown cultivars produced small plants prior to bulb initiation and subsequently small bulbs that resulted in low crop yields.

4.4.2. Harvest Index

The harvest index of a crop is the ratio of its yield (bulb in the case of onions) to the total above ground dry matter (biological yield) at harvest (Charles-Edwards 1982). The onion plant has a high harvest index in comparison to other crops (Brewster 1990b). With the exception of Golden Brown (February – 67.2%) all cultivars at all sowing times produced a harvest index of between 75.1 (July) and 82.0 (June). The results support the findings of Brewster (1982), that the onion plant is good at partitioning the dry matter to harvestable material. A high harvest index was achieved by all cultivars irrespective of the sowing date. For the cultivar Golden Brown, successive sowing dates resulted in progressively smaller plants. This did not affect the harvest index. Indeed, the small plants of this cultivar produced a high harvest index (81%) from the July sowing at time when temperatures would be rising and encouraging more bulb development (Brewster and Butler 1989a). The earliest sowings (February and March), those where bulb development coincided with the lowest temperatures, did result in lower harvest indices than other sowings (Table 4.2), adding weight to the hypothesis that higher temperature during bulbing encourages bulb growth. Evaluation of the harvest index for this series of experiments did not yield any information that could be used to forecast or predict crop yields based on this characteristic. The results presented here support the work of other onion researchers (Brewster 1990b; Robinson 1973; Steer 1980a) who have determined the harvest index of onions to be between 70 and 90%.

4.4.3. Yield

4.4.3.1. Marketable Yield

Marketable yield within cultivars varies as a result of time of sowing (Jackson and Duff 1997). Choice of sowing date, and cultivar selection for the selected sowing date, is critical if marketable yield is to be maximised (Brewster 1990a). Correct sowing date ensures that optimal plant growth occurs resulting in maximum yield (Magruder and Allard 1937).

Bulbs of the No. 1 Large Grade dominated the total marketable yield for early season sowings. As the sowings progressed the distribution of bulb sizes changed dramatically. In July the total marketable yield was dominated by bulbs in the pickler and No. 1 Grade sizes. This can be attributed to the changes in temperature as the sowings progressed. The later season sowings experienced low temperatures during the early growth stage of the plant prior to the onset of bulbing. These low temperatures restricted the initiation and development of leaves that would later contribute to bulb growth and development. The appearance of leaves and their number is further discussed in Chapter 5. Consequently, small plant size prior to the onset of bulbing resulted in the development of a greater proportion of pickler and No. 1 Grade bulbs than that of early sowings. The total marketable yields for cultivars sown in July were markedly less than from earlier sowings. Similar reductions in total marketable yield as a result of smaller plant size have been recorded previously (Jackson and Duff 1998; Lancaster *et al.* 1986; Schrodter 1990).

Besides the effects of early bulb initiation (Chapter 5, Figure 5.1) on plant size for later sowings, the effect of high temperatures during October and November will also have had an effect on the maturity and bulb size of late-sown onions. High temperatures have been shown to increase the rate of leaf senescence and therefore hasten maturity (Thompson and Smith 1938). The high temperatures after bulb initiation will have hastened the maturity of cultivars sown in July, resulting in a reduced bulb size and, consequently, yield.

Local open-pollinated cultivars Golden Brown, Early Lockyer White and Brown and Wallon Brown have been developed over the last fifty years by Lockyer Valley seedsmen for their capacity to bulb as the days are shortening (Jackson *et al.* 1993; Jackson *et al.* 1989). Consequently they have been selected for a very specific environment. In contrast, the commercial hybrids, including Cavalier and Gladiator, have a fair degree of long day parentage (Lydon, Terranova Seeds, pers. comm.) and are therefore more suited to the later part of the Queensland growing season. Golden Brown has demonstrated the capacity to undergo bulbing throughout the Queensland growing season. This characteristic will be further examined in Chapter 5.

Golden Brown was sown at all planting times. Although this cultivar underwent bulb initiation and produced bulbs at all sowing dates the total marketable yield varied considerably as the sowing dates progressed. Total marketable yield was lowest in February (23.3 t ha^{-1}) primarily as a result of large numbers of double bulbs being produced. The production of excessive double bulbs also affected the marketable yield of the March sowing (39.6 t ha^{-1}). Largest total marketable yield resulted from the April sowing (82.3 t ha^{-1}). As the sowing date progressed into the winter months the total marketable yield decreased to 33.7 t ha^{-1} (July sowing). The yield in July consisted to a large extent of pickler size bulbs (65% of bulb number). As the sowing date progressed the proportion of bulb sizes changed from being predominantly large bulbs (>70 mm diameter) in February (Figure 4.8) to being smaller bulbs (<70 mm diameter) in July (Figure 4.18). The characteristic of Golden Brown to produce bulbs irrespective of sowing date may result in this cultivar being considered qualitatively day neutral. (Schrodter 1990) reported similar findings for this cultivar in that it has the capacity to produce bulbs throughout the year. The relationship between leaf development and final marketable yield is important in the growth and development of this cultivar despite its ability to bulb throughout the year. If environmental conditions result in the production of a small leaf area or short leaf area duration (Figure 4.6) then the resultant yield will be small. This relationship is further examined in Chapter 5.

4.4.3.2. Double Bulbs

Historically local selections were the mainstay of the Queensland onion industry (Jackson, QDPI, pers. comm.). As the market became more discerning of quality eg supermarket development since the late 1980's, quality has become more important. Doubling in onion bulbs is a characteristic that is no longer tolerated in the market.

The research undertaken to date on doubling in onions indicates that there is a great diversity of opinion on the causes of doubling. Consequently, it is difficult to attribute the occurrence of doubling to any specific cause. The proportion of doubling in onions has been variously attributed to environmental shock (Lydon 1996), low plant density (Wilson 1934) high average daily temperatures (Robinson 1971), low temperatures and long days (Steer 1980a) and soil moisture stress (Pelter *et al.* 2004).

A number of cultivars produced significant quantities of double bulbs. Local Queensland cultivars, when sown early, produced the greatest number of double bulbs. This result supports the evidence of previous research (Jackson and Duff 1998; Jackson *et al.* 1997; Jackson *et al.* 2000). Greater than fifty percent of the total yield of the local selection Golden Brown when sown in February comprised double bulbs. Double bulbs occurred in the majority of cultivars, especially at earlier sowing dates. As the sowing date moved into the cooler months the number of double bulbs decreased from an average of 40% in February to an average of 1.0% in July. Time of sowing is therefore an important factor in controlling the level of double bulb production. Evidence from previous research (Jackson and Duff 1997; Jackson and Duff 1998; Jackson *et al.* 2000) has indicated that although doubling has occurred irrespective of sowing date there is a general trend suggesting that the level of doubling decreases as the sowing date is delayed. As onion plants increase in size apical dominance is diminished resulting in an increase in the development of axillary buds leading to double bulb formation. This is evident in the early sowings (February to April) when large plants are produced prior to bulb initiation.

Robinson (1971) linked the incidence of doubles with bulb size. He suggested that the larger the bulb the greater the likelihood of a double bulb to occur. This is as a direct consequence of increased plant size that enabled the onion plant to translocate large quantities of carbohydrates stored in the leaves to bulb growth. Therefore greater numbers of doubles are likely to be produced when conditions dictate that there is high percentage of large plants that will produce large bulbs.

Low plant population (Wilson 1934) has resulted in larger bulbs and an increase in the proportion of double bulbs. In contrast, irrigation deficits (Pelter *et al.* 2004) have resulted in reduced bulb size and an increase in the proportion of doubles. These results respectively support and contradict the findings presented here. The evaluation of these factors is beyond the scope of this study.

An extensive examination, in particular of the effects of temperature into the causes of doubling, is presented in Chapter 6.

4.4.3.3. Bolters

The production of bolters (bolters) is basically a cultivar phenomenon (Brewster and Butler 1989b; Jones and Mann 1963). This is supported by trial results where the majority of bolters were produced by three early season open-pollinated cultivars. These cultivars, Early Lockyer Brown (20.4 % - March), Early Lockyer White (21.9 % - March) and Wallon Brown (15.1% - April), had the highest levels of bolters. Very small numbers (approx. 1.0%) of bolters were produced in the May sowing, by any cultivar.

Further extensive results and discussion of the factors influencing bolting in onions in the Lockyer Valley, Queensland are presented in Chapter 6.

4.4.4. Bulb Sugar Concentration (brix %)

There were differences in sugar content within a cultivar based on the maturity of the bulb, and between individual cultivars and between sowing dates. Early sowings (February and March) tended to promote an increase in brix level within the bulb for all cultivars as the bulb matured. As the onions matured, the temperature during this time declined. The temporal variation in sugar content of cultivars sown in April or May (mid-season) varied considerably. This may be as a result of environment factors and cultivar differences (Randle 1994). There were increases and decreases in brix levels across cultivars as the bulbs matured. In general, brix levels decreased as the bulbs matured in later sowings (June and July)

The cultivar Golden Brown has shown a trend for increasing brix level (Figure 4.26) as the bulb matures during the early season sowings but the reverse occurs during the later sowings. It may be argued that a decreased respiration of the bulbs harvested during the winter months may result in higher sugar content. Later sowings result in bulbs being harvested in the warmer spring and summer months when there would be a higher rate of respiration therefore reducing the sugar content within the bulb. A low ‘maintenance respiration’ (Brewster 1990b) during the winter months when compared to the warmer summer months may prove to be a suitable explanation for this result.

It is apparent that careful selection of cultivar, harvest date and sowing time is required to ensure that the onion bulbs meet the required sugar levels (> 8.0% brix) for the targeted market. This is especially important if the sweet mild onion market is the target market as low sugar levels are unacceptable (Pike and Randle, USA, pers. comm.).

4.5. Conclusions

Time of sowing is a critical factor in the production of marketable bulbs of a size required by the marketplace. Market requirements for a specific bulb size will dictate the time of sowing chosen by the grower (Muller 2001). If No. 1 Large bulbs are required then, based on the results, cultivars will be selected for sowing from February to May in an effort to ensure maximum returns to the grower. The local open-pollinated selections in the Lockyer Valley were developed to meet these requirements, in particular, early sowing for the early market (Neuendorf pers. comm.). The selection of the correct cultivar for the specific sowing date ensures achieving the market requirements for bulb size.

Sowing date, cultivar selection and harvest date are important factors that must be considered if a producer is growing for the sweet onion market. Cultivars that will produce high concentrations of sugars at the designated harvest date need to be grown.

CHAPTER 5

5. GROWTH ANALYSIS OF THE ONION (*Allium cepa* L.) CULTIVAR GOLDEN BROWN FOR SIX CONSECUTIVE SOWING DATES

5.1. Introduction

Onions in Queensland are grown under subtropical to tropical conditions; resulting in a very large sowing window (late February to late June). Consequently a large number of cultivars (Jackson and Duff 1997) are available for selection by producers to accommodate the extensive range of photoperiods likely to be experienced by onion crops sown at different times of the year. Currently, the onions grown in Queensland are short-day mild types and there are few cultivars available adapted to sequential sowings throughout the sowing window. Problems that are encountered include reduced yield and excessive bolting.

The local cultivar Golden Brown is particularly well adapted to the Lockyer Valley and is bolt-tolerant. Consequently, this cultivar is adapted to an extended sowing window – late February through to late April. This perhaps indicates that Golden Brown is day neutral or at the least insensitive to the varying daylength experienced in the Lockyer Valley during this growing period. A somewhat reduced yield is experienced when sown from May to late July. It produces a globe-shaped bulb that is golden brown in colour with only one or two skins. Marketable yield varies according to the sowing date and also from year to year. In general, maximum yield is obtained from a March sowing (Duff and Jackson 1997).

The growth stages of the onion plant have been vigorously investigated under long day growing conditions. The three stages of leaf growth, as outlined by

Heath (1943) and Nagai and Hanaoka (1967), have been determined as (i) an initial period of slow leaf growth, (ii) a period of rapid leaf growth until the onset of bulbing and (iii) rapid bulb growth and development during which time leaf initiation and growth ceases. Investigations into the relationship between leaf growth and bulb growth of short-day onion cultivars is limited (Robinson 1973).

Studying the interaction between leaf growth and bulb development, Robinson (1973) found that high temperature growing conditions played the major role. He found that increasing temperatures were responsible for premature and rapid bulb swelling resulting in a cessation of leaf growth.

In this chapter, the local open-pollinated cultivar Golden Brown was evaluated across consecutive sowing dates to develop an understanding of the effects of time of sowing on bulbing and leaf area accumulation and the interaction between these plant characteristics.

The growth analyses undertaken in this chapter were used to determine the relationships between leaf growth via leaf area index (LAI), net assimilation rate (NAR), bulb development (bulbing ratio - BR) and total dry matter accumulation of the subtropical onion cultivar Golden Brown.

5.2. Materials and Methods

The open-pollinated local Queensland cultivar Golden Brown was selected for evaluation due to its bolt tolerance and ability to form bulbs irrespective of sowing date throughout the year (Schrodter 1990). As outlined in Chapter 3, Golden Brown was sown at monthly intervals from late February through to mid July 2000. The complete trial description is outlined in 3.4.1.

A destructive plant sampling procedure (Chapter 3.4.1) was implemented to obtain an extensive growth analysis data set. Data were generally collected at fortnightly intervals, consisting of five plants per plot for each of two blocks (replicates) for six sowing dates. The data collected on individual plants for the study reported in this chapter included minimum stem and maximum bulb diameters for calculation of bulbing ratio, number of days to 50% and 100% bulbing, number of leaves per plant appeared, individual plant leaf area, final bulb yield (fresh weight) and total dry matter accumulation. Data collected in the growth development study (Chapter 3.4.2) experiments was utilised to supplement the growth study data for bulbing. The data collected were used to determine the following crop growth indices: net assimilation rate (NAR) and leaf area index (LAI).

The maximum bulb diameter (mm) was measured at the equator of the bulb. The stem diameter (mm) was a measure of the minimum stem diameter between the bulb and the first leaf on the stem. These measurements were then used to calculate the bulbing ratio (diameters of bulb:stem) (Jones and Mann 1963). Bulbing was considered to have occurred when the ratio exceeded 2.0. From these data it was possible to determine the time to 50% and 100% bulbing.

Total individual plant green leaf area (cm^2) was determined using a Licor® electronic leaf area meter. The individual green leaves were removed from the plant, flattened and passed through an electronic leaf area meter. To determine the total plant leaf area (LA), it was assumed that the onion leaves were cylindrical and when flattened formed two equally sized leaf surfaces. The leaf area meter measured the upper surface and consequently the actual LA was twice that measured by the meter. Wickramasinghe *et al* (2000) also measured the leaf area of both sides of the leaves in his studies albeit using a different more time-consuming methodology, splitting each leaf and flattening it prior to leaf area determination. The leaf area index (LAI) was calculated from plant leaf area.

The number of leaves per plant for each sowing date was recorded on each sampling occasion; leaves were counted from the leaf hook stage, as they emerged from the pseudostem. A record of the number of leaves emerged was made in the field and for each of the plants sampled. The number of leaves produced by individual plants was tracked by marking every fifth leaf on the plant with a small bright green ribbon. Where individual plants produced more than one pseudostem the leaves for each pseudostem were counted separately and the total number of leaves per plant was calculated as the number of leaves counted prior to the visual emergence of more than one pseudostem plus the number of leaves per pseudostem. The date at which each leaf died was also recorded. The results obtained thus gave an indication of the number of functional leaves that were present at any stage throughout the life of the plant.

The individual average bulb weight (g) data was determined as outlined in the Growth Study section of Chapter 3. The final yield was determined as outlined in Section 3.4.1. These plots were harvested three weeks after the final destructive sampling for each sowing. The data collected included number of bulbs and weight for picklers (bulb diameter < 40 mm), No. 1 Grade bulbs (bulb diameter 40-70 mm), No. 1 Large Grade bulbs (bulb diameter > 70 mm), double bulbs and bolters.

Leaf area at each sampling date was utilised to calculate the leaf area index (LAI) as outlined by Watson (1947). The leaf area (cm^2) used for the calculation of the LAI was the total leaf area of the ten plants sampled. The area of land was calculated as 2500 cm^2. LAI is defined as total leaf area per unit of land as follows:

$$LAI = LA/AR$$

where AR equals unit land area (cm^2) and LA equals the leaf area (cm^2) above the specified land area.

Net assimilation rate (NAR) for each sampling interval was calculated using the formula (Hunt 1982):

$$\frac{(DW_2 - DW_1)(\ln LA_2 - \ln LA_1)}{(T_2 - T_1)(LA_2 - LA_1)}$$

where DW_1 and DW_2 are total plant dry weight (g) excluding roots (resulting in a slight under estimation of NAR) and LA_1 and LA_2 are total leaf area per plant (cm^2) at times T_1 and T_2 respectively.

Although an extensive data set including leaf number and days to bulbing was collected from the growth development study, it has been decided that this data will not be presented to compliment the data collected from the growth study. The growth study was collected through destructive sampling and direct measurements compared to the data from the growth development study which was observational data, in particular bulb development.

Data for all treatments were subject to a one-way analysis of variance using Genstat for Windows Version 6.1 statistical software (Lawes Agricultural Trust). Means were separated using Fishers Protected LSD at $p<0.05$.

Linear regression analyses and all graphs were created using SigmaPlot 2001 for Windows Version 7.101 (SPSS Inc).

5.3. Results

5.3.1. Bulbing – Growth Study

The timing of onset of bulbing (bulbing initiation – BI) was determined utilising data on the bulbing ratio (BR). Figure 5.1 illustrates the average BR for the ten plants at each sampling date. Plants were determined to have initiated bulbing when the BR was greater than 2.0 (Mann 1952). This is illustrated on the figure by the solid horizontal line.

During the February sowing the first indications of bulb initiation (20%) occurred at 43 days after sowing (DAS). There was an early indication that bulb initiation (more than 50% bulbs with BR>2.0) had occurred at 61 days after sowing (DAS). Fifty percent of the plants had a BR greater than 2.0, averaging 2.45. For subsequent samplings the figure dropped below 2.0 until 117 DAS when 60% of the plants had a BR greater than 2.0 (average: 2.41). One hundred percent bulbing, based on the BR, did not occur until 145 DAS, fourteen days prior to final harvest.

Fifty percent bulbing did not occur in the March sowing until 129 DAS although forty percent of bulbs showed signs of bulb initiation at 115 DAS. The length of time taken from sowing to reach 50% bulbing was the greatest for this sowing date. At that date, eight out of ten plants had a bulbing ratio greater then 2.0 (average: 2.22). One hundred percent bulbing did not occur until 143 DAS.

For the April sowing, bulbing was determined to have commenced before 116 DAS (70% of plants with a BR >2.0). The sampling date prior to this one yielded less than 50% bulbing. Complete bulbing (100%) did not occur until 143 DAS, twenty-eight days prior to maturity. First indications of bulbing (10% of plants with BR>2.0) occurred at 101 DAS.

The May sowing provided results similar to those of the February, March and April sowings. The first time that more than fifty percent (80%) of plants displayed bulbing occurred at 118 DAS. Initial indications of bulb initiation (BR>2.0) were detected at 104 DAS (10%). Complete (100%) bulb initiation occurred 12-14 days earlier than for the February, March and April sowings.

Initial indications that bulbing had commenced in the June sowing was evident at 92 DAS (10%). All plants sampled at 104 DAS had initiated bulbing. Although 100% of plants had initiated bulbing at 104 DAS, plant maturity did not occur until 154 DAS. This is in contrast to early to mid season sowings when maturity occurred from 14 to 27 days after 100% bulbing.

Bulb initiation commenced at 79 DAS (20%) for the July sowing. With the exception of the anomaly that occurred in the February sowing, which is to be discussed in the Section 5.4, this is shortest time from sowing to bulb initiation for all sowing dates. One hundred percent bulbing occurred at 94 DAS, 36 days prior to maturity.

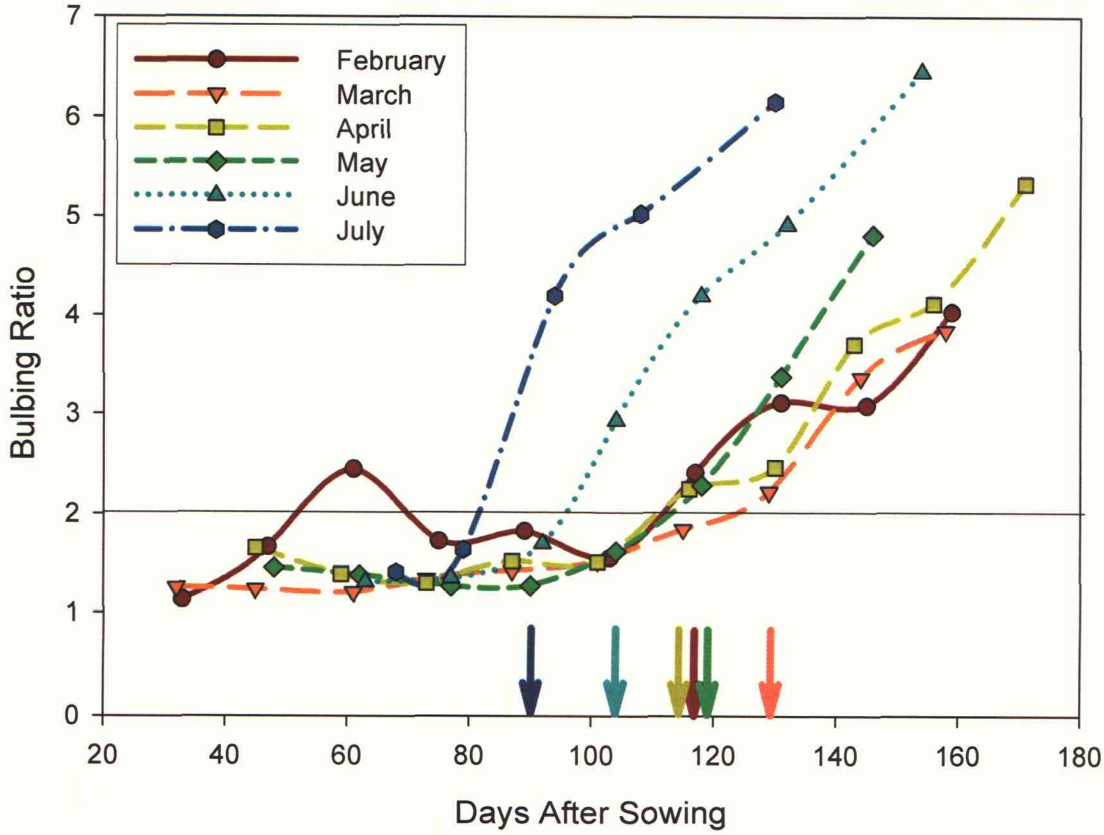

Figure 5.1. Bulbing ratios (average for ten plants) of the cultivar Golden Brown sown at monthly intervals from February to July (inclusive) 2000 at Gatton Research Station. Arrow (↓) indicates day at which 50% bulbing occurred for each sowing date.

