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GROWTH RESPONSE TO TEMPERATURE OF TWO MAIZE  
(Zea mays L) HYBRIDS WITH DIFFERING  
LEVELS OF COLD TOLERANCE.

A thesis presented in partial fulfillment  
of the requirement for the  
Degree of Master of Agriculture Science  
in plant science (Seed Technology).  
Massey University,  
Palmerston North, New Zealand.

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## ABSTRACT.

Low temperatures are a hazard to maize production especially in high altitude and high latitude areas (Eagles, 1979; Hardacre and Eagles, 1986) where it may cause substantial yield reductions through its accumulated effect on vegetative and reproductive growth. Cold tolerant cultivars with rapid emergence and growth at low temperatures have been identified in highland tropical genotypes and are being developed in New Zealand (Eagles, 1979; Hardacre and Eagles, 1986).

Growth of one such hybrid A665 x NZ1A was compared in this study to that of an established hybrid, A665 x H99, but identified as of warm weather at two field and one glass house environments. The hybrids were planted in the field on 26<sup>th</sup> October and 26<sup>th</sup> November, 1991, and in the glass house on 30<sup>th</sup> April, 1992. Glass house grown plants were later transferred to two controlled temperature environments set at 28/22°C and 16/6°C during the grain filling period.

Both hybrids had comparable high percentage laboratory germination. However A665 x NZ1A emerged earlier than A665 x H99 at all plantings, though only significantly so at the October planting where mean temperatures were lowest (< 15°C). Seedling emergence rates did not differ significantly. Seedling dry weights at about 7 weeks after planting were highest in the glass house planting where mean temperatures were highest (19°C) and lowest in the

October planting, where temperatures the lowest.

A665 x H99 had faster leaf growths than A665 x NZ1A at all plantings although differences were not significant between the hybrids. Across plantings the hybrids had their greatest leaf appearance rates and leaf area growth rates in the November planting where temperatures were the highest and their lowest rates in the glass house where the photoperiod was longest (14 hrs). Maximum leaf area and leaf area index were however attained in the October planting where although temperatures were lowest and hence suppressed leaf growth, the extended growth periods resulted in larger leaf areas and leaf area indices. The lowest leaf areas and leaf area indices were obtained in the glass house primarily because the plants there were much smaller than those in the field.

Days to anthesis did not differ significantly between the hybrids though A665 x NZ1A reached mid-silk earlier than A665 x H99 at all plantings. Across plantings the hybrids reached mid-silk earliest in the November planting and latest in the glass house planting where temperatures were highest and the photoperiod longest, respectively.

At anthesis total plant dry weights (TPDWT) at all plantings did not differ significantly between the hybrids. Across plantings the TPDWT were highest in the October planting and lowest in the glass house where temperatures were

lowest and highest, respectively. During the reproductive period A665 x H99 still maintained a larger but non significant TPDWT than A665 x NZ1A in the field plantings. At both temperatures (28/22°C and 16/6°C) in the controlled temperature environments, A665 x H99 had significantly greater TPDWT than A665 x NZ1A. These temperatures did not influence the coefficients of growth, which must already have been established during the first 30 days of grain growth prior to moving plants from the glass house.

A665 x H99 had significantly greater cob and grain growths than A665 x NZ1A in the October and glass house plantings where mean temperatures were higher ( $> 16^{\circ}\text{C}$ ) during the early reproductive period and the onset of the linear dry matter accumulation phase. In the November planting where mean temperatures were low ( $< 16^{\circ}\text{C}$ ) during the early phase of reproduction and then further declined, cob and grain growth of the hybrids did not differ significantly. However the cob and grain growths of A665 x H99 were more retarded than those of A665 x NZ1A. In the October planting and at 28/22°C where the hybrids had time to reach physiological maturity days, to physiological maturity and the duration of the grain filling period did not differ significantly between the hybrids.

A665 x H99 had greater final crop grain yield than A665 x NZ1A in the environments where temperatures were higher during the reproductive growth (October and glass house plantings). In the November planting where temperatures were lower A665 x NZ1A yielded higher though only slightly.

Across plantings grain yields were highest in the October planting where temperatures were the highest during grain growth, and lowest in the controlled environments which was mainly a reflection of the small plant size. The main yield component which was different between the hybrids was total grain number. A665 x H99 had more total grains than A665 x NZ1A at all plantings and these differences were significant so in the October and glass house plantings.

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## TABLE OF CONTENTS.

|                                                                | Page.  |
|----------------------------------------------------------------|--------|
| ABSTRACT.                                                      | ii     |
| ACKNOWLEDGEMENTS.                                              | vi     |
| LIST OF FIGURES.                                               | ix     |
| LIST OF APPENDICES.                                            | xii    |
| <br>CHAPTER 1. INTRODUCTION.                                   | <br>1  |
| CHAPTER 2. LITERATURE REVIEW.                                  | 6      |
| 2.1 Maize Description.                                         | 6      |
| 2.2 Adaptation, Production and uses<br>of Maize.               | 7      |
| 2.3 Climatic requirements.                                     | 9      |
| 2.3.1 Temperature.                                             | 10     |
| 2.3.2 Precipitation.                                           | 12     |
| 2.3.3 Daylength.                                               | 14     |
| 2.4. Effect of Temperature on Plant Growth<br>and Development. | 15     |
| 2.4.1 Germination and Seedling Emergence.                      | 16     |
| 2.4.2 Vegetative Growth and Development.                       | 20     |
| 2.4.2.1 Seedling growth.                                       | 20     |
| 2.4.2.2 Leaf growth.                                           | 26     |
| 2.4.2.2.1 Leaf initiation and appearance.                      | 26     |
| 2.4.2.2.2 Leaf number.                                         | 29     |
| 2.4.2.2.3 Leaf expansion.                                      | 33     |
| 2.4.2.2.4 Leaf area.                                           | 35     |
| 2.4.2.3 Plant height and Biomass.                              | 38     |
| 2.4.3. Reproductive Growth and Development.                    | 41     |
| 2.4.3.1 Tassel initiation and anthesis.                        | 41     |
| 2.4.3.2 Grain growth.                                          | 44     |
| 2.4.3.2.1 Grain filling rate and duration.                     | 46     |
| 2.4.3.2.2 Grain weight.                                        | 50     |
| <br>CHAPTER 3. EXPERIMENTAL METHODS AND MATERIAL.              | <br>55 |
| 3.1 Plant Genetic Material.                                    | 55     |
| 3.2 Methods.                                                   | 56     |

|            |                                      |     |
|------------|--------------------------------------|-----|
| 3.2.1      | Experiment 1.                        | 56  |
| 3.2.1.1    | Culture and environment.             | 56  |
| 3.2.1.2    | Growth measurements.                 | 58  |
| 3.2.2      | Experiment 2.                        | 62  |
| 3.2.2.1    | Culture and enviroment.              | 62  |
| 3.2.2.1.1  | Glass house.                         | 62  |
| 3.2.2.1.2  | Climate room.                        | 66  |
| 3.2.2.2    | Growth measurements.                 | 67  |
| CHAPTER 4. | RESULTS.                             | 70  |
| 4.1        | Seedling emergence.                  | 70  |
| 4.2        | Leaf number and leaf appearance.     | 72  |
| 4.3        | Leaf area and leaf area index.       | 72  |
| 4.4        | Days to silking.                     | 79  |
| 4.5        | Crop growth rate.                    | 80  |
| 4.6        | Total plant dry weight.              | 81  |
| 4.7        | Cob growth.                          | 84  |
| 4.8        | Grain growth.                        | 88  |
| 4.9        | Yield and yield components.          | 92  |
| CHAPTER 5. | DISCUSSION AND CONCLUSIONS           | 94  |
| 5.1        | Discussion.                          | 94  |
| 5.1.1      | Seedling emergence and growth.       | 94  |
| 5.1.2      | Leaf growth and development.         | 95  |
| 5.1.3      | Reproductive growth and development. | 97  |
| 5.1.3.1    | Grain growth and yield.              | 98  |
| 5.2        | Conclusions.                         | 100 |
| REFERENCES |                                      | 102 |
| APPENDICES |                                      | 134 |

## LIST OF FIGURES

| Figure.                                                                           | Page. |
|-----------------------------------------------------------------------------------|-------|
| 1. Minimum and maximum temperatures, and rainfall of the 1991-92 season.          | 64    |
| 2. Minimum and maximum temperatures in the Glass house.                           | 65    |
| 3a. Total plant leaf area of A665 x H99 and A665 x NZ1A, October planting.        | 73    |
| 3b. Total plant leaf area of A665 x H99 and A665 x NZ1A, November planting.       | 73    |
| 4a. Total plant leaf area of A665 x H99 and A665 x NZ1A, Glass house and 28/22°C. | 74    |
| 4b. Total plant leaf area of A665 x H99 and A665 x NZ1A, Glass house and 16/6°C.  | 74    |
| 5a. Leaf area index of A665 x H99 and A665 x NZ1A, October planting.              | 76    |
| 5b. Leaf area index of A665 x H99 and A665 x NZ1A, November planting.             | 76    |
| 6a. Leaf area index of A665 x H99 and A665 x NZ1A, Glass house and 28/22°C.       | 77    |

|      |                                                                                |    |
|------|--------------------------------------------------------------------------------|----|
| 6b.  | Leaf area index of A665 x H99 and A665 x NZ1A, Glass house and 16/6°C.         | 77 |
| 7a.  | Total plant dry weight of A665 x H99 and A665 x NZ1A, October planting.        | 82 |
| 7b.  | Total plant dry weight of A665 x H99 and A665 x NZ1A, November planting.       | 82 |
| 8a.  | Total plant dry weight of A665 x H99 and A665 x NZ1A, Glass house and 28/22°C. | 83 |
| 8b.  | Total plant dry weight of A665 x H99 and A665 x NZ1A, Glass house and 16/6°C.  | 83 |
| 9a.  | Cob dry weight of A665 x H99 and A665 x NZ1A, October planting.                | 85 |
| 9b.  | Cob dry weight of A665 x H99 and A665 x NZ1A, November planting.               | 85 |
| 10a. | Cob dry weight of A665 x H99 and A665 x NZ1A, at 28/22°C.                      | 86 |
| 10b. | Cob dry weight of A665 x H99 and A665 x NZ1A, at 16/6°C.                       | 86 |
| 11a. | 100-grain dry weight of A665 x H99 and A665 x NZ1A, October planting.          | 89 |
| 11b. | 100-grain dry weight of A665 x H99 and A665 x NZ1A, November planting.         | 89 |

- 12a. 100-grain dry weight of A665 x H99 and A665 x NZ1A, at  
28/22°C. 90
- 12b. 100-grain dry weight of A665 x H99 and A665 x NZ1A, at  
16/6°C. 90

## LIST OF APPENDICES

| Appendix.                                                                                                                                                                                                    | Page. |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| 1. Soil description for the trial area, at Massey University at Palmerston North.                                                                                                                            | 134   |
| 2. Minimum and maximum temperatures (°C), and rainfall (mm) of the 1991/92 season.                                                                                                                           | 135   |
| 3. Minimum and maximum temperatures in the Glass house experiment, 1992.                                                                                                                                     | 136   |
| 4. Mean germination (%), and field emergence (%) and emergence index (days) for the hybrids A665 x H99 and A665 x NZ1A at 2 field and 1 Glass House plantings.                                               | 137   |
| 5. Rates of seedling emergence, leaf appearance and leaf growth of A665 x H99 and NZ1A at 2 field and 1 glass house plantings.                                                                               | 138   |
| 6. Total seedling dry weight and total plant dry weight (TPDWT) at anthesis and maximum TPDWT during reproductive growth of A665 x H99 and A665 X NZ1A at 2 field and glass house / controlled environments. | 139   |
| 7. Mean leaf number, leaf area and leaf area index of A665 X H99 and A665 x NZ1A at anthesis for 2 field and 1 Glass house plantings.                                                                        | 140   |

8. Days to mid-silk, grain filling period and days to physiological maturity of A665 x H99 and A665 x NZ1A of 2 field and 1 Glass house / 2 climate room plantings. 141
9. Vegetative crop growth rate ( $CGR_v$ ) and the reproductive crop growth rate ( $CGR_r$ ) of A665 x H99 and A665 x NZ1A under 2 field and 2 controlled environments. 142
10. Mean cob dry weight and cob moisture content of A665 x H99 and A665 x NZ1A for 2 field and 2 controlled environments. 143
11. Rates of cob, 100-grain growth of A665 x H99 and A665 x NZ1A for 2 field and 2 controlled environments. 144
- 12a. Mean grain number, 100-grain dry weight, grain moisture content and crop yield of field grown A665 x H99 and A665 x NZ1A. 145
- 12b. Mean grain number, 100-grain moisture content and crop yield of A665 x H99 and A665 x NZ1A under controlled environmental conditions at 28/22 and 16/6°C. 146

## CHAPTER 1.

### INTRODUCTION.

Maize is a warm weather crop which requires frost free conditions during the growing season for reliable yields (Shaw, 1977). Its growth and developmental processes occur within a temperature range of between 10 and 30°C (Duncan and Hesketh, 1968; Duncan, 1975), and are optimal at temperatures of between 21 and 27°C (Sprague, 1955; Shaw, 1977).

Temperature forms one of the major environmental variables which influences grain yield of maize through its accumulated effect on vegetative growth (McCormick, 1979), assimilate production and supply to the developing grain (Tollenaar and Daynard, 1978b; McCormick, 1979; Tollenaar and Bruulsema, 1988), and directly on grain growth (i.e., rate and duration of grain filling) (Hunter et al., 1977; Jones et al., 1981, 1984, 1985; Badu-Apraku et al., 1983; Muchow, 1990).

In high altitude and high latitude regions low temperature is a common hazard to maize production during the vegetative and/or the reproductive phase (Derieux, 1978; Eagles, 1979; McCormick, 1979; Hardacre and Eagles, 1986). Low temperatures will adversely affect the growth of maize plants

from sowing to maturity in one or more of the following ways (Eagles, 1979; Dolstra and Miedema, 1986):

- (1) by promoting seed and seedling rot by soil fungi in cold and wet soil,
- (2) by inhibiting or slowing germination and seedling emergence,
- (3) by inhibiting or slowing autotrophic (photosynthetically) based growth,
- (4) by freezing plant tissue after emergence or mature plants at the end of the season,
- (5) by stopping dry matter accumulation in the grain.

The minimum temperature for germination and emergence of maize is about 10°C (Lehenbauer, 1974; Grobbelaar, 1963; Blacklow, 1972; Eagles and Hardacre, 1979a; Eagles, 1982; Warrington and Kanemasu, 1983a; Menkir and Larter, 1987) while for photosynthesis it is generally considered to be about 15°C (McWilliam and Naylor, 1967; Duncan and Hesketh, 1968; Alberda, 1969). Cold tolerant cultivars which are capable of rapid and reliable emergence and growth are therefore desirable in the low temperature areas. Perhaps because of faster and/or more efficient respiration based growth at low temperature, faster emerging genotypes utilize endosperm reserves faster than slower genotypes and thus maintain a growth and developmental advantage (McWilliam and Naylor, 1967).

Photosynthesis occurs slowly or not at all at temperatures below 15°C.

Continual exposure to temperatures below 15°C in light, for example, results in the failure of the photosynthetic system, characterised by chlorosis of the

leaves and ultimately death of the plant (McWilliam and Naylor, 1967; Miedema, 1982). Reduced photosynthetic rates drastically reduce growth rates and consequently reduce grain yield (Teeri et al., 1977).

Total plant dry weight, leaf area and leaf area duration (Beauchamp and Lathwell, 1966; Wilson et al., 1973; Thiagarajah and Hunt, 1982; Badu-Apraku et al., 1983; Hardacre and Turnbull, 1986), and leaf number (Stevenson and Goodman, 1972; Hunter et al., 1974; Bonaparte, 1975; Aitken, 1977; Warrington and Kanemasu, 1983c; Hardacre and Turnbull, 1986) decrease with increase in mean temperature over the 15 to 30°C temperature range. However, Duncan and Hesketh (1968), Arnold (1969), Hesketh et al. (1969), Coligado and Brown (1975), Eagles (1979), and Tollenaar et al. (1979) among others have reported leaf number increases over the same temperature range.

Rates of leaf initiation (Beauchamp and Lathwell, 1966; Eagles, 1979), leaf appearance (Brouwer et al., 1973; Aitken, 1977; Warrington and Kanemasu, 1983b; Hardacre and Turnbull, 1986), and leaf expansion (Grobelaar, 1963; Beauchamp and Lathwell, 1966; Kleinendorst and Brouwer, 1970; Barlows and Boersma, 1972; Watts, 1972a,b; Auld et al., 1978; Gallanger, 1979) increase with increase in mean temperature over the 15 to 30°C temperature range.

Grain yield in maize is a function of the rate and duration of dry matter accumulation in the grain (Johnson and Tanner, 1972). The influence of temperature on grain growth is reflected by its effect on sink capacity (i.e., grain size and number) (McCormick, 1979; Capitanio et al., 1983; Jones et al., 1981,1984,1985; Reddy and Daynard, 1983) during cell division (lag phase), and the rate and duration of grain filling (Hunter et al, 1977; Jones et al, 1981,1984,1985; Badu-Apraku et al, 1983; Muchow, 1990) during the effective grain filling period (EGFP).

Increased rates and duration of grain filling have been reported to correlate well with grain yield (Hanway and Russel, 1969; Daynard et al., 1971). Mock and Pearce (1975) suggested that the grain filling period in maize should be as long as practically possible to allow maximum production and storage of dry matter.

In the temperature range of 15 to 30°C, Jones et al. (1984), Major and Schaalje (1885), and Tollenaar and Bruulsema (1988) found that lowering temperature promoted sink development, while rates and duration of grain filling decreased and increased, respectively. Cool temperature extends the cell division phase resulting in increased sink capacity (Wardlow, 1970; Kolderup, 1979), and it has been concluded from long term weather data that higher mean season temperature is correlated with lower grain yield (Kiesselbach, 1950; Thompson, 1986).

In the high altitude and high latitude areas grain yields may therefore be maximised by the use of cold tolerant genotypes. Such genotypes should allow early planting so as to extend the length of the growing season and be able to withstand adverse low temperature effects during the vegetative and the reproductive periods.

The objectives of this study were therefore to compare the effect of seasonal temperature (field) and controlled temperature (controlled environment) on:

- (1) plant growth and development,
- (2) grain growth, and
- (3) yield components of two genotypes,

one a warm weather hybrid and another bred for cold tolerance. Hereafter, growth is defined as dry matter production and development as progression toward maturity.

## CHAPTER 2.

### LITERATURE REVIEW.

#### 2.1 MAIZE DESCRIPTION.

Maize is native to Central America and numerous theories of its origin have been proposed. Two of which have received the most serious consideration are that (i) teosinte (*Zea mexicana*) is the wild ancestor of maize or (ii) a wild popcorn, now extinct was the ancestor of domesticated maize (Brown et al., 1984).

Maize is a tall annual plant belonging to the grass family (*Gramineae*). It has a fibrous root system and an erect stalk with a single leaf at each node and leaves in two opposite ranks. Each leaf consists of a sheath surrounding the stalk and an expanded leaf blade connected to the sheath by a blade joint (collar).

Maize is a cross-pollinated species and is monoecious i.e., it has separate male (tassel) and female (ear) flowers located on the same plant. The tassel is

located at the top of the main stalk and the ears are located at the end of short branches (shanks) that develop from lower nodes on the stalk. Commercial cultivars in some cases do develop elongated branches (tillers or suckers), but they normally develop only one or two ears per plant. The ears grow to contain 300 to 1000 developed kernels arranged in rows along a rachis (cob) (Benson and Pearce, 1987).

## **2.2 ADAPTATION, PRODUCTION AND USES OF MAIZE.**

Maize is one of the world's most important cereals and on a world wide scale comes third in area sown and quantity produced after wheat and rice (FAO, 1991). Maize is widely used as both a food crop for human consumption and feed for animals in the tropics and sub-tropics. In the temperate regions it is the main grain used for animal feed, and it is the most important feed grain entering international trade today (FAO, 1991).

World maize production has increased since 1930, with a dramatic increase occurring in the last 35 years (Arnon, 1975). This increase can be attributed both to increased land area used in maize production and to increased yield per unit of land area, brought about by better crop management (i.e., better pest and disease control measures) and the use of hybrid maize (Benson and Pearce, 1987). North and central America produce nearly 50 percent of the world's

total, 40 percent of which is produced in the U.S. Corn Belt (FAO, 1991). World production of grain maize in 1991 was estimated at 463.7 million metric tonnes harvested from 131.5 million hectares (FAO, 1991).

Maize, because of its many divergent types, high yield potential and dual purpose as grain or forage is often planted near the fringe limits of its adaptability (Neild and Richman, 1981), and has proved to be as adaptable and variable as any other crop (Shaw, 1977). The range of adaptation of maize has been extended mainly because of the development of new hybrids. Future prospects for increasing the range of adaptation will most probably be restricted to selection for a shorter period between emergence and anthesis, faster grain-drying rates and more uniformity among populations (Major and Hamilton, 1978).

Maize has cultivars adapted to climates from the tropics to temperate regions (0 to 55 degrees latitude), to altitudes from sea-level to 3600m and to growing seasons ranging from 42 to 400 days (Benson and Pearce, 1987). Although tropical in origin, over two-thirds of the world's maize is produced in temperate regions between latitudes 30 and 47 degrees which constitutes only 40% of the growing area (Neild and Richman, 1981). The average maize yield in high latitudes exceeds that in the tropics by 4 times in the field and 2.5 times in experimental plots (Chang, 1981). The difference in field yield largely reflects the technological inferiority of tropical farming, while the difference in experimental yield is largely caused by climatic factors. Cooler

night temperatures and longer day lengths are primarily responsible for the higher yields in the temperate zone (Chang, 1981).

Maize is harvested for grain and/or forage or silage between latitudes 0 and 47 degrees, but usually for grain when the season is favourable and taken for forage or silage when the season is too short or too dry (Neild and Richman, 1981). In the higher latitudes ( $> 47$  degrees) temperatures early in the season are usually too cool and the growing season too short for successful maize production so that most of what is grown is for forage or silage and not for grain (Arnon, 1975; Nough, 1981; Benson and Pearce, 1987).