5.3.2. Leaf Area Index – Growth Study

The greatest amount of leaf area was produced in the February and March sowings with a maximum LAI of 4.41 and 4.21 respectively (Figure 5.2). The April sowing produced the next greatest leaf area and retained its leaf area (Table 5.1.) for the same period of time (126 days) as the February and March sowings. Results indicated that the leaf area from the May sowing was continuing to increase up to and including the final sampling date even although greater than 70% of the tops had collapsed, indicating maturity. The July sowing produced the smallest amount of leaf area as indicated by its low maximum LAI of 0.53. As the sowing dates progressed the duration of leaf function (green leaves) and the LAI decreased (Table 5.1).

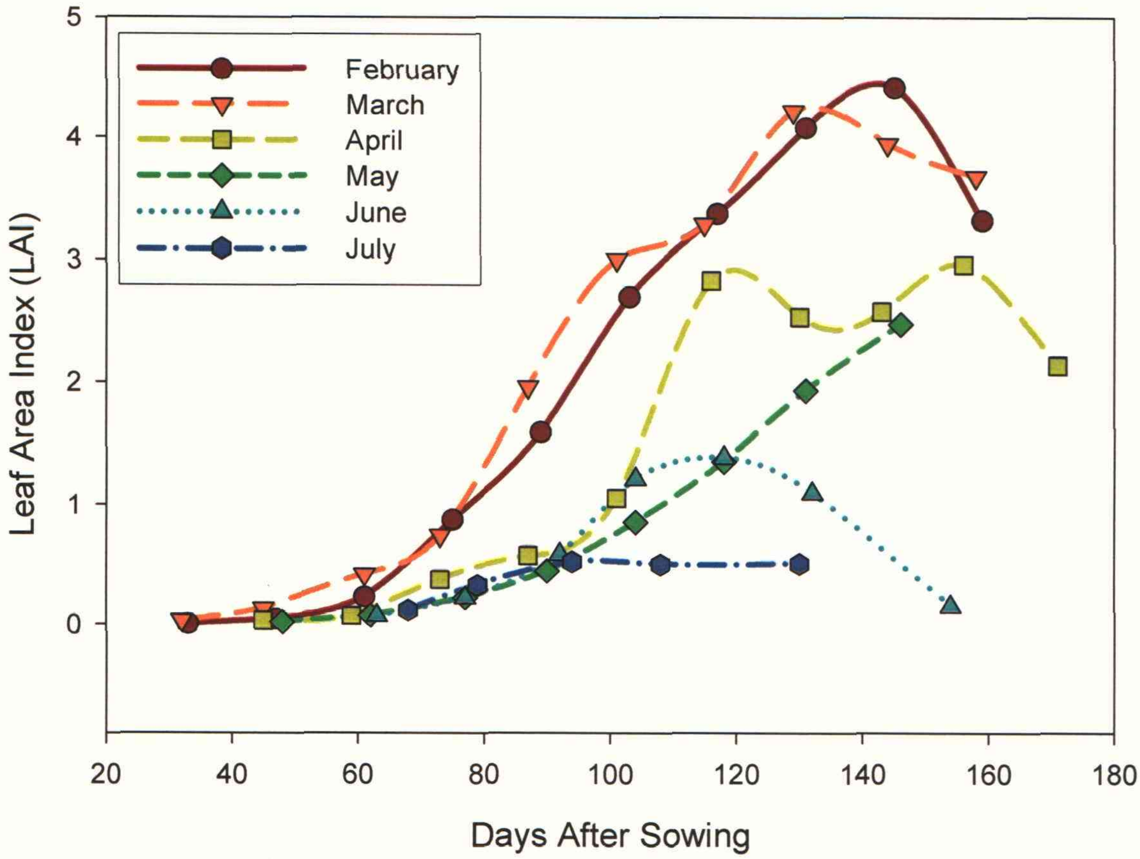

Figure 5.2. Leaf area index of the onion cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

Table 5.1. Duration of leaf function (days), from initial sampling date to final sampling date, of the onion cultivar Golden Brown sown at monthly intervals from February to June 2000 at Gatton Research Station.

	February	March	April	May	June	July
Duration of leaf function (days)	126	126	126	98	91	62

5.3.3. Number of Leaves per Plant – Growth Study

Data on the number of leaves produced per plant are presented in Figure 5.3. These data were obtained from the average of ten plants, and represent all leaves initiated per plant.

The rate of leaf appearance was the same for all sowings once the second leaf had appeared. The date of commencement of rapid leaf production differed for the each sowing. For the February, March and April sowings leaf production commenced at approximately 20 DAS. For the later sowings (May, June and July) the increase in leaf number did not occur until approximately 40 DAS.

Plants sown in March produced the greatest number of leaves of any sowing, averaging 14.5 leaves per plant. The plants sown in July produced only half that number of leaves (7.6) per plant. The number of leaves per plant from the other sowings ranged from 9.6 (June) to 12.8 (February).

During the February sowing the rate of leaf production progressed at approximately one leaf per week until day 87. From this time the rate of leaf production decreased dramatically to two leaves during the next 61 days. From this point plants produced two leaves within seven days followed by a negligible increase in leaf numbers until the final harvest. Plants in all other sowings produced approximately one leaf per week for the life of the plant until approximately 21-28 days prior to harvest (maturity) when leaf production had all but ceased.

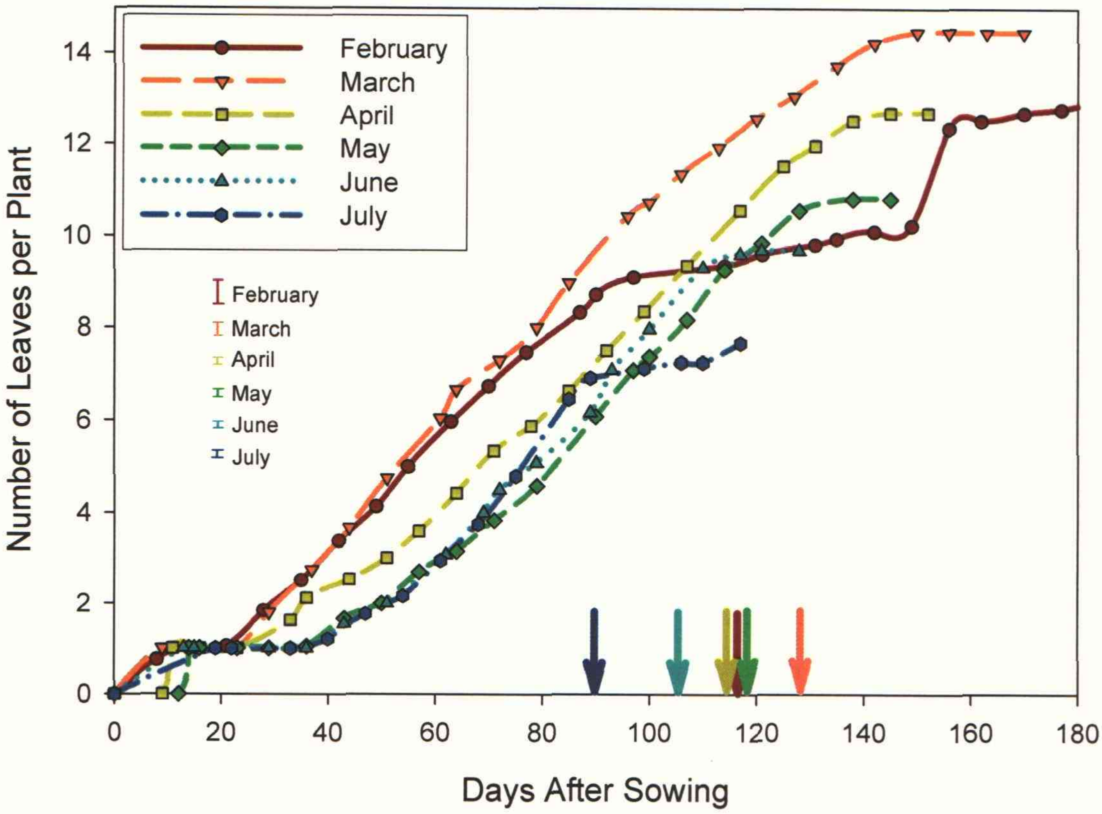

Figure 5.3. Number of leaves per plant (including the cotyledon or hook leaf), average of ten plants, of the onion cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station. Arrow (↓) indicates day at which 50% bulbing occurred for each sowing date. Vertical bars indicate standard error of the difference of the means for successive samples within each sowing.

5.3.4. Bulbing vs Leaf Area – Growth Study

A comparison of individual plant leaf area (cm^2) and time to bulb initiation based on a BR>2.0 for February to July sowings is illustrated in Figure 5.4.

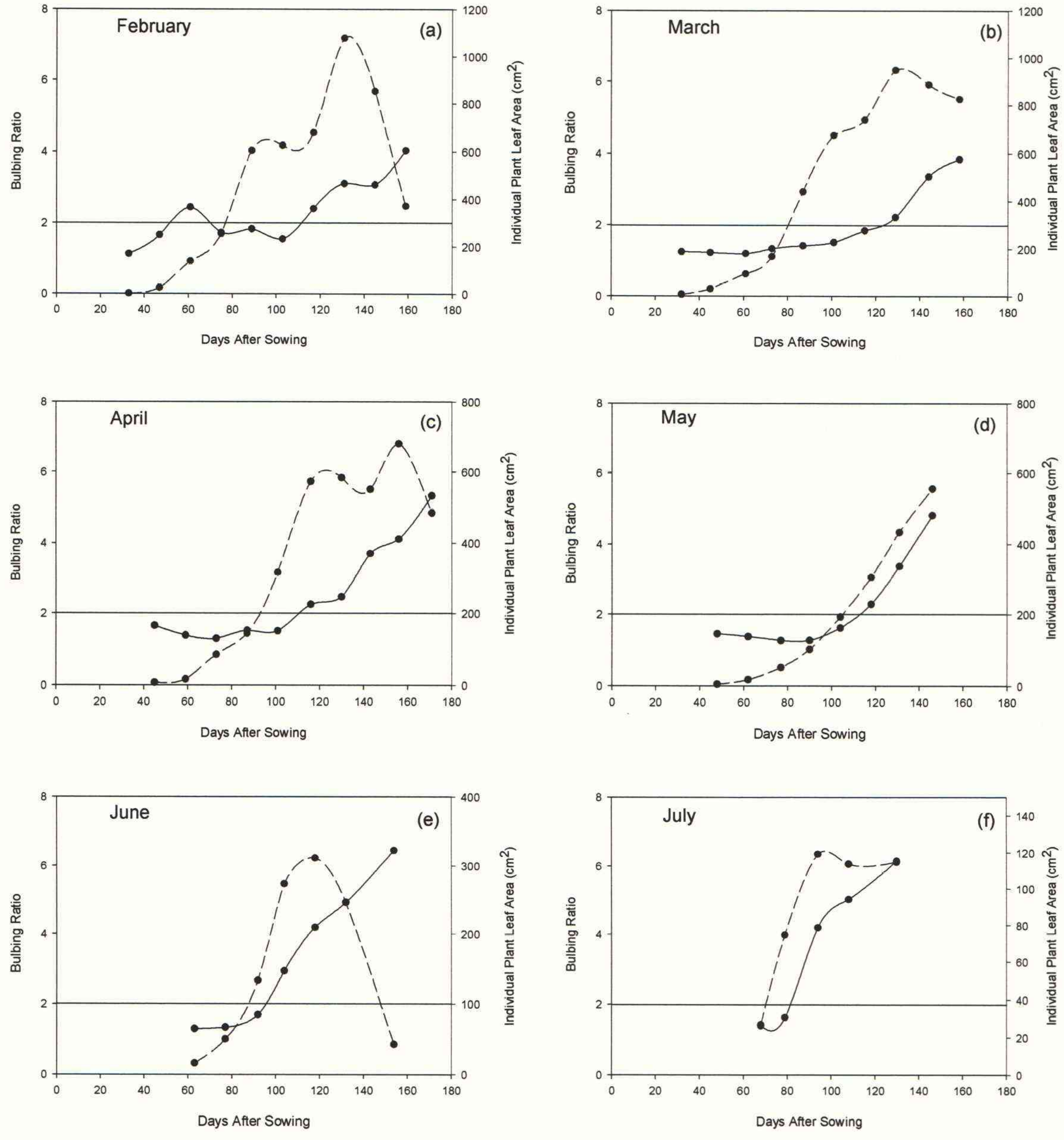

Figure 5.4. Average (10 plants) bulbing ratio (—•—) and average individual plant leaf area (cm^2) (--•--) of the onion cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station. Bulbing has commenced when the bulbing ratio equals 2.0 (——).

During the initial stages of plant growth (up to 103 DAS) for the February sowing (Figure 5.4(a)), excluding the anomaly at 61 DAS, there was a large increase in leaf area while there was little increase in BR. After that time the leaf area and BR increase together until the maximum leaf area was reached. The leaf area then started to decline (131 DAS) but the BR continued to increase.

The leaf area from the March sowing (Figure 5.4(b)) began to decrease after fifty percent of the onion plants have commenced bulbing. In a similar vein to the February sowing, the leaf area underwent a large increase with little increase in the BR in the early stages of growth (0 to 129 DAS). As the leaf area reached its maximum and started to decrease the BR began to increase dramatically.

During the April sowing (Figure 5.4(c)) the leaf area increased rapidly while the BR remained relatively unchanged during the first 100 days of plant growth. As the bulbing began the leaf area tended to remain constant until the plants started to senesce and the leaf area then decreased.

During the May sowing (Figure 5.4(d)) after 100 DAS the BR increased and that increase mirrored that of the leaf area which continued until maturity and final harvest. The maximum leaf area corresponded with the harvest date of the plants and maximum BR.

The leaf area during the June sowing (Figure 5.4(e)) increased rapidly from 80 DAS and the BR from 90 DAS. Following the commencement of bulbing the leaf area continued to increase until 37 days after bulbing when it reached its maximum. As the plants matured the leaf area declined rapidly, but BR continued to increase.

During the initial stages of growth for the July sowing (Figure 5.4(f)) the leaf area increased to 75% of its maximum while there was only a small increase in BR. After bulbing (BR=2.0) the leaf area and BR increased together but maximum leaf area was reached at 100 DAS while the BR continued to increase until harvest.

5.3.5. Net Assimilation Rate – Growth Study

Figure 5.5 illustrates the relationship between net assimilation rate (NAR) and leaf area index (LAI) for the onion cultivar Golden Brown for each sampling interval.

During the February sowing the LAI increased steadily to a maximum while the NAR decreased slightly. NAR and LAI increased together during the March sowing. Onions in the April sowing experienced large fluctuations in NAR while the LAI increased to a maximum and remained constant until the final sampling when there was a decrease. The LAI and NAR in the May sowing increased together. Results indicated that perhaps the LAI and NAR for the May sowing had not reached a maximum prior to the final sampling. NAR and LAI followed the same pattern in the June sowing: increasing to a maximum and then gradually decreasing. During the July sowing the NAR and LAI progressed together to a maximum before maintaining this maximum until the final sampling.

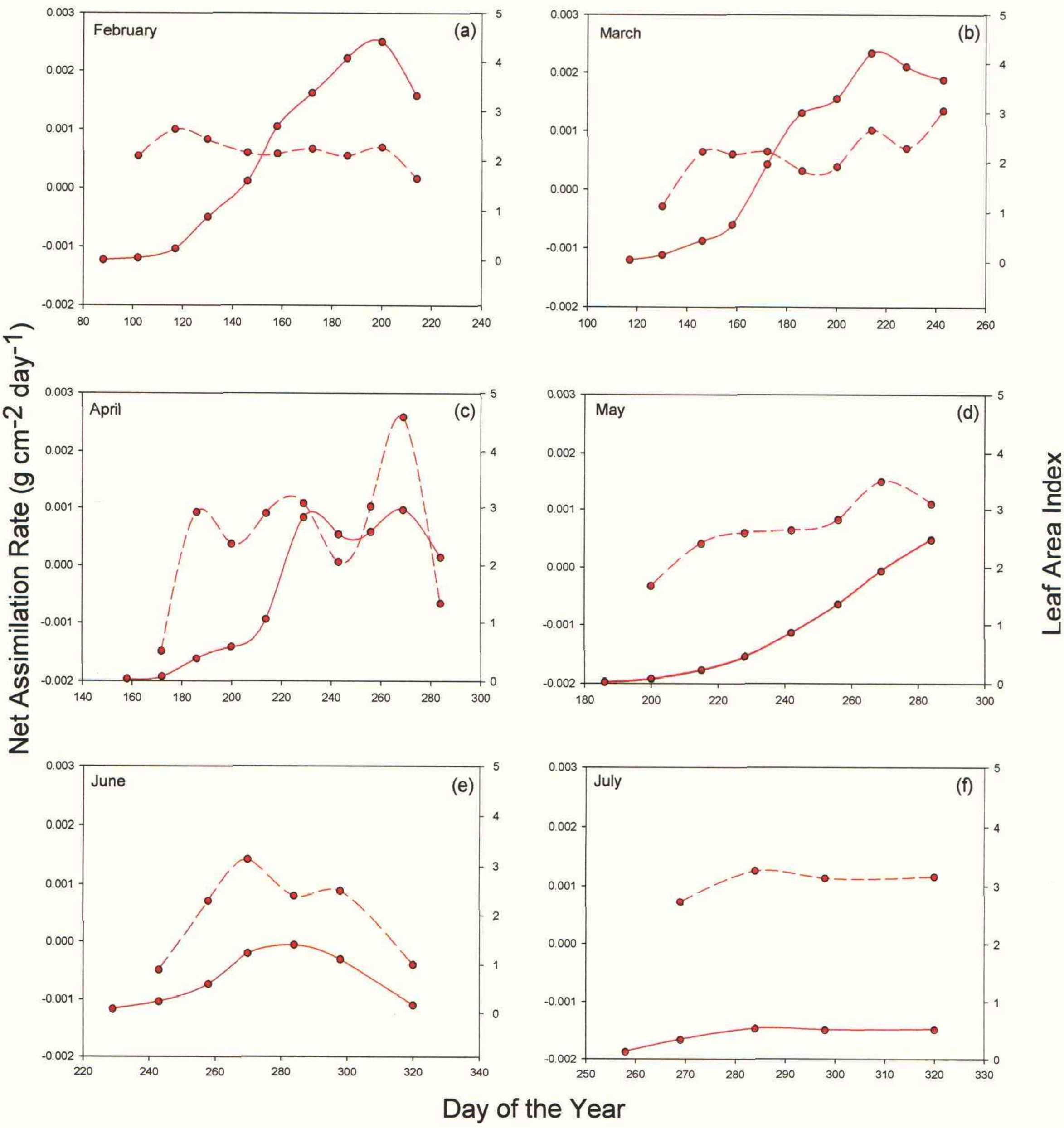

Figure 5.5. Comparison of net assimilation rate (NAR) (g cm^{-2} day^{-1}) (– – ● – –) and leaf area index (LAI) (—●—) for the onion cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

There were considerable fluctuations between the NAR curves for the various sowing dates (Figure 5.6). Consequently, the results were difficult to interpret as highlighted by Robinson (1973) and Watson (1947).