### **2.3 CLIMATIC REQUIREMENTS.**

Maize is grown over a wide range of climatic conditions, from the tropical climates characterised by short daylength and long growing seasons to the higher latitudes where summer daylengths are longer and the frost-free season is short (Major and Hamilton, 1978). Temperature, moisture and daylength are ultimately the key environmental factors determining major production areas (Shaw, 1977; Major and Hamilton, 1978; Benson and Pearce, 1987). Temperature affects both growth and development, whereas the main effect of moisture is on growth and the main effect of daylength is on development (Major and Hamilton, 1978).

### 2.3.1 TEMPERATURE.

Although maize is generally called a warm weather crop, it is not a hot weather crop (Shaw, 1977). It is widely grown in areas where the mean mid-summer temperature is not less than 19 degrees and the mean summer night temperature is not below 13 degrees (Shaw, 1977). The closest correlation between the rate of development of maize and temperature is at temperatures between 10 and 20°C (Chirkov, 1965). Below 10°C, both development and growth are virtually halted, whereas above 20°C, the rate of development increases with increasing temperature at the expense of growth (Chirkov, 1965). Hardacre and Turnbull (1986), and Hardacre and Eagles (1989) reported that maximum leaf size and plant dry weight at any particular growth stage are greatest at 20°C.

High temperature ( $> 26^{\circ}\text{C}$ ) may result in rapid loss of moisture by transpiration so that the plant wilts. If wilting occurs, the rate of photosynthesis is reduced and normal growth processes are arrested (Thompson, 1966). Extremely high temperatures ( $> 32^{\circ}\text{C}$ ), especially when accompanied by deficient moisture may be very injurious to maize (Thompson, 1966). The plants are most susceptible to such injury at the tasselling stage. High temperatures may blast the entire tassel or kill the pollen grains after they are shed, and may also interfere with pollination by causing the silks to wilt rapidly thus hastening the loss of their receptivity. Such interference at pollination has adverse effects on fertilization and will result in reduced seed

set (Herrero and Johnson, 1980).

On the other hand low temperatures ( $< 20^{\circ}\text{C}$ ) may delay and reduce seed germination and emergence, and retard growth resulting in poor stands (Harper, 1955; Groot, 1976). Although young maize plants can withstand temperatures as low as  $-2^{\circ}\text{C}$  for short periods of time ( $< 12\text{h}$ ) (Shaw et al., 1954; Aberg and Akerberg, 1958; Rossman and Cook, 1966; Buican, 1969) the young leaves will usually die but the protected growing point below the soil surface still remains capable of producing new growth. A late freeze may, however, kill early planted maize whose growing point is at or above the soil surface.

Frost damage reduces leaf chlorophyll concentration and causes leaf damage. Early frost in autumn may cause pre-mature death of the plants. However, if the grain has already reached a dry matter content of 60% yields will not be adversely affected (Arnon, 1975; Hardacre, personal communication). Frost at harvest can result in higher grain moisture, lower dry matter content and consequently economic losses because of poor storability and reduced kernel weight, respectively.

### 2.3.2 PRECIPITATION.

Soil moisture received as rainfall represents the most important form of precipitation for maize production. A desirable climate for maize is one in which precipitation is sufficient to wet the soil to field capacity down to root depth before sowing and a rainfall of at least 375mm during the growing season (Arnon, 1975). Large areas of maize are, however, sown in areas in which moisture supply is generally below optimum for maximum maize production (Arnon, 1975; Shaw, 1977). In these areas of deficient rainfall, water stored in the root zone during the autumn and winter preceding sowing is generally a primary factor in ensuring the success of the crop (Shaw and Burrows, 1966).

In the drier regions of the lower latitudes the combined effect of high temperature and low precipitation is a major factor limiting the areas devoted to rainfed maize production (Arnon, 1975). This and periodic droughts caused by irregular rainfall distribution cause sizeable reductions in maize yields, especially so when accentuated by soils with low water-holding capacity. Maize is more drought resistant in the early stages of growth than when fully developed, and during reproductive development the stage of inflorescence differentiation is more adaptable than the anthesis and silking stages (Glover, 1959; Slayter, 1973). Early sown maize, therefore, has the advantage of a longer growing season than later sown maize, though the latter may be sown under more favourable moisture conditions.

Studies conducted on the effect of moisture stress at various times of the life cycle show that water deficits at anthesis or silking are the most detrimental to yield (Robins and Domingo, 1953; Denmead and Shaw, 1960; Slayter, 1973). Drought stress during early tassel development causes stunted growth and poor tassel development. It may also cause a failure of the pollen to germinate or prevent the pollen tube from growing. Drought occurring around flowering also has a major effect on grain yield because it promotes transpiration and as the plant loses water, photosynthesis and photosynthate translocation to the grains is reduced. Drought during the grain-filling period may cause as much as a 22% reduction in yield (Robin and Domingo, 1953).

Although maximum yield is likely to be obtained only if adequate water status is maintained throughout the life cycle of the crop, mild or relatively brief stress can usually be compensated for by subsequent growth under favourable conditions (Major and Hamilton, 1978). Excess water on the other hand can also reduce yields. This is obvious where plants are lodged and killed due to flooding. However, the greatest reductions are due to saturated soil conditions where soil laden water can smother young maize plants and poor aeration caused by ponding can influence root growth and nutrient availability (Arnon, 1975; Benson and Pearce, 1987). Excess water also often delays planting which reduces the length of the growing season and inevitably, yield.

### 2.3.3 DAYLENGTH.

Maize is considered a short-day species because the time required for floral initiation decreases as daylength shortens (Kiesselbach, 1949). Long daylengths delay floral initiation, increasing the duration of the vegetative phase, the number of leaves and the potential height of the plant (Stevenson and Goodman, 1972; Francis, 1973; Arnon, 1975; Warrington and Kanemasu, 1983b,c). Variation in daylength is one of the main causes of failure of introduced varieties from a region of a different daylength.

Maize is one of the most responsive crops to light and this is one of the reasons for its high production potential. Light is the source of radiant energy required for photosynthesis, the rate of which increases with increase in light intensity up to a point where other factors such as CO<sub>2</sub> become limiting (Ngugi et al., 1978). Under extremely low light intensities seedlings become tall, pale and etiolated. Maize is more sensitive to light reduction during reproduction. According to McIlrath and Earley (1961), reduction of light at reproduction causes a far greater reduction in grain yield than comparable shading at other times of growth because assimilate supply from current photosynthesis, which forms the main source of photosynthates for grain growth, is reduced.

## 2.4 EFFECTS OF TEMPERATURE ON MAIZE GROWTH AND DEVELOPMENT.

Maize is a warm weather crop whose growth and developmental processes are strongly influenced by temperature between 10 and 30°C (Duncan and Hesketh, 1968; Duncan, 1975), and are optimal at temperatures between 21 and 27°C (Sprague, 1955; Shaw, 1977).

The occurrence of sub-optimal soil temperature at the time of seeding is a major constraint in adaptability and commercial production of maize, especially in the high altitude and high latitude areas of the world. Temperatures low enough to suppress the growth of seedlings occur frequently in these areas (Eagles and Hardacre, 1979b). Soil temperatures of approximately 6 to 8°C and air temperatures of approximately 15°C are considered to be the minimum for maize growth (Hardacre, personal communication).

Coligado and Brown (1975), White (1978) and Eagles and Hardacre (1979a,b) have clearly demonstrated that temperature is of primary importance in determining the rate of development of maize plants. Hence, *cold tolerance* i.e the ability of a genotype to emerge from the soil and grow vigorously after emergence from cold soil and air temperatures (Mock and Eberhart, 1972; Mock and McNeill, 1979; Eagles and Hardacre, 1979a; Hardacre and Greer, 1989), becomes an important trait for genotypes that are to be grown

successfully in these areas.

Cold tolerant maize characterised by high percentage germination, and rapid seedling growth (Mock and Eberhart, 1972; Mock and Bakri, 1976; Mock and Skrdla, 1977; Mock and McNeill, 1979; Hardacre and Eagles, 1979a,b; Hardacre and Eagles, 1980; Eagles, 1982,1988; Menkir and Larter, 1985,1987; Hardacre and Eagles, 1989) must, therefore, not only germinate and emerge well, but must also be capable of growing autotrophically.

#### **2.4.1 GERMINATION AND SEEDLING EMERGENCE.**

At warm temperatures germination will start early and proceed faster. Maize will emerge in 5 to 6 days at an average temperature of 21°C, 8 to 10 days at 16 to 18°C and 18 to 20 days at 10 to 13°C (Wallace and Bressman, 1937). Low air and soil temperatures at the time of sowing can result in delayed and reduced seed germination and emergence, as well as a poor stand and retarded growth (Pinell, 1949; Harper, 1955; Dubtez et al., 1962; Groot, 1976). Under these conditions seedlings are also more subject to injury by soil-borne fungi which cause seed rots and seedling blight, and also reduce seedling vigour (Schultz and Bateman, 1968).

Early work on cold tolerance in maize suggested that pericarp injuries in the region of the embryo permitted seed-rotting micro-organisms to invade the seed and cause poor stands under adverse climatic conditions (Tatum and Zuber, 1943). Even though the use of seed dressing fungicides has largely reduced these problems, protection may never be total (Eagles and Brooking, 1981; Menkir and Larter, 1987; Eagles, 1988), especially under cool soil conditions where the seed may be exposed to these pathogens for longer periods due to slower germination and emergence. Rapid emergence may therefore be of importance in eluding infection.

Hooker and Dickson (1952) reported that faster emerging seedlings reach resistant stages of seedling development sooner than slower emerging seedlings, as the level of resistance to infection by at least one pathogen of germinating maize, *Pythium debaryanum* (Hesse), increases with the age of the seedling. Rapid emergence has been associated with high percentage emergence in both field and controlled environment studies (Mock and Eberhart, 1972; Mock and Skrdla, 1978; Eagles and Hardacre, 1979a; Mock and McNeill, 1979; Eagles and Brooking, 1981).

An anatomical feature of the maize plant which renders it more susceptible to sub-optimal soil temperature is the fact that the growing point of the shoot is below the soil surface for nearly 5 weeks post-germination (Cooper and Law, 1977). This corresponds to the development of 5 to 6 fully emerged leaves (Hanway, 1966). Cooper and Law (1977) reported a significant positive

correlation between the size of the plant at 5 weeks post-emergence and grain yield. They further demonstrated that temperature, coupled with soil moisture, at 5 weeks post-emergence accounted for 70 percent of the variation in dry matter and 82% of the variation in the yield.

For many grain crops there is a definite moisture-sensitive period during which a relatively small water deficit may greatly reduce the yield. Denmead and Shaw (1960), and Dale and Shaw (1965) have shown that for the maize crop, the period from six weeks before silking to three weeks after silking is most critical. Moisture stress, coupled with unfavourable temperature (i.e., high temperature) hastens evapotranspiration rates, adversely affecting photosynthesis and translocation of assimilates within the plant which inevitably reduces the build up of plant and grain dry matter (Dale and Shaw, 1965).

Time to emergence will inevitably affect grain yield through its association with reliable plant establishment (Eagles and Brooking, 1981), which is a requirement for consistently high yields. Dugan (1944), Cardwell (1967), and Pendleton and Egli (1969) also reported that early planted maize would out-yield late planted maize. With early planting, however, there is increased probability for reduced seedling emergence and growth because of low soil temperatures (Mock and Bakri, 1976), which may result in a poor stand.

A poor stand reduces the potential plant population which inevitably reduces yield through reduced ear number per unit area. McCormick (1979) has shown that poor maize grain yields in New Zealand's major maize growing area of the south Auckland/Bay of Plenty region is associated with cool spring temperatures. Hence, there is a need for cold tolerant maize for locations where low temperatures are likely during germination and the early seedling growth stages.

The lower temperature range for germination and emergence is reported to be around 10°C (Lehenbauer, 1914; Grobbelaar, 1963; Blacklow, 1972; Eagles and Hardacre, 1979a; Eagles, 1982; Warrington and Kanemasu, 1983; Stamp, 1984; Menkir and Larter, 1987). Eagles and Hardacre (1979a) showed poor germination and emergence of US Corn Belt Dent hybrids at temperatures below a constant 11°C.

Under diurnal temperature conditions, Eagles (1982) reported maize emergence to be slower at 15/5°C than at 15/10°C (day/night) while, Warrington and Kanemasu (1983) reported that maize seedlings took 16 days at 16/6°C and only 3 days at a constant temperature of 30°C. Menkir and Larter (1987) reported that lowering root zone temperatures significantly delayed seedling emergence of 12 inbred lines. Compared to emergence rate at the control temperature of 18°C approximately, 5 and 12 additional days were required for emergence at 14 and 10°C, respectively.

On the other hand, the upper temperature for germination and emergence is reported to be close to 30°C (Duncan and Hesketh, 1968; Duncan, 1975; Warrington and Kanemasu, 1983). At this temperature both germination and emergence are rapid and because developmental rates are faster than growth rates seedling dry weight is lower than at lower temperatures at any developmental stage. Similar temperature effects on germination and emergence are reported by Bierhuizen (1973) for a number of vegetable crops and by Kanemasu et al. (1975) for sorghum [*Sorghum bicolor* (L.) Moench].

## **2.4.2 VEGETATIVE GROWTH AND DEVELOPMENT.**

### **2.4.2.1 SEEDLING GROWTH.**

Growth of maize seedlings depends on the utilisation of seed reserves (heterotrophic growth) until 3-4 leaves have fully emerged (Cooper and MacDonald, 1970). Before photosynthesis or autotrophic growth commences the rate of seedling growth depends on the rate of conversion of endosperm into new root and shoot tissue, which in turn depends on the rate of utilisation of the endosperm and efficiency of the conversion process (Yoshida, 1973; Yamaguchi, 1978). Eagles (1982) reported that the rate of seedling emergence under cool conditions is primarily determined by nuclear genes, which affect the rate of conversion of seed reserves into new root and shoot tissue rather than the efficiency of the conversion process.

As seed reserves are exhausted the seedlings enter a transition phase, where Hardacre (personal communication) found that growth may be checked briefly at 20°C or halt for periods in excess of 25 days at 13°C. At this stage the rate of assimilate production from photosynthesis is of increasing importance and either becomes sufficient to sustain autotrophic growth or the plant declines and eventually dies (Hardacre and Eagles, 1980). Failure of the photosynthetic system is characterised by chlorosis of the leaves and drastic reductions in the growth rate; necrotic patches may appear on the leaves followed by the death of the plant (McWilliam and Naylor, 1967; Miedema, 1982).

Heterotrophic and autotrophic growth of maize have been shown to have different temperature minima. Blacklow (1972), and Eagles and Hardacre (1979a) showed heterotrophic growth to occur at temperatures below 13°C and as low as 10°C. However, autotrophic growth of maize at temperatures below 15°C is slow (Duncan and Hesketh, 1968; Alberda, 1969) and chlorophyll production is greatly reduced in plants grown from emergence at temperatures below 15°C (Alberda, 1969), especially under conditions of high light intensity (McWilliam and Naylor, 1967).

Seedling maize plants may withstand temperatures as low as -2°C for short periods of time (< 12hrs), long exposure could be fatal (Eagles and Hardacre, 1979b; Hardacre et al., 1990). Hardacre et al. (1990) reported damage of up to 57, 67 and 100 percent to the leaf area of seedling plants of three maize

varieties exposed to temperatures of -1.5, -2 and -3°C, respectively, for 50 minutes. Twenty eight days after treatment seedling mortality for the -2 and -3°C temperature regimes was 5 and 35 percent, respectively.

During heterotrophic growth faster emerging genotypes utilise endosperm reserves faster than slower genotypes, perhaps because of faster and/or more efficient respiration based growth at low temperatures, and thus maintain a growth and developmental advantage (McWilliam and Naylor, 1967). This advantage gained during early growth may be maintained throughout subsequent growth and development of the plant.

Wilting and discoloration of the leaves are usually the first visible symptoms of chilling injury. Hanna (1924) found that air temperature of -1.7°C injured maize and -4.4°C killed it. Sageta (1964) investigated the effect of a 28 day cold treatment on six varieties of maize and found an average mortality of 36 and 21 percent at 4 and 6°C respectively and practically no damage at about 10°C.

Lehenbauer (1914), Grobbelaar (1963), Blacklow (1972) and Miedema (1982) studied the response of very young plants to temperature and found pronounced effects on shoot and root growth. Lehenbauer (1914) and Blacklow (1972) reported shoot and radicle elongation to be at a minimum at 9 to 10°C, optimum at 30°C and damaged at a constant 40°C. Grobbelaar

(1963) found optimum shoot and root growth temperature occurred at a temperature range of 25 to 35°C while it was practically inhibited at 5°C. Root growth was also inhibited at 40°C while shoot growth proceeded at a retarded rate.

Miedema (1982) found that the minimum temperature for shoot growth was 8°C, at which shoots emerged from the pericarp but elongation ceased after a time. The optimum temperature was 32°C. The increase in shoot growth with increasing temperature was explained as being due to a proportionally higher extension rate of the mesocotyl. The mesocotyl length at 12°C was 54 percent of the total shoot length, at 18°C was 64 percent, and at 24°C, 70 percent. Similar reduction in mesocotyl growth was found by Burke and Grant (1974) at diurnal temperature fluctuations of 35/20°C, 30/15°C, and 25/10°C. Potter and Jones (1977) found that shoot relative growth rate increased by 2.5 times between 21/10°C and 32/21°C (day/night) conditions.

Menkir and Larter (1987) demonstrated the effect of sub-optimal soil temperature on root growth on a number of maize inbred lines. At a temperature of 14°C the root dry weights of all the lines studied varied from 12.5 to 25.2 percent of those obtained at the control temperature of 18°C, while at 10°C the range was from 7.8 to 17.6 percent. An important observation in this experiment was that differences in root dry weight among the inbred lines became smaller with decreasing root-zone temperature.

Grobbelaar (1963) found root-zone temperature also influenced the proportion of shoots to roots. A relatively greater increase in shoot weight than in root weight occurred as the root temperature increased from 5 to 40°C. At 40°C root growth was inhibited much more than shoot growth which resulted in a progressive increase in shoot to root ratio. Brouwer (1962) found shoot to root ratios of maize grown in glasshouses at 25 and 16°C were 5.0 and 3.0 respectively. He attributed this response to an excess of assimilates at low temperatures which promoted root more than shoot growth. Van Dobben (1962) reported that the shoot to root ratio of various crops decreased with lowering growth temperature.

Sub-optimal soil temperature restricts root extension and reduces overall root mass (Menkir and Larter, 1987). It also reduces water uptake which may also result in reduced nutrient uptake by the roots (Grobbelaar, 1963). The possible reasons for restricted water uptake at low temperatures are; increased viscosity of water in the root medium, decreased permeability of the root membrane (Kramer, 1956; Lal, 1974), increased viscosity of the protoplasm in the roots and poor development of the root system (Kramer, 1956; Nielsen, 1971). In addition, however, it is recognized that root development is also a function of leaf and stem development which in turn are also influenced temperature.

The effects of low temperature, such as delayed germination and emergence, and retarded growth may be overcome by delaying planting until conditions

become more favourable. Late planting, however, increases harvest difficulties or, alternatively, requires the use of shorter season cultivars which are inherently lower yielding (Hardacre and Eagles, 1980). Furthermore, this approach exposes the crop to the occurrence of hot, dry periods at the time of flowering, risks of damage from autumn frosts, and also restricts the potential heat units available for that particular season, thus delaying maturity (Menkir and Larter, 1985).

Early maturing genotypes and/or early dates of planting are required in short season environments. Cold tolerant genotypes with reliable plant establishment under cool soil conditions would allow earlier sowing, which would increase the effective length of the growing season provided that the seedlings could continue to grow under cool conditions and were not irreversibly damaged by low temperatures (Mock and Pearce, 1975).

Pendleton (1965) suggested other advantages of early planting were (1) short plants with low ears and good stand-ability, (2) drier grain allowing earlier harvest, (3) pollination before hot, dry days of late summer, (4) grain-filling during the long-light days of the growing season, and (5) early canopy development that would reduce evaporation of soil water. Pendleton and Egli (1969) also showed that early planted maize, which flowered before later planted maize, produced more grain per unit leaf area, suggesting that early established plants could be more efficient grain producers. In Illinois, Pendleton and Egli (1969) obtained yield reductions of 103 kg per hectare per

day when seeding was delayed by at least 2 weeks from April 30 to May 14.

#### **2.4.2.2 LEAF GROWTH.**

##### **2.4.2.2.1 LEAF INITIATION AND APPEARANCE.**

Coligado and Brown (1975), and Beauchamp and Lathwell (1966) have reported increased leaf initiation rates in maize with temperature over ranges of 15 to 30°C and 15 to 25°C, respectively. Coligado and Brown (1975) reported the rates of leaf initiation at 15°C for two hybrids, United 108 and Guelph GX 122, to be 0.7 leaves /day, which doubled to 1.4 leaves /day at 30°C for United 108 and to over 1.6 leaves /day for Guelph GX 122.

Beauchamp and Lathwell (1966) reported a reduction in the rate of leaf initiation and maximum number of leaves finally initiated per plant when grown at cold root zone temperatures of 15°C when compared to 20°C and 25°C. They interpreted their results as being due to the direct effect of root zone temperature on meristematic activity, the reduced rate of leaf initiation resulting in reduced leaf number.

Watts (1971) reported the relative rate of leaf extension to be dependent on the

temperature of the meristem when he measured leaf extension continuously while changes were made to the temperatures of the root system and of the shoot meristematic region. The rate of leaf extension doubled with each 10°C rise in meristem temperature between 0 and 30°C. Warrington and Kanemasu (1983b) found maximum rates of leaf primordia initiation for hybrids W346 and XL45 to be 1.1 and 1.0 primordia /day, respectively, at a constant temperature of 30°C.

The rate of leaf appearance is equally influenced by temperature, and increases with increase in temperature. Leaf appearance rate increases between 2.5 and 3 times between 16 and 26°C (Brouwer et al., 1973; Aitken, 1977; Warrington and Kanemasu, 1983b). Hardacre and Turnbull (1986) obtained a temperature coefficient of 2.9 between the temperature range of 16 and 28°C. They noted that leaf appearance rate increased at a much faster rate with temperature than either mean relative growth rate or mean relative leaf expansion rate. This they suggested could be due to the fact that at higher temperatures the demand for assimilates for the initiation and expansion of new leaves reduced the assimilate available for expansion of older leaves.

Both the rates of leaf initiation and appearance have been found to be constant at any specific temperature regime, at least for the appearance of the first 11 leaves (Thiagarajah and Hunt, 1982) and 12 leaves (Warrington and Kanemasu, 1983b). After this the appearance rate increases rapidly. The rapid increase in apical activity at this stage is probably related to the

commitment of the apex to reproductive development (Thiagarajah and Hunt, 1983), characterised by rapid stem elongation and relatively quick expansion of the upper stem leaves (Aitken, 1980; Warrington and Kanemasu, 1983b). A similar observation has been made in rye 'cv. Petkus' (Suderland, 1961) where there was a marked acceleration in the rate of primordium production following the transition to reproductive growth. Langer and Busell (1964) noted that increased rate of leaf primordium production was a widespread occurrence as a preliminary to floral initiation.

Warrington and Kanemasu (1983b) reported near-linear increases in leaf initiation and appearance rates as mean temperatures were increased from 15 to 28°C, maximum rates occurring at 30 to 32°C. However, there was a non-linear response at differential day and night temperatures within the same temperature range. Where temperature regimes had means lower than 20°C, rates were considerably higher with differential temperature treatments than with constant temperature conditions with the same temperature range. At mean temperatures above 20°C, although the relative differences were smaller, the relationship was similar but reversed, i.e. at 28/18 and 38/18°C rates were generally lower than at a constant 23 and 30°C, respectively.

The temperatures required for faster leaf initiation and leaf appearance rate occurred in the range of 30 to 34°C, beyond which rates declined (Warrington and Kanemasu, 1983b). Both Tollenaar et al. (1979), and Thiagarajah and Hunt (1982) also demonstrated that leaf tip appearance rate declined when

temperatures were above 30°C (35/30 and 35/35°C).

#### 2.4.2.2.2 LEAF NUMBER.

All the leaves that develop on the main stalk of a maize plant are initiated prior to the initiation of the flower primordia (Coligado and Brown, 1975). Therefore the period from emergence to tassel initiation is the critical phase in determining leaf number. The number of leaves formed in maize is determined by the number of leaves present in the seed embryo, the rate of leaf initiation at the apical meristem and the duration of the vegetative phase (Warrington and Kanemasu, 1983a,b,c). These processes are in turn influenced by photoperiod and temperature.

Reports by Chase and Nanda (1967), Duncan and Hesketh (1968), Hesketh et al. (1969), Bonaparte (1975), Coligado and Brown (1975), Eagles (1979), and Warrington and Kanemasu (1983b,c) all show that leaf number increases with an increase in photoperiod. Duncan and Hesketh (1968), Hesketh et al. (1969), Bonaparte (1971) and Hunter et al. (1974), using different combinations of day and night temperatures and photoperiods have reported increases in leaf number with increasing temperature and with lengthening photoperiod. Eagles (1979) found that the average leaf number for hybrids Guelph GX 122 and United 108 increased by 2.1 leaves as the photoperiod

was increased from 10 to 20h.

Research reports on the relationship between leaf number and temperature suggest both a positive and negative response. In most reports (Duncan and Hesketh, 1968; Arnold, 1969; Hesketh et al., 1969; Cal and Obendorf, 1972; Stevenson and Goodman, 1972; Bonaparte, 1975; Coligado and Brown, 1975; Hunter et al., 1977; Eagles, 1979; Tollenaar et al., 1979; Warrington and Kanemasu, 1983c) an overall increase in leaf number in response to an increase in mean daily temperature is recorded. The above workers generally showed that leaf number increased in response to an increase in mean temperature from 15 to 30°C at the rate of between 0.13 and 0.44 leaves for each 1°C rise in temperature.

Hesketh et al., (1969) in a glasshouse experiment noted that an increase in temperature from 15/10 to 30/25°C increased mean leaf number of 18 single cross hybrids by 2.8. Arnold (1969) observed that plants of sweet corn Golden Cross Bantam developed on average 17.5 leaves under a warm treatment (35/27°C) and 14.5 leaves under a cool treatment (21/13°C) when these treatments were applied from the 4th to the 9th leaf stages.

Cal and Obendorf (1972) reported an increase in leaf number for four hybrids for root zone temperatures of 12, 16 and 20°C. Approximately 2 more weeks were required to reach a comparable leaf number for each 4°C drop in

temperature up to 11 weeks after seeding. Eagles (1979) reported a large increase in leaf number between temperature environments of 20/11.4°C and 25/7.8°C (day/night), and suggested the difference may be due to greater accumulation of photosynthetic products since respiration was expected to be lower for the 25/7.8°C temperature than for the 20/11.4°C.

Warrington and Kanemasu (1983c) found that within the 16 to 28°C temperature range, leaf number was higher under diurnal than constant temperature conditions, i.e. leaf number obtained at 23/9 and 23/13°C was higher than that obtained at constant 16 and 18°C, respectively.

In contrast to the above reported positive leaf number and temperature relationship, some of these workers (Stevenson and Goodman, 1972; Hunter et al., 1974; Bonaparte, 1975; Warrington and Kanemasu, 1983c), as well as Aitken (1977), and Hardacre and Turnbull (1986) have shown that an increase in temperature may result in a decrease in leaf number over all or part of the mean temperature range of 15 to 30°C. Bonaparte (1975) contends that because an increase in temperature results in the acceleration of developmental rate, flowering is induced early and this results in fewer leaves. Hardacre and Turnbull (1986) found that total leaf number per plant of two Corn Belt Dent hybrids, A665 X W153R and A665 X H99, was between 16 and 16.5 at temperatures between 20 and 28°C but increased to 17.5 at 16°C and 19.5 at 16/6°C.

Warrington and Kanemasu (1983c) have suggested that where there is a lower temperature induced increase in leaf number, the response is apparently to night temperatures of below 18°C and would occur over a wide range of day temperatures from 16 to 26°C. That response can be seen in the field data of Aitken (1977) and the controlled environment data of Warrington and Kanemasu (1983c). Aitken (1977) reported results of two hybrids grown at high altitude (2250m) which showed this negative response between leaf number and temperature and suggested that the findings were contrary to reports which showed a positive response.

It is likely that the high altitude site that was used would have had cool night temperatures which would account for the negative response. Warrington and Kanemasu (1983c) compared results of a series of day/night temperature treatments and (for unstated reasons) found a decrease in leaf number occurred with a decrease in night temperature down to 18°C, but then an increase in leaf number occurred with a further decrease in night temperature.

The decline in leaf number at temperatures above 30°C, on the other hand, may indicate a possible response to high temperature stress as plants growing at these temperatures show stunted growth and considerable senescence of lower leaves at anthesis (Warrington and Kanemasu, 1983c).

#### 2.4.2.2.3 LEAF EXPANSION.

There appears to be a genetically determined upper limit to the size of a leaf at any node. This size is governed by ontogeny, and environmental factors such as temperature, water supply and irradiance (Hay and Walker, 1989). Leaf expansion is largely controlled by the temperature of the surface layers of the soil surrounding the leaf extension zone during early vegetative development (Peacock, 1975a) or by air temperature for the leaves expanding during later stages when stem extension has carried the leaf extension zone above the soil surface (Gallagher et al., 1979).

The rate of leaf expansion increases with temperatures between 10 and 30°C (Grobelaar, 1963; Beauchamp and Lathwell, 1966; Kleinendorst and Brouwer, 1970; Barlows and Boersma, 1972; Watts, 1972a,b; Auld et al., 1978; Gallagher, 1979). Barlows and Boersma (1972) reported leaf elongation responded rapidly to changes in root temperature, decreasing steadily as the soil temperature was decreased from 28 to 10°C, and elongation ceased at 12.5°C. The cessation of leaf elongation at 12.5°C was correlated with very low turgor pressure induced by low plant water potential. Below a soil temperature of 15°C, the adverse effect of water stress on leaf elongation becomes more severe, eventually stopping leaf elongation at 12.5°C (Barlow and Boersma, 1972).

Earlier findings have inferred that the initial effects of sub-optimal soil

temperatures on plant growth were largely mediated by water stress resulting from a decrease in water uptake which also decreased leaf expansion and growth (Kuiper, 1964). Ward (1969), Boyer (1970), and Acevedo et al., (1971) have also reported leaf elongation and hence expansion to be very sensitive to water stress.

Grobbelaar (1963) concluded that the ultimate lengths of individual maize leaves were greater at root zone temperatures of 15 and 20°C, although the rate of leaf elongation proceeded most rapidly at root zone temperatures of 25 and 30°C. The width of the leaves was greatest at a root zone temperature of 20°C. The ultimate lengths of wheat (*Triticum vulgare*) leaves have also been reported to generally increase with increasing temperature in the range of 10 to 30°C (Friend et al., 1962), the longest leaves occurring at 25°C, the widest at 15°C and the largest at 20°C.

However, increased rates of leaf expansion at higher temperature are generally associated with shortening of the duration of leaf expansion (Auld et al., 1978; Gallanger, 1979) which results in reduced leaf size. Beauchamp and Lathwell (1966) suggested that reduction in cell lengths with increasing root zone temperature could help explain the reduction in leaf lengths. They showed leaf cell lengths to decrease as temperature was decreased from 30 to 15°C.

Low soil temperature can also decrease the rate of leaf elongation by lowering

the temperature of the shoot apical meristem region in young maize plants (Kleinendorst and Brouwer, 1970; Watts, 1972a,b). Beauchamp and Lathwell (1966) reported leaf elongation decreased to 28% of its non-stress rate at 28°C when temperature of the apical region was reduced to 5°C.

#### 2.4.2.2.4 LEAF AREA.

Most of the solar radiation absorbed by a crop canopy is intercepted by leaves, although leaf sheaths, stems and reproductive structures can make a considerable contribution to photosynthesis under certain conditions, i.e. when there is a shortfall in current photosynthesis from the leaves. The leaves, as the primary sources, therefore support the growth of sinks by maintaining a supply of assimilates from current photosynthesis and stored reserves. Due to this, the capacity of a crop to intercept solar radiation may be expressed by its leaf area index (the area of the leaf per unit of soil surface area) (Hay and Walker, 1989).

In cereal crops such as maize and wheat, it has been found that a leaf area index of at least 3 is generally required for the interception of 90 to 95 percent of incoming radiation (Hipps et al., 1983). Therefore, a crop must develop a functional leaf area as quickly as possible.

Plant leaf area is a reflection of the length and width dimensions of the leaves at a given time as determined by the date of crop emergence, the rate of leaf production, the rate of leaf expansion, the duration of leaf expansion and the rate of leaf senescence (Hay and Walker, 1989), and the number of leaves (Warrington and Kanemasu, 1983c). Leaf area development in maize occurs during the period from seedling emergence to anthesis (Warrington and Kanemasu 1983c), within which all leaf growth will have been attained.

Beauchamp and Lathwell (1966), Wilson et al., (1973), Thiagarajah and Hunt (1982), and Hardacre and Turnbull (1986) have all indicated that at a given stage of development maize leaf area is greatest when the mean growing temperature is near 20°C, although maximum growth rate occurs at a higher temperature of about 30°C. Beauchamp and Lathwell (1966) in a glasshouse experiment at constant root zone temperatures of 15, 20 and 25°C, obtained maximum leaf area at 20°C and the smallest at 25°C.

Wilson et al. (1973) in field studies of maize at three altitudes in Rhodesia where mean temperatures were 25, 21 and 18°C showed that the greatest leaf area index was in the 21°C environment, even though maximum crop growth rate occurred in the 25°C environment. Thiagarajah and Hunt (1982) in growth cabinets under a controlled environment at 15/10, 25/20, 30/25 and 35/30°C temperature conditions found leaf area tended to be greatest at the 25/20°C temperature condition. Similarly, Hardacre and Turnbull (1986) reported that mean leaf area of eight Highland tropical and Corn Belt Dent

hybrids at the 5 and 8 leaf stages was highest in a 25/20°C environment rather than in lower (16/6°C) or higher (35/30°C) temperature environments. The hybrids showed a 55 and 60 percent reduction in relative leaf area at 16/6 and 35/30°C, respectively.

Temperature also affects the persistence and productivity of leaves. In a study of 10 short-season maize hybrids, Tollenaar and Daynard (1978a) observed a faster rate of leaf senescence when the environment during the grain-filling period was warmer. Earlier, Peters et al. (1971) had reported that high night temperatures resulted in earlier leaf senescence which resulted in reduced leaf area duration and hence grain yield. Badu-Apraku et al. (1983) found that at 25/15°C, leaf area duration was more than twice that at 35/25°C.

Hardacre and Turnbull (1986) also found maximum leaf area duration occurred at a mean temperature of 20°C. The results of the above studies suggest that maximum leaf area and leaf area duration should occur in environments with mean temperature near 20°C during the vegetative growth phase. Such crops would be expected to have greater leaf areas and hence maximum potential for silage and grain yield.

Hardacre and Turnbull (1986) also showed the rate of leaf area accumulation to be affected by temperature. When compared on a developmental basis, defined by the number of visible leaves, they found that the relative rate of

leaf area accumulation decreased slowly as temperature was increased. The rate of leaf area accumulation with time showed a fourfold increase with temperature between 16/6 and 28°C, and the temperature coefficient for the 16 and 28°C temperature range was 2.4, a result close to that of Potter and Jones (1977) of 2.5.

#### **2.4.2.3 PLANT HEIGHT AND PLANT BIOMASS.**

Plant height in crops like maize is an expression of the number and length of stalk nodes. Although the maximum number and length of nodes is genetically controlled, environmental variables such as temperature and photoperiod may be important. High temperature increases the rate of elongation of the nodes thus increasing plant height (Ketcheson, 1968; Cal and Obendorf 1972; Struik et al., 1985).

Cal and Obendorf (1972) assessed plant heights of 4 hybrids grown at root zone temperatures of 12, 16 and 20°C and found height to be reduced most when sown at low temperature. Eleven weeks after seeding at 16°C, height of the hybrids was 60 to 100 percent of the control (20°C), but only 13 to 37 percent of the control after seeding at 12°C, while stem dry weight was 61 to 89 percent and 14 to 50 percent of the control at 16 and 12°C, respectively. Similarly, Struik et al., (1985) in their study of the growth of a maize hybrid

(cv. LG 11) exposed to low 18/12 or high 30/24°C temperatures found plant height to be greater at the higher temperature. Ketcheson (1968) reported a doubling in height of 17 day old maize during 10 days growth at 21°C compared to a 17°C soil temperature.

Maize biomass is reported to decrease with increase in temperature over part or most of the temperature range of 10 to 30°C. A rise in temperature has also been reported to have similar effects on dry matter production in wheat (Spiertz, 1977) and various other arable crops (Van Dobben, 1962). In a study of a short season maize hybrid (cv. Guelph GX 122) at day/night temperatures of 25/15, 25/25, 35/15 and 35/25°C from 18 days post-silking to grain physiological maturity, Badu-Apraku et al. (1983) observed that the lowest daily rate of dry matter production was associated with the highest temperature treatment.

The low mean rate of dry matter production at the 35/25°C temperature regime probably resulted, at least in part, from both increased rates of respiration and reduced rates of photosynthesis (Thiagarajah et al., 1979; Thiagarajah and Hunt, 1982). The reduction in whole plant yield under the higher temperature regimes (>27°C) would undoubtedly be reflected by a considerable reduction in grain yield per plant (Badu-Apraku et al., 1983).

Cold soils at planting appear to be most critical for dry matter accumulation

after emergence. Mederski and Jones (1963) reported more dry matter was accumulated when soil temperature was increased at seeding rather than during plant emergence. They found that 50 percent more dry matter was accumulated when temperature was increased during the latter than the former. Cal and Obendorf (1972) found that seeding at cold temperatures resulted not only in delayed leaf elongation and leaf area accumulation but also in delayed dry matter accumulation. Struik et al.(1985) in their studies on the growth of a maize hybrid exposed to temperatures of 18/12 or 30/24°C found that high final dry-matter yield depended on high temperatures during early plant growth. Processes during seedling establishment may therefore be crucial in determining plant biomass.

Hunter et al. (1977), Hardacre and Turnbull (1986), and Hardacre and Eagles (1989) have reported that maximum maize plant dry weight occurred at temperatures near 20°C, while Beauchamp and Lathwell (1966) found plant dry weight to be greater at 15°C than at 20 or 25°C. Hunter et al.(1977) grew plants at 20 and 30°C and found that plant dry weight at any stage of development tended to be greater at 20°C than at 30°C.

Hardacre and Turnbull (1986) reported a fourfold increase at the twelfth visible leaf stage in the rate of dry weight accumulation between 16/6 and 28°C and a coefficient of 2.4 between 16 and 28°C. Maximum dry weight occurred at 20°C. Hardacre and Eagles (1989) reported that the mean dry weight of eight Highland and Corn Belt Dent hybrids at 5 or 8 mature leaf

stages was higher at 25/20°C than at 16/6 or 35/30°C. Mean dry weight of the hybrids was lowest at 35/30°C. The hybrids showed a 27 and 69 percent reduction in dry weight at 16/6 and 35/30°C, respectively.

The reduction in dry weight at temperatures above 20°C may have been due to interactions between developmental and growth processes, while reductions at 16 and 16/6°C in particular, were due to early reductions in potential leaf area (Hardacre and Turnbull, 1986).

### **2.4.3 REPRODUCTIVE GROWTH AND DEVELOPMENT.**

#### **2.4.3.1 TASSEL INITIATION AND ANTHESIS.**

Anthesis, tasselling and silking mark the start of reproduction in maize. The timing of anthesis also determines the start of the grain filling phase (Warrington and Kanemasu, 1983a). Environmental variables, particularly temperature and photoperiod are the two factors that play major roles in determining the rate and duration of tassel initiation and anthesis (Coligado and Brown, 1975; Warrington and Kanemasu, 1983a). Temperature stresses are known to delay tasselling but more so silking such that silk emergence may occur after most or all the pollen has been shed. This asynchrony may result in barrenness or poorly filled ears (Struik et al., 1985).

Jones and Mederski (1963), Cal and Obendorf (1972), Bonaparte (1975), Coligado and Brown (1975), and Warrington and Kanemasu (1983a) have all reported that increases in temperature reduce the time to anthesis. Bonaparte (1975) observed that an increase in temperature resulted in the acceleration of developmental rate, as evidenced by a substantial reduction in days to anthesis. Days to tassel emergence of hybrids Warwick SL209, Dekalb XL45A and Funk's G4384 were reduced by at least 30 days between 18/10 and 34/10°C (day/night). Similarly, Wallace and Bressman (1937) showed that a 115 day cultivar took 74 days from planting to tasselling at 20°C but only 54 days at 23°C.

Jones and Mederski (1963) reported that increasing soil temperature by 4.4 to 10°C above normal reduced the time to silking by about 7 to 10 days in some inbreds but had less effect on others. Cal and Obendorf (1972) planted four maize hybrids at three different root zone temperatures of 12, 16 and 20°C, and found that days to tasselling reduced with increased temperature. Similarly, Coligado and Brown (1975), reported a decrease in time to tassel initiation as growing temperature was increased from 15 to 25°C in two maize hybrids (cv. Guelph GX 122 and United 108). There was no difference at the 25 and 30°C suggesting that the optimum temperature for development in this period occurs between these temperatures. These results agree with the findings of Hunter et al. (1974) who used temperatures of 20, 25 and 30°C.

Warrington and Kanemasu (1983a) studied temperature effects on tassel

initiation and anthesis of two maize hybrids (cv. XL 45 and W 346). They found that under warm temperatures ( $>23^{\circ}\text{C}$ ) floral initiation was rapid, occurring in 17 days or less after planting, whereas under continuous cool temperatures ( $<15^{\circ}\text{C}$ ) plants took 40 days or more to reach that developmental stage. Minimum temperatures of 8 and  $7^{\circ}\text{C}$  were determined for tassel initiation and anthesis, respectively. Tassel initiation and anthesis rates responded linearly to mean temperatures within 11 to  $28^{\circ}\text{C}$ , for both cultivars. The optimum temperature was  $28^{\circ}\text{C}$ , above which developmental rates declined. Both time to tassel initiation and time to anthesis were delayed under warm temperatures of 33/28 and 38/33 $^{\circ}\text{C}$ .

Coligado and Brown (1985) reported increased time to tassel initiation as photoperiod was increased from 10 to 20h at temperatures of 15, 25 and  $30^{\circ}\text{C}$ . The increase in time to tassel initiation with photoperiod was greatest at the lowest temperature ( $15^{\circ}\text{C}$ ). There was an increase of 7 days for both hybrids at  $15^{\circ}\text{C}$  compared to an increase of 2 to 3 days at 25 and  $30^{\circ}\text{C}$ . This supports the finding of Roberts and Struckmeyer (1938) and Hunter et al (1974) that sensitivity decreases at high temperature.

#### 2.4.3.2 GRAIN GROWTH.

In reproductive crops such as maize temperature will influence grain growth and yield through the accumulated effect on vegetative growth and the time for which assimilate supply is available for the developing grain (Hardacre, personal communication; McCormick, 1979). The reported reduction in yield with low temperature during the vegetative period in the Waikato region of New Zealand could be the result of a limitation on the extent of vegetative growth, crop leaf area and later the rate at which assimilate is available to fill the grain during a relatively fixed length of time between mid-silk and maturity (McCormick, 1979).