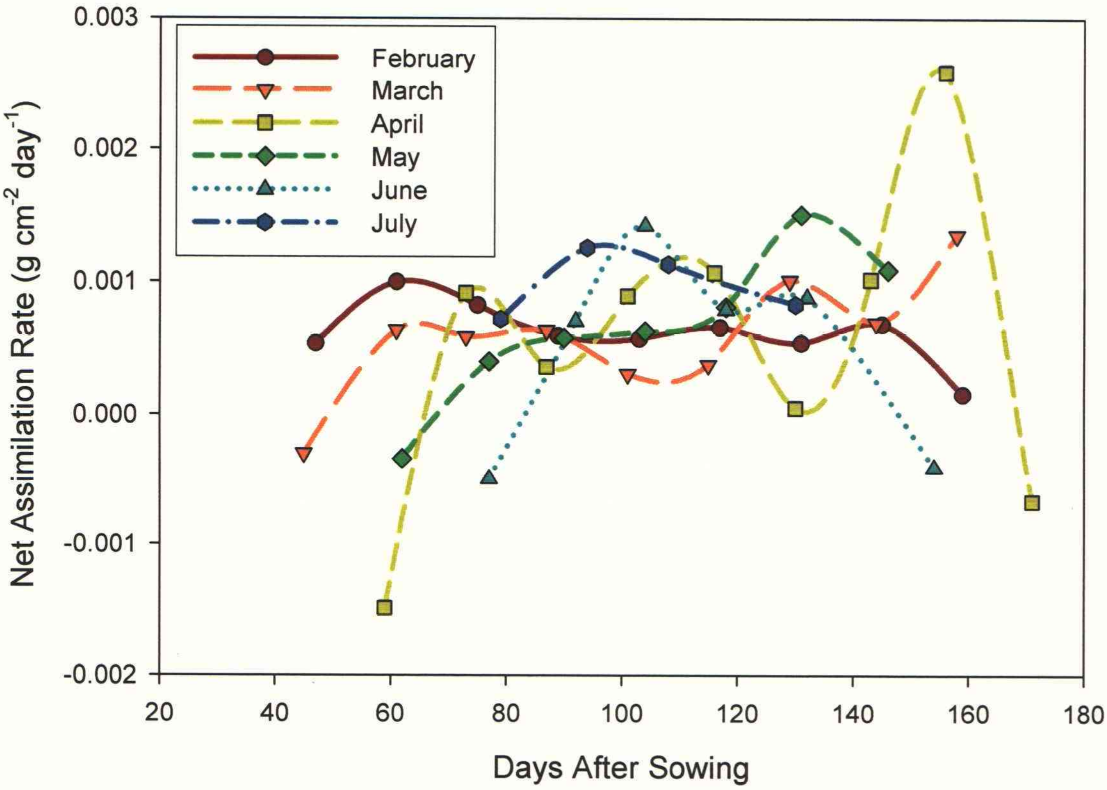

Figure 5.6. Net assimilation rate (NAR) (g cm^{-2} day^{-1}), calculated at fortnightly intervals, for the onion cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

Figure 5.7 illustrates the relationships between season mean net assimilation rate and final total dry weight for the onion cultivar Golden Brown. NAR data presented are the mean figure for each crop cycle based on the NAR for the individual fortnightly sampling intervals. The total dry weight per plant is the maximum dry weight produced by the plant, excluding the roots.

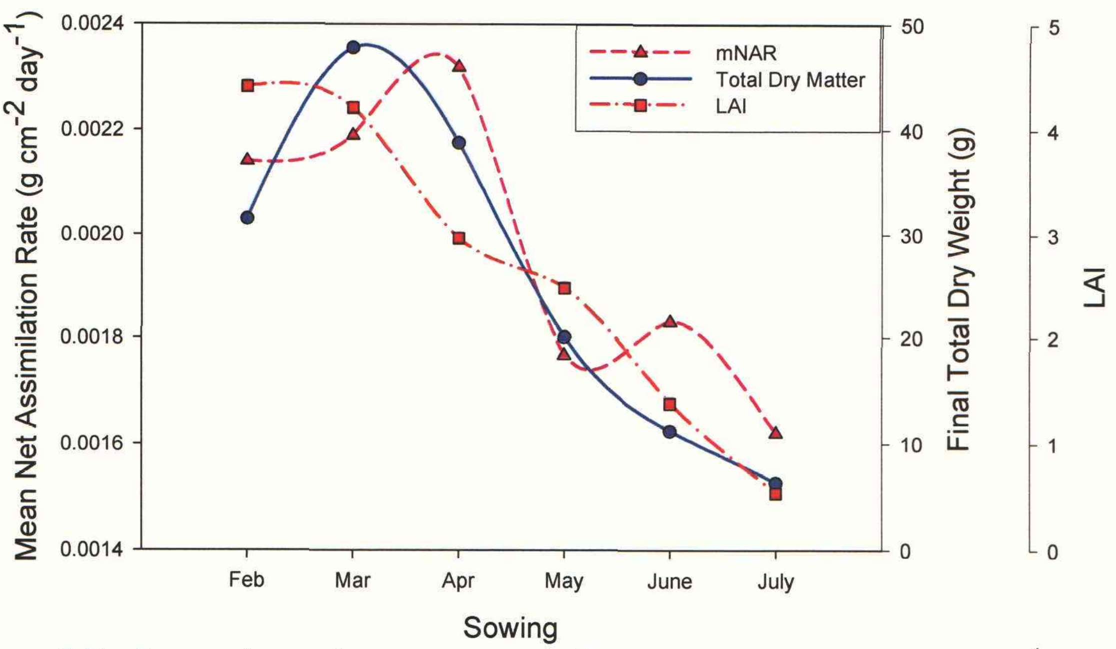

Figure 5.7. Comparison of mean net assimilation rate (mNAR) (g cm^{-2} day^{-1}), maximum leaf area index and the maximum total dry weight (g) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

In general terms, as the sowing date progressed, the mNAR, maximum LAI and total dry weight production decreased with maximum levels for each growth index reached during February (LAI), March (dry weight) and April (mNAR).

There was a slight increase in mNAR from February to March associated with a large increase (50%) in dry weight but a decrease in LAI. The mNAR increased (5%) from the March to the April sowing but the dry weight decreased (20%). During this time the maximum LAI fell rapidly. As the mNAR increased from February to April there was a corresponding decrease in LAI.

The increase in mNAR from May to June did not result in an increase in dry weight. The differences in mNAR were relatively small (0.0015-0.0023 g cm^{-2} day^{-1}) compared to differences in dry matter (6 g to 47 g) and leaf area index (0.53 to 4.41).

As would be expected from the close associations between the parameters plotted in Figure 5.7, correlations between them were significant (p>0.05) (Table 5.2).

Table 5.2. Correlations (r^2) between season mean net assimilation rate (NAR), maximum leaf area index (LAI) and total plant dry weight (g).

	NAR	LAI	Total Dry Weight
NAR	1.00		
LAI	0.6478	1.00	
Total Dry Weight	0.8287	0.7739	1.00

5.3.6. Final Bulb Weight – Growth Study

Average individual final bulb weights (g) as affected by sowing date are illustrated in Figure 5.8.

There was a significant (p<0.05) effect of time of sowing on the final bulb weight for all bulbs (marketable and unmarketable). The final weight of the bulbs from the March (321.4 g) and April (302.7 g) sowings was significantly greater than for all other sowings. Bulb weight of the February (219.6 g) sowing was significantly (p<0.05) greater than that of the June (134.2 g) and July (71.2 g) sowings but not that of the May (167.2 g) sowing. The weight of the bulb from the July sowing was substantially less than that of all other sowings.

The individual bulb weight represents the actual weight irrespective of whether it is a double bulb or a bolter. Sixty percent of the bulbs from the February sowing were double bulbs. Although a small number of doubles were produced during the April sowing this was insignificant in comparison to the number of doubles produced during the February and March sowings. When the incidence of double bulbs was taken into account, and the resultant individual marketable bulb weight calculated, bulbs from the March and April sowings were still substantially larger than for all other sowings. Individual bulb weight from the February sowing was significantly greater only than the bulb weight from the July sowing. Extremely small numbers (economically insignificant) of bolters were produced in the February, March and April sowings. This supports the anecdotal evidence that Golden Brown is a bolt-tolerant cultivar.

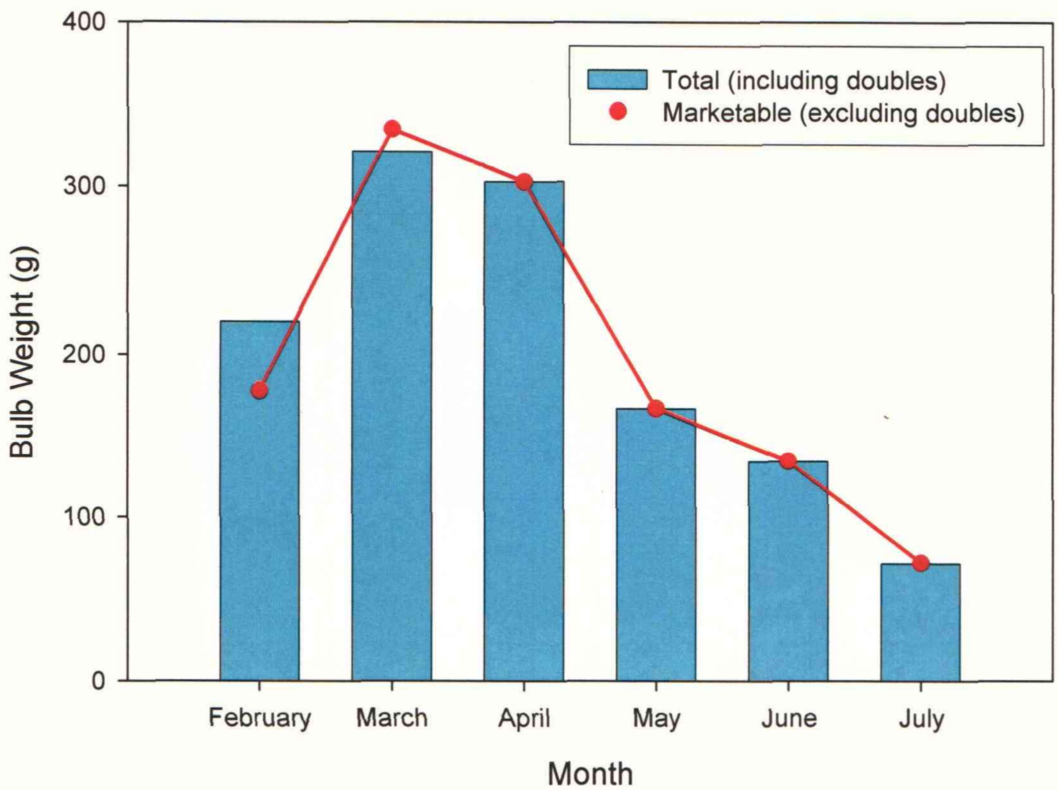

Figure 5.8. Final individual fresh bulb weight (g) (marketable and total) for the cultivar Golden Brown sown at monthly intervals from February to July in 2000 at Gatton Research Station.

5.3.7. Final Yield – Growth Study

Final yield (t ha^{-1}) for each of the sowings is illustrated in Figure 5.9.

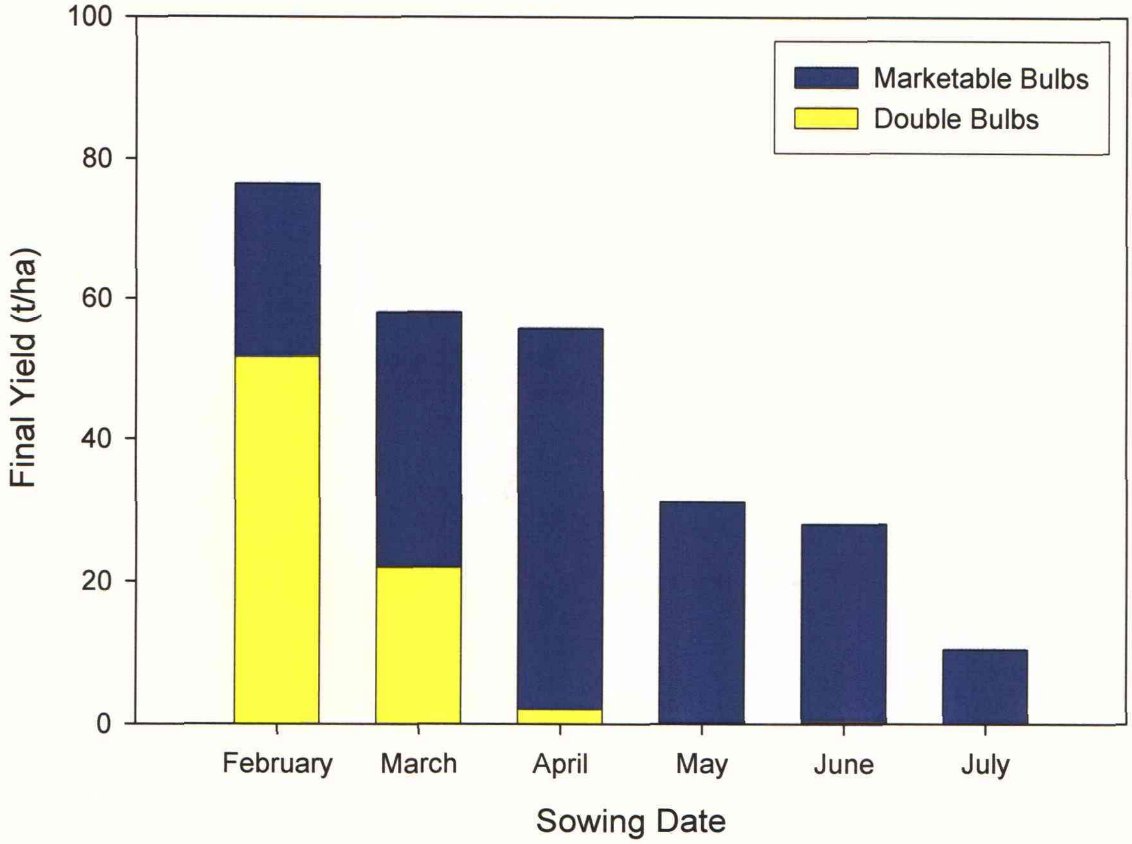

Figure 5.9. Final fresh yield (t ha^{-1}) (doubles, marketable and total) for the cultivar Golden Brown sown at monthly intervals from February to July in 2000 at Gatton Research Station.

Economically significant yield of doubles was produced in February and March; 51.6 and 22.0 t ha^{-1} respectively. The February sowing produced a substantially greater yield of doubles than that of all other sowing dates. March produced a substantially greater yield of doubles than that of subsequent sowings.

The February sowing produced a greater total yield (76.4 t ha^{-1}) than that of all other sowings. The April sowing produced a substantially greater marketable yield (53.5 t ha^{-1}) than that of all other sowings. The July sowing produced the smallest marketable yield of all the sowings.

A comparison between the effects of sowing date on average individual final bulb weight (g) (calculated from final yield of harvested sub-plot – 2 m^2) and individual plant leaf area (cm^2) is illustrated in Figure 5.10.

As the sowing date progressed, the individual bulb weight decreased as did individual plant leaf area. The February sowing produced a significantly ($p<0.05$) larger bulb than for all other sowings. The bulb weight for the March and April sowings were substantially greater than for subsequent sowings.

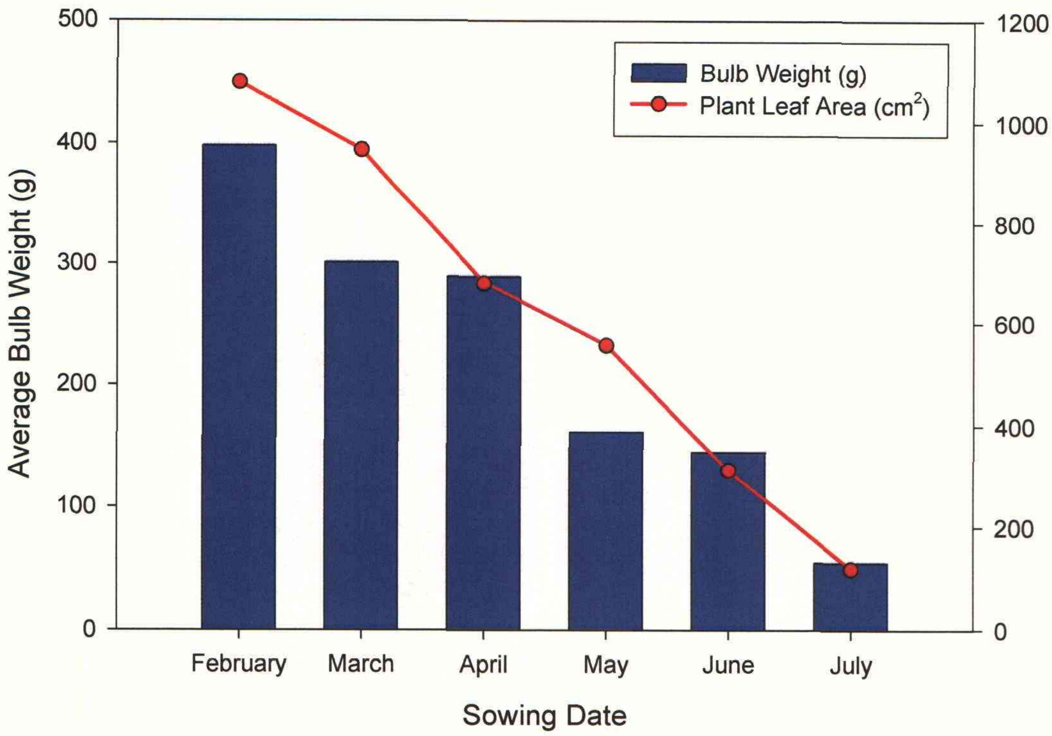

Figure 5.10. Final individual fresh bulb weight (g) calculated from total final yield, and maximum individual plant leaf area (cm^2) achieved for the cultivar Golden Brown sown at monthly intervals from February to July in 2000 at Gatton Research Station.

5.4. Discussion

The effects of temperature and photoperiod on the growth and development of the onion plant are well documented for crops grown under temperate northern hemisphere growing conditions (Brewster 1990a; Coolong and Randle 2003; Heath 1945; Jones and Mann 1963). There is evidence (Abdalla 1967) that high temperatures during the initial growth stages of the onion plant (prior to bulbing) have a dramatic effect on the growth of the onion plant by promoting leaf emergence and delaying the onset of bulbing. High temperatures during bulb development (Robinson 1971; Robinson 1973; Wiles 1994) increase the rate of leaf senescence and hasten neck fall subsequently reducing the time to maturity, and apparently enhance partitioning of dry matter to bulbs (ref Table 4.2.).

5.4.1. Bulbing and Leaf Production

Jones and Mann (1963) suggested that most short-day onion cultivars that bulbed prematurely did not generally re-start vigorous leaf growth again until up to three months after this premature bulbing. The reason for premature bulbing is unclear but may be a result of the thickening of the leaf sheaths in the absence of bulb scale initiation or formation (Brewster 1997). The results from the February sowing support this theory. Heath (1943) observed that once bulb formation had commenced very little leaf emergence or expansion occurred until the bulb had undergone a period of dormancy. Robinson (1971) obtained results from experiments in Rhodesia that concur with this. At 61 DAS in the February sowing, there were indications that the onion plant went through a phase of premature bulbing as the BR was greater than 2.0. After that time a number of leaves emerged and there was a dramatic increase in leaf area up until 89 DAS. This increase in leaf area and leaf number can be accounted for by the number of leaves that had initiated prior to the premature bulbing and subsequently emerged as a result. After this time the evidence suggests that the plant became dormant resulting in minor increases in BR, leaf area and leaf number. During this time the bulbing ratio decreased. This decrease may be explained as a response to a reduction in daylength resulting in a reversal of bulbing in response to a non-inductive photoperiod (Kedar *et al.* 1975). The dormancy period (56 days) coincided with the period prior to actual bulbing date, 117 DAS. From that stage plant growth progressed as was expected i.e. increases in BR and leaf senescence resulting in maturity of the plant.

For later successive sowings, the total number of leaves steadily declined, as did the number of days from sowing to bulbing. This cessation of leaf emergence was likely to be accompanied by bulb scale formation (onset of bulbing) resulting in a decrease in time to the onset of bulbing as sowings progressed. The daylength at the 'onset of bulbing' from the March sowing onwards increases with each sowing. The noted time lag between the commencement of bulbing and the cessation of leaf emergence is as a result of the emergence of bladed leaf initials formed prior to the commencement of bulbing.

5.4.2. Leaf Area and Individual Bulb Weight

Robinson (1973) reported that the greatest leaf area was obtained from early sowings (February to April) in Rhodesia. During this time the plants are exposed to high daytime temperatures prior to bulb initiation. Abdalla (1967) observed that the positive effect of high daytime temperatures on bulbing may counteract any role that shortening daylength may play in slowing down bulb initiation, resulting in greater leaf production. The evidence supports this indicating that the high daytime temperatures experienced by plants sown in February, March and to a lesser degree April were responsible in part for the large plant leaf area pre-bulbing when compared to the later sowings of May, June and July. This can be partially attributed to the greater number of leaves produced by plants sown at this time. The difference in final individual bulb weight has been attributed to the variations in individual plant size and leaf area (Watson 1947; Wiles 1994). The large individual leaf area and consequently large plant produced during the February, March and April sowings were therefore directly responsible for the larger individual bulb weight produced from these sowings (Figure 5.7). The fact that the individual plant bulb weight of the February sowing (Figure 5.11) was less than that of the March and April sowing can be attributed to the premature bulbing resulting in a period of plant dormancy (Robinson 1971) and subsequently fewer leaves produced than in March and April sowings.

The evidence of the continued production of leaves, even after bulbing, supports the findings reported by Abdalla (1967). This continued post-bulbing leaf production in short-day onions is perhaps influenced more by temperature than photoperiod. Continued mild to high temperatures during the growth of the onion may promote continued leaf production. This increased leaf production results in a greater leaf area which then leads to an increased individual bulb weight (Figure 5.7). The results of the February, March, April and May sowings support this theory. This continued leaf production was delayed somewhat in the February sowing for the reason discussed earlier. Continued leaf production after bulbing did not occur for the July sowing. Increasing temperatures during the bulb growth stage of this sowing resulted in increased leaf senescence and a reduced time to maturity.

Wiles (1994) and Robinson (1973) reported that high temperatures during bulb development increased the rate of leaf senescence resulting in a contracted period prior to neck fall and hence maturity. Evidence from the July sowing supports this. Plants sown in July commenced bulb growth (BR>2.0) early in October. From this time onwards the mean daily maximum temperature was greater than the optimum growing temperature (25°C) for onions. During the 2000 growing season the mean maximum growing temperatures experienced by July sown onions during the bulb development stage were September: 28.4°C; October 28.2°C; November 27.0°C and December 31.9°C. These high temperatures resulted in a hastened maturity of the onions and are therefore, a likely factor in contributing to the lower yield than for early sowings.

Even though leaf number for the July sowing was only 50% that of the February and March sowings, LAI barely reached 10% those of February and March, reflecting both smaller individual leaf size and shorter leaf longevity (data not presented).

The time of sowing significantly affected bulb initiation. With successive sowing dates there was a decrease in the number of days to bulb initiation (>50% bulbs with BR>2.0). This will be investigated further in Chapter 7.

5.4.3. Net Assimilation Rate and Leaf Area Index

Brewster (1997) and Wilson (1986) reported that as the leaf area index (LAI) increases there is trend for the net assimilation rate (NAR) to decrease. This occurs as a result of an increase in shading within the plant structure with greater LAI. The results from the February sowing support this theory although in general there was a tendency for the NAR to follow the LAI i.e. NAR increasing when LAI increasing and vice-versa (Figure 5.5). Watson (1947) reported that NAR tended to decrease when crop growth progressed from the warmer summer months to cooler winter months. The results for the mean NAR for the April to July sowings (Figure 5.7) support this theory although the mean NAR determined for the warmer February and March sowings, or cooler April sowing would appear to contradict this result. However, the higher LAI for the February and March sowings than the subsequent sowings provide in part an explanation for this anomaly, where increasing LAI has been reported to result in a decreased NAR (Watson 1947).

Variation in leaf area has been reported to be the main factor in determining a crop's dry matter yield (Watson 1947). Data in Figure 5.7 support this suggestion, the dry weight decreased as the LAI decreased. It has been suggested (Robinson 1973) that the duration of the leaf area is also an important contributing factor in the dry weight yield. The July sowing resulted in a very low dry weight. This sowing also produced the lowest LAI (Figure

5.7) and the duration of leaf function was the shortest (Table 5.1). Duration of leaf function for the March and April sowing were identical but the reduction of LAI from March to April may prove to be responsible for the reduction in dry weight. The corresponding increase in NAR from the March sowing to April sowing did not compensate for the reduced LAI. The decrease in dry weight from the April sowing to the July sowing is explained as a result of the decreasing LAI and duration of leaf function as the sowings progressed.

5.5. Conclusions

Anecdotal evidence has suggested that the local Queensland onion cultivar Golden Brown is bolt-tolerant. The results from these experiments have shown this to be true. This cultivar has produced marketable bulbs when sown at various times spanning the Queensland planting window. Acceptable marketable sized bulbs were obtained from February, March, April and May sowings. The bulb size produced at each sowing will impact on the choice of sowing date. This is a direct consequence of the market being targeted. Different markets have different bulb size requirements, although these can be addressed, and modified through appropriate between-plant spacing (Duff and Jackson 1997).

Based on the large numbers of leaves and large leaf areas from the February to April sowings, this is the optimal sowing time to maximise the size of the "factory" that is required to maximise the marketable yield of the cultivar Golden Brown. These sowings also provided the largest duration for the leaf area resulting in a greater likelihood of increased yield due to the capacity of the plant to capture more solar radiation and utilise a greater percentage of its stored carbohydrates for bulb growth. In the Lockyer Valley optimum marketable yield will be obtained from a March or April sowing. The likelihood of a high percentage of double bulbs (up to 38%) from a March sowing warrants further investigations into a more precise optimal sowing date for the

March sowing in an attempt to reduce the number of doubles. The issues associated with the formation of double bulbs will be discussed in Chapter 6.

CHAPTER 6

6. EFFECT OF SOWING DATE ON THE INCIDENCE OF DOUBLING AND BOLTING IN FIVE ONION (*Allium cepa* L.) CULTIVARS

6.1. Introduction

The formation of double bulbs (or bulb splitting) and the incidence of bolting are undesirable characteristics that can dramatically reduce the marketable yield of an onion crop. The causes of bolting (flowering) in onion have been well documented (Brewster 1977a; Brewster 1983; Jones and Mann 1963; Warid and Loaiza 1993). The factors involved in the formation of double or split bulbs are considerably less well understood.

Bolting is induced almost entirely by cool temperatures (Jones and Mann 1963) although plant size plays a role in the percentage of bolting that occurs. Small plants are less susceptible to the inducing effects of cold on the incidence of bolting (Corgan and Montano 1975; Lawadale and Kale 1986; Madisa 1993). The duration of cold (Call 1986) required for bolting also differs between cultivars. The cultivar Golden Brown is a local Lockyer Valley open-pollinated cultivar that is bolt-tolerant. This characteristic has resulted in it possessing an extensive sowing window that spans the peak of winter and underpins its excellent adaptability to a number of growing environments throughout Queensland, Australia. This cultivar has also contributed to the development of the hybrid cultivar Cavalier. This hybrid has proven very popular as it possesses a high level of bolt tolerance and is adapted to an extensive growing environment throughout Australia.

Double bulbs, bulb splitting, multiple centres and 'pregnant' bulbs all refer to the same phenomenon: the growth of more than one growing point from a bulb in a single season (Currah and Proctor 1990). There is limited knowledge available on the causes of double bulb formation (Currah and Proctor 1990; Robinson 1971; Wilson 1934). In general terms, the causes of double or split bulbs may include high temperatures (Robinson 1971), environmental stress factors (Lydon 1996), soil moisture stress (Pelter *et al.* 2004), plant density (Wilson 1934) and perhaps bulb size (Jackson et al. 1997). There is evidence to suggest that the incidence of double bulbs may be related to high temperatures (Robinson 1971; Steer 1980a). Anecdotal evidence throughout Queensland supports this evidence as high levels of doubles are generally only found in early season (February and March) sown crops. This is the period when there is the likelihood of extended periods (7-10 days) of unseasonably high daytime temperatures. The reason for doubling is not fully understood. Wilson (1934) found that doubling tended to be initiated at an early growth stage and was influenced by plant density. Low plant density tended to stimulate doubling. Doubling may occur as a result of undue stress (Lydon 1996) on the onion plant at a critical growth stage. Pelter (2004) found that soil moisture stress at the 3-5 leaf stage resulted in an increased number (30%) of bulbs with multiple centres when compared to plants that had not experienced this level of soil moisture stress. In direct contrast, Gilbert and Henderson (2002) found that deficit irrigation techniques resulted in a decreased level of doubles. The greater the moisture levels the greater the proportion of doubles produced. This may be linked to the increased plant and bulb size as a consequence of ideal growing conditions. Gilbert and Henderson (2002) identified significant varietal differences where one cultivar produced a greater proportion of doubles than that of the other cultivars irrespective of the irrigation levels. Duff and Jackson (1997) reported similar results.

As Queensland has an extensive growing season, temperature plays an important role in the success or failure of a Queensland onion crop. High incidences of doubling in onions in Queensland are generally restricted to the early season crops. The cultivar Golden Brown was evaluated in field trials at

Gatton Research Station in an effort to assess the effects of sowing date on the incidence of doubling and bolting. The effects of environmental conditions (i.e. temperature) on doubling and bolting in four additional cultivars (Gladiator, Wallon Brown, Contessa and Cavalier) were also evaluated.

6.2. Materials and Methods

The experimental designs for the growth study trials and the growth development trials were outlined in Chapter 3, sections 3.4.1 and 3.4.2, respectively. The cultivar Golden Brown was selected for evaluation because it was the only cultivar sown in all growth study trials. It is particularly well adapted to the Lockyer Valley and produced a bulb at all of the chosen sowing dates.

A destructive plant sampling procedure (Chapter 3.4.1) was implemented to obtain an extensive growth analysis data set. The data utilised in this chapter included evidence and time of doubling and bolting for each plant, individual plant leaf number and percentage of doubles and bolters. These data were collected on a fortnightly basis. Data collected for all five cultivars in the growth development experiments (Chapter 3.4.2) included individual plant leaf number, number of days to doubling and bolting for each plant, number of plants that produced doubles and/or bolters and evidence of multiple centres. Data from the growth development experiments were collected on a weekly basis.

The number of visible leaves per plant for each sowing date was recorded, commencing at the leaf hook/flag stage, as the leaves emerged from the pseudostem. A record of the number of leaves emerged was made in the field (growth development study) and for each of the plants sampled (growth study). The number of leaves produced by individual plants in the field was tracked by marking every fifth leaf on the plant with a small bright green ribbon. Where individual plants produced more than one pseudostem (double) the leaves for each pseudostem were counted separately and the number of leaves per plant was calculated by combining the total number of leaves per pseudostem. The date at which each leaf died was also recorded. The results obtained thus gave an indication of the number of true leaves that were active at any stage throughout the life of the plant.

Plants were recognised to have formed doubles when either (i) the plant produced more than one pseudostem during the growth stages, prior to maturity, of the plant (Plate 6.1 right) or (ii) only a single pseudostem was produced, but double or pregnant bulbs were evident at or close to maturity (Plate 6.1 left and centre respectively). The time that the pre-double stage occurred was recorded for each plant when it became evident.

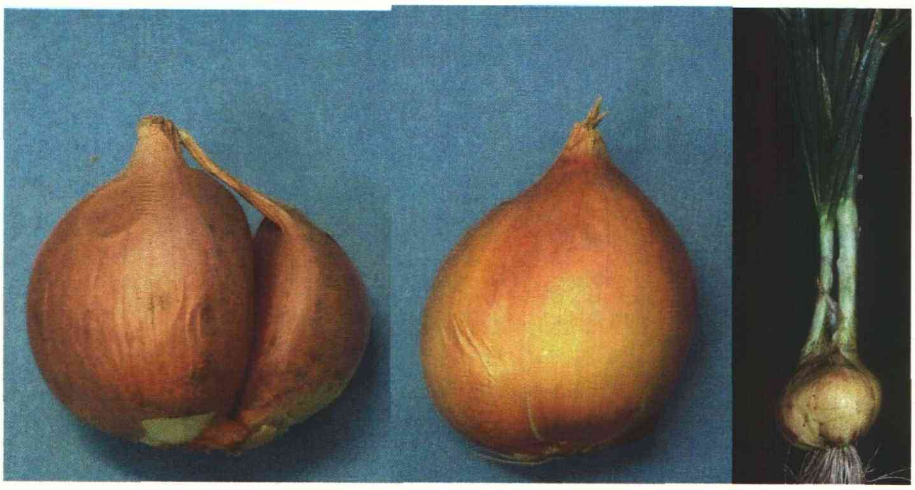

Plate 6.1. Double bulb (left), pregnant bulb (centre) and twin stem (right).

When the bulb diameter of the individual sample plants from the growth study exceeded 35 mm the bulbs where cut in half horizontally at the equator. The bulb was inspected for single centeredness (Plate 6.2). There is some suggestion that multiple–centres (Pelter *et al.* 2004) may be the pre-cursor to doubles. The number of centres was recorded for each bulb.

Plate 6.2 Single-centred onion bulb (left) and multiple-centred bulb (right).

The incidence of doubling in the growth study and the growth development trials was sporadic. In some instances the level of doubling across the trial plots and between replicates proved to be uneven, consequently, analysis of the data was difficult. An example of this is the unevenness of doubling in cultivar Cavalier sown in the February when only three out of the four replicates produced doubles. The differences could not be accounted for via any nutritional (nitrogen) differences in the soil or as a result of traditional location differences eg edge effect.

The total number of days from emergence to bolting for each of the sowing dates where part of the day experienced a temperature of 9-13 °C was calculated. This data were used to investigate the relationship between bolting and temperature. Numerous studies (Rabinowitch 1990) have reported that the optimal temperatures for flowering and therefore bolting varies considerably between cultivars. Time required for flower initiation is reported to be minimal when the temperature range is 5-12 °C (Rabinowitch 1990). A temperature range of 9-13 °C was chosen for analysis of data in this study as Sinclair (1989) reported that a long enough period at this temperature range was sufficient to induce bolting.

The percentage data were calculated from the original data collected from each experiment. The original data was converted to give the percentage data results. Data for all treatments were subjected to a one-way analysis of variance using Genstat for Windows Version 6.1 statistical software (Lawes

Agricultural Trust). Means were separated using Fishers Protected LSD at $p<0.05$.

All graphs created to display results have been created using SigmaPlot 2001 for Windows Version 7.101 (SPSS Inc).

6.3. Results

6.3.1. Doubling - Golden Brown

The percentage of double bulbs, as doubles or pregnant bulbs (Plate 6.1), produced by the cultivar Golden Brown for the February until June sowings in 2000 is presented in Figure 6.1.

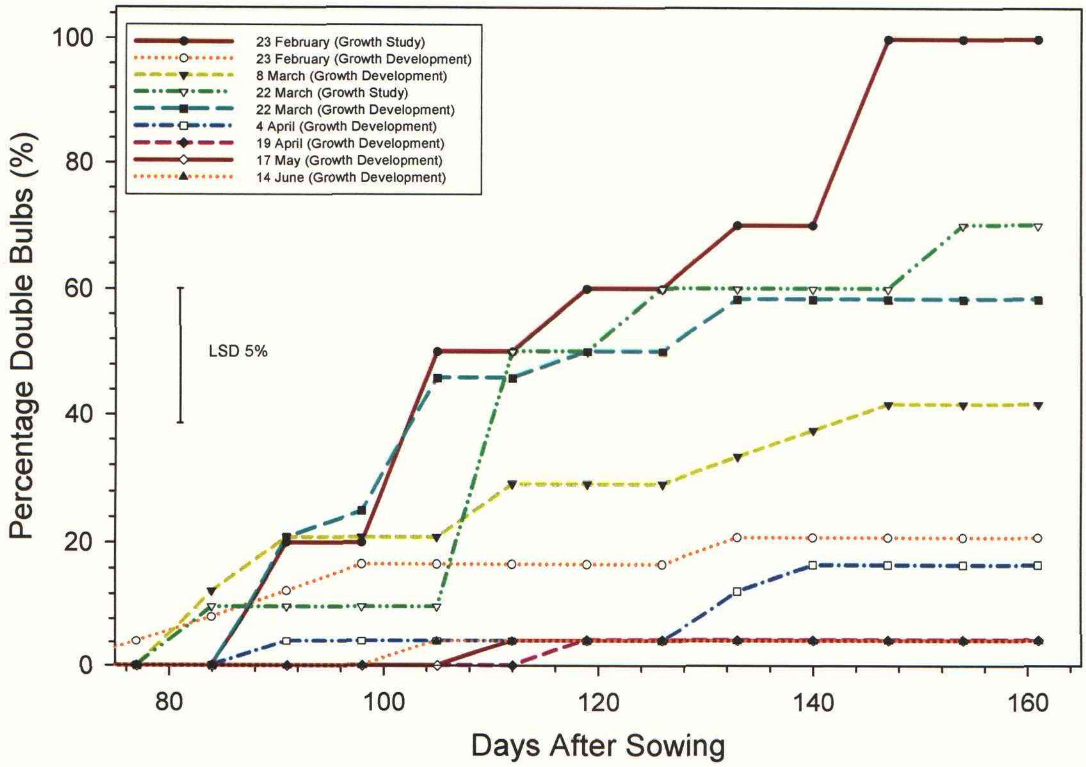

Figure 6.1. The number of double bulbs (as a percentage of the total bulb number) produced by the cultivar Golden Brown from the growth study and growth development study trials sown at Gatton Research Station from February to June 2000.

There was a significant ($p<0.05$) effect of sowing time on the final percentage of doubles produced by the cultivar Golden Brown. Doubles were produced during the February, March, April, May and June sowings. The late February (growth study trial) sowing produced 100% double bulbs. This was significantly ($p=0.05$) greater than for all other sowings. Double bulbs (20%)

became evident at 91 DAS in this experiment. In the growth development study experiment (23rd February) only 21% of the bulbs resulted in doubles. This was significantly ($p<0.05$) less than the March 22 sowings (growth development study and growth study) but not significantly ($p>0.05$) less than the March 8 growth development study sowing. The doubles first became evident at 77 DAS (4%) for this sowing.

The early March sowing (growth development study) only produced a maximum of 42% double bulbs. The later March sowing produced 70% and 58% double bulbs for the growth study and growth development study trials respectively. Double bulbs started to appear at approximately 90 DAS.

The April sowings produced very few doubles; 17 % from the early April sowing and 5 % from the mid April sowing. In most instances this would be considered negligible. Negligible numbers of double bulbs were also produced during the May 17 and June 14 sowings (4.17% each sowing). There was evidence of multiple centres in bulbs harvested from the May (50% of bulbs) and June (20% of bulbs) growth study experiments.

6.3.2. Doubling - All Cultivars

The percentage of doubling in five cultivars in the growth development study field trials is illustrated in Figure 6.2.

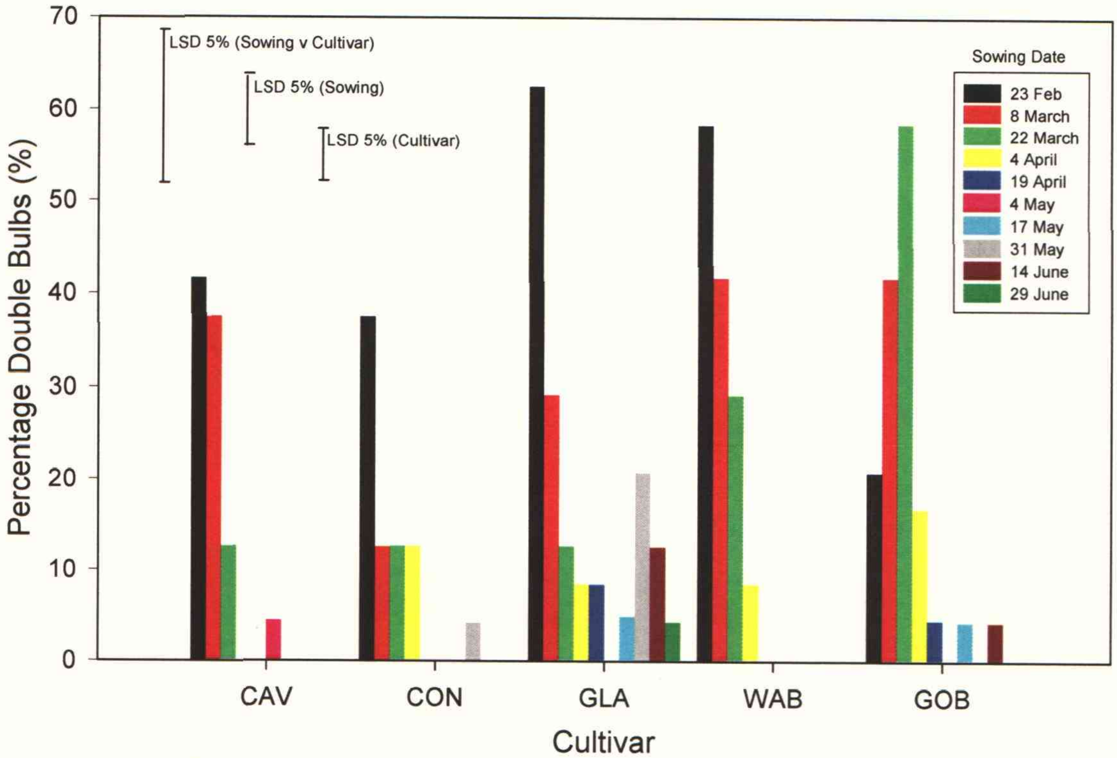

Figure 6.2. The total number of double bulbs (as a percentage of the total bulb number) produced by the cultivars Cavalier (CAV), Contessa (CON), Gladiator (GLA), Wallon Brown (WAB) and Golden Brown (GOB) from the growth development study trials at the Gatton Research Station sown at fortnightly intervals from February to June during the 2000 growing season.

There was a significant ($p<0.05$) effect of sowing time and cultivar on the final percentage of doubles produced for all cultivars. For all cultivars, the production of double onion bulbs was significantly greater during the February and March sowings than at all other sowings.

Gladiator produced a significantly ($p<0.05$) greater percentage of doubles, as multiple stems, from the February sowing than CAV, CON and GOB. The percentage of doubles produced by Wallon Brown in the February sowing, although high, was only significantly ($p<0.05$) greater than the percentage of doubles produced by Golden Brown.

CAV, GLA, WAB and GOB produced double bulb percentages significantly ($p<0.05$) greater than CON during the March 8 sowing. Golden Brown produced a significantly ($p<0.05$) greater percentage of doubles than all cultivars in the March 22 sowing.

Small (or nil) percentages of doubles were produced in the sowings after March. Gladiator produced a significantly ($p<0.05$) greater proportion of double bulbs in the May 31 sowing than all the other cultivars.

The maximum percentage of doubles produced by CAV, CON, GLA and WAB occurred during the February sowing. The maximum percentage of doubles for Golden Brown occurred during the March 22 sowing. CAV, GLA and WAB produced substantial percentages of doubles during the March sowing. Gladiator produced a large percentage (21 %) of double bulbs in the late May sowing. Wallon Brown did not produce any doubles after the early April sowing. A minimal number of doubles were produced by CAV and CON after the late April sowing. Gladiator continued to produce a small proportion of double bulbs from February to late June.

The effect of the number of degree-days (> 5 °C) (Chapter 2) accumulated by individual onion plants prior to the first double bulb appearing is presented in Figure 6.3.