Low temperature (i.e. frost) is a hazard to maize production not only when plants are small but also when physiological maturity is approaching (Derieux, 1978; Eagles, 1979; Hardacre and Eagles, 1986). Frost damage at critical reproductive development stages may place irreversible limitations on the extent of grain development or sink size, i.e., kernel number and weight. Severe frost after anthesis would kill the plants and grain filling would cease. However, considerable increases in grain weight sometimes may occur by the transfer of soluble carbohydrates from the stalk to the grain after the leaves are killed by a frost or during periods of shortfalls in current photosynthesis, to maintain the growth rate of the kernels (Duncan et al., 1965; Daynard et al., 1968; Daynard, 1978). This transfer, however, inevitably depletes the soluble carbohydrates in the stalk and markedly increases the susceptibility of the

plants to lodging (Mortimore and Ward, 1964).

Soft maize results when grain maize is killed by freezing before reaching maturity (Shaw and Thom, 1951). The two properties of soft maize of most interest from an economic stand point are its reduced dry matter content and its high moisture percentage. Reduced dry matter inevitably results in lowered yield while high moisture percentage creates a storage problem if the maize is picked too early and/or if weather conditions following freezing are unfavourable for drying. The maximum weight of the maize kernel is limited so that regardless of how favourable conditions are for filling, the number of kernels available may limit yield (Duncan, 1975). It is also considered that the kernel size x number limitation is rarely reached (Shaw, 1977).

Kernel number could be restricted at the cob initiation stage or at pollination. High temperature can affect pollination and kernel set but usually the environmental restriction is moisture stress (Shaw, 1977). On the other hand the developing cob meristem is accepted as being determinate and potential kernel number unaffected by environment (Duncan, 1975; Iremiren and Milbourn, 1979).

An increase in yield as a result of higher temperatures at the cob initiation stage and a higher kernel number per cob has been recorded (Cooper and Law, 1977). The difference found, though was considered to be the effect of

temperature on the number of viable kernel sites rather than on the total number formed. An overall consideration of these effects of low, early season temperatures on final grain yield tends to favour an overall reduction in crop vegetative growth as the limiting factor.

#### 2.4.3.2.1 GRAIN FILLING RATE AND DURATION.

Maize is primarily grown for its grain and its yield is a function of the rate and duration of the grain filling period (Daynard et al., 1965). The grain filling period in maize begins at anthesis and continues until black layer formation or physiological maturity (Daynard and Duncan, 1969).

Hanway and Russel (1969), Daynard et al. (1971) and Cross (1975) have reported a close correlation between grain yield and grain filling period duration in maize. Research results on the relationship between yield and the duration of the filling period have also been reported in other grain and seed crops. In barley (*Hordeum spp*) Gardener (1966), soybean (*Glycine max L.*) Hanway and Weber (1965), rice (*Oryza sativa L.*) Tsunoda (1964) and wheat (*Triticum aestivum L.*) Stoy (1965), positive correlations between grain yield and the duration of the grain filling period have been shown. Therefore because of its relationship with grain yield, an extension of the grain filling period would appear to be of potential to increase yield.

Extension of the grain filling period may be the result of earlier flowering date, later black layer formation or some combination of the two (Cavaliere and Smith, 1985). Early flowering dates, however, may reduce the time available for leaf area development and may reduce the potential photosynthate supply (Tollenaar, 1977). Although reserve carbohydrates stored in the stems, husks and shanks (Daynard et al., 1969) may be available to buffer shortfalls in plant photosynthesis, data reported by Duncan et al. (1969) indicate that these may not be able to wholly substitute photosynthetic losses for kernel growth. Mock and Pearce (1975) suggested that the grain filling period of maize should be as long as practically possible (i.e., sufficiently long to allow maximum production and storage of dry matter) but not so long that leaf death occurs before physiological maturity.

Temperature is one of the major environmental factors which may affect grain yield through its influence on grain filling (Hunter et al., 1977; Jones et al., 1981, 1984, 1985; Badu-Apraku et al., 1983; Muchow, 1990). Several workers (e.g., Kiesselbach, 1950; Thompson, 1986) have concluded from long term weather data that higher mean season temperature is correlated with lower grain yield. For maize grown at 20 and 30°C in controlled environment growth cabinets, Hunter et al. (1977) observed higher grain yield at lower temperature because of an increase in the length of the grain filling period. Similarly, Badu-Apraku et al. (1983) found that the higher grain yield at lower temperature was almost entirely determined by a longer duration of grain filling.

The grain filling period in maize may be divided into the lag (cell division) phase and the effective grain filling period (EGFP). The lag phase occurs between anthesis and the onset of the linear dry matter accumulation phase, while EGFP occurs between the end of the lag phase and physiological maturity. Both the lag phase and the EGFP are genetically determined but temperature may greatly influence them.

Results of reported studies (Duncan et al. 1965; Hunter et al. 1977; Jones et al., 1981, 1984, 1985; Badu-Apraku et al., 1983; Major and Schaalje, 1985; Setter and Flannigan, 1986; Tollenaar and Bruulsema, 1988; Knievel, 1989; Muchow, 1990) on the response of the rate and duration of maize kernel growth to temperature during the period of linear dry matter accumulation suggest that the duration of the linear phase declines with increase in temperature, while both neutral and positive responses of the rate of dry matter accumulation to temperature are also reported.

Badu-Apraku et al. (1983) reported reductions in the duration of the EGFP but no effect on the rate of kernel dry matter accumulation over a range of day/night temperature regimes from 25/15 to 35/25°C for maize grown under controlled environment conditions. Setter and Flannigan (1986) also found no differences in kernel growth rate when ear temperatures were controlled over a temperature range from 6 to 32°C for two 10 day periods for field grown maize. Thorne (1974), and Ford and Thorne (1975) in experiments with

wheat found that a temperature increase from 15 to 20°C, from 21 to 37 days post-anthesis reduced EGFP but did not lead to significant increases in kernel filling rate. These results are in agreement with assertions of Reddy and Daynard (1983), and Tollenaar and Bruulsema (1988) that kernel growth rate is not influenced much by temperature after the onset of the linear dry matter accumulation phase.

In contrast, Duncan et al. (1965) reported a small but statistically significant correlation between daily temperature and daily increments in kernel dry matter for field grown maize. Knievel (1989) obtained a highly significant linear relationship between temperature regimes, ranging from 10 to 25°C, and the rate of kernel dry matter accumulation when ear temperature of field grown maize was controlled. Similarly, Muchow (1990) in a field study found that as mean daily temperature increased from 25 to 32°C, the rate of grain growth increased while the duration of the EGFP shortened.

Hunter et al. (1977) observed a higher grain growth rate at the higher temperature for maize grown at 20 and 30°C in controlled environment growth cabinets. Using grains cultured in-vitro at 15 and 30°C, Jones et al. (1981) observed a higher rate of grain growth, a shorter duration of the grain filling period and smaller grain size at maturity at the high temperature. Similarly, Major and Schaalje (1985) observed that in-vitro grain growth rate, measured at 5°C increments from 15 to 30°C increased as temperature increased.

#### 2.4.3.2.2 GRAIN WEIGHT.

Final kernel dry weight is determined by the amount of assimilates deposited in the kernel during the grain filling period, and the amount of fill may be affected by the thermal environment during this period. Thermal environment during the lag phase of kernel growth may be important in determining the patterns of subsequent kernel growth during EGFP and kernel weight at maturity (Jones et al., 1984, 1985).

In-vitro grain growth results (Jones et al., 1984) demonstrated that temperature during the lag phase is important in determining kernel mass at maturity and may be as important as, or perhaps more important than, temperature during the EGFP. Extreme temperatures of 15 and 35°C during the lag phase were found to have detrimental effects on kernel development even after the kernels were transferred to a more conducive thermal environment of 30°C during the EGFP. For example, kernels exposed to 15°C during the lag phase and transferred to 30 or 35°C during the EGFP had final mass similar to that obtained for kernels grown continually at 15°C.

Similarly, exposing the kernels to 35°C during the lag phase and transferring them to 15 or 30°C during the EGFP produced a final mass similar to that obtained for kernels grown continually at 35°C, and was lower than that of

any other treatment. In contrast to 15 and 35°C, 30°C during the lag phase resulted in a more favourable weight notwithstanding transfer to a less conducive (15 or 35°C) environment for the EGFP. Transferring kernels to 15 or 35°C during the EGFP resulted in final kernel masses greater than those observed for any treatment in which the thermal environment during the lag phase was not 30°C.

These results show that while kernel mass will be reduced when unfavourable temperatures occur during grain growth, reductions will be more severe when unfavourable temperatures occur during the lag phase. The adverse and essentially irreversible effects could have been due to a reduction in the number and/or size of endosperm cells formed during the lag phase, therefore reducing kernel sink capacity. In wheat (*Triticum aestivum* L.), kernel sink capacity or potential to accumulate dry matter is determined by the number and size of endosperm cells formed during the lag phase (Asana and Williams, 1965; Bingham, 1969; Jenner, 1979) which determine the size and/or number of sites for starch deposition during the EGFP.

Final kernel mass then becomes a function of the rate and duration of starch deposition during the EGFP. The possible negative effects of a cool temperature period may be balanced by an increase in kernel number which occurs during the extended lag period (Wardlaw, 1970; Kolderup, 1979). Final kernel mass may also have been in part mediated by the kernel inhibition of starch synthesis or by a reduction in kernel sink capacity when high (35°C)

temperature occurred during the lag phase. Cessation of kernel growth at 35°C during EGFP after being exposed to that temperature during the lag phase suggests mainly thermal inhibition of starch synthesis. Temperature may also exert an influence on kernel weight (i.e., dry matter accumulation) by its effect on potential assimilate production, assimilate supply and assimilate translocation to the kernels (Tollenaar and Daynard, 1978b; Tollenaar and Bruulsema, 1988).

Kernel weight is a function of the size and number of endosperm starch granules which in turn is related to endosperm cell number. Reddy and Daynard (1983), and Jones et al. (1985) have reported kernel mass to be highly correlated to the number of endosperm cells. Although the maximum number of cells and starch granules in the endosperm is genetically controlled, Jones et al. (1985) reported that thermal regulation of the number of endosperm cells was a mechanism by which final kernel mass may be mediated. Final kernel weights were greater when a favourable thermal environment was provided during endosperm cell division, when a potential sink capacity or sink strength potential ( or both ) are established, and in large measure may be mediated by the number or size (or both) of endosperm cells or starch granules formed or some combination of these factors (Capitanio et al., 1983; Reddy and Daynard, 1983).

Studies in wheat have also shown that unfavourable temperature during endosperm cell division reduces endosperm sink capacity mainly by reducing

endosperm cell size (Hoshikawa, 1961; Wardlaw, 1970; Radley, 1978).

Jones et al. (1985) observed in grains grown in-vitro that the rate and duration of endosperm cell division, and the number and the size of endosperm cells were reduced in kernels grown at 35°C compared with 30°C. Cessation of kernel development at 35°C was due in part to a reduction in endosperm sink capacity (i.e. endosperm cell number). At 15°C a longer period of cell division compensated for the decreased rate of division resulting in a similar number of endosperm cells although there was still a 49 percent reduction in kernel mass, suggesting that rates of dry matter accumulation were not high enough at this temperature. The maximum number of starch granules occurs when endosperm cell division is nearing completion (Duvick, 1975). Therefore thermal environment during this period may affect cell division or starch granule formation and may partly explain why unfavourable temperatures during endosperm cell division have adverse and irreversible effects on subsequent kernel development (Jones et al., 1984).

The implications of thermal mediation of endosperm development are that extended periods of extreme temperature during endosperm cell division will result in less than optimal mature kernel mass even though a more conducive thermal environment might occur during the EGFP. Thermal effects on the number of endosperm cells and starch granules might also be associated with changes in hormonal levels. Cytokinins have been suggested to play a role in the establishment of kernel sink capacity of barley (*Hordeum vulgare* L.) by stimulating cell division in the endosperm (Micheal and Seiler-Kelbitsh, 1972; Seiler-Kelbitsh et al., 1975), whereas abscissic acid (ABA) may regulate sink

strength via regulation of sugar transport.

## CHAPTER 3.

### EXPERIMENTAL METHODS AND MATERIAL.

#### 3.1 PLANT GENETIC MATERIAL.

Two single cross hybrids, A665 x H99 and A665 x NZ1A were used in this study. Lines A665 and H99 are of U.S.A. Corn Belt Dent (CBD) origin and together produce a hybrid adapted to the Corn Belt Dent region of the U.S and able to produce high grain yields in the cool-maritime New Zealand environment (Hardacre and Greer, 1989). Line NZ1A was developed in New Zealand from CYMMIT Pool 5 and contributes cold tolerant characteristics in crosses (Eagles and Hardacre, 1979a,b; Eagles, 1982). It produces hybrids (i.e., A665 x NZ1A) with rapid seedling emergence and faster growth than CBD hybrids (Eagles et al., 1983; Eagles and Hardacre, 1985; Hardacre and Eagles, 1986,1989).

Although, both hybrids produce grain yields comparable to or higher than current commercial hybrids in the New Zealand environment in warm seasons, A665 x NZ1A is reported to yield significantly higher in cool seasons (Eagles, 1983; Eagles and Hardacre, 1985).

## **3.2 METHODS.**

The study was carried out under two environmental conditions. The first part (Experiment 1) was a field study and the second part (experiment 2) was a controlled environmental study designed to assess the effects of seasonal and controlled temperature on the parameters under study (experimental objectives).

### **3.2.1 EXPERIMENT 1.**

#### **3.2.1.1 CULTURE AND ENVIRONMENT.**

The study was carried out at the Seed Technology Centre trial fields, Massey University in Palmerston North on Ohakea silt loam soil (appendix 1). Temperature and rainfall data during the growing season were collected at the nearby Agresearch Institute and are reported in Figure 1 and Appendix 2.

Two sowings were made a month apart on the same field block and adjacent to each other on the 26th October and 26th November, 1991. The block had previously been cropped with Dahlia (1988/89), White Clover (1989/90) and Sugar beet crop (1990/91). The block was ploughed in two months before

planting and had a further raking 3 days before planting.

To ensure maximum plant establishment, two seeds were sown per station and these were later thinned to one plant per station at the fourth leaf stage. The experimental design in each case was a randomised complete block with four replicates. Each plot consisted of one row, 9m long and 0.75m wide, and a plant to plant spacing of 0.15m gave a population density of 88 888 plants per hectare, within commercial recommendations (Hardacre, personal communication).

A fertiliser regime aimed at producing high yields was applied by evenly broadcasting 360kg per hectare of a compound fertiliser, Nitrophoska (12N:10P:10K:1S:6Ca) before planting. A side dressing of Urea at 230kg per hectare was later applied on 19th December, 1991 to both crops. A pre-emergence herbicide, Primextra II 500 FW (a.i.; 320g /litre metolachlor plus 180g /litre terbuthylazine) was applied 5 days after seeding, thereafter any weeding was done by hand. After signs of infestations an insecticide, Hallmark 5 EC (a.i.; 50g /litre esfenvalerate plus 741g /litre xylene) and a Snail and Slug bait, Mesurol (a.i.; 20g /kg methiocarb) were applied to control Cutworms, and Snails and Slugs, respectively, applied rates were in accordance with the manufacturers' recommendations.

### 3.2.1.2 GROWTH MEASUREMENTS.

The number of seedlings emerging each day was recorded and these data were used to calculate percentage emergence and emergence index, an estimate of emergence rate (i.e., time to 50% emergence).

Percentage emergence was calculated as:

$$= \frac{\text{total emerged}}{\text{total planted}} \times 100$$

Emergence index was calculated following the method used by Smith and Millett (1964), Mock and Eberhart (1972), and Mock and Skdla (1978) as:

$$= \frac{(\text{plants emerged on a day})(\text{days after planting})}{\text{total plants emerged, 30d after planting}}$$

During the vegetative period at 3 weekly intervals starting at 14 days after 50 percent seedling emergence, 4 and 3 harvests of above ground plant parts were harvested from the October and November plantings, respectively. Three plants were harvested per replicate and mean leaf area, and total plant (leaf and stalk, including sheath) dry weights determined. Leaf area was determined using a LI-3100 area meter (LI-Cor, inc. Lincoln, NE, USA) and this was used to estimate the Leaf Area Index (LAI).

LAI (L) was defined according to Watson (1947) and Hunt (1978) as:

$$= \frac{L_A}{P}$$

where  $L_A$  is the total plant green leaf area, and  $P$  is the land area occupied by the plant.

Dry weights were determined by drying in a conventional oven at 70°C for up to 6 days. The combined leaf and stalk dry weights were summed to determine the total plant dry weight at each particular harvest. The vegetative crop growth rate ( $CGR_v$ ) was estimated as the change in plant dry weight with time by linear regression analysis.

The mean number of days to 50 percent silk emergence was determined by visual inspection of 20 adjacent plants in each replicate.

During the reproductive period starting 10 days after 50 percent silk emergence 13 and 12 weekly harvests of 3 ears per replicate were made from the October and the November plantings, respectively. The ears were dehusked and the cobs and husks dried separately at 70°C for up to 7 days for mean cob, husk and 100-grain dry weight determinations. During this same period at fortnightly intervals 6 and 4 harvests of above ground plant parts

were also harvested from the October and November plantings, respectively. The combined cob, husk, leaf and stalk dry weights were summed to obtain total plant dry weight for each particular harvest. Mean 100-grain dry weight was determined from 100-grains taken from the bottom third of the cob (not including the butt grains).

Reproductive crop growth rate (CGR<sub>r</sub>), cob (excluding the husk) and 100-grain growth rates were estimated as the change in dry weight with time by linear regression. The duration of grain filling was estimated by dividing rate of grain filling into the final grain dry weight.

Cob and grain moisture contents in the October planting were determined at physiological maturity (at maximum dry weight) and in the November planting at the last harvest. Physiological maturity was not attained in the November planting because grain growth was halted by the killing frost of 23<sup>rd</sup> April, 1991 before physiological maturity was reached.

Moisture content percentage was calculated as:

$$= \frac{\text{fresh weight} - \text{dry weight}}{\text{fresh weight}} \times 100.$$

The number of leaves per plant and the rate of leaf appearance were recorded

as the total number of leaves at tasselling and the rate as the frequency (days) with which leaves become visible within the uppermost whorl of the leaves. Counts were made by regular inspection of 20 adjacent plants per replicate and rates of leaf appearance were estimated by linear regression analysis.

A Cumulative Growing Degree Days (Heat units) system similar to that used by Newton and Eagles (1991) was used to quantify durations between different developmental stages. Terms measured were seeding to 50 percent seedling emergence, seeding to 50 percent silk emergence, duration of the grain filling period, seeding to physiological maturity and rates of plant, cob and grain growth.

Growing Degree Days (GDD) were calculated as:

$$= \frac{(T_{\max} + T_{\min})}{2} - 6^{\circ}\text{C}.$$

where  $T_{\max}$  and  $T_{\min}$  are daily maximum and minimum temperatures ( $^{\circ}\text{C}$ ). The base temperature of  $6^{\circ}\text{C}$  was used because it has provided the best fit in New Zealand (Brooking and McPherson, 1989) and is also the base used for the cool maritime environments in Europe (Derieux, 1978).

### 3.2.2 EXPERIMENT 2.

#### 3.2.2.1 CULTURE AND ENVIRONMENT.

The whole of this study was carried out at the Horticulture and Food Research and the Crop and Food Research Institutes of the Crown Research Institutes, Palmerston North in 1992. The hybrids were started off in a glass house and later during the grain filling period an equal number of plants of each hybrid were transferred to controlled climatic environments set at temperatures of 28/22 and 16/6°C (day/night).

##### 3.2.2.1.1 GLASS HOUSE.

Two seeds with embryos in a vertical position were sown per pot on 30th April, 1992 in 10 litre plastic pots (diameter: 25cm top and 20 cm bottom, height: 25cm) to a depth of 3 to 4 cm. These were later thinned to one plant per pot at the fourth leaf stage. The culture media was composed of fine gravel chips, peat and vermiculite (70:15:15 v/v).

The pots were arranged in a randomised complete block design with four replicates. Each plot consisted of two rows of four pots each. A plot to plot

and row to row spacing of 0.75m and a 0.30m spacing between plants gave a population density of 44 444 plants per hectare.

During the first two weeks following planting the pots were watered with tap water. For the next two weeks and two weeks after that 300ml and 600ml, respectively and 1200ml thereafter of nutrient solution ( Modified Hoagland's solution - 1/2 strength) was dissolved in 20l of water and applied daily to the pots using a watering can. The nutrient solution was composed of 2 stock solutions and 200ml per 100l of water of concentrated hydrochloric acid. Stock solution A was made up of 14 759.5ml of Calcium Nitrate [  $\text{Ca}(\text{NO}_3)_2 \times 4\text{H}_2\text{O}$ ] and 520gm of sequestrene (10% DTPA NaFe) per 100l of water. Stock solution B was made up of 1 701gm of Potassium dihydrogen phosphate ( $\text{KH}_2\text{PO}_4$ ), 6 319.5gm of Potassium Nitrate ( $\text{KNO}_3$ ) and 6 162ml of Magnesium sulphate ( $\text{MgSO}_4 \times 7\text{H}_2\text{O}$ ) per 100l of water.

The few weeds that emerged were removed by hand.

Temperature data over this period are reported in Figure 2 and Appendix 3.