In general terms, for all cultivars the number of degree-days accumulated by the onion plant prior to double bulbs first becoming evident decreased as the sowing date advanced. In sowings where doubles were produced the open pollinated cultivars GOB and WAB accumulated fewer degree-days prior to doubling than the hybrid cultivars (CAV, CON and GLA).

Cavalier required the greatest number of degree-days for the production of doubles in the February and March sowings. Wallon Brown required the least number of degree-days prior to the initiation of doubling in the February, March and April 4 sowings.

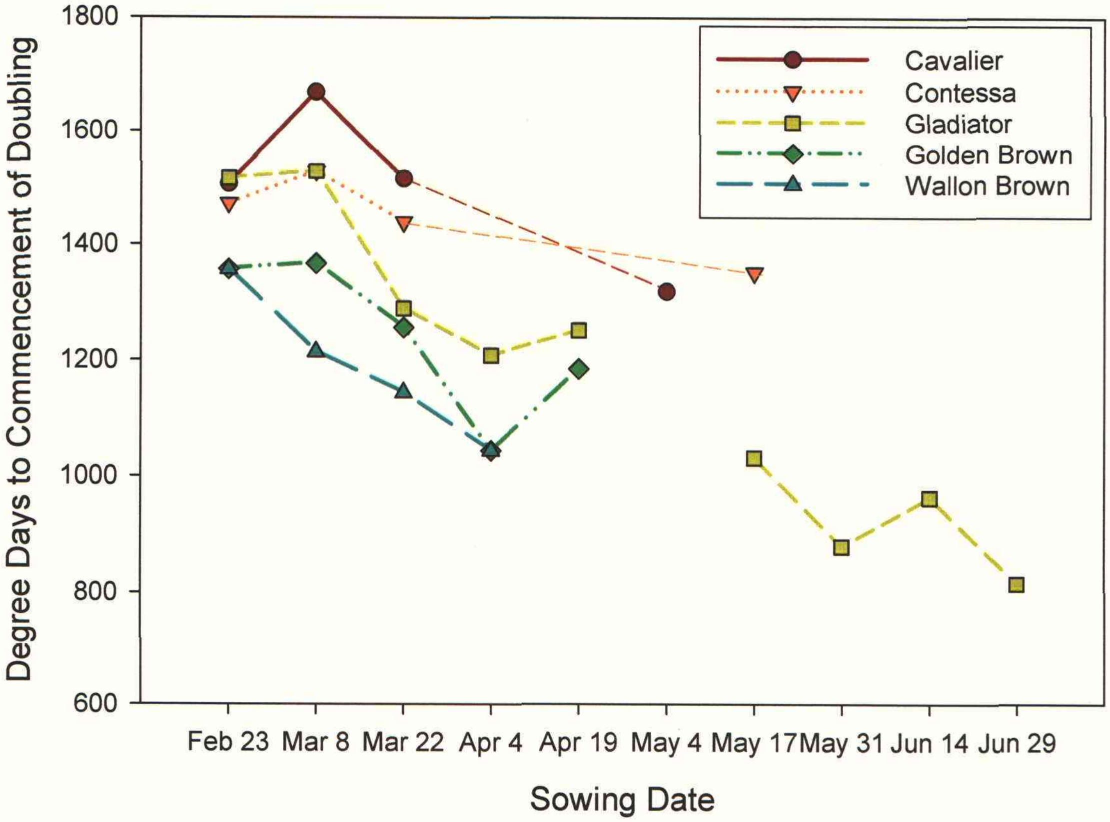

Figure 6.3. Number of accumulated degree-days until commencement of doubling in the cultivars Cavalier, Contessa, Gladiator, Golden Brown and Wallon Brown from the growth development study trials sown at fortnightly intervals from February to June 2000 at Gatton Research Station.

The relationship between average bulb weight (at maturity) and percentage double bulb production (at maturity) for all cultivars in the growth development study is presented in Table 6.1.

In general terms the percentage of double bulbs decreased as the bulb size decreased. In these cases bulbs were classified as doubles from an external visual viewpoint. Since bulbs were classified from an external visual assessment, multiple-centres were not included in the double bulb count. There were a number of exceptions to these results.

For Golden Brown (growth development study trials) the average bulb size from the February sowing was small in comparison to the March and April sowings. Correspondingly, the number of double bulbs was somewhat less than these later sowings. The May 4 sowing produced quite a large bulb but no doubles. The final bulb size of this cultivar was larger from the growth study trials (February to April) with a correspondingly large percentage of doubles from these sowings.

Gladiator produced the maximum number of doubles, as multiple stems, when the plants had not actually formed bulbs: February to early May. This cultivar also produced significantly ($p<0.01$) more doubles from late sowings than all other cultivars.

Table 6.1. Average individual bulb weight (g) at maturity and number of double bulbs (%) at maturity for the cultivars Cavalier, Contessa, Gladiator Golden Brown and Wallon Brown sown at fortnightly intervals in the growth development trials study from 23rd February 2000 to 14th June 2000 at Gatton Research Station. Figures in brackets for the cultivar Golden Brown are from the growth study trials, the final destructive sampling for each sowing date.

Sowing	Cavalier		Contessa		Gladiator		Golden Brown		Wallon Brown	
	Bulb Wt	% Doubles	Bulb Wt	% Doubles	Bulb Wt	% Doubles	Bulb Wt	% Doubles	Bulb Wt	% Doubles
Feb23	619.32	41.67	519.30	37.50	0.00*	62.50**	164.40 (219)	20.80 (100)	390.48	58.33
Mar8	459.57	37.50	219.13	12.50	0.00*	29.17**	302.52	41.70	441.00	41.67
Mar22	370.55	12.5	232.50	12.50	0.00*	12.5**0**	248.40 (321)	58.33 (70)	302.52	29.17
Apr4	298.65	0.00	197.05	12.50	0.00*	8.30	213.17	16.67	269.20	8.33
Apr19	408.40	0.00	306.83	0.00	0.00*	8.33**	274.67	4.34	286.78	0.00
May4	405.70	4.34	273.93	0.00	0.00*	0.00	286.80	0.00	287.28	0.00
May17	209.52	0.00	180.22	0.00	211.25	4.76	115.91	4.17	187.75	0.00
May31	183.90	0.00	174.15	4.17	164.20	20.80	157.20	0.00	162.38	0.00
June14	212.42	0.00	205.30	0.00	213.73	12.50	168.60	4.17	134.08	0.00
LSD (5%) Bulb Wt: 43.18; % Doubles: 8.57										

* No bulbing occurred; ** Doubling evident as multiple stems for this cultivar.

6.3.3. Bolting – All Cultivars

During the growth study trials for the cultivar Golden Brown a negligible number of bolters was recorded. Bolters (20%) were only produced during the April sowing at 156 DAS.

The percentage of bolting in the five cultivars included in the growth development study field trials is illustrated in Figure 6.4.

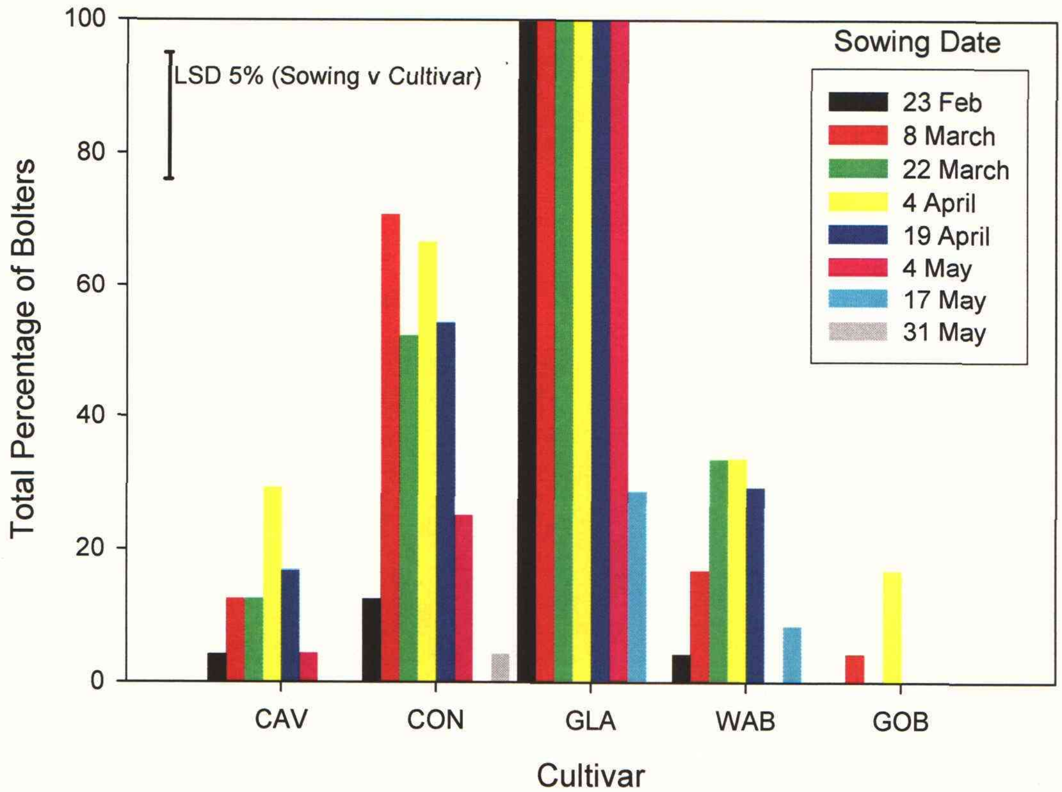

Figure 6.4. The total number of bolters (as a percentage of the total bulb number) produced by the cultivars Cavalier (CAV), Contessa (CON), Gladiator (GLA), Wallon Brown (WAB) and Golden Brown (GOB) from the growth development study trials at the Gatton Research Station sown at fortnightly intervals from February to June during the 2000 growing season.

There were significant ($p<0.05$) effects of sowing time, cultivar and the interaction between the two, on the final percentage of bolters.

The effect of time of sowing on the production of bolters is presented in Figure 6.5.

Significantly ($p<0.05$) greater percentages of bolters were produced in the March and April than other sowings. The maximum percentage of bolters, significantly greater than all other sowings ($p<0.05$), was produced during the April 4 sowing. Few bolters were produced in the May sowings and no bolters were produced in the June or July sowings.

Gladiator produced a significantly ($p<0.05$) greater percentage of bolters during the February to 4th May sowings than the other cultivars. Contessa produced a significantly ($p<0.05$) greater percentage of bolters for the March 8 and both April sowings than all other cultivars.

Combining the results from all sowing dates, Gladiator produced a significantly ($p<0.05$) greater percentage of bolters than did other cultivars. Golden Brown produced significantly ($p<0.05$) fewer bolters than CAV, CON and WAB.

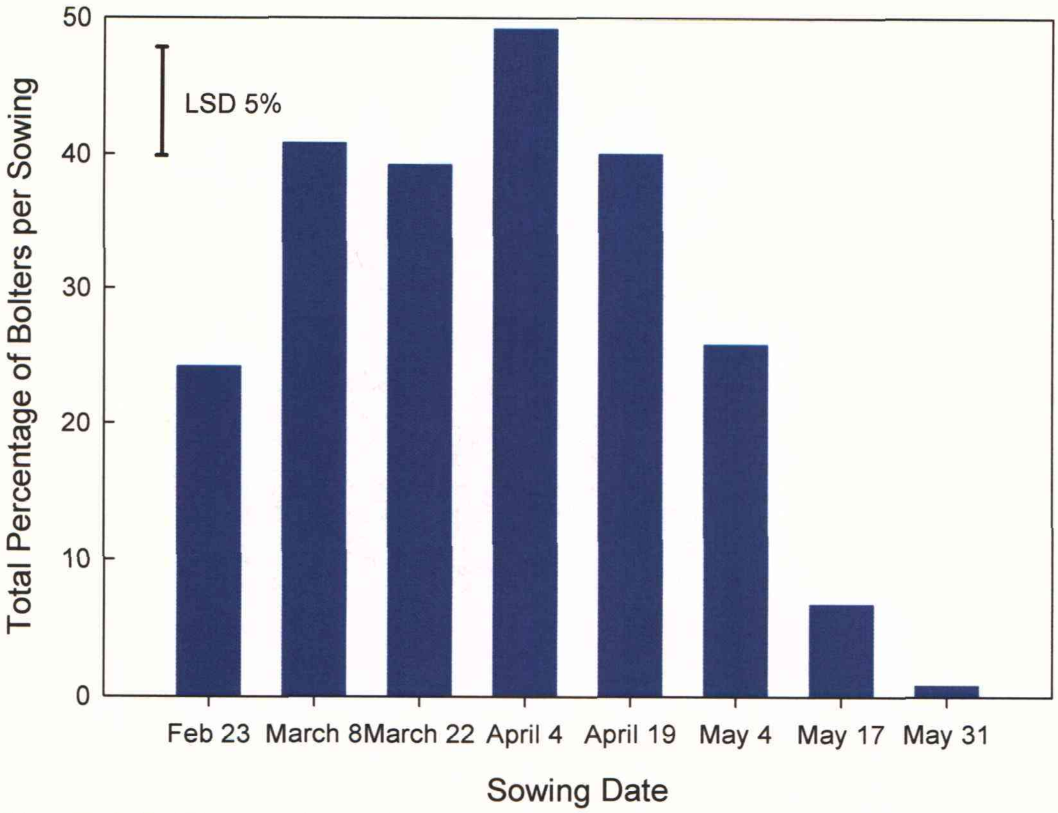

Figure 6.5. The total number of bolters (as a percentage of the total bulb number) per sowing (fortnightly intervals) for the growth development study trials for all cultivars at the Gatton Research Station from February to May during the 2000 growing season.

The total average number of days where part of the day experienced a temperature of 9-13 °C prior to bolting occurring and final bolting percentage is presented in Table 6.2 for all cultivars.

As the sowing date progressed, the number of days with a temperature of 9-13 °C was recorded prior to bolting increased for all cultivars. Contessa and Gladiator required a minimum of *c.*105 days with temperatures at 9-13 °C for bolting to occur.

Table 6.2. Total average number of days where part of the day experienced a temperature of 9-13 °C prior to bolting occurring for all cultivars in each sowing where bolting occurred and final bolting percentage per cultivar for each sowing date.

Cultivar		Sowing Date						
		23 Feb	8 Mar	22 Mar	4 Apr	19 Apr	4 May	17 May
Cavalier	#Days 9-13°C	75	92	102	111	131	123	
	% Bolting	4	13	13	30	17	4	
Contessa	#Days 9-13°C	107	111	123	121	139	138	126
	% Bolting	12	71	50	67	54	25	0
Gladiator	#Days 9-13°C	106	115	123	125	139	143	131
	% Bolting	100	100	100	100	100	100	29
Golden Brown	#Days 9-13°C		67		110			
	% Bolting		5		17			
Wallon Brown	#Days 9-13°C	75	96	103	111	121		127
	% Bolting	9	17	46	33	29	0	8

6.4. Discussion

6.4.1. Doubling

The causes of doubling or bulb splitting in onions are unclear. A number of theories have been put forward (Abdalla and Mann 1963; Lydon 1996; Robinson 1971; Wilson 1934) in an effort to explain this phenomenon. In general terms, studies have indicated that an external shock, environmental, chemical or cultural (Lydon 1996) to the onion plant results in additional growing points in the base plate being activated resulting in double or split onions. Prolonged periods of higher than average daytime temperatures (Brewster 1990b; Robinson 1971) have been suggested as a likely cause for the production of high percentages of double onions. Doubling is the result of the development of axillary buds prior to bulb initiation. These axillary bulbs produce either bladed leaves (see twin-stem in Plate 6.1) or bulb scales. The results for all cultivars (Figure 6.2) indicate that onions sown early in the season (February and March) are more susceptible to doubling/splitting than when sown later in the season. This confirms the findings of Robinson (1971) where a higher percentage of split bulbs occurred from a February sowing during which time high daytime temperatures are experienced.

Axillary bulbs do not tend to occur in young plants (prior to approximately the eighth leaf). Early sowings produced the greatest leaf number (> 8 leaves) prior to bulb initiation (Figure 5.3) and consequently there was an increased likelihood of the development of axillary buds from these sowings. These sowings also produced the greatest percentage of double bulbs.

For the cultivar Golden Brown in the growth study trial (Figure 6.1), the percentage of doubles decreased from the February to March sowings whereas the percentage of doubles increased from February to March in the growth development study trial. For all other cultivars in the growth development study trial the percentage of doubles increased from February to March. This difference in the number of doubles between the February growth study trial and the February growth development study trial for the cultivar Golden Brown (Figure 6.1) is difficult to explain. Both trials were sown on the same date and were managed identically in regard to nutrition, irrigation and pest management practices. There was no problem with trial design as replication was used in both instances and consistent results were obtained across replicates. The large number of double bulbs in the growth study trial appears to be an anomaly. Anecdotal evidence (Lockyer Valley onion growers, pers. comm.) suggests that the percentage of double onions produced from a February sowing date can be quite high but not usually as high as experienced in the growth study trial. Research findings supporting this anecdotal evidence were reported by Duff and O'Donnell (2002), Jackson and Duff (1998) and Jackson *et al* (2000). These findings reported a higher incidence of double bulbs in a number of cultivars, including Golden Brown, sown at fortnightly intervals (1994-1996) and monthly intervals (1997-2001) from February to April than that of May to June sowings. From February to late March (growth development trials) the number of doubles increased and then decreased with subsequent sowings.

It has been recorded that large percentages of double onions have resulted when the size of the onion bulb is large (Jackson *et al.* 1997). The results for the cultivar Golden Brown sown concurrently in the growth development study and growth study trials (Table 6.1) support this finding. Large bulbs resulted in a greater percentage of doubles and smaller bulbs have resulted in a lower percentage of doubles. The results for the cultivars Cavalier and Contessa, however, contradict this as the sowing date progressed. This may be explained if a specific minimum bulb weight has to be exceeded in combination with a stress event (eg temperature) before doubling can occur. This is also an indication that plant genetic makeup contributes to the susceptibility of cultivars to doubling. There is evidence from the results to suggest that plant size prior to bulb initiation is important in the incidence of doubling although further investigations may be warranted. There may be a similar link between plant size and doubling as there is between plant size and bolting, where small plants are less susceptible to bolting than larger plants under bolt-inducing cold conditions. Data collected (but not reported on here) in the growth development study and growth study trials (Chapter 3) in 1999 support this theory of large plants being more susceptible to double than smaller plants. A greater proportion of doubles were produced from large plants than from smaller plants in the 1999 trials (Duff unpublished).

Joubert and Strydom (1968) reported that although bulb splitting is affected by environmental factors the genetics of the cultivars play an important role in the susceptibility or otherwise of certain cultivars to splitting. The level of doubling varied between cultivars sown on the same date in the current experiment, giving credence to a marked genetic control of bulb splitting.

Although the cultivar Gladiator produced a large number of doubles from the February sowing through to the mid-May sowing no bulbs (by bulbing ratio definition) were formed. The plants produced multiple pseudostems without producing bulbs. This cultivar (hybrid) is an intermediate day type requiring intermediate to long daylengths for bulb initiation and is adapted to a June sowing in Queensland. This explains the lack of bulb formation until the late May sowing.

6.4.2. Bolting

In general terms, bolting results from exposure to long periods of temperatures between 9-13 °C (Brewster 1977b; Sinclair 1989). Cultivars differ in the amount of cold required for bolting (Sinclair 1989). Some cultivars will not bolt unless they receive extended periods of low temperatures (Brewster 1977b) while others require shorter periods of low temperatures (Heath 1943). This is analogous to 'low-chill' and 'high-chill' requirements of stone fruit.

The open-pollinated Lockyer Valley selection Golden Brown is bolt tolerant (Schrodter 1990). Due to its bolt-tolerance this cultivar was selected as a parent for the development of the hybrid Cavalier (Terranova Seeds formerly Yates Vegetable Seeds). The number of bolters produced by the cultivar

Golden Brown in all the current trials was negligible. Under these circumstances Golden Brown may be termed high-chill, requiring long periods of low temperatures to induce floral bud initiation at the growing point in the base of the bulb. There was an insufficiently long period of chilling temperatures in the current trials to initiate bolting. The other factor that may affect the level of bolting in this cultivar is the effect of temperature on the post-vernalisation floral bud development. If the plant is exposed to extended periods of warm temperature at this stage, as is likely to occur under Queensland growing conditions, floral bud development may be terminated and the plant continues bulbing. It has been reported that high temperatures in the field or in storage (Kamenetsky and Rabinowitch 2002) may cause reversion from the floral stage to the vegetative stage. The more plausible explanation for the bolt resistance in the cultivar Golden Brown is the fact that it may be termed a 'high-chill' cultivar. Exposing the cultivar to extensive periods of cold temperature (Jackson and Duff 1997; Schrodter 1990) in trials throughout winter resulted in a very low incidence of bolting (< 2.0%). The evidence collected in the growth study and growth development study trials supports these results.

Contessa and Gladiator displayed bolting characteristics that would describe them as 'low-chill' cultivars. The greatest percentage of bolters for these cultivars occurred as a result of early sowings, when they would have been exposed to sufficiently long periods of temperatures at 9-13 °C. The level of bolting in Wallon Brown and Cavalier indicates a slightly increased bolt tolerance than that of Contessa and Gladiator. These cultivars produced small numbers of bolters for a small number of 9-13 °C days.

During the initial sowings the plant size was quite large for all cultivars (Chapter 5) with large leaf area and leaf number. Correspondingly the number of 9-13 °C days required before the first bolter appeared was low (Table 6.2). As the sowings progressed plant growth was slowed and the time required to reach a plant size that would result in bolting lengthened. Consequently, the number of 9-13 °C days prior to flower initiation increased with each subsequent sowing. This supports the work of previous researchers (Kamenetsky and Rabinowitch 2002; Rabinowitch 1990; Sinclair 1989) who have found that plant size plays an important role in flower initiation. The onion plant must be a minimal size (Rabinowitch 1990) for flower initiation to occur.

6.5. Conclusions

The mechanism that results in high levels of doubling in onions has not been fully explained. There are indications that the interaction between genotypes and the environment, in particular temperature, are the principle factors determining the final percentages from any given sowing date. There is evidence to suggest that doubling can be controlled or reduced by manipulating plant size thereby minimising the effects of any undue stress on the onion plant. Large plants produced large bulbs (Chapter 5) resulting in an increased level of doubles above that of smaller bulbs that have been produced from smaller plants. Large plants are capable of intercepting more light than smaller plants. This may also have a role to play in the proportion of double bulbs produced. Further investigations are required to determine the effects of light, temperature and plant size on the incidence of doubles.

The complex effects of temperature on bolting and the likely seasonal differences from year to year makes bolting behaviour variable and at times erratic. Management of sowing date to minimise the effect of temperature is critical to reduce bolting and its effect on the marketable yield of an onion crop.

Temperature prediction models (similar to the Southern Oscillation Index rainfall models) that are currently being evaluated by researchers of the Queensland Department of Primary Industries and Fisheries may prove to be a useful tool for growers when attempting to minimise the impact of temperature on the incidence of doubling in their onion crops. The use of these models would facilitate improved varietal selection and the selection of the optimal sowing date for the cultivars selected.

The use of temperature models may also prove useful in the selection of correct cultivars and optimal sowing windows to avoid a high level of bolting in the onion crop. Models that can predict when there is an increased chance of extended periods when temperatures will be in the vicinity of 9-13 °C will prove to be invaluable to the onion industry. Investigations are required to provide additional data to develop this capability.

CHAPTER 7

7. DRY MATTER PARTITIONING AND RADIATION INTERCEPTION OF THE ONION (*Allium cepa* L.) CULTIVAR GOLDEN BROWN IN THE LOCKYER VALLEY

7.1. Introduction

Many authors have evaluated the relationships between onion dry matter accumulation, temperature and radiation interception in the northern hemisphere temperate growing conditions (Austin 1972; Brewster 1982; Grevsen 1989; Kedar *et al.* 1975; Kretschmer and Strohm 1988). Information on onion dry matter accumulation versus radiation interception in the southern hemisphere, in particular tropical environments, is limited (Lancaster *et al.* 1996; Wiles 1994), although work has been done on other crops eg potatoes (Sale 1973; Sale 1977). The dry matter yield of a crop is the result of the radiation absorbed by the canopy, the efficiency of conversion of the radiation absorbed into plant dry matter and the subsequent dry matter partitioning into the harvested bulb and remainder of the plant (Charles-Edwards 1982; Hay and Walker 1989). Onion adheres to this model although its canopy structure and plant physiology result in varying degrees of radiation use efficiency throughout the growth of the plant (Brewster 1990b). The plant has a low radiation use efficiency early in its growth and an extremely high radiation use efficiency in the later growth stages (Tei *et al.* 1996).

Temperature and photoperiod are known for their contribution to the growth of the onion plant at the various stages of growth (Brewster 1990b; Tei *et al.* 1996). Little research has been undertaken examining the photothermal contributions to onion growth under field grown conditions in the southern hemisphere. Lancaster et al. (1996) and De Ruiter (1986) investigated the relationships between thermal time and bulbing, and concluded that a minimum thermal time must be reached prior to the onset of bulbing (Lancaster *et al.* 1986) and bulb size at top down is related to thermal time from emergence to top down (de Ruiter 1986).

The photothermal quotient and its relationship with crop growth has been examined in a number of crops (Andrade 1992; Cantagallo *et al.* 1997; Lamelas *et al.* 2002; Ortiz-Monasterio *et al.* 1994). This relationship has not been previously investigated in tropical onions. Dry matter production has been shown to increase with increased radiation (Brewster *et al.* 1986; Midmore and Roca 1992; Tei *et al.* 1996) but this increase in radiation also results in increased temperatures (Charles-Edwards 1982). The use of the photothermal quotient may prove to be useful in evaluating dry matter production in the onion in the face of the often-times confounded relationship between temperature and radiation.

No studies have been undertaken to evaluate the effect of radiation interception and/or thermal time (degree days) on dry matter production of onions in Australia. The current study was undertaken to investigate the dry matter production (bulb and total weight) of the onion plant under tropical conditions. This investigation examined the relationships between dry matter accumulation and the photothermal requirements of the onion plant under Queensland growing conditions.

7.2. Materials and Methods

The open-pollinated local Queensland cultivar Golden Brown was selected for evaluation due to its bolt tolerance and ability to form bulbs irrespective of sowing date (Schrodter 1990). As outlined in 3.4.1, Golden Brown was sown at monthly intervals from late February through to mid July 2000. The complete trial description is outlined in 3.4.1. Golden Brown was the only cultivar evaluated at all sowing dates.

Dry matter accumulation was determined by a process of destructive sampling. Complete plants were removed from the individual plots, thoroughly washed and air dried prior to dissection into their plant components of leaves, pseudostems, bulbs, roots and flower stems (Plate 3.1). The sampling method did not facilitate the collection of all the roots produced by the plant. Consequently, roots were not included at any stage in the calculations for the total dry weight of the plant. Dead leaves were removed and discarded. Their weight was not included in fresh or dry weight measurements or calculations.

Destructive sampling occurred at fortnightly intervals commencing at approximately the 1-2 leaf stage of the onion plant. As the sowing date progressed the number of days after sowing for the commencement of sampling progressively increased as a result of slow growth due to lower soil temperatures in the winter. At each sampling date, five plants per replicate were selected at random for assessment. The fresh weight of the plant components was determined and then the plants were dried in a forced air-drying oven at 45°C for 48 hours to obtain the dry weight for each component of the plant.

Percentage light interception of the crop was also determined at each sampling date (fortnightly intervals). A separate bed containing three permanent light interception sites was used to determine the light interception of the crop. These sites were used every time light interception was evaluated. In the first instance, the sites were selected at random within the bed; one in the centre of the bed and the others 2 m in from either end of the bed. The readings were measured using equipment manufactured by Monitor Sensors® (Plate 3.3). A single point light sensor was placed outside the crop to determine the total incident radiation (IR) (MJ m^{-2}) on the crop. A 1 m wand with sensors along the length of it was placed inside the crop at ground level at an angle of 45° to the rows. This wand gave a measurement of the amount of radiation penetrating the canopy (CR) of the onion crop. Two readings were made for each of the three permanent sites: the point sensor reading and the sensor wand reading.

Percentage of radiation intercepted was calculated using the formula 100 x (1 – CR/IR). Intercepted radiation (MJ m^{-2} day^{-1}) for each day was calculated as the product of the interception radiation fraction (1 – CR/IR) and the daily incident radiation as measured at the University of Queensland Gatton Campus meteorological station *c.* 500 m from the trial site. Daily values for the intercepted radiation were estimated by linear interpolation between the measurements taken at fortnightly intervals.

The daily thermal time was calculated from the formula

Degree day sum = (Tmax + Tmin)/2 – T_b

where Tmax and Tmin are the recorded daily maximum and minimum temperatures respectively. The base temperature for onions (T_b) for onion is reported to be 5°C (Lancaster *et al.* 1996). The degree-day sum for each sampling period was calculated from the sum of the individual degree-days between each sampling and only included days when the mean temperature exceeded the base temperature (T_b).

As determined in Chapter 5, the number of days after sowing to 50% bulbing for each of the sowing dates (Table 7.1) was used as the commencement of bulb growth for the development of relationships between bulb growth and the photothermal components.

Table 7.1. The number of days to a minimum of 50% bulbing and a total of 100% bulbing for the onion cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

	February	March	April	May	June	July
Days to ≥50% bulbing	117	129	116	118	104	94
Days to 100% Bulbing	145	143	143	130	104	94

Data for all treatments were subjected to a one-way analysis of variance using Genstat for Windows Version 6.1 Statistical Software (Lawes Agricultural Trust). Means were separated using Fishers Protected LSD at $p<0.05$.

Linear and non-linear regression analysis was used to determine the extent of relationships between variables. SigmaPlot 2001 for Windows Version 7.101 (SPSS Inc) was used to determine the regression equations and produce the graphical representations of the regression lines, together with the equation and a plot of the data. All linear regression analyses for total plant dry weight (Sections 7.3.3 and 7.3.6) were carried out while forcing the equation through the origin.

Additional information concerning the materials and methods is outlined in section 3.4.1 Growth Study.

7.3. Results

7.3.1. Dry Weight Partitioning

7.3.1.1. Green Leaf

The green leaf dry weight accumulation over time, the regression equations and the regression lines for the cultivar Golden Brown sown at monthly intervals for February to July 2000 are presented in Figure 7.1.

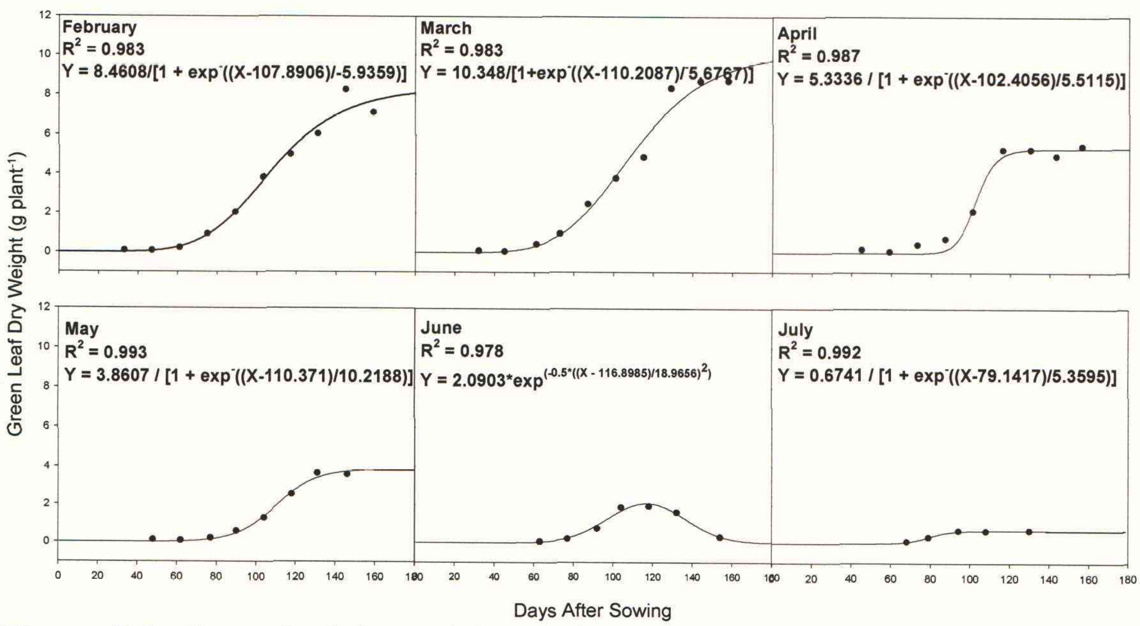

Figure 7.1. Green leaf dry weight (g $plant^{-1}$) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

There were highly significant ($p<0.0001$) regressions (Figure 7.1) at all sowing dates for green leaf dry weight (g $plant^{-1}$) versus time (days after sowing).

The maximum green leaf dry weight per plant was greatest in the March sowing and steadily decreased as the sowings progressed. For all sowings, except the June sowing, the green leaf dry weight reached its maximum and maintained this until the final harvest.

Regression equations for February, March, April, May and July are sigmoidal (3-parameter logistic) equations. The regression equation for the June sowing is a peak (3-parameter Gaussian).

7.3.1.2. *Pseudostem*

The pseudostem dry weight accumulation over time, the regression equations and the regression lines for the cultivar Golden Brown sown at monthly intervals for February to July 2000 are presented in Figure 7.2.

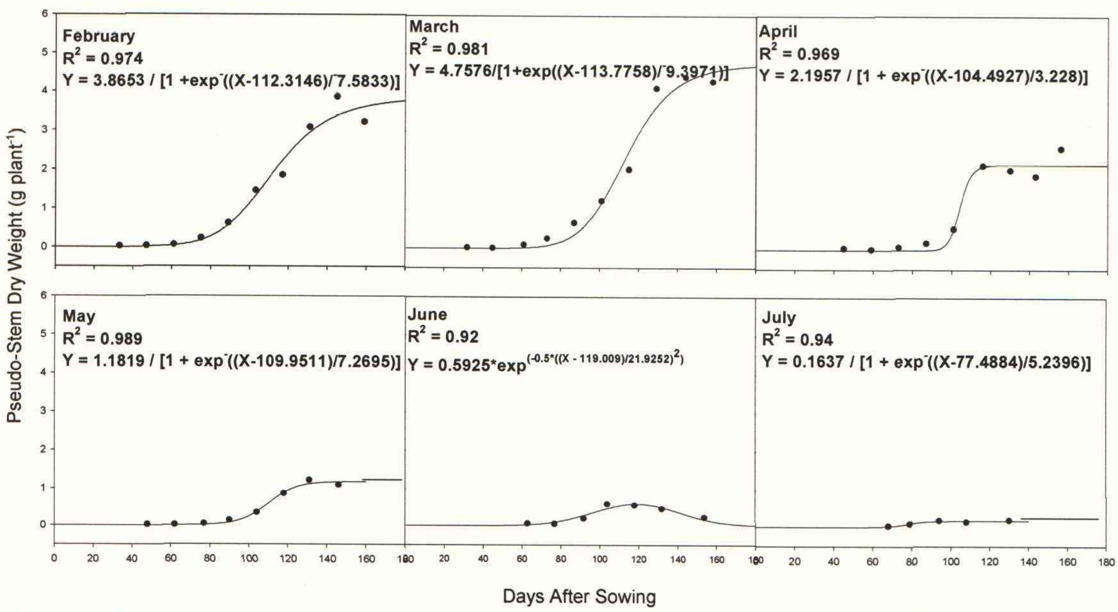

Figure 7.2. Pseudostem dry weight (g plant^{-1}) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

There were highly significant ($p<0.01$) regressions (Figure 7.2) for the February to June sowings and a significant ($p<0.05$) regression in the July sowing for pseudostem dry weight (g plant^{-1}) versus time (days after sowing).

As for leaf dry weight, greatest pseudostem dry weight (4.4 g) was achieved during the March sowing. As the sowing date progressed from the March sowing the dry weight of the pseudostem produced by the onion plant decreased.

Regression equations for February, March, April, May and July are sigmoidal (3-parameter logistic) in nature. The regression equation for the June sowing is a peak (3-parameter Gaussian).

7.3.1.3. Bulb

The bulb dry weight accumulation over time, the regression equations and the regression lines for the cultivar Golden Brown sown at monthly intervals for February to July 2000 are presented in Figure 7.3.

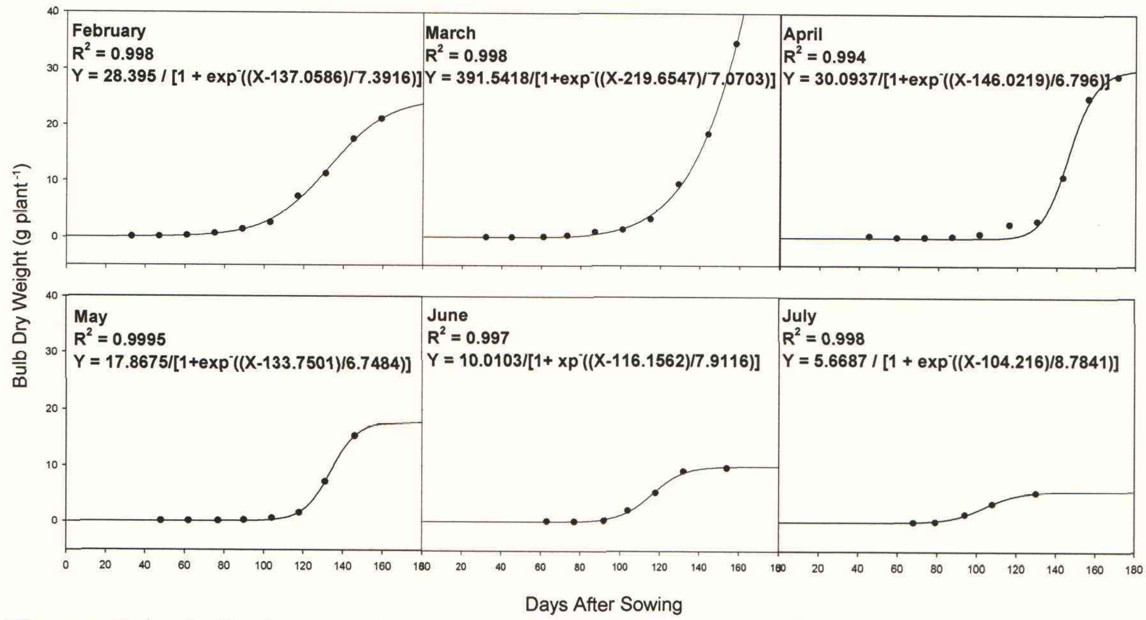

Figure 7.3. Bulb dry weight (g $plant^{-1}$) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

There were highly significant ($p<0.0001$) regressions (Figure 7.3) at all sowing dates for bulb dry weight (g $plant^{-1}$) versus time (days after sowing). All regression equations are sigmoidal (3-parameter logistic) in nature.

Maximum bulb dry weight (34.78 g) was achieved in the March sowing. According to the regression equation, the bulb dry weight for this sowing had not reached its maximum at the final harvest. Subsequent to this sowing the final bulb dry weight per plant decreased.

7.3.1.4. *Total Dry Weight*

The total dry weight accumulation over time, the regression equations and the regression lines for the cultivar Golden Brown sown at monthly intervals for February to July 2000 are presented in Figure 7.4.

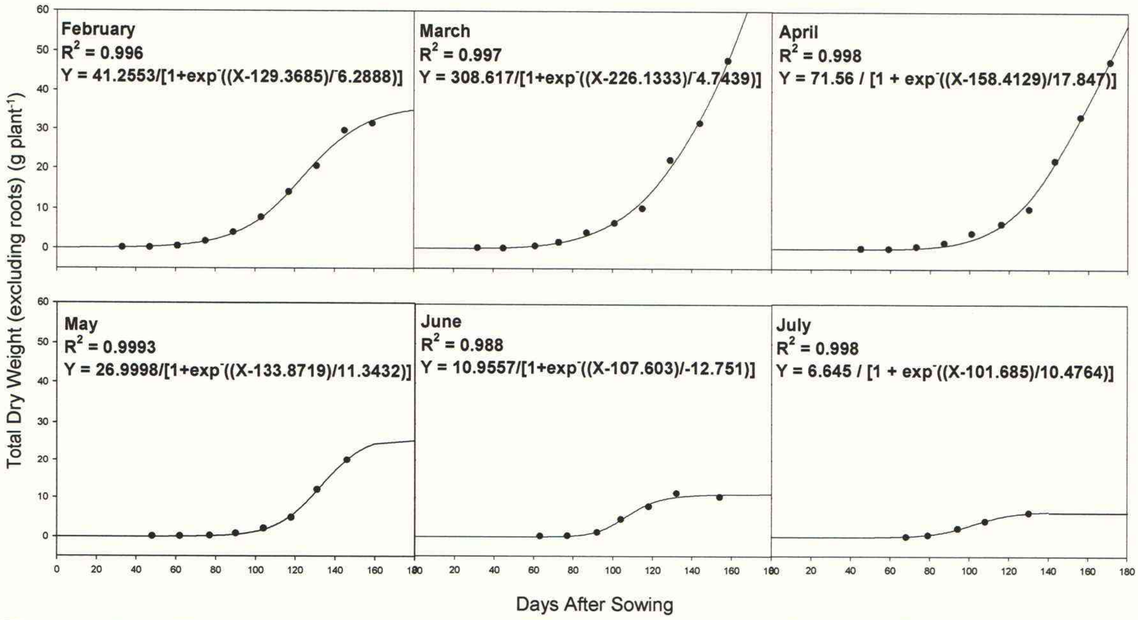

Figure 7.4. Total dry weight (g $plant^{-1}$) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

There were highly significant ($p<0.0001$) regressions (Figure 7.4) at all sowing dates for total plant dry weight (g $plant^{-1}$) versus time (days after sowing). All regression equations are sigmoidal (3-parameter logistic) in nature.

Maximum total dry weight was achieved at the March and April sowings (47.78 g for both). According to the regression equations, the total plant dry weight for these sowing had not reached its maximum at the final harvest. Subsequent to the April sowing the total dry weight per plant steadily decreased.

7.3.2. Dry Weight Partitioning

Figure 7.5 illustrates the average total plant dry weight as the sum total of partitioned components consisting of bulb, green leaves and pseudostem.

For the early sowings (February and March) the leaf and pseudostem contributed the greatest proportion of dry weight until approximately 120-130 DAS. This date coincided with the onset of bulbing (Table 7.1). After this time, bulb growth was accelerated and the total dry weight was predominantly comprised of the bulb although the green leaf and pseudostem contributed a substantial proportion to the total plant dry weight until maturity.