# TEMPERATURE AND RAINFALL CHART. 1991-92 SEASON.

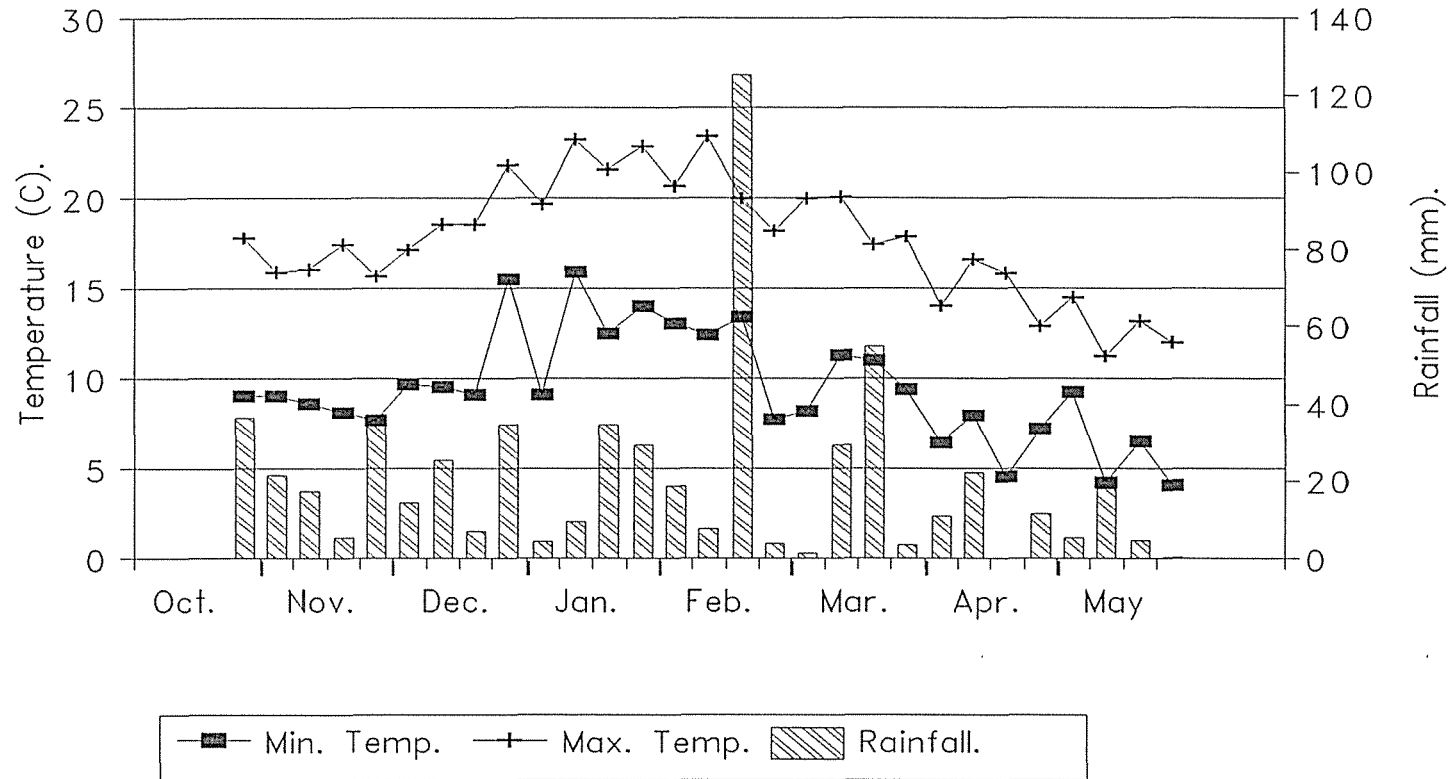


Figure 1. Minimum and maximum temperatures, and rainfall of the 1991-92 season.

TEMPERATURE.  
Glass house (1992).

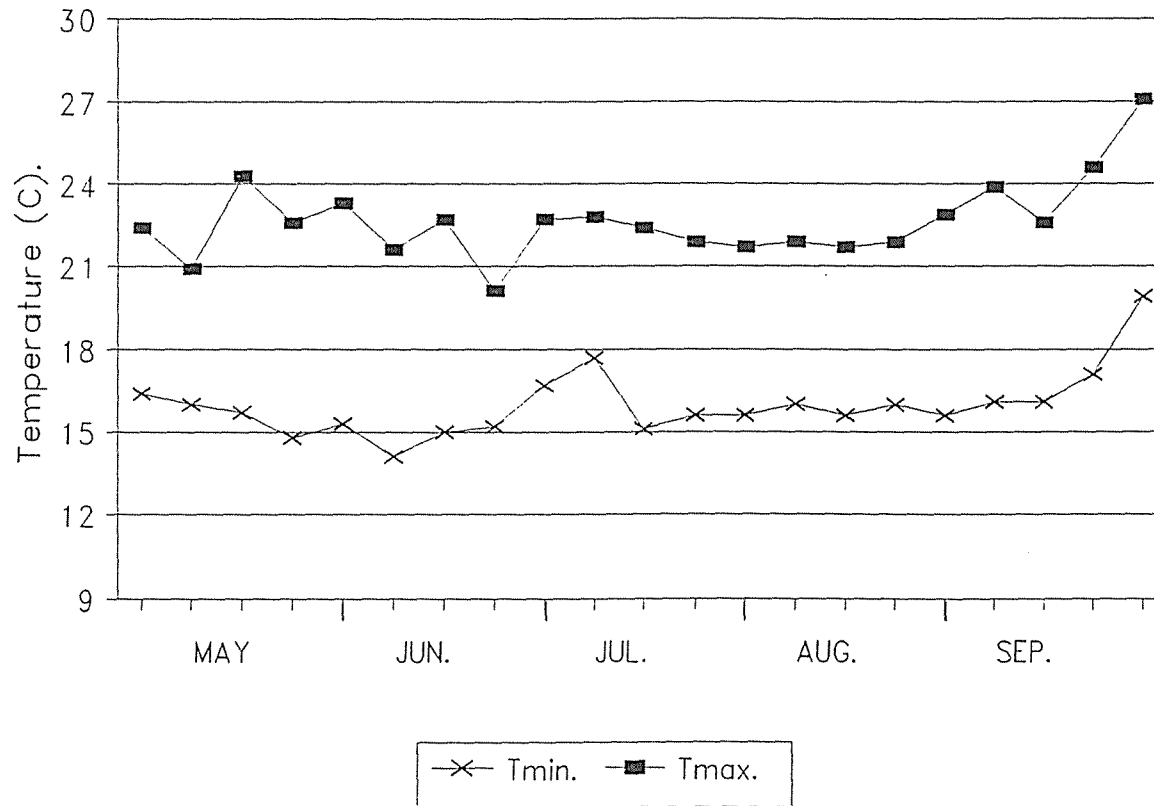


Figure 2. Minimum and maximum temperatures in the Glass house.

### 3.2.2.1.2 CLIMATE ROOM.

The climate room experiments were carried out in two controlled environment rooms at the Climate Laboratory of the Horticulture and Food Research Institute. The rooms were set at day/night temperatures of 16/6 and 28/22°C. These temperatures were chosen because the mean of 16/6°C is close to the minimum temperature (Hardacre and Eagles, 1980) and that of 28/22°C is within the optimum temperature range (Hardacre and Turnbull, 1986; Brouwer et al., 1973) for autotrophic growth, respectively.

The light intensity used in the climate rooms was similar to that used by Greer and Hardacre (1989). Photosynthetic irradiance was maintained at 700  $\mu\text{E m}^{-2} \text{s}^{-1}$  for 12hrs; the lights were turned on from 24.00hrs to 12.00hrs. Vapour pressure deficit (VPD) was set at 3.6 kPa (day) and 12.6 kPa (night) in the 16/6°C room. In the 28/22°C room these were set at 7.6 kPa and 24.2 kPa (day/night), respectively. The day and night temperatures were all of 10hr duration. Temperature changeovers from day to night and night to day were programmed to occur over 2 hours.

A complete treatment of each hybrid was set up in the 28/22°C and 16/6°C climate rooms 139 and 143 days after planting, respectively. In the 28/22°C and 16/6°C this was 25 and 29, and 29 and 33 days after silking for A655 x H99 and A665 x NZ1A, respectively. Each treatment consisted of 15 plants,

placed 5 to a trolley in a randomised complete block design. The six trolleys holding the plants were each designated as a replicate (3 per hybrid). A complete mineral nutrient, Hoagland's solution (Brooking, 1976) was automatically supplied via a micro-tube system at regular intervals up to five times a day. 200ml of the nutrient solution was applied at each time, the amounts used ensured drainage at each application and avoided any outward symptoms of plant moisture stress.

#### **3.2.2.2 GROWTH MEASUREMENTS.**

Percentage emergence and emergence index (emergence rate) were calculated as in experiment 1.

Three harvests each of 2 representative plants of each hybrid were made in the glass house and climate rooms, respectively. The harvests were made at 35, 50 and 74 days after planting (DAP) for hybrid A665 x NZ1A and at 35, 50 and 81 DAP for A665 x H99 while in the glass house. The last harvest in each case was at anthesis. In the climate rooms harvests of both hybrids were made 140, 150, 160 DAP and 144, 154, 164 DAP in the 28/22 and 16/6°C rooms, respectively. The first harvest date in this case was the day the plants

were transferred to the climate rooms from the glass house.

At each of these harvests leaf area and total plant (leaf and stalk) dry weights were determined. The cob and 100-grain dry weights were also determined in the climate rooms. Leaf area was determined using a LI-3100 area meter (LI-Cor, inc. Lincoln, NE, USA) and this was used to estimate Leaf Area Index. Dry weights were determined by drying in a conventional oven at 70°C for up to 7 days. The combined dry weight of the leaves, stalk, husk and cob at each harvest was recorded as the total plant dry weight. Crop growth rates were estimated by linear regression as change in plant dry weight with time (day).

Each replicate in both climate rooms had two plants of about the same silking date selected for grain sampling. All the plants selected from each hybrid had silked within 2 days of mid-silking (i.e.,  $\pm 2$  days of mid-silking). A sampling procedure similar to that used by Duncan and Hatfield (1964) and Badu-Apraku et al. (1983) was used for grain sampling. The procedure involved slitting a rectangular flap through the husks with a surgical blade which was then pulled upward to expose 2 to 3 rows of grain. The husks were not cut on the proximal end of the flap. The flap was returned to its original position after sampling and held in place by an elastic band placed around the ear.

A total of 12 to 14 grains above the butt grains were removed carefully from 2 adjacent rows with the help of a surgical blade. The 10 most intact grains selected from the lot were oven dried for 4 days at 65°C. Subsequent grain samples were obtained from the same ear by opening additional flaps in an ordered pattern around the ear. To ensure the least disturbance to subsequent samples a minimum of two kernel rows were left between consecutive sampling areas. Three samples in all were taken from each ear at 2 day intervals after which subsequent samples were taken from the second ear. When the last sample had been taken the ears were harvested and the number of kernel rows and total kernels per cob recorded.

The dry weight data were used to calculate 100-grain dry weight and rates of grain dry matter accumulation for each hybrid. Percentage moisture content of the grains was determined at physiological maturity at 28/22°C and at the last harvest at 16/6°C, the experiment ended before physiological maturity was attained. The rates of grain growth and percentage moisture content were calculated as in experiment 1.

## CHAPTER 4.

### RESULTS.

#### 4.1 SEEDLING EMERGENCE AND GROWTH.

Field experiments were planted on the 26<sup>th</sup> October and 26<sup>th</sup> November, 1991 and the Controlled Environment experiment was pot planted in the glass house on the 30<sup>th</sup> April, 1992. Hybrids A665 x H99 and A665 x NZ1A, did not differ in percentage laboratory germination or field emergence, but A665 x H99 had greater glass house emergence (Appendix 4).

A665 x H99 emerged (emergence index) earlier ( $P < 0.05$ ) than A665 x NZ1A in the October planting but not in the November and glass house plantings (Appendix 4). However at all three plantings, emergence differences were less than half a day. Both hybrids emerged more than a day earlier when sown on 26<sup>th</sup> November as against 26<sup>th</sup> October. Glass house sown A665 x H99 and A665 x NZ1A emerged 4.8 days earlier than in the October sowing, and 3.6 and 3.7 days earlier than in the November sowing, respectively.

Rates of seedling emergence did not differ significantly ( $p < 0.05$ ) between the hybrids at all plantings, though rates of A665 x H99 were greater than those of A665 x NZ1A in all cases (Appendix 5). Across plantings rates of seedling emergence were highest in the glass house and lowest in the November planting.

Although days to seedling emergence differed between hybrids and between the plantings, the Growing Degree Days (GDD) were similar. A665 x H99 reached 50 percent seedling emergence after 79.6, 71.7 and 91.1 GDD, while it took A665 x NZ1A 77.6, 70.2 and 88.5 GDD, respectively in the October, November and glass house plantings.

The seedling dry weights of the hybrids measured at 46 days after planting (DAP) in the October and glass house plantings and 45 DAP in the November planting were similar between the hybrids at each planting (Appendix 6). Across plantings the seedling dry weights of November sown A665 x H99 and A665 x NZ1A were greater than those of the October and glass house plantings and those of the glass house were greater than those of October.

#### 4.2 LEAF NUMBER AND LEAF APPEARANCE RATE.

In the October and November plantings A665 x H99 and A665 x NZ1A attained a maximum of 19 and 17 leaves at anthesis and a maximum of 16 and 14 leaves in the glass house. October sown A665 x H99 and A665 x NZ1A attained maximum leaf number 86 and 77 DAP. This was 20 and 14 days later than in the November planting, and 28 and 33 days earlier than in the glass house planting. November sown A665 x H99 and A665 x NZ1A attained maximum leaf number 48 and 47 days earlier than in the glass house, respectively.

Leaves of both hybrids appeared within the leaf whorl at the same rate at each planting (Appendix 5). Estimates of leaf appearance rates by linear regression analysis indicate that leaves of both hybrids in the November sowing appeared faster than those of the October sowing. In the glass house the rates of leaf appearance were 50 and 40 percent slower than the rates of November and October sown maize.

#### 4.3 LEAF AREA AND LEAF AREA INDEX.

Figures 3a, 3b, 4a and 4b show that leaf growth of A665 x H99 and A665 x

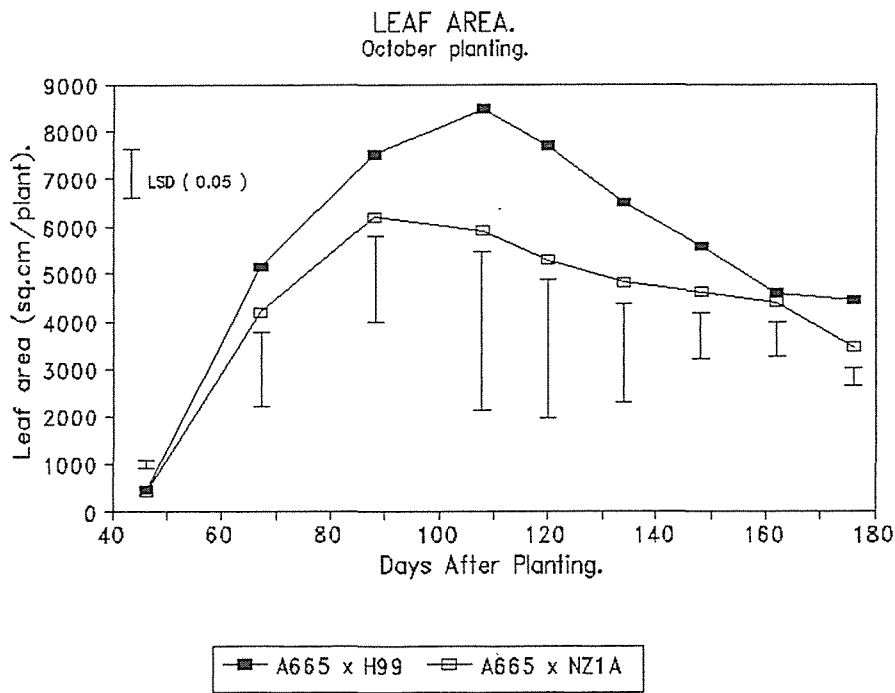


Figure 3a. Total plant leaf area of A665 x H99 and A665 x NZ1A, October planting.

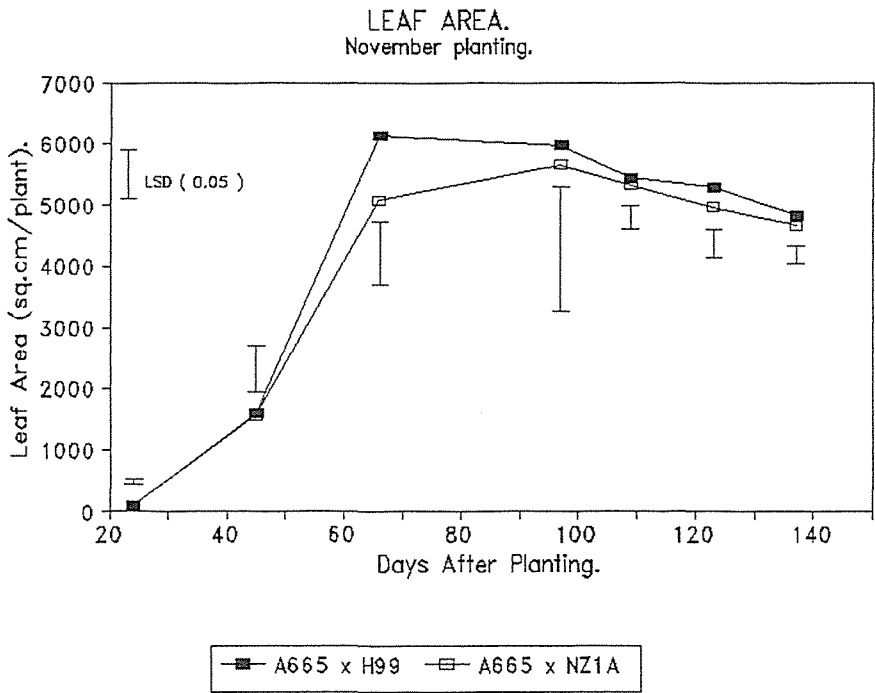
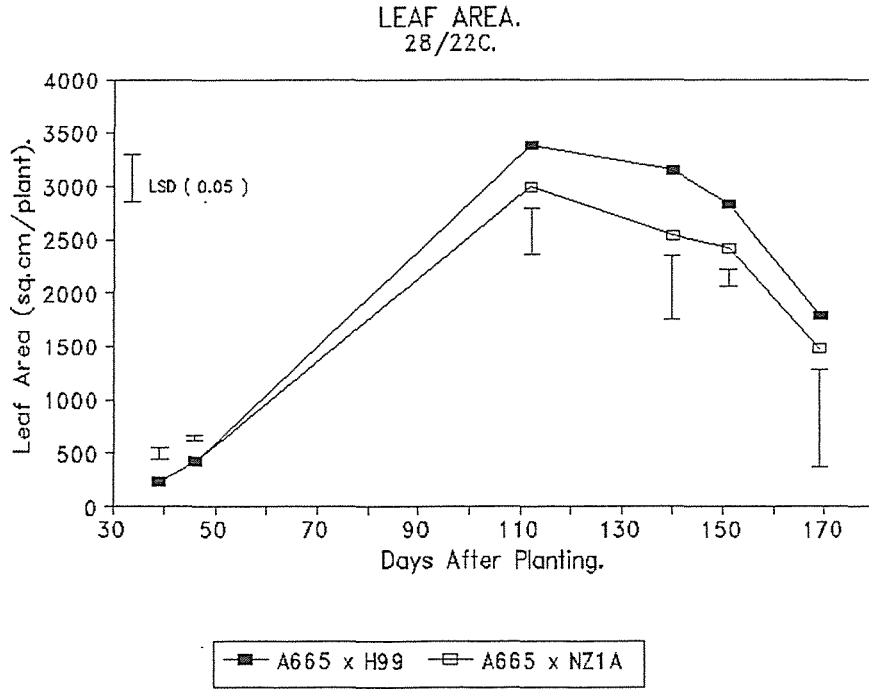
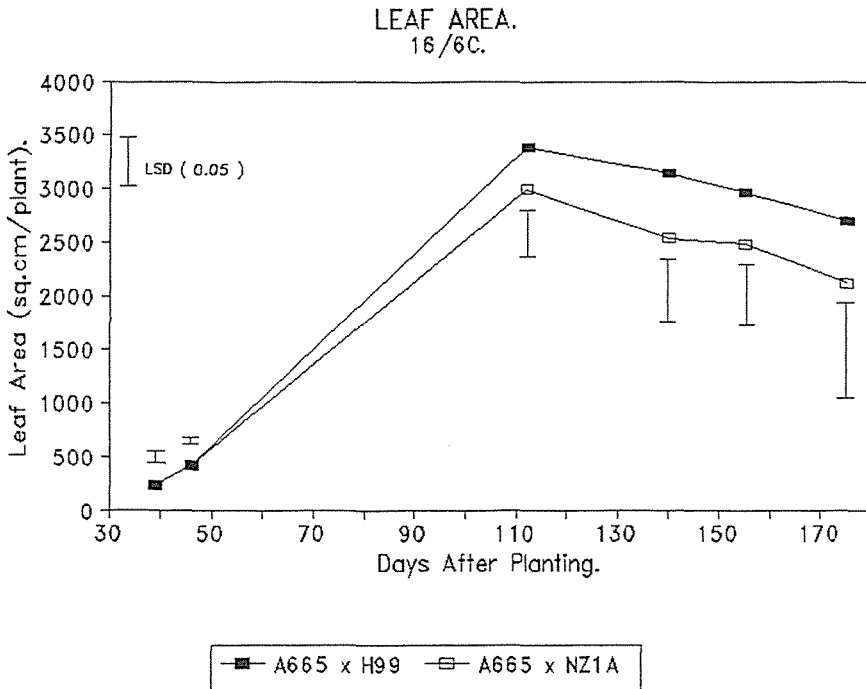


Figure 3b. Total plant leaf area of A665 x H99 and A665 x NZ1A, November planting.



**Figure 4a.** Total plant leaf area of A665 x H99 and A665 x NZ1A, Glass house and 28/22°C.

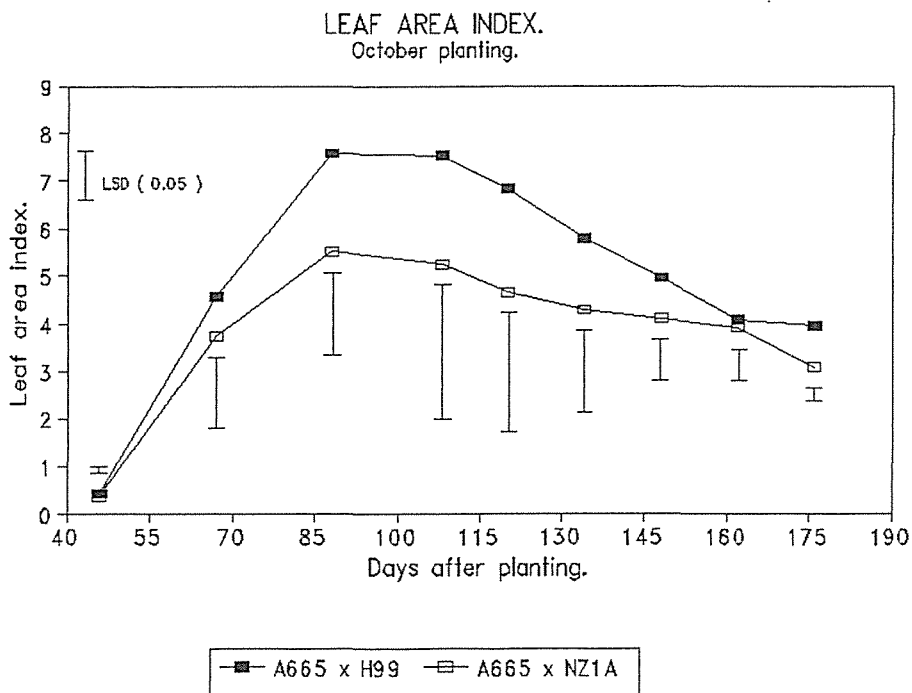


**Figure 4b.** Total plant leaf area of A665 x H99 and A665 x NZ1A, Glass house and 16/6°C.

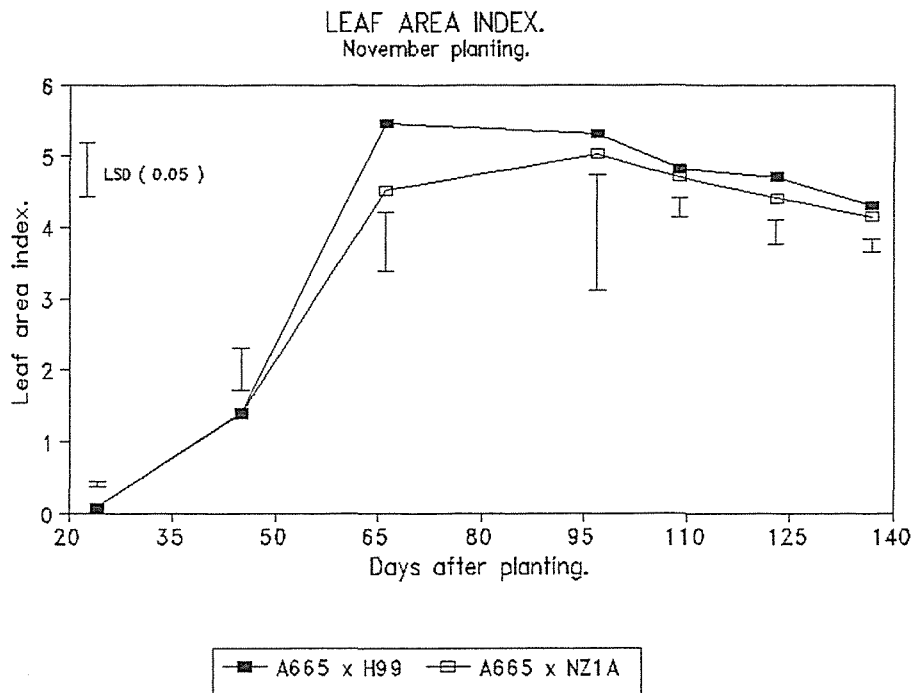
NZ1A did not differ significantly ( $P < 0.05$ ) between the hybrids at all plantings. Maximum leaf area attained by the hybrids at anthesis was greater, but not significantly, in favour of A665 x H99 at all plantings (Appendix 7). At anthesis leaf area A665 x H99 had 30, 3, and 12 percent more leaf area than A665 x NZ1A in the October, November and Glass house sowings, respectively. Across plantings, at anthesis, the leaf area of October sown A665 x H99 was greater than that of the November and glass house plantings. The maximum leaf areas of October and November sown A665 x NZ1A were similar and greater than those of the glass house planting.

October and November sown plants had leaf area growth rates which did not differ significantly between the hybrids at both plantings and rates for both hybrids were greater in the November than in the October sowing. However estimates by linear regression analysis showed that the rates of leaf area growth of A665 x H99 were 18 and 17 percent greater than those of A665 x NZ1A in the October and November plantings, respectively (Appendix 5). In the glass house the leaf area growth rate of A665 x H99 was significantly greater than that of A665 x NZ1A. Across plantings the leaf area growth rates of November sown A665 x H99 and A665 x NZ1A were greater than those of the October and glass house plantings, and those of the October sowing were greater than those of glass house.

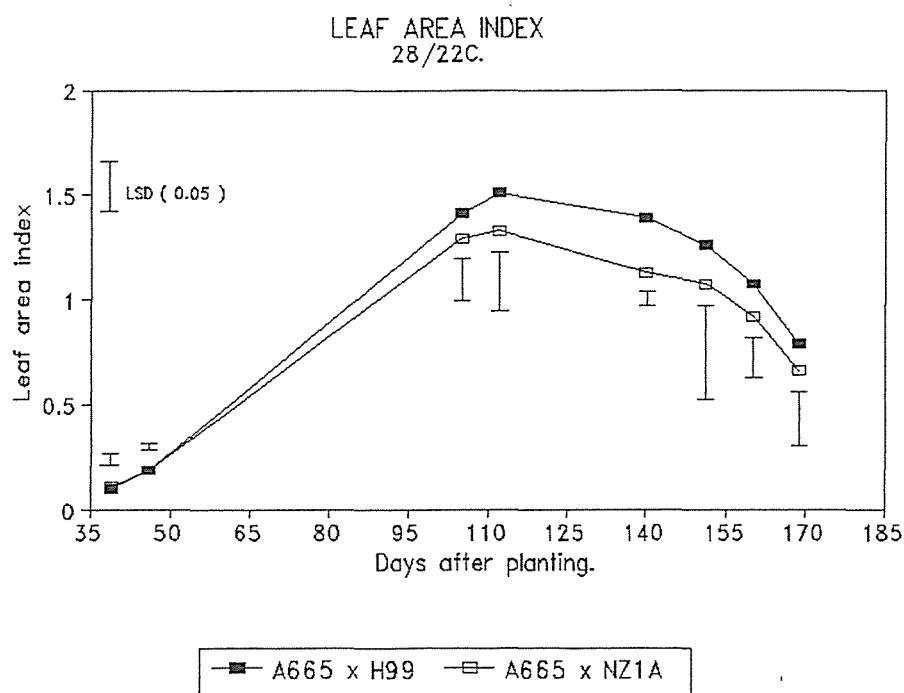
Leaf Area Index (LAI) a product of leaf area also developed on similar lines to leaf area between the hybrids and the planting dates. A665 x H99



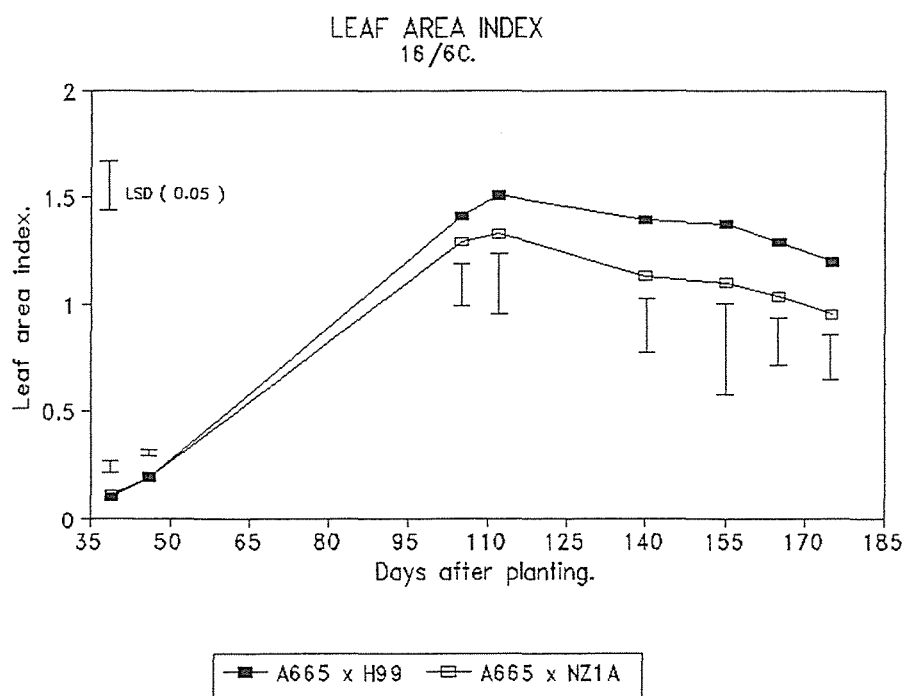
**Figure 5a.** Leaf area index of A665 x H99 and A665 x NZ1A, October planting.



**Figure 5b.** Leaf area index of A665 x H99 and A665 x NZ1A, November planting.



**Figure 6a.** Leaf area index of A665 x H99 and A665 x NZ1A, Glass house and 28/22°C.



**Figure 6b.** Leaf area index of A665 x H99 and A665 x NZ1A, Glass house and 16/6°C.

maintained a greater, but not significant, LAI between the hybrids at all plantings (Figures 5a, 5b, 6a and 6b). In the October sowing despite initial low LAI because of low leaf areas early in the season, October sown hybrids attained larger LAI at anthesis than those of the November and glass house sowings (Appendix 7). At anthesis the LAI of A665 x H99 was 28, 18 and 14 percent greater than those of A665 x NZ1A in the October, November and glass house plantings, respectively. Across plantings the LAI of October sown A665 x H99 and A665 x NZ1A at anthesis were greater than those of November and glass house sowings and those of November sown A665 x H99 and A665 x NZ1A were greater than those of the glass house.

In the October planting both hybrids maintained an LAI of more than 3.9 until physiological maturity (175 DAP) and in the November planting an LAI of at least 4 was maintained until the last sampling date (172 DAP) (Figures 5a, 5b, 6a and 6b). There was no further sampling after this date because green leaves were completely bleached by the killing frost of 23<sup>rd</sup> April, 1991. In the Glass house the hybrids attained a maximum LAI of not more than 1.51. When the hybrids were transferred to the 28/22°C (140 DAP) and 16/6°C (144 DAP) environments after about 4 weeks of grain growth in the glass house both hybrids lost green leaf area and LAI faster at the higher temperature environment than at the lower one. After a month in the controlled temperature environments A665 x H99 and A665 x NZ1A had lost 43 and 42 percent, and 15 and 16 percent of their leaf area and LAI at 28/22°C and 16/6°C, respectively.

#### 4.4 DAYS TO SILKING.

October sown A665 x H99 and A665 x NZ1A reached mid-silk 99 and 97 DAP; this was 14 and 13 days later than in the November planting, respectively (Appendix 8). In the glass house A665 x H99 and A665 x NZ1A reached mid-silk 114 and 110 DAP, respectively. This was 15 and 13 days, and 29 and 27 days later than in the October and November plantings, respectively.

In Heat Unit terms October sown A665 x H99 and A665 x NZ1A reached mid-silk after 893.5 and 849.5 growing degree days (GDD), respectively. In the November planting the hybrids reached mid-silk after 858.5 and 838.1 GDD, respectively. Hybrids adapted to the Manawatu region require about 900 GDD (base 6°C) to proceed from sowing to silking (Hardacre et al., unpublished : Maize and weather in the Manawatu). In the Glass house using the same temperature base of 6°C, A665 x H99 and A665 x NZ1A reached mid-silk after 1485.5 and 1420 GDD, respectively.

#### 4.5 CROP GROWTH RATE.

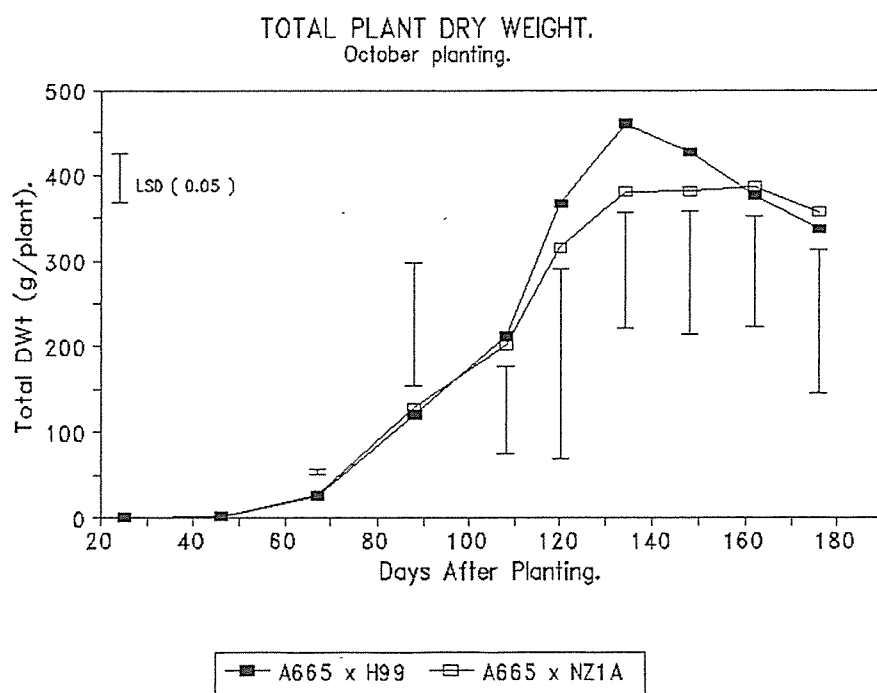
Both hybrids had similar vegetative crop growth rates ( $CGR_v$ ) in the October and November plantings (Appendix 9). In the glass house, however, the  $CGR_v$  of A665 x H99 was significantly greater than that of A665 x NZ1A. In the October and November plantings the  $CGR_v$  of A665 x H99 was 7 percent higher and 4 percent lower than that of A665 x NZ1A, respectively. In the glass house the  $CGR_v$  of A665 x H99 was 11 percent greater than that of A665 x NZ1A. Across plantings the  $CGR_v$  of October sown A665 x H99 and A665 x NZ1A were greater than those of the November and the glass house sowings, and the  $CGR_v$  of the November sowings were greater than those of the glass house.

In the October and November plantings the reproductive crop growth rates ( $CGR_r$ ) of A665 x H99 were greater than those of A665 x NZ1A at both plantings but only significant in the November planting (Appendix 9). Similarly in the controlled temperature environments the  $CGR_r$  of A665 x H99 was greater than those of A665 x NZ1A at both 28/22°C and 16/6°C but only significant at 28/22°C. The  $CGR_r$  of A665 x H99 was 27 and 22 percent, and 35 and 29 percent greater than that of A665 x NZ1A at the October and November plantings, and at 28/22°C and 16/6°C, respectively. Across plantings the  $CGR_r$  of October sown A665 x H99 and A665 x NZ1A were greater than those of the November planting, 28/22°C and 16/6°C. The  $CGR_r$  of November sown A665 x H99 and A665 x NZ1A were greater than those

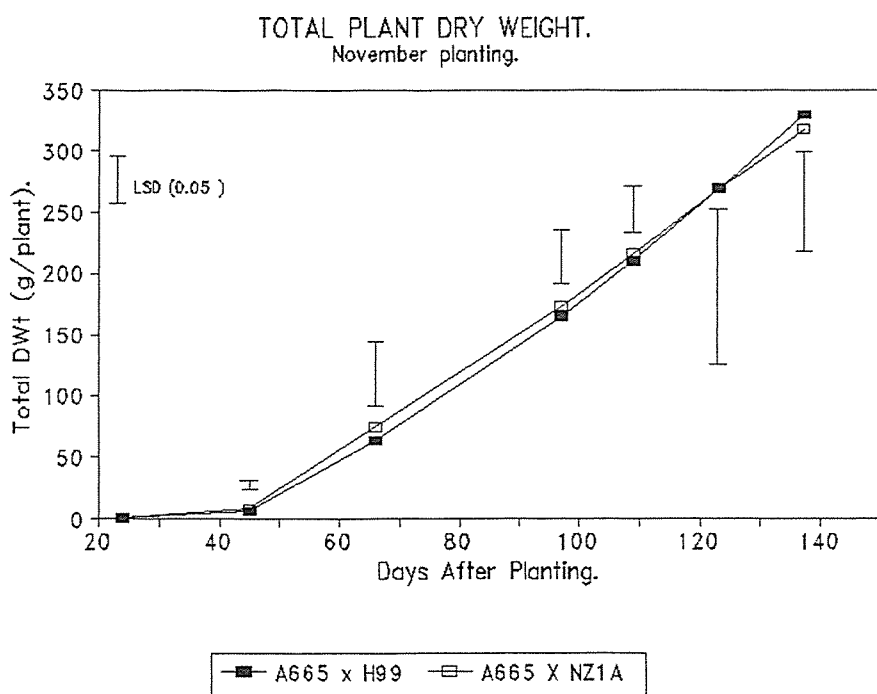
at 28/22°C and 16/6°C, and those at 28/22°C were greater than those at 16/6°C. Since almost all growth during the reproductive period is from the ear (husks, shank and grains)(Hanway, 1963; Tetio-Kagho and Gardner, 1988), the above results indicate that ear growth rates of A665 x H99 were greater than those of A665 x NZ1A at both field plantings and under both controlled environments but only significantly so in the November planting and at 28/22°C.

#### 4.6 TOTAL PLANT DRY WEIGHT.

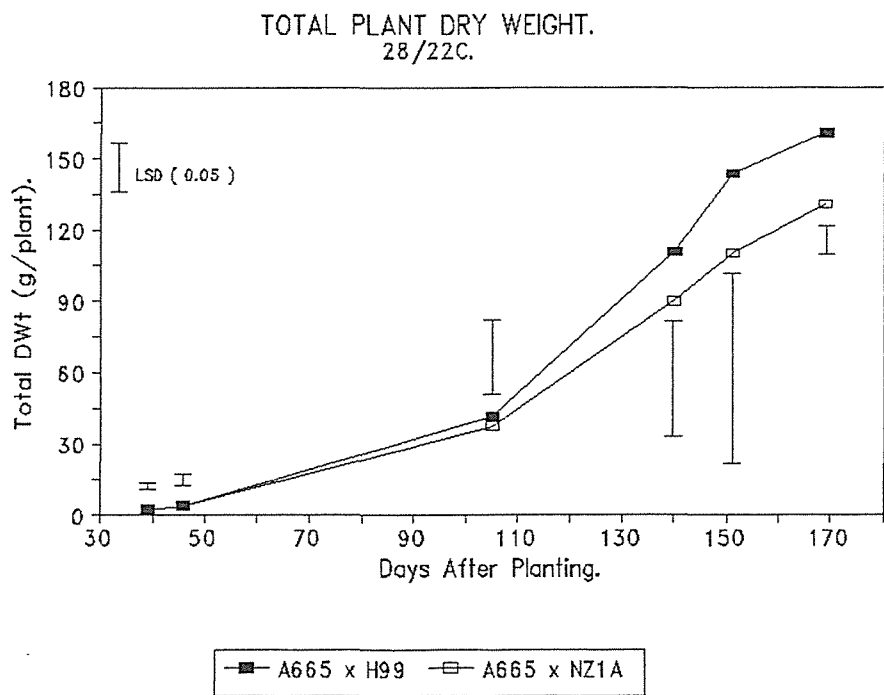
Figures 7a and 7b, and 8a and 8b show the total plant dry weight (TPDWT) accumulation patterns of the hybrids in the October and November plantings, and in the glass house through to 28/22°C and 16/6°C controlled temperature environments. The hybrids accumulated total plant dry weight similarly at all plantings. At anthesis the TPDWT of A665 x H99 was greater, but not significantly different from that of A665 x NZ1A in the October and glass house plantings (Appendix 6). However, in the November planting the TPDWT of A665 x H99 was smaller, but again not significantly different from that of A665 x NZ1A. The TPDWT of A665 x H99 was 6 and 10 percent greater than that of A665 x NZ1A in the October and glass house plantings but 5 percent smaller in the November planting. Across plantings October sown A665 x H99 and A665 x NZ1A accumulated more TPDWT than those sown in November and the glass house, and those of the November sowing had



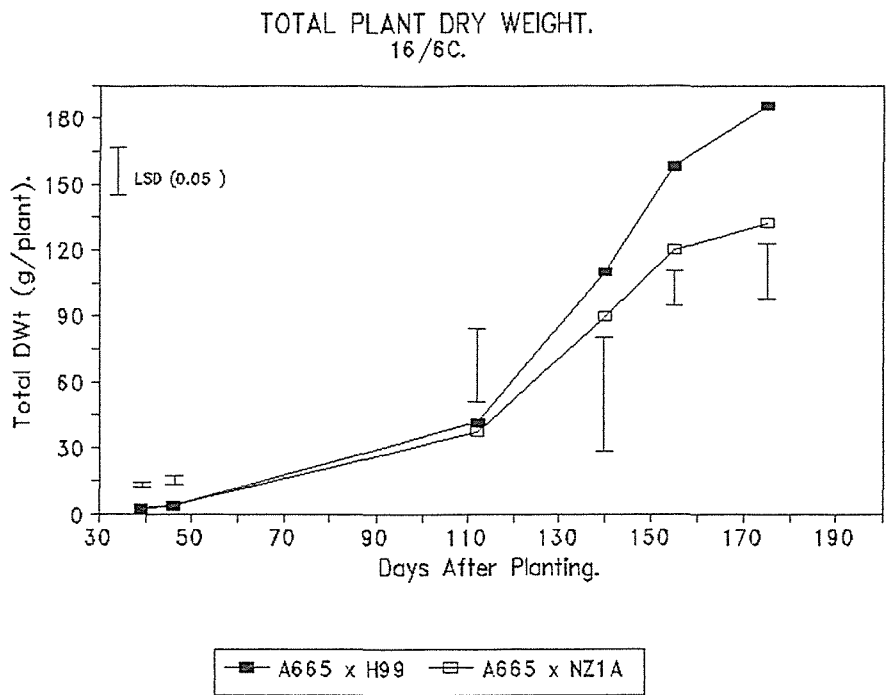
**Figure 7a.** Total plant dry weight of A665 x H99 and A665 x NZ1A, October planting.