For the mid season sowings (April and May), the plant dry weight consisted predominantly of green leaf until 120 DAS. After this time there was a switch to bulb production with more than 50% total plant dry weight comprising the bulb. For the June and July sowings the bulb contributed more than 50% of plant total dry weight from 116 DAS and 94 DAS respectively.

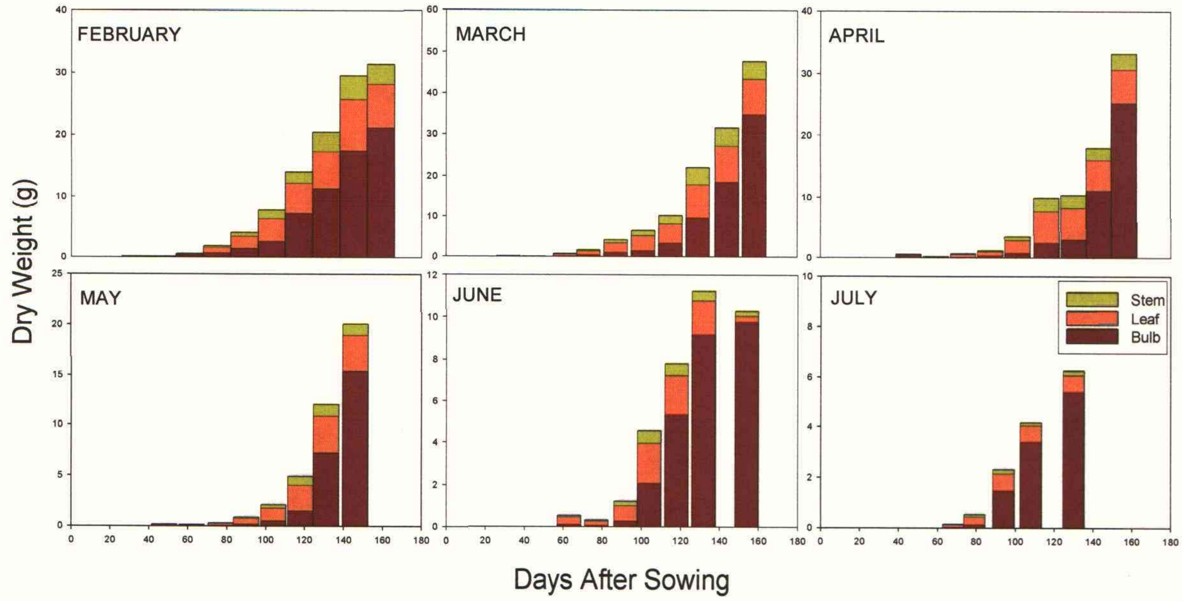

Figure 7.5. The proportions of bulb, pseudostem and green leaf dry weight (g plant^{-1}) within the total individual plant dry weight (g plant^{-1}) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

7.3.3. Cumulative Intercepted Radiation (MJ m^{-2})

The linear relationships between average total plant dry weight (g) and average bulb dry weight accumulation (g) and cumulative intercepted radiation (MJ m^{-2} day^{-1}), for the cultivar Golden Brown sown from February to July 2000 are presented in Figures 7.6 and 7.7 respectively.

The analysis of the results for all sowings showed that cumulative intercepted radiation (CLI) explained high percentages of the variance in total plant and bulb dry weight. The correlations for total plant and bulb dry weight with CLI at all sowing dates were high (r^2=0.926 to r^2=0.994).

Plotting the bulb dry matter data against CLI for each of the sowings resulted in a concentration of data points at the origin as a consequence of very small increases in leaf area over time in the early growth stages resulting in negligible increases in radiation interception.

In general, for all sowing dates increased bulb dry weight coincided just before the visual determination of commencement of bulbing (Figure 7.7).

7.3.3.1. *Total Dry Weight*

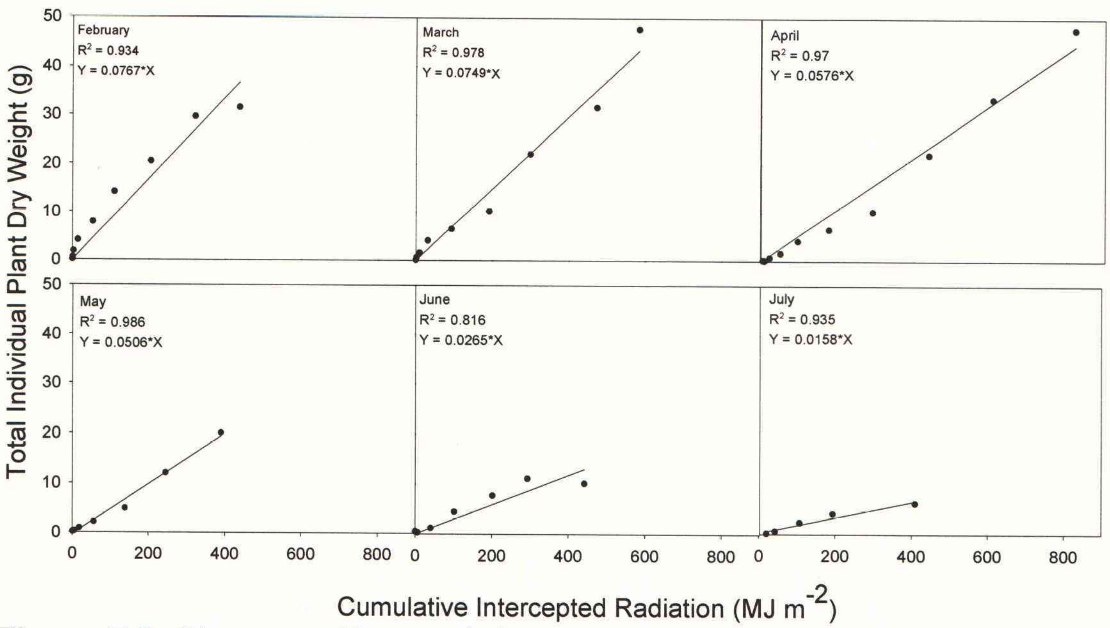

Figure 7.6. Changes with cumulative intercepted radiation (MJ m^{-2} day^{-1}) of average total individual plant dry weight (g $plant^{-1}$) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

There were highly significant ($p<0.01$) regressions for February to June sowings and a significant ($p<0.05$) regression for the July sowing for total plant dry weight accumulation (g $plant^{-1}$) versus cumulative intercepted radiation (MJ m^{-2} day^{-1}).

The greatest total plant dry weight was achieved from the March and April sowings (47.8 g). The total dry weight per plant decreased to a low of 6.25 g for the July sowing.

If the slope of the relationship between dry matter accumulation and cumulative intercepted radiation is taken to represent the efficiency of utilisation of intercepted radiation (RUE), then there was a strong tendency for the efficiency to decline substantially as the sowing date progressed. There were significant ($p<0.001$) differences between the slopes of the lines (Table 7.2). The slope of the lines (RUE) for the February and March sowings were significantly ($p<0.001$) greater than that of the other sowings. The slope of the lines (RUE) for the April and May sowings were significantly ($p<0.001$) greater than that of the June and July sowings.

Table 7.2 Comparison of the slope of the regressions of total dry weight per plant (g) on cumulative intercepted radiation (MJ m^{-2} day^{-1}) for Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

Sowing§	Slope
February	0.0767a
March	0.0749a
April	0.0576b
May	0.0506b
June	0.0265c
July	0.0157c
Probability†	<0.001

§ means within a column followed by the same letter are not significantly different at the 5% level

† F probability (treatment effect in the ANOVA): >0.05 is non significant

7.3.3.2. *Bulb Dry Weight*

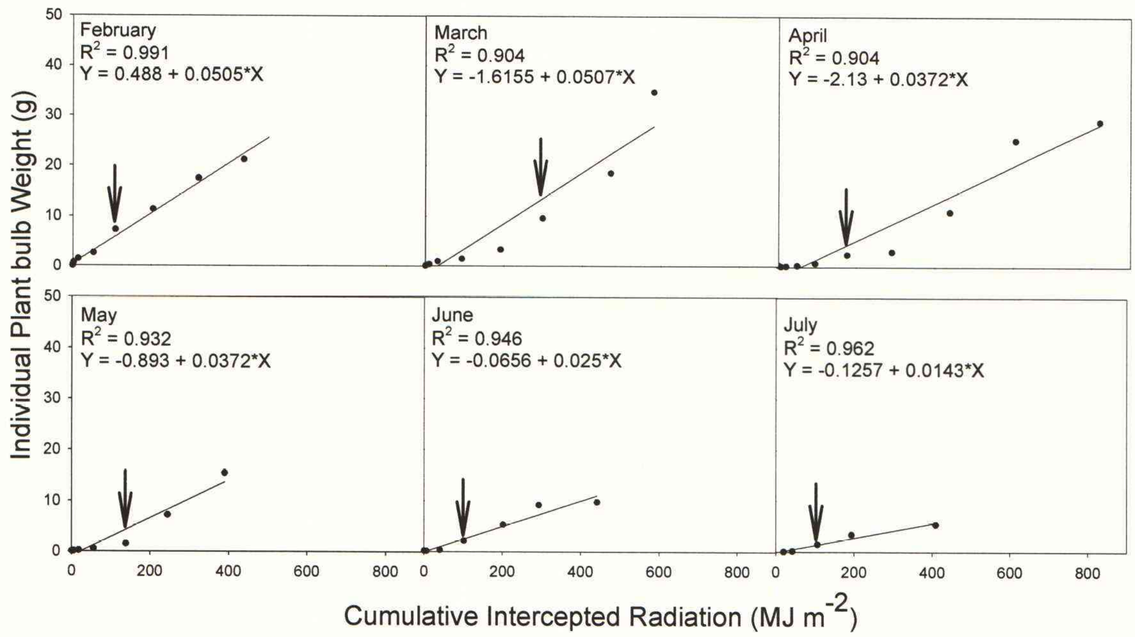

Figure 7.7. Changes with cumulative intercepted radiation (MJ m^{-2} day^{-1}) of average individual plant bulb dry weight (g $plant^{-1}$) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station. Arrow indicates bulb initiation based on the bulbing ratio.

There were highly significant ($p<0.01$) regressions at all sowing dates for bulb dry weight accumulation (g $plant^{-1}$) versus cumulative intercepted radiation (MJ m^{-2} day^{-1}).

In general, as for total dry weight, the slope of the relationship between bulb dry weight and cumulative intercepted radiation declined as the sowing date progressed. If the slope of the relationship between bulb dry matter accumulation and cumulative intercepted radiation is taken to represent the efficiency of utilisation of intercepted radiation (RUE) for bulb production, then again there was a strong tendency for the efficiency to decline substantially as the sowing date progressed. There were significant ($p<0.01$) differences between the slopes of the lines (Table 7.3).

Table 7.3 Comparison of the slope of the regressions of bulb dry weight per plant (g) on cumulative intercepted radiation (MJ m^{-2} day^{-1}) for Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

Sowing§	Slope
February	0.0505a
March	0.0507ab
April	0.0371b
May	0.0372bc
June	0.025bc
July	0.0143c
Probability†	<0.001

§ means within a column followed by the same letter are not significantly different at the 5% level
† F probability (treatment effect in the ANOVA): >0.05 is non significant

Maximum bulb dry weight (34.78 g) was obtained from a March sowing with a cumulative intercepted radiation of 582 MJ m^{-2}. Plants sown in April intercepted the greatest quantity of radiation (821 MJ m^{-2}) with a resultant bulb dry weight of 28.96 g.

7.3.4. Thermal Time (Degree Days)

The non-linear relationships between average bulb dry weight accumulation (g plant^{-1}) and degree-days (°C), for the cultivar Golden Brown sown from February to July 2000 are presented in Figure 7.8.

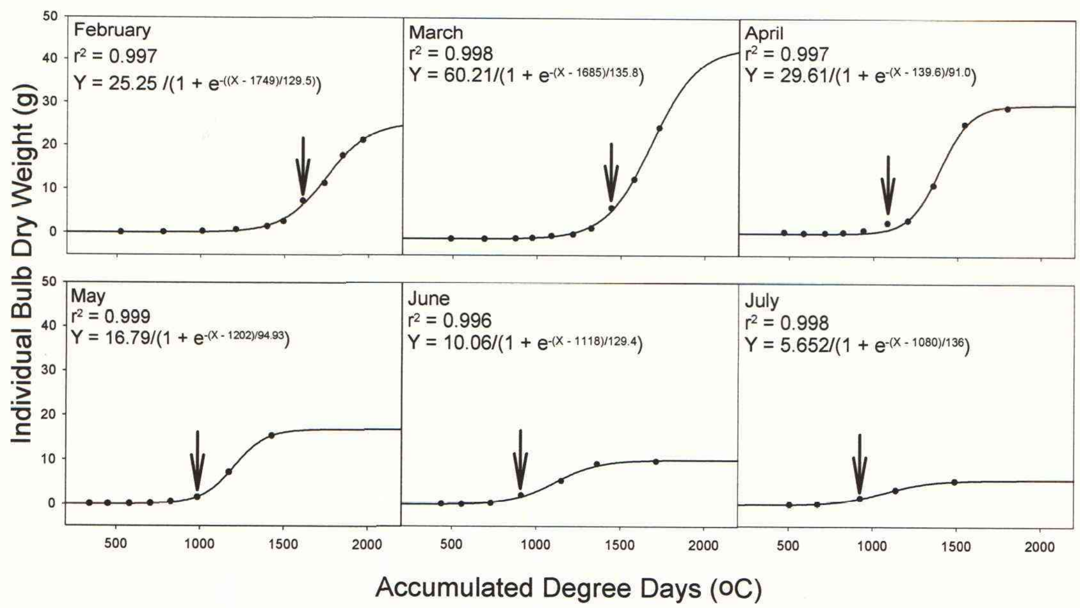

Figure 7.8. The relationship between individual bulb dry weight accumulation (g plant^{-1}) and accumulated degree-days (°C) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station. Arrow indicates the onset of bulbing based on the calculation of the bulbing ratio.

Plotting the bulb dry matter data against CLI for each of the sowings (7.3.2) resulted in a concentration of data points near the origin. When the data were plotted against degree-days (DD) (Figure 7.8) the points were spread giving an improved picture of the biological growth of the onion bulb and the increase in dry weight. Linear regressions were inadequate for this analysis. Consequently, 3-parameter sigmoidal equations ($Y = a/(1 + e^{-(X - Xo)/b})$ were selected to best describe the biological growth of the bulb.

For all sowings the growth of the bulb was very slow in the initial stages with a rapid growth rate from approximately bulb initiation to maximum bulb weight. Bulb growth then slowed dramatically until harvest for all sowings except for

March. The results (Figure 7.10) indicated that for the March sowing the maximum bulb weight had not been reached at the final sampling. For each of the other sowings the results indicated that maximum bulb weight had been reached at the final sampling.

The analysis of the results for all sowings showed that DD explained high percentages of the variance in bulb dry weight within a sowing date. The correlations for bulb dry weight at all sowing dates were high (r^2=0.966 to 0.999). For the DD relationships, all regression coefficients (a, b and Xo) possessed high levels of significance ($p<0.01$ for the February to June sowings and $p<0.05$ for the July sowing).

7.3.5. Daylength

The daylength experienced by Golden Brown prior to bulbing at each of the sowing dates from February to July (Table 7.4) varied from a minimum of 10.60 h (February to June sowings) to a maximum of 12.86 hrs (July sowing). Consequently, since bulbing took place in all sowings, an absolute critical photoperiod for the onset of bulbing could not be determined given the range recorded. It would appear to be somewhat less than 10.60 h.

Table 7.4. Daylength (h) at emergence, the onset of bulbing (50%) and the minimum and maximum daylength prior to bulbing experienced by the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

Daylength (h)	February	March	April	May	June	July
Emergence	12.92	12.03	11.26	10.83	10.63	10.94
Onset of bulbing	10.62	11.05	11.38	12.08	12.48	12.86
Minimum (h) emergence to bulbing	10.62	10.62	10.62	10.62	10.63	10.94
Maximum (h) emergence to bulbing	12.92	12.03	11.38	12.08	12.48	12.86

The relationship between thermal time, daylength and day of bulbing is presented in Figure 7.9. Irrespective of daylength, bulbing did not occur until a minimum of 900 °C DD was accumulated. As the sowing date progressed the thermal time requirement decreased with a corresponding increase of daylength at the onset of bulbing.

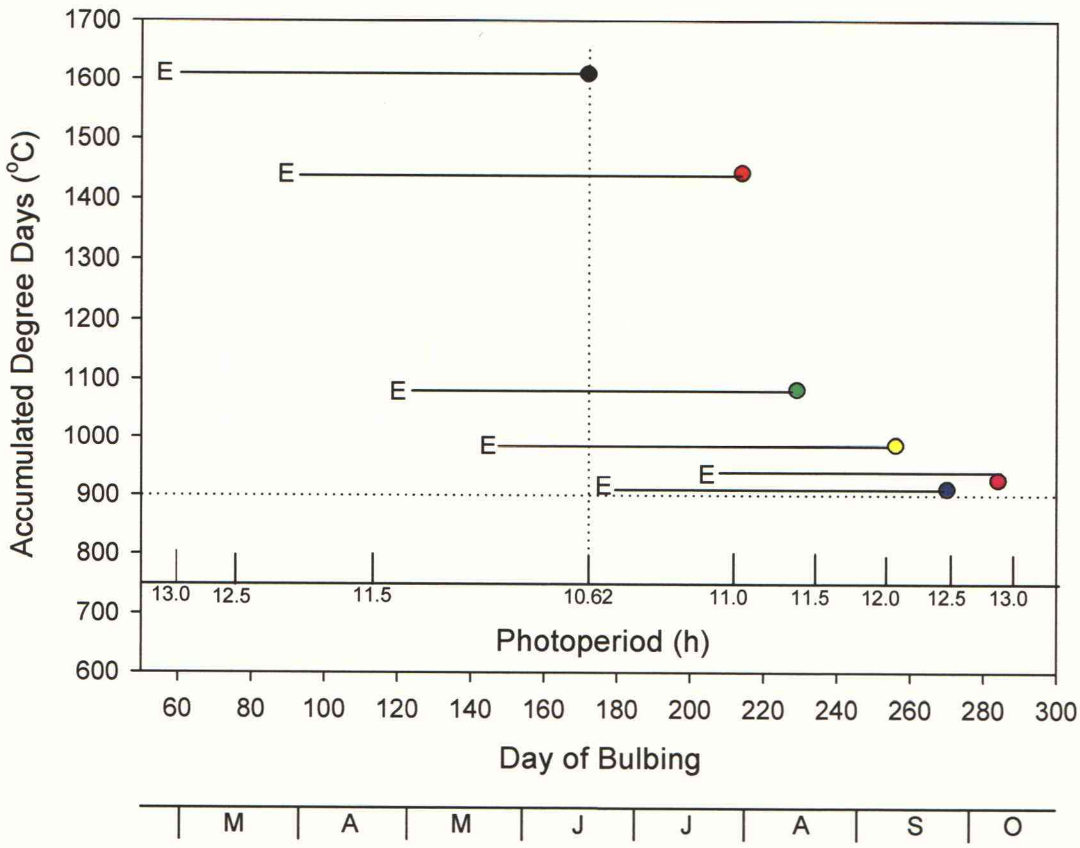

Figure 7.9. Accumulated degree-days (°C) and day of year on which the visual determination of the commencement of bulbing occurred for Golden Brown sown in February (•) March (•), April (•), May (•), June (•) and July (•) 2000 at Gatton Research Station. Dotted lines indicate daylength = 10.62 h (vertical) and degree-days = 900 °C (horizontal). E = emergence date.

7.3.6. Photothermal Quotient

Total plant dry weight increased as the accumulated photothermal quotient increased (Figure 7.10). There was a highly significant ($p<0.0001$) regression for total plant dry weight accumulation (g plant^{-1}) versus the accumulated photothermal quotient (MJ m^{-2} °C^{-1} >5 °C).

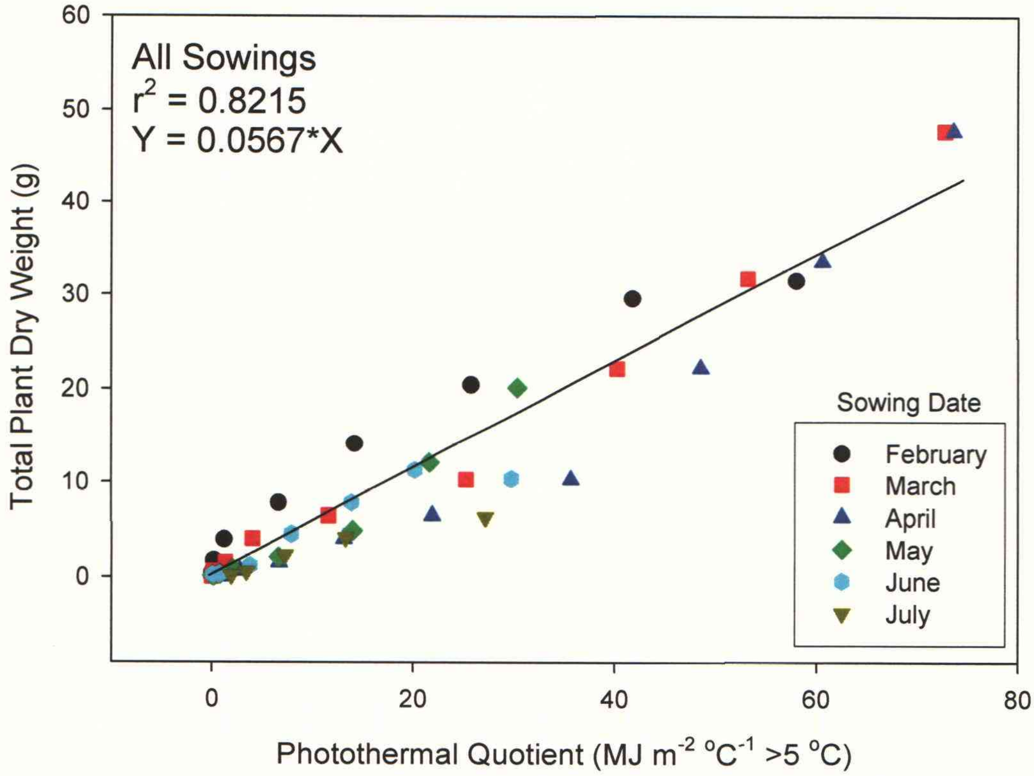

Figure 7.10. Relationship between total plant dry weight (g plant^{-1}) and the photothermal quotient (MJ m^{-2} °C^{-1} >5 °C) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

Individual bulb dry weight (g) increased as the accumulated photothermal quotient increased (Figure 7.11). There was a highly significant ($p<0.0001$) regression for individual bulb dry weight accumulation (g $plant^{-1}$) versus the accumulated photothermal quotient (MJ m^{-2} $°C^{-1}$ >5 °C).