**Figure 7b.** Total plant dry weight of A665 x H99 and A665 x NZ1A, November planting.



**Figure 8a.** Total plant dry weight of A665 x H99 and A665 x NZ1A, Glass house and 28/22°C.



**Figure 8b.** Total plant dry weight of A665 x H99 and A665 x NZ1A, Glass house and 16/6°C.

greater TPDWT than those of the glass house.

The maximum TPDWT between the hybrids during the reproductive phase was not significantly different at either planting in the field but was significantly different ( $P < 0.05$ ) at both temperatures in the controlled environments. The TPDWT of A665 x H99 was 17 and 4 percent, and 19 and 29 percent greater than that of A665 x NZ1A in the October and November plantings and at 28/22°C and 16/6°C, respectively. Across plantings the TPDWT of October sown A665 x H99 and A665 x NZ1A was greater than those of the November planting, 28/22°C and 16/6°C. The TPDWT of November sown A665 x H99 and A665 x NZ1A were greater than those at 28/22°C and 16/6°C, but those at 28/22°C had similar TPDWT to those at 16/6°C.

#### 4.7 COB GROWTH.

Figures 9a and 9b, and 10a and 10b illustrate cob dry matter accumulation patterns of A665 x H99 and A665 x NZ1A in the October and November sowings and at 28/22°C and 16/6°C, respectively. Maximum cob dry weight did not differ significantly between the hybrids at the October (at physiological maturity) and November (at the last harvest) plantings (Appendix 10). At 28/22°C (at physiological maturity) and 16/6°C (at the last harvest) the maximum cob dry weight of A665 x H99 was significantly greater ( $P < 0.05$ )

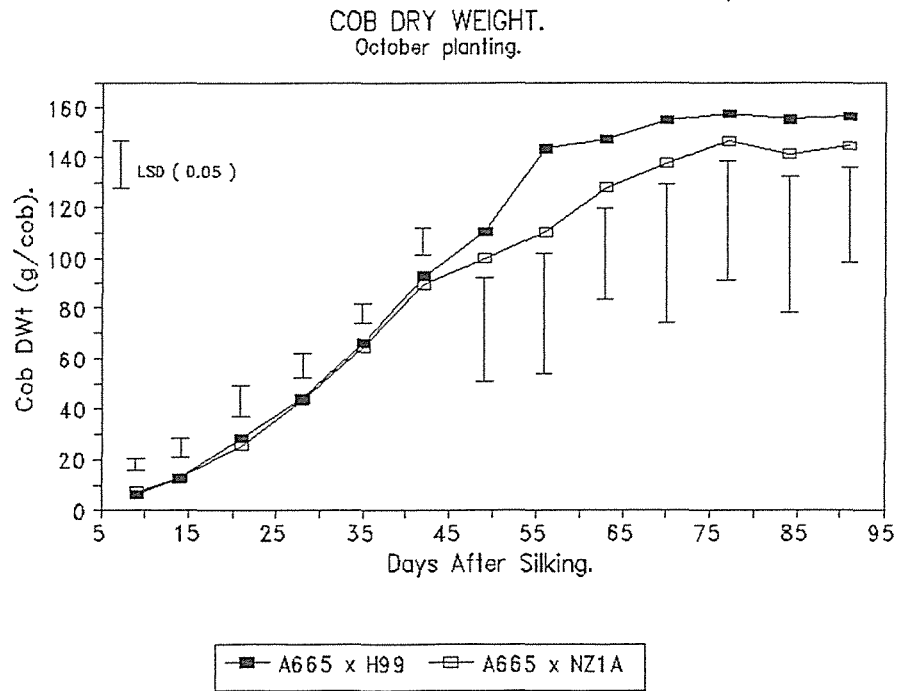


Figure 9a. Cob dry weight of A665 x H99 and A665 x NZ1A, October planting.

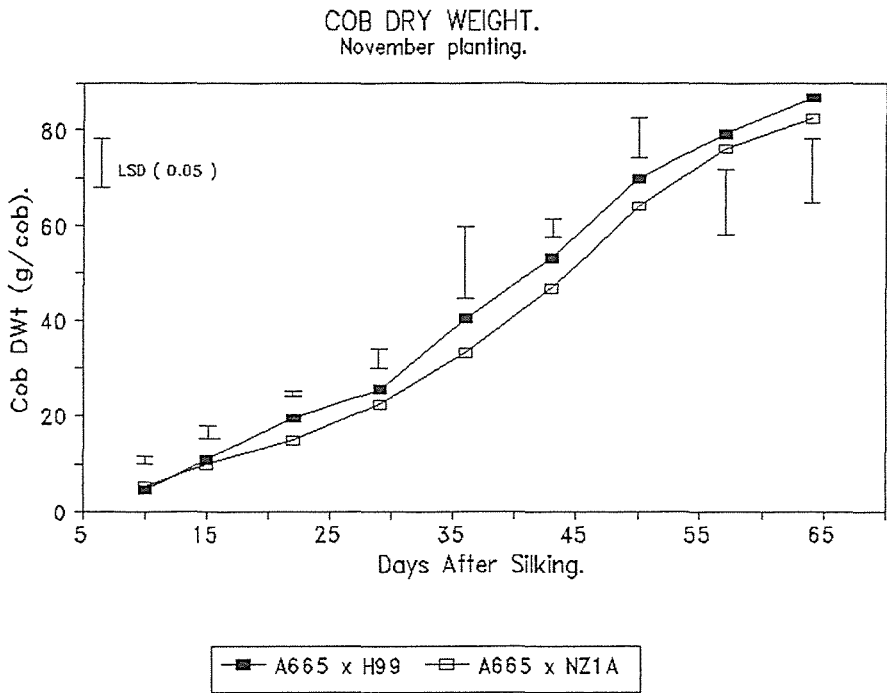


Figure 9b. Cob dry weight of A665 x H99 and A665 x NZ1A, November planting.

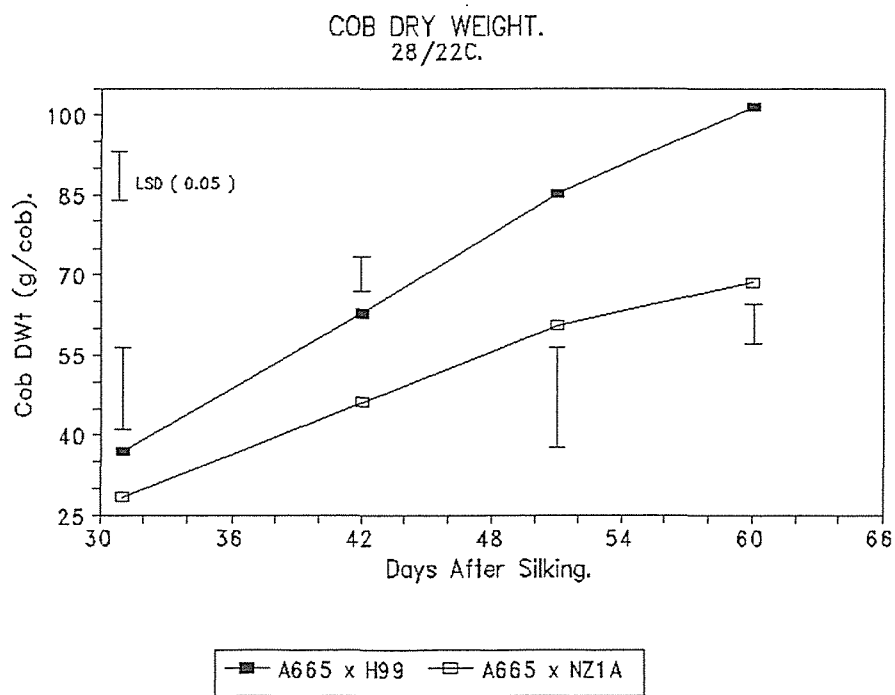


Figure 10a. Cob dry weight of A665 x H99 and A665 x NZ1A at 28/22°C.

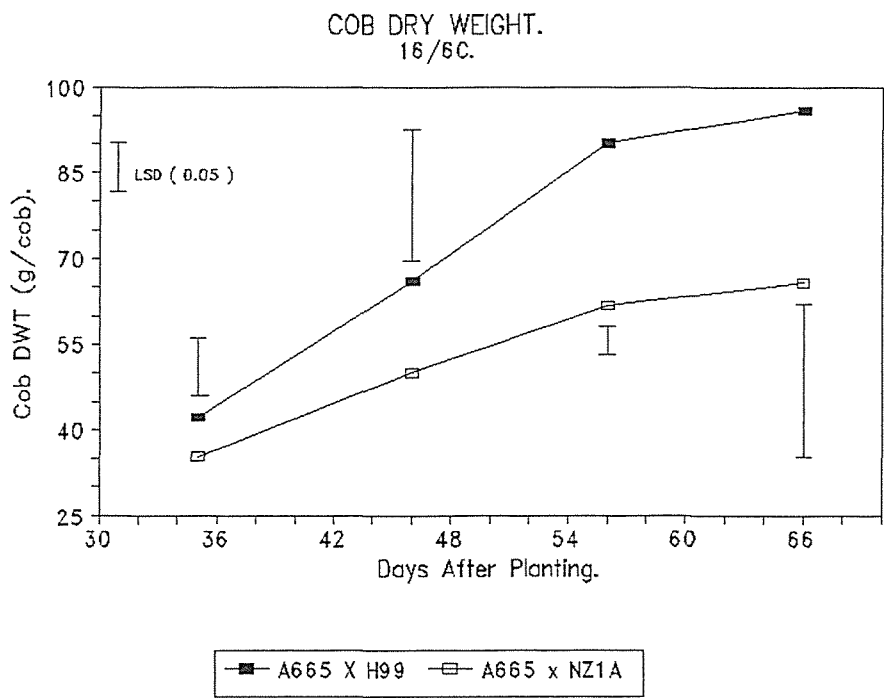


Figure 10b. Cob dry weight of A665 x H99 and A665 x NZ1A at 16/6°C.

than that of A665 x NZ1A. Cob growth did not reach physiological maturity in the November planting and at 16/6°C because in the former growth had ceased prematurely because of the killing frost of 23<sup>rd</sup> April, 1991, while in the latter, the experiment was terminated before physiological maturity had been attained.

The cob dry weight of A665 x H99 was 7 and 5 percent greater than that of A665 x NZ1A in the October and November plantings, respectively (Appendix 10). At 28/22°C and 16/6°C A665 x H99 had 32 and 31 percent more cob dry matter than A665 x NZ1A, respectively. Across plantings the maximum cob dry weights of October sown A665 x H99 and A665 x NZ1A were greater than those of the November planting, 28/22°C and 16/6°C. Mean cob dry weight of November sown A665 x H99 was smaller than those at 28/22°C but greater at 16/6°C. The maximum cob dry weights of A665 x H99 and A665 x NZ1A at 28/22°C were similar to those at 16/6°C.

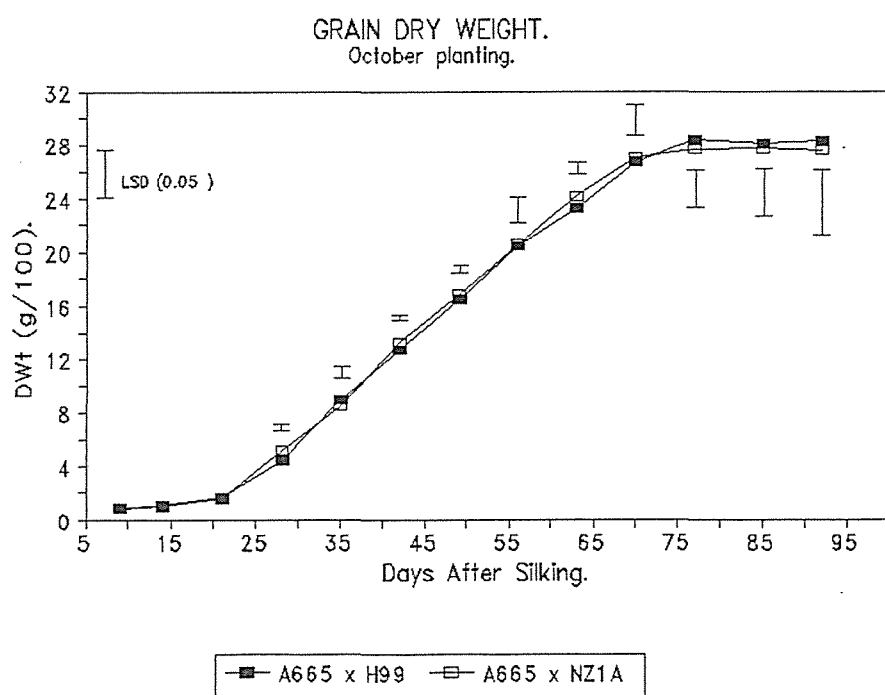
Estimates by linear regression analysis show that the cob growth rates of A665 x H99 were significantly greater than those of A665 x NZ1A in all environments except for the November planting where rates were the same (Appendix 11). The cob growth rates of A665 x H99 were 13 and 5 percent greater than those of A665 x NZ1A in the October and November plantings, and 38 and 44 percent greater at 28/22°C and 16/6°C, respectively. Across plantings the cob growth rates of the hybrids in the October planting were greater than those of the November planting, 28/22°C and 16/6°C. Rates at

28/22°C were higher than those at 16/6°C.

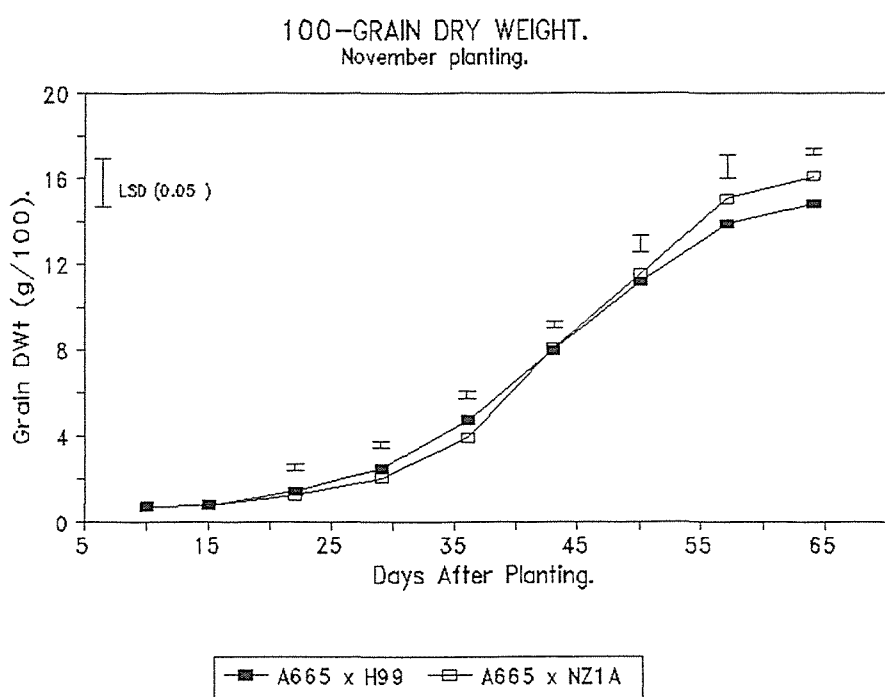
No significant differences in cob moisture content of the hybrids were recorded at any planting (Appendix 10). In the two plantings which reached physiological maturity (October and 28/22°C), cob moisture contents were similar.

#### 4.8 GRAIN GROWTH.

Figures 11a and 11b, and 12a and 12b illustrate patterns of grain dry matter accumulation in the October and November plantings and at 28/22°C and 16/6°C, respectively. There were no significant differences in grain dry matter accumulation rates between the hybrids at both field plantings and in both controlled environments (Appendix 11). However, the rates of grain growth of A665 x H99 were marginally greater than those of A665 x NZ1A at 28/22°C, while in the October planting and at 16/6°C the rates were similar. In the November planting A665 x NZ1A had a greater grain growth rate than A665 x H99. Across plantings the grain growth rates of the hybrids were greatest at 28/22°C followed by those of the October planting, and were lowest in the November planting and at 16/6°C, where rates were similar.



**Figure 11a.** 100-grain dry weight of A665 x H99 and A665 x NZ1A, October planting.



**Figure 11b.** 100-grain dry weight of A665 x H99 and A665 x NZ1A, November planting.

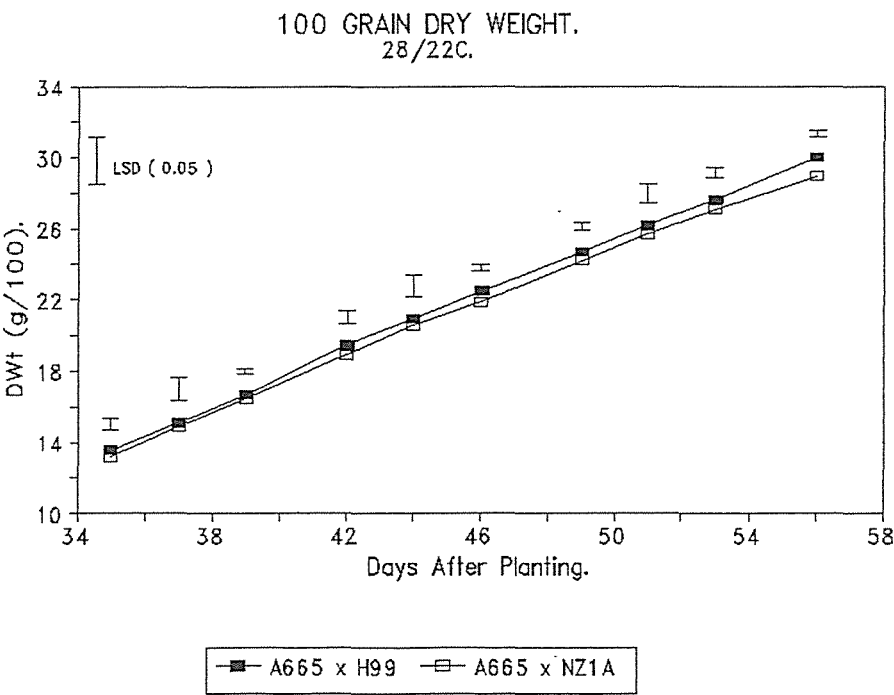


Figure 12a. 100-grain dry weight of A665 x H99 and A665 x NZ1A at 28/22°C.

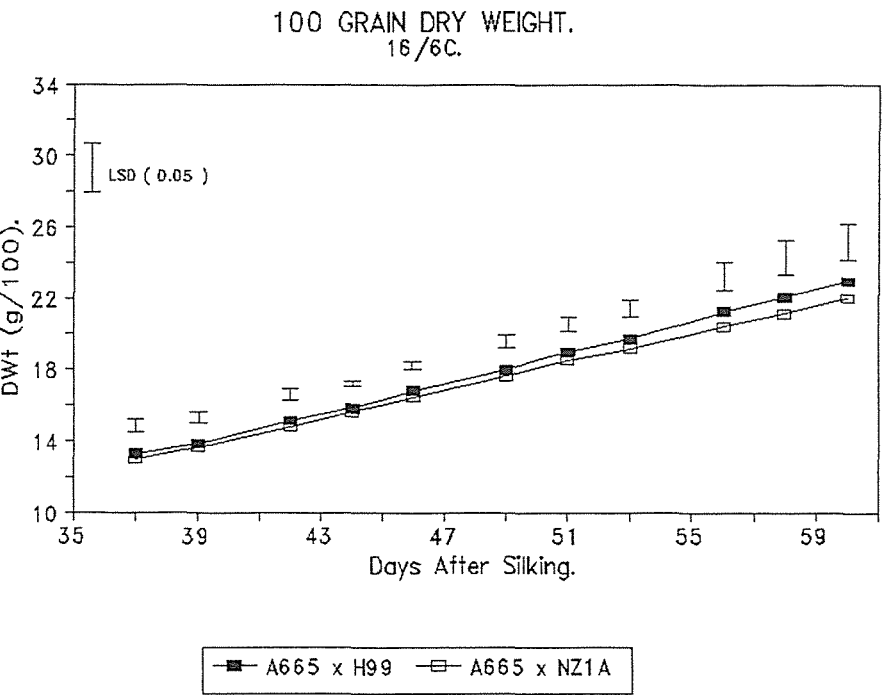


Figure 12b. 100-grain dry weight of A665 x H99 and A665 x NZ1A at 16/6°C.

There were no significant differences in grain dry weights between the hybrids either in the October and November plantings (Appendix 12a) or at 28/22°C and 16/6°C (Appendix 12b). At physiological maturity A665 x H99 had 100-grain dry weights around 1g heavier than A665 x NZ1A in the October planting and at 28/22°C. However, at the last harvests in the November planting and at 16/6°C A665 x NZ1A had heavier 100-grain dry weights than A665 x H99. Across plantings the 100-grain dry weights of the hybrids were greatest at 28/22°C followed by those of the October planting and then at 16/6°C and lowest in the November planting.

In the environments where the hybrids had reached physiological maturity (October and 28/22°C) there were no significant differences between the hybrids in the durations of the grain filling periods and the number of days from planting to physiological maturity (Appendix 8). Across these plantings the durations of the grain filling periods and days to physiological maturity of the hybrids were shorter at 28/22°C than in the October planting.

The growing degree days (GDD) required to reach physiological maturity in October sown A665 x H99 and A665 x NZ1A were 1534.2 and 1514.1, respectively. Hybrids adapted to the Manawatu region require about 1700 GDD (base 6°C) to reach physiological maturity (Hardacre et al., unpublished: Maize and weather in the Manawatu). Using the same temperature base of 6°C as in the field for both the glass house and the 28/22°C environments A665 x H99 and A665 x NZ1A reached physiological maturity after 2421 and

2383 GDD, respectively. Durations of the grain filling periods and days to physiological maturity were not recorded in the November planting because grain growth was considered to have ceased after the killing frost of 23th April, 1991. At 16/6°C these data were not recorded because the experiment was not continued up to the attainment of physiological maturity.