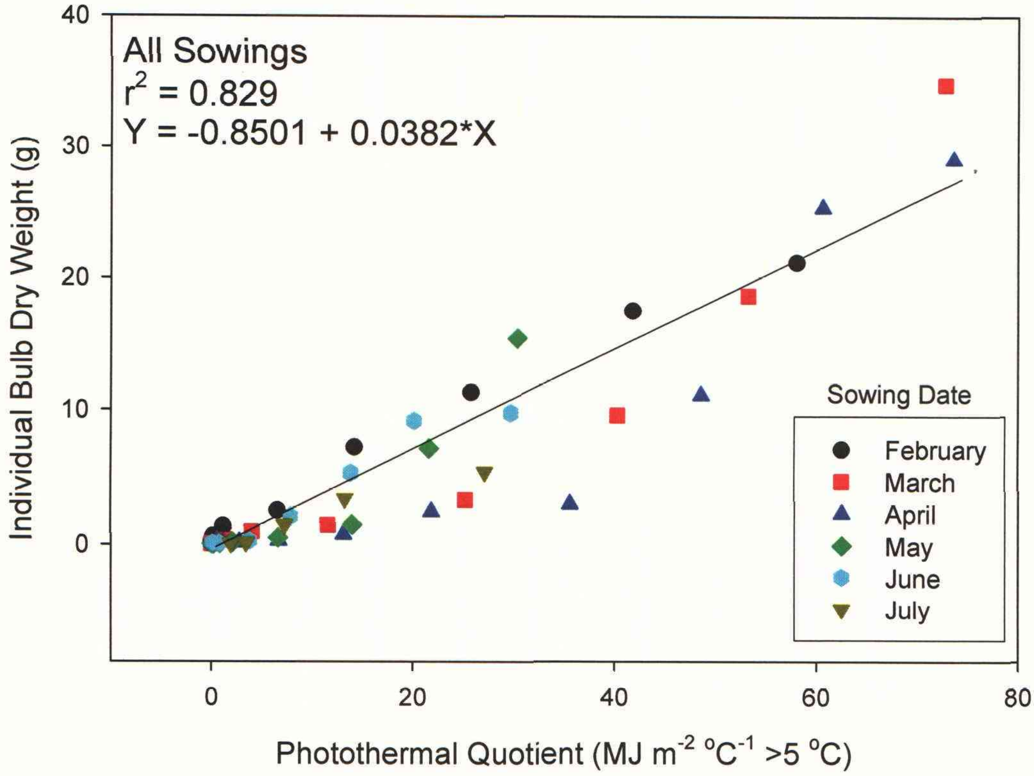

Figure 7.11 Relationship between individual bulb dry weight (g $plant^{-1}$) and the photothermal quotient (MJ m^{-2} $°C^{-1}$ >5 °C) for the cultivar Golden Brown sown at monthly intervals from February to July 2000 at Gatton Research Station.

The photothermal quotient as the explanatory variable for the regression analysis of total plant and bulb dry weight in most cases did not improve the relationship within a sowing date over that of the cumulative intercepted radiation (Table 7.5), but when combining the data from all of the sowing dates, there was a closer relationship between total or bulb dry matter accumulation and the photothermal quotient than with intercepted radiation alone.

Table 7.5 Comparison of the regression components (intercepts, slopes and r^2) of total plant and bulb dry weight (g $plant^{-1}$) on cumulative intercepted radiation (MJ m^{-2}) and on the photothermal quotient (MJ m^{-2} $°C^{-2}$) for Golden Brown sown at monthly intervals in 2000 at Gatton Research Station.

Sowing	Intercepted Radiation			Photothermal Quotient		
	Intercept	Slope	r^2	Intercept	Slope	r^2
TOTAL						
February		0.0767	0.934		0.5790	0.904
March		0.0749	0.978		0.6140	0.978
April		0.0576	0.970		0.5979	0.894
May		0.0506	0.986		0.6222	0.940
June		0.0265	0.816		0.3972	0.845
July		0.0157	0.935		0.2429	0.944
Combined Sowings		0.0567	0.820		0.5786	0.920
BULB						
February	0.488	0.0505	0.991	0.6097	0.3789	0.988
March	-1.616	0.0507	0.904	-1.7419	0.4149	0.901
April	-2.130	0.0371	0.904	-2.8877	0.3824	0.863
May	-0.893	0.0382	0.932	-1.1652	0.4493	0.866
June	-0.066	0.0250	0.946	-0.2822	0.3763	0.943
July	-0.126	0.0142	0.962	-0.2577	0.2204	0.962
Combined Sowings	-0.850	0.0382	0.830	-0.9585	0.3793	0.880

7.4. Discussion

The bulb dry matter yield of an onion crop when agronomic factors are non-limiting (eg adequate water and nutrients) is a combination of the capacity of the plants to maximise the radiation interception, to efficiently convert this intercepted radiation into dry matter and the partitioning of the total dry matter into the harvestable bulb and the remainder of the plant (Charles-Edwards 1982; Hay and Walker 1989; Tei *et al.* 1996). In addition, Lancaster *et al* (1996) reported the requirement for a minimum amount of accumulated thermal time from emergence, in combination with a minimum daylength, had to occur before bulb initiation occurs.

This study investigated the dry matter production and partitioning over time and the relationships between bulb and total dry weight and radiation interception. The relationship between bulb dry weight and accumulated thermal time (degree-days) during the growth of the crop was also investigated in an effort to determine the usefulness of these relationships in predicting bulb yield.

There are a number of anomalous graphs presented in Figures 7.1 and 7.2 (June) and Figure 7.3 (March). The anomalous graphs for the June sowing presented in Figures 7.1 and 7.2 are a result of the final sampling for this sowing at a time when the plant had been desiccated for quite some time. The exclusion of this data point would result in curve of a similar structure as those of the other sowings. The anomalous graph for the March sowing in Figure 7.3 was as a result of the curve fitting process. There is also the likelihood that an additional sampling (although the plants had "gone over") for this sowing may have produced a result similar to that of the other sowings.

7.4.1. Light Interception

The leaves of the onion plant are aligned in two opposite vertical ranks (distichous phyllotaxy) (DeMason 1990). In comparison to crops such as sunflowers this structure is less efficient at intercepting radiation. The light interception is improved as a result of early sowings (Mondal *et al.* 1986a). Early sowing resulted in an increased leaf area (Chapter 5) with a subsequent increase in accumulated light interception (Figure 7.6). The increased leaf area aided in overcoming the light interception deficiencies that occur as a result of the onion plant's inefficient leaf arrangement. As the sowing date progressed the decrease in light interception can be attributed to a decrease in leaf area and a greater exposure of the weaknesses in the phyllotaxy of the onion.

7.4.2. Dry Weight Partitioning

Green leaf dry weight increased rapidly to the time when the onset of bulbing occurred. At this point there was a rapid increase in bulb development as the carbohydrates produced in the leaves were utilised by the rapidly developing bulb. As the bulb developed the production of additional green leaf declined and eventually ceased completely. The plant maintained its leaf area at or near its maximum during this period of bulb growth. Consequently changes in percentage light interception over this period were minor (data not presented). At this point, the pseudostem began to weaken and collapse as a result of the cessation of bladed leaf initiation. The weight of the plant top resulted in the plant falling sideways towards the horizontal resulting in the capacity to intercept the incoming radiation being maintained or slightly depressed as a result of the combination of leaves lower down on the plant being more directly exposed to the incoming radiation (increase in interception) and an increase in shading compared to the upright position as the plants tend to lie on top of each other (decrease in interception). This pattern of senescence of the pseudostem may result in the percentage light interception being maintained despite the decrease in leaf area as the leaves senesced. This pattern of growth has also been reported by Brewster *et al.* (1986).

Brewster *et al* (1986) reported that changes in total dry weight were correlated with total radiation interception. In the present study, the linear relationships between individual bulb dry weight and intercepted radiation were found to be highly significant ($p<0.01$) at all sowing dates. Similar relationships between total plant dry weight and intercepted radiation were also highly significant ($p<0.01$) for the February to June sowings and significant ($p<0.05$) for the July sowing.

7.4.3. Radiation Use Efficiency

Radiation use efficiency (RUE) is characterised as a measure of the efficiency of the conversion of the intercepted radiation into dry matter (Brewster *et al.* 1986; Tei *et al.* 1996). The slope of the linear regression line produced from the relationship between total plant dry weight and total intercepted radiation forced through the origin (Brewster *et al.* 1986) gives an empirical measure of RUE (g MJ^{-1}). Taking the slope of the lines in Figure 7.6, and a plant population of 33 plants per m^2, the computed RUE indicated a decrease from 3.18 g MJ^{-1} in the February sowing to 0.78 g MJ^{-1} in the July sowing. During the early season (February to April) the cultivar Golden Brown was very efficient at converting intercepted radiation into plant dry matter. The mean RUE for all sowing dates was 1.82 g MJ^{-1} which compares favourably with the value (1.58 g MJ^{-1}) reported by (Brewster *et al.* 1986). The data (Figure 7.6) did not suggest that the RUE was lower in the earlier stages of growth, in contrast to those of Tei *et. al* (1996), and suggest that onion has a stable efficient conversion of intercepted radiation into dry matter over the life of the crop in the sub-tropics.

The decline in RUE over sowing dates, which progressively moved into cooler winter, may be a consequence of the lower than optimum temperature for photosynthesis for onion (Brewster 1990b). By adjusting for the low temperature by way of the photothermal quotient (Table 7.5) it was possible to improve on the regression between cumulative intercepted radiation and total dry matter production for the combined sowings as was done to compensate for the effects of high temperature on the RUE of potato (Midmore and Roca 1992). Indeed the impact of sowing date, and time after sowing, on total dry weight and intercepted radiation (Figures 7.4 and 7.6) shows that the reduced total dry weight with later sowings was in part due to the lower amount of intercepted radiation, and in part due to some other factor(s). Use of the photothermal quotient reduced the variance around the regression, suggesting that differences in temperature between sowing dates was indeed in part responsible for the marked differences in total dry weight between sowings.

7.4.4. Thermal Time

Lancaster *et al* (1996) reported that the onset of bulbing in onion only occurred when the dual threshold of a minimum daylength and a minimum accumulated thermal time of 600 degree-days was met. Based on the current results, the onset of bulbing in cv. Golden Brown did not occur until accumulated thermal time from emergence had reached a minimum of approximately 900 degree-days (June sowing) as shown in Figure 7.9. This contrasts with 600 degree days as calculated by Lancaster *et al* (1996) for the long day cultivars grown in New Zealand. It is not possible to determine the accuracy of this figure for the cv. Golden Brown, as the data are not precise enough.

The cumulative thermal time to bulbing progressively decreased for each sowing to the minimum recorded which occurred in the June sowing (Figure 7.9). Lancaster et al. (1996) suggested that the high levels of accumulated degree days recorded for some sowings was a result of the critical photoperiod for the onset of bulbing not having been reached at those sowings. The current data support this suggestion where the accumulated degree-days for the February and March sowings were higher (1608 and 1443 °C respectively) than that recorded for June (911 °C).

Examining the combination of daylength and thermal time for each of the sowings yielded interesting results. For the early sowings (February and March) the data suggest that a short photoperiod and large accumulation of thermal time (approximately 1500 °C degree-days) were required to initiate bulbing. The premature bulbing during the February sowing at 61 DAS cannot be explained with a minimum 900 °C degree-days minimum requirement. The onset of bulbing in the latest sowings (June and July) occurred under conditions of a longer photoperiod and an accumulated thermal time of approximately 900 °C degree-days. The results for the onset of bulbing in the cultivar Golden Brown support the dual threshold model as suggested by Lancaster *et al* (1996). The results indicate that as the daylength increased the thermal time requirement decreased lending support to the theory that there is an interaction between thermal time and photoperiod. The daylength recorded at the onset of bulbing for each of the sowings was between 10.62 h (annual minimum) and 12.82 h. This supports the findings of Schrodter (1990) who reported that the cv. Golden Brown produced a bulb irrespective of time of sowing in the Lockyer Valley (annual daylength variation 10.62 to 14.5 h). Consequently, it is not possible to determine a precise daylength threshold for the onset of bulbing for the cv. Golden Brown. These results indicate that perhaps Golden Brown may be daylength insensitive under the subtropical conditions of the Lockyer Valley.

7.5. Conclusions

This study has indicated that the development of basic easy to use models, based on radiation interception, daylength and temperature, to enable onion producers to predict economic crop yield in a subtropical environment is possible. These tools will enable producers to enhance their on-farm management decisions.

Cumulative intercepted radiation (CLI) proved to be useful in predicting the bulb and total dry weight per plant of Golden Brown sown throughout the growing season in Queensland. The strong linear relationships between CLI and crop dry weight accumulation can be used to develop simple models for the prediction of crop yield.

Plotting total dry weight against accumulated thermal time allowed for a very good interpretation of the biological growth of the onion bulb. Future research to evaluate the regression equations developed as a result of the evaluation of the relationships between total and bulb dry weight per plant and thermal time is required if a crop modelling tool for the prediction of crop yield is to be developed.

The combination of accumulated thermal time and daylength (the dual bulb threshold) did not yield the results expected. A minimum figure for thermal time was determined but the selection of a minimum daylength proved to be more difficult. The minimum daylength identified was the minimum to occur at the latitude of the testing site. Bulbing occurred at photoperiods between 10.62 and 12.86 h. Additional, more precise experiments are required to determine whether the dual threshold can be used to model bulb initiation and ultimately crop yield.

If a model is to be developed for the prediction of onion crop yield its primary requirement will need to be its simplicity of use. The measure of the success and usefulness of the model will be its adoption by onion growers as a tool in their farming business. It should enable them to select cultivars and planting times based on crop yield as predicted by the model.

The photothermal quotient proved to be useful in predicting dry matter production from winter sown onions. It accounts for the effects of the lower winter temperatures in combination with intercepted radiation on the growth of the onion plant. Its use in the prediction of a commercial crop yield based on bulb dry weight production, irrespective of sowing date, requires further examination with additional cultivars.

CHAPTER 8

8. CONCLUSIONS

Short-day type onions are grown in Queensland, in particular, in the Lockyer Valley, over an extended period. Sowings commence as early as late February and continue until late June. An extensive variation in environmental conditions occurs during this time period. This includes changes in temperature and daylength. Consequently, an extensive selection of adapted germplasm is drawn upon to meet the environmental conditions to which the onion crop will be exposed.

This study was undertaken to examine the growth and development of onions in a subtropical environment. The aim was to develop an understanding of the effects of the environment on dry matter production and marketable yield. The study also included a close examination of the causes of doubling in onions in this environment. Doubling is a serious problem in early sowings in the Lockyer Valley resulting in high marketable yield losses as a result of double bulbs that are unacceptable on the domestic market. Bolting was also studied in an effort to understand the factors behind the occasional seasons in the Lockyer Valley when the incidence of bolting was high.

The extensive sowing period available to producers in the Lockyer Valley resulted in the availability of an extensive suite of onion cultivars. Local seedsmen have selected several short-day open-pollinated cultivars over the decades that are particularly well adapted to the first half of the onion season in Queensland – late February to early May. The local cultivars evaluated in this study included Early Lockyer White (ELW), Early Lockyer Brown (ELB), Golden Brown (GOB) and Wallon Brown (WAB). These cultivars produced large yields when sown in February, March and April. The incidence of doubles in the cultivars ELW, ELB and GOB when sown in February and

March resulted in a large reduction in marketable yield. The marketable yield for GOB from the February sowing was reduced dramatically.

The high marketable yield produced by the local cultivars, in particular from a March and April sowing, has allowed producers to supply the domestic market with fresh onions at a time when onions are in short supply. There is, however, a need to negate the effect of the production of a high proportion of doubles in the February sowing in order to increase marketable yield. Currently, there are no cultivars available for a February sowing that are free of doubling. Consequently, the producer does not have the option of growing resistant cultivars in a February sowing.

The second half of the growing season, May to June, is dominated by hybrid cultivars. These cultivars are intermediate day types and are available from Australian and international seed companies. These cultivars are well adapted to their particular sowing date and produce good marketable yields with very few doubles. It would appear that their slightly longer (yet undefined) critical photoperiod delays bulbing until a suitably-sized canopy has been achieved, in contrast to the open-pollinated cultivars which initiate bulbs soon after they have been sown. These cultivars will continue to be popular with producers for sowing later in the season.

Evaluation of the total dry weight production for several cultivars found that there was little difference between cultivars when sown at the same time. Differences for this character occurred between the sowing dates. As the sowing dates progressed the quantity of dry weight produced by cultivars decreased. The decrease in dry weight coincided with a decrease in average daily temperature during the early growth stages of the plant indicating a possible relationship between temperature and dry weight production. Further evidence is required to support this conclusion.

The results have shown that under subtropical growing conditions onions have a relatively high (70-90%) harvest index. Consequently, there is a good relationship between total dry weight and final bulb yield.

Bulb sugar concentration is becoming an increasingly important factor in onion quality, in particular, for the development of a domestic sweet mild onion market. High sugar levels (> 6.5% brix) in the bulb are required for onions to be marketed as a sweet mild onion. The results showed that for early sowings the sugar levels increased as the bulb matured. For the later sowings the sugar levels decreased as the bulb matured. The selection of the correct harvest date is therefore crucial if high sugar levels are a market requirement.

The growth and development of the local open-pollinated cultivar Golden Brown was studied in depth. This included time to the onset of bulbing, leaf production, the examination of various growth indices and the effects of temperature (thermal time), photoperiod and radiation on dry matter partitioning.

There was evidence of premature bulbing in the February sowing. This has been attributed to a thickening of the leaf sheaths rather than bulb scale initiation. Subsequently, a reversal of this premature bulbing occurred. The results indicated that high temperatures during the early growth stages may be responsible for the premature bulbing and a subsequent reduction in daylength resulted in bulbing reversal due to a bulbing non-inductive photoperiod being experienced by the plants. In general terms, as the sowing date progressed from the March sowing, the number of days to bulb initiation decreased, quite possibly because bulbing in all sowings but the first took place with increasing photoperiods after the winter solstice.

The early season sowings produced the greatest number of leaves and consequently the greatest leaf area. These sowings also produced the longest leaf area duration. This result in combination with the high temperatures experienced during plant growth contributed to the early sowings producing the largest leaf number and subsequently greatest leaf area. This resulted in the highest total bulb yield but not necessarily the highest marketable yield in some cultivars.

There was a strong linear correlation between the leaf area index and maximum plant dry weight. As the sowing date progressed there was a corresponding decrease in the leaf area index accompanied by a decrease in maximum plant dry weight. Hence, maximum dry weight production is greatly affected by sowing date. Early sowings are required to ensure the greatest maximum dry weight production for the cultivar Golden Brown.

The cultivar Golden Brown produced a high proportion of double bulbs in the February and March sowing. These sowings generally experienced higher average daily temperatures during the early growth stages than those of the later sowings. The bulb size from the early sowings is greater that for the later sowings. Larger plants as a result of high temperatures in the early sowings resulted in the production of larger bulbs that have proven to be more susceptible to doubling. The results have also indicated that genetic makeup contributed to the level of doubling in onions. Some cultivars were more susceptible to doubling than others when sown on the same date.

The results have shown that Golden Brown is a bolt-tolerant cultivar. This cultivar produced very small numbers of bolters in comparison to the other cultivars evaluated, irrespective of the sowing date. Bolters were produced during early (February to April) sowings. Plant size is important in determining the likelihood of the production of bolters. If the plant is too small (1-3 leaf) then bolting is unlikely to occur when temperatures are sufficiently low enough to induce flower initiation. During the early sowings plants were sufficiently large enough when temperatures were low enough to induce flower initiation for bolting to occur.

This study has shown that there are highly significant correlations between dry weight production and the environmental factors radiation, temperature and photoperiod.

Cumulative intercepted radiation was shown to be a useful predictor of total and bulb dry weight production. Examination of the photothermal quotient versus dry weight production did not consistently within a sowing date produce an improvement in the regression obtained with the cumulative intercepted radiation. However, when grouping data across sowing dates, the use of the photothermal quotient gave an improved explanation compared to cumulative intercepted radiation for winter sown onions by accounting for the effects of the lower winter temperatures.

The use of thermal time (degree-days) and photoperiod as a dual threshold scenario for bulbing, although not producing specific results for photoperiod, has its potential and warrants further examination for the modelling of short-day onions.

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