The grain moisture contents of A665 x H99 at physiological maturity (October planting and 28/22°C) and at the last harvests (November planting and 16/6°C) were greater, but not significantly different from than those of A655 x NZ1A at both field plantings and in both controlled environments (Appendix 12a, 12b). The grain moisture contents of October sown hybrids were similar to those at 28/22°C.

#### **4.9 YIELD AND YIELD COMPONENTS.**

Grain number of A665 x H99 was significantly greater ( $P < 0.05$ ) than that of A665 x NZ1A in the October planting and highly significantly greater ( $P < 0.01$ ) in the glass house planting (Appendix 12a, 12b). In the November planting however, there was no significant difference in grain number between the hybrids though A665 x H99 had a greater grain number than A665 x NZ1A. A665 x H99 had 36, 16 and 3 percent more grains than A665 x NZ1A in the glass house, October and November plantings, respectively.

Across plantings grain number of the hybrids in the October planting was greater than that of the November and glass house plantings, and that of the November planting was greater than that of the glass house planting.

Final crop grain yields of the hybrids were not significantly different in the October and November plantings (Appendix 12a). At 28/22°C and 16/6°C the crop grain yields of A665 x H99 were significantly greater ( $P < 0.05$ ) than those of A665 x NZ1A (Appendix 12b). The crop grain yield of A665 x H99 was 8, 30 and 7 percent greater than that of A665 x NZ1A in the October planting, and at 28/22°C and 16/6°C, respectively. In the November planting A665 x NZ1A outyielded A665 x H99 by 5 percent. Across plantings the crop grain yields of the hybrids in the October planting were greater than those of the November planting, 28/22°C and 16/6°C. Yields of the November planting were greater than those of 28/22°C and 16/6°C, and those of 28/22°C were greater than those of 16/6°C.

## CHAPTER 5.

### DISCUSSION AND CONCLUSIONS.

#### 5.1 DISCUSSION.

##### 5.1.1 SEEDLING EMERGENCE AND GROWTH.

Comparisons of percentage laboratory germination and seedling emergence in the field and the glass house for the two hybrids suggested they had similar seedling vigour levels. As such it had been expected that any differences in days to 50 percent emergence could give an indication of genetical differences i.e., response to temperature. Significant emergence differences however occurred only in the October planting where temperatures were lowest at planting, here A665 x NZ1A emerged significantly early than A665 x H99. This agrees with the results of Hardacre and Eagles (1989) who under controlled temperature environments found that A665 x NZ1A emerged significantly earlier than A665 x H99 at low temperature (16/6°C).

At the warmer temperatures in the November and glass house plantings A665 x NZ1A did not differ significantly in emergence to A665 x H99. Hardacre

and Eagles (1989) also found similar results at high temperatures of 25/20°C and 35/30°C. The implication of this is that since A665 x NZ1A emerged faster than A665 x H99 at low temperatures its cold tolerance levels should be higher than those of A665 x H99 indicating that the male parent may be a valuable source of genes for improving emergence and growth at low temperatures in the field.

Although A665 x NZ1A emerged earlier it did not accumulate more seedling dry matter than A665 x H99. Indications from this experiment were that once temperature rose during subsequent growth A665 x NZ1A was unable to maintain its growth advantage. This was perhaps because A665 x H99 was then able to accumulate dry matter faster than A665 x NZ1A because of its higher autotrophic growth capabilities in warmer conditions (Hardacre, personal communication). Hardacre and Eagles (1989) showed that A665 x NZ1A maintained higher seedling dry weights only when the hybrids were grown continuously at low temperatures (16/6°C).

### **5.1.2 PLANT GROWTH AND DEVELOPMENT.**

The similarities between the hybrids at all environments in accumulating leaf number and reaching mid-silk indicated that the effect of temperature on plant development rate was similar for both hybrids. With about similar leaf areas

and leaf area indexes accumulation of dry matter was not surprisingly similar between the hybrids. The largest differences in the amount of dry matter accumulated was shown in the glass house where A665 x H99 had greater plant dry matter than A665 x NZ1A. This was probably as a result of its higher autotrophic growth capability at warm and uniform temperature conditions.

It would perhaps have also been expected that A665 x NZ1A could have maintained a higher growth advantage over A665 x H99 especially in the October planting where it had superior germination. However since this was not so it indicated that faster germination in cold temperature conditions did not necessarily have to persist into later growth because heterotrophic and autotrophic growths are based on different mechanisms. Heterotrophic growth is a respiratory based growth based on the utilisation of seed reserves while autotrophic growth is photosynthetically based and the effect of temperature on these is not the same (Blacklow, 1972; Eagles and Hardacre, 1979a). This observation agrees with that of Eagles and Hardacre (1979a) who reported that early processes of fast growth at low temperature did not result in equally fast subsequent growth as temperature rose during the season.

### 5.1.3 REPRODUCTIVE GROWTH AND DEVELOPMENT.

Crop growth of A665 x H99 during reproductive growth was higher than that of A665 x NZ1A in the environments where temperatures were high (October and glass house plantings) but lower, though slightly, where temperatures were low (November planting). Since most growth during this period is from the ear (Hanway, 1967; Tetio-Kagho and Gardner, 1988) this indicated that ear growths of A665 x H99 were higher than those of A665 x NZ1A only where temperatures were high.

The largest differences in reproductive growths between the hybrids were in the plantings of the glass house, where growth rates of A665 x H99 were greater than those of A665 x NZ1A. In spite of having transferred the hybrids to higher (28/22°C) and lower (16/6°C) day and night temperatures (30 days after silking) growths of A665 x H99 were still higher in both environments. This was perhaps because the coefficients of growth had already been established by then.

However the faster growth of A665 x H99 and its higher accumulated dry matter indicated that its photosynthetic activity was greater than that of A665 x NZ1A, considering that the hybrids had similar leaf areas. Perhaps, the higher growths of A665 x H99 was a carried over effect from its superior seedling growth. Since it is a hybrid adapted to warm temperature conditions

this was expected.

In the field the reduced growths of both hybrids in the November planting compared to those of the October planting, clearly suggested a response to temperature. The growths of A665 x H99 reduced more than those of A665 x NZ1A. The higher growths of A665 x NZ1A though slight showed that it withstood low temperatures better, this therefore indicated that its genes for early germination at cold temperature may also be useful for low temperature conditions during the reproductive growth.

#### **5.1.3.1 GRAIN GROWTH AND YIELD.**

Since the rates of grain growth and the accumulated grain dry matter between the hybrids were similar at all environments, this indicated that the effect of temperature was equally similar, considering that the hybrids silked at about the same time and therefore grain growth was in similar temperature conditions. However, there was an indication of grain growths of A665 x H99 being higher than those of A665 x NZ1A in the warmer temperature environments (October planting and 28/22°C) but lower in the lower temperature environments (November planting and 16/6°C). These results give further evidence that A665 x NZ1A may have genes which are useful at low temperatures for grain growth as well. Perhaps then the male parent

(NZ1A) may also be a source for cold tolerance during grain growth.

Similarly the final crop grain yields of A665 x H99 were higher than those of A665 x NZ1A in the warmer temperature environments especially in the glass house planting where temperatures were highest. This was expected since the reproductive growths of this hybrid were higher in these environments, there was therefore a carried over effect into grain growth. Where temperatures were lower during reproductive growth (November planting) A665 x NZ1A yielded better, though only slightly, than A665 x H99. This as well reflects the higher reproductive growth of A665 x NZ1A at this temperature. Similar cold tolerant hybrids have also shown increased field yields at cool site i.e., Aorangi in Palmerston North (Hardacre, personal communication).

The sink factor that however distinguished the crop grain yields between the hybrids was total grain number. These were higher for A665 x H99 at all environments especially where temperatures were higher (October and glass house). This result indicated that temperature was important in the determination of grain numbers. An increase in yield as a result of higher temperatures at the cob initiation stage and a higher kernel number per cob have been reported by Cooper and Law (1977). Since A665 x NZ1A maintained a similar grain number at both the high (October planting) and the low (November planting) environments while A665 x H99 had lost a sixth of its October rates in the November planting indicates that A665 x NZ1A was not adversely affected by this temperature change because it is cold tolerant.

This is in further agreement that A665 x NZ1A possesses cold tolerance genes which are useful for grain development.

## 5.2 CONCLUSIONS.

Both hybrids performed well in the field environments considering that this was one of the coldest seasons in many years. Their performance should rate them as both being well adapted to the generally cool climatic temperature conditions of the Manawatu region.

A665 x NZ1A has in this study and that of Hardacre and Eagles (1989) been shown to be an early emerging hybrid though it did not translate that into faster rates of seedling emergence nor did it show significantly greater seedling dry weights over A665 x H99 at any of the plantings. It has also shown to be tolerant to low temperatures during reproductive growth, and has good dry matter distribution capability at low temperatures. Therefore its high yielding ability at low temperatures makes it an ideal optional hybrid were early planting and short seasons are envisaged.

A665 x H99 on the other hand grew more aggressively in warmer temperature environments such those of the glass house, where it had especially higher

reproductive yields. These results agree with those of Hardacre and Eagles (1989) who showed that A665 x H99 grew rapidly at high temperature. At low temperatures it showed more weaknesses than A665 x NZ1A though it was still equally competitive. Despite being a warm weather hybrid it has shown it is able to grow and yield well even under low temperature conditions. It is should therefore be a useful hybrid for Manawatu especially when temperatures are not too severe.

Perhaps however because of a common maternal parent (A665) they have also shown to have many attributes in common and could be easily used to substitute one other to fit the expected environmental temperature conditions without much loss in yield.

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**Appendix 1.** Soil description for the trial area at Massey University,  
Palmerston North.

**Soil name:** Ohakea silt loam.

**Parent material:** Colluvium.

**Slope topographic position:** Flat; old fans overlaying low terraces.

**Description representative:**

A<sub>1</sub> 0-23cm; dark brown silt loam; few reddish brown mottles; friable; moderate nut structure,

B<sub>1gc</sub> 23-41cm; greyish brown silt loam; few to many yellowish brown mottles; abundant black concretions; friable; moderate nut structure,

B<sub>2g</sub> 41-71cm; light grey clay loam; abundant yellowish brown mottles; firm; weak blocky structure,

B<sub>2g</sub> 71-99cm; mottled light grey and yellowish brown heavy silt loam; few light grey vertical veins; very firm; massive,

D; on iron stained gravels and stones.

**Distinguishing features of soil and environment:**

Occurs on low terrace from old colluvium overlaying stony alluvium. Characterised by compact light grey heavy silt loam to clay loam subsoil with yellowish brown mottles and black concretions, overlaying gravels and stones below about 1m from the surface.

**Drainage:** Overall; imperfectly to poorly drained, internal; slow.

**Appendix 2.** Mean minimum and maximum temperatures (°C), and rainfall (mm) of the 1991/2 season.

|       | Week 1.       |               |                | Week 2.       |               |                | Week 3.       |               |                | Week 4.       |               |                |
|-------|---------------|---------------|----------------|---------------|---------------|----------------|---------------|---------------|----------------|---------------|---------------|----------------|
| Month | Tmin.<br>(°C) | Tmax.<br>(°C) | Rainf.<br>(mm) | Tmin.<br>(°C) | Tmax.<br>(°C) | Rainf.<br>(mm) | Tmin.<br>(°C) | Tmax.<br>(°C) | Rainf.<br>(mm) | Tmin.<br>(°C) | Tmax.<br>(°C) | Rainf.<br>(mm) |
| Oct.  | -             | -             | -              | -             | -             | -              | -             | -             | -              | 9.0           | 17.8          | 36.3           |
| Nov.  | 9.0           | 15.9          | 21.4           | 8.6           | 16.1          | 17.1           | 8.1           | 17.4          | 5.2            | 7.6           | 15.7          | 37.3           |
| Dec.  | 9.7           | 17.1          | 14.3           | 9.5           | 18.6          | 25.4           | 9.1           | 18.6          | 6.8            | 15.5          | 21.8          | 34.7           |
| Jan.  | 9.1           | 19.7          | 4.1            | 15.9          | 23.3          | 9.5            | 12.5          | 21.6          | 34.5           | 14.0          | 22.9          | 29.1           |
| Feb.  | 13.0          | 20.7          | 18.5           | 12.4          | 23.4          | 7.7            | 13.4          | 20.0          | 125.4          | 12.4          | 18.2          | 3.6            |
| Mar.  | 8.2           | 20.0          | 1.4            | 11.3          | 20.1          | 29.3           | 11.0          | 17.4          | 54.9           | 9.4           | 17.9          | 3.3            |
| Apr.  | 6.4           | 14.0          | 10.9           | 7.9           | 16.6          | 22.0           | 4.5           | 15.8          | 0.0            | 7.2           | 12.9          | 11.5           |
| May   | 9.2           | 14.5          | 5.2            | 4.2           | 11.2          | 17.9           | 6.5           | 13.2          | 4.4            | 4.1           | 12.0          | 0.1            |

**Appendix 3.** Mean minimum and maximum temperatures in the Glass house experiment, 1992.

|           | Week 1.       |               | Week 2.       |               | Week 3.       |               | Week 4.       |               |
|-----------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Month     | Tmin.<br>(°C) | Tmax.<br>(°C) | Tmin.<br>(°C) | Tmax.<br>(°C) | Tmin.<br>(°C) | Tmax.<br>(°C) | Tmin.<br>(°C) | Tmax.<br>(°C) |
| May       | 16.4          | 22.4          | 16.0          | 20.9          | 15.7          | 24.3          | 14.8          | 22.6          |
| June      | 15.3          | 23.3          | 14.1          | 21.6          | 15.0          | 22.7          | 15.2          | 20.1          |
| July      | 16.7          | 22.7          | 17.7          | 22.8          | 15.1          | 22.4          | 15.6          | 21.9          |
| August    | 15.6          | 21.7          | 16.0          | 21.9          | 15.6          | 22.9          | 16.1          | 23.9          |
| September | 16.1          | 22.6          | 17.1          | 24.6          | -             | -             | -             | -             |

Appendix 4. Mean germination (%), and field emergence (%) and emergence index (days) for hybrids A665 x H99 and A665 x NZ1A at 2 Field and 1 Glass House plantings.

|             |                      | October<br>planting.   |                        | November<br>planting.  |                        | Glass house<br>planting. |                        |
|-------------|----------------------|------------------------|------------------------|------------------------|------------------------|--------------------------|------------------------|
| Hybrid      | Lab.<br>germ.<br>(%) | field<br>emerg.<br>(%) | emerg.<br>index<br>(d) | field<br>emerg.<br>(d) | emerg.<br>index<br>(d) | field<br>emerg.<br>(%)   | emerg.<br>index<br>(d) |
| A665 x H99  | 96                   | 76.9                   | 11.6                   | 73                     | 10.4                   | 100                      | 6.8                    |
| A665 x NZ1A | 98                   | 77.8                   | 11.3                   | 74                     | 10.2                   | 96                       | 6.5                    |
| LSD         | ns<br>6.35           | ns<br>9.20             | *<br>0.24              | ns<br>7.32             | ns<br>0.33             | **<br>3.32               | ns<br>2.54             |
| Cv (%)      | 0.5                  | 5.3                    | 0.5                    | 4.4                    | 1.4                    | 0.4                      | 3.0                    |

Statistical differences between hybrid means.

\* = significant at  $P < 0.05$ .

ns = non significant at  $P < 0.05$ .

**Appendix 5.** Rates of seedling emergence, leaf appearance and leaf area growth of A665 x H99 and A665 x NZ1A at 2 field and 1 Glass House plantings. Rates are estimated by linear regression of number or size against time (days).

|             | October<br>planting.                          |                                         |                                                             | November<br>planting.                         |                                         |                                                             | Glass House<br>planting.                      |                                         |                                                             |
|-------------|-----------------------------------------------|-----------------------------------------|-------------------------------------------------------------|-----------------------------------------------|-----------------------------------------|-------------------------------------------------------------|-----------------------------------------------|-----------------------------------------|-------------------------------------------------------------|
| Hybrid      | seedl.<br>emerg.<br>rate<br>(seedl/<br>100/d) | leaf<br>appear<br>rate<br>(lv/<br>pl/d) | leaf<br>area<br>growth<br>rate<br>(cm <sup>2</sup><br>pl/d) | seedl.<br>emerg.<br>rate<br>(seedl/<br>100/d) | leaf<br>appear<br>rate<br>(lv/<br>pl/d) | leaf<br>area<br>growth<br>rate<br>(cm <sup>2</sup><br>pl/d) | seedl.<br>emerg.<br>rate<br>(seedl/<br>100/d) | leaf<br>appear<br>rate<br>(lv/<br>pl/d) | leaf<br>area<br>growth<br>rate<br>(cm <sup>2</sup><br>pl/d) |
| A665 x H99  | 18.90<br>(4.46)                               | 0.25<br>(0.01)                          | 129.31<br>(26.40)                                           | 16.00<br>(5.03)                               | 0.30<br>(0.01)                          | 143.75<br>(41.74)                                           | 34.80<br>(11.86)                              | 0.15<br>(0.03)                          | 43.82<br>(1.36)                                             |
| A665 x NZ1A | 16.50<br>(5.51)                               | 0.25<br>(0.01)                          | 106.35<br>(21.35)                                           | 13.70<br>(4.14)                               | 0.30<br>(0.01)                          | 118.71<br>(28.02)                                           | 20.40<br>(7.21)                               | 0.14<br>(0.04)                          | 38.14<br>(0.97)                                             |

seedl/100/d = out of 100, seedlings emerging per day.

lv/pl/d = leaves per plant per day.

values in brackets are standard errors.

**Appendix 6.** Total seedling dry weight and total plant dry weight (TPDWT) at anthesis and maximum TPDWT during reproductive growth of A665 x H99 and A665 x NZ1A at 2 field and glass house /controlled environments.

|             | October<br>planting.                                         |                                                             |                                                             | November<br>planting.                                        |                                                             |                                                             | Glass house<br>planting.                                     |                                                             | C.E<br>28/22°C                                              | C.E<br>16/6°C.                                              |
|-------------|--------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|
| Hybrid      | Total <sup>1</sup><br>seedl.<br>dry<br>weight<br>(g<br>/sdl) | Total <sup>3</sup><br>plant<br>dry<br>weight<br>(g<br>/plt) | Total <sup>4</sup><br>plant<br>dry<br>weight<br>(g<br>/plt) | Total <sup>2</sup><br>seedl.<br>dry<br>weight<br>(g<br>/sdl) | Total <sup>3</sup><br>plant<br>dry<br>weight<br>(g<br>/plt) | Total <sup>4</sup><br>plant<br>dry<br>weight<br>(g<br>/plt) | Total <sup>1</sup><br>seedl.<br>dry<br>weight<br>(g<br>/sdl) | Total <sup>3</sup><br>plant<br>dry<br>weight<br>(g<br>/plt) | Total <sup>4</sup><br>plant<br>dry<br>weight<br>(g<br>/plt) | Total <sup>4</sup><br>plant<br>dry<br>weight<br>(g<br>/plt) |
| A665 x H99  | 1.36                                                         | 213.25                                                      | 460.54                                                      | 6.39                                                         | 164.16                                                      | 329.69                                                      | 3.94                                                         | 41.43                                                       | 160.64                                                      | 185.34                                                      |
| A665 x NZ1A | 1.19                                                         | 201.03                                                      | 381.00                                                      | 7.21                                                         | 173.39                                                      | 316.53                                                      | 3.99                                                         | 37.19                                                       | 130.29                                                      | 132.32                                                      |
| LSD         | ns<br>0.46                                                   | ns<br>47.64                                                 | ns<br>96.70                                                 | ns<br>3.26                                                   | ns<br>17.33                                                 | ns<br>35.11                                                 | ns<br>3.05                                                   | ns<br>27.32                                                 | *<br>10.55                                                  | *<br>26.85                                                  |
| Cv (%)      | 16.1                                                         | 10.2                                                        | 10.2                                                        | 21.3                                                         | 14.4                                                        | 4.8                                                         | 6.1                                                          | 5.5                                                         | 0.6                                                         | 10.6                                                        |

<sup>1</sup> = 46 Days after planting.

<sup>2</sup> = 45 Days after planting.

g /sdl = g /seedling.

g /plt = g /plant.

<sup>3</sup> = At anthesis.

<sup>4</sup> = Maximum TPDWT during reproduction.

**Appendix 7.** Mean leaf number, leaf area and leaf area index of A665 x H99 and A665 x NZ1A at anthesis for 2 field and 1 Glass House plantings.

|             | October planting. |                                  |                 | November planting. |                                  |                 | Glass House planting. |                                  |                 |
|-------------|-------------------|----------------------------------|-----------------|--------------------|----------------------------------|-----------------|-----------------------|----------------------------------|-----------------|
| Hybrid      | leaf number       | leaf area (cm <sup>2</sup> /plt) | leaf area index | leaf number        | leaf area (cm <sup>2</sup> /plt) | leaf area index | leaf number           | leaf area (cm <sup>2</sup> /plt) | leaf area index |
| A665 x H99  | 19                | 8486                             | 7.57            | 19                 | 6127                             | 5.45            | 16                    | 3384                             | 1.39            |
| A665 x NZ1A | 17                | 5913                             | 5.51            | 17                 | 5972                             | 4.51            | 14                    | 2987                             | 1.13            |
| Mean        | 18                | 7199                             | 6.54            | 18                 | 5600                             | 4.98            | 15                    | 3185                             | 1.26            |
| LSD         | -                 | ns<br>3825                       | ns<br>1.19      | -                  | ns<br>1091                       | ns<br>0.98      | -                     | ns<br>761                        | ns<br>0.38      |
| CV (%)      | -                 | 23.6                             | 8.1             | -                  | 8.7                              | 8.7             | -                     | 1.9                              | 2.4             |

Statistical differences between the means of the two hybrids.

\* = significant at P< 0.05.

\*\* = significant at P< 0.01.

ns = non significant at P< 0.05.

Appendix 8. Days to mid-silk, grain filling period and days to physiological maturity of A665 x H99 and A665 x NZ1A of 2 field and 1 Glass House/ 2 Climate room plantings.

|             | October planting.    |            |                | November planting.   |            |                       | Glass House          | Controlled environment 28/22C. |                | Controlled environment 16/6C. |                       |
|-------------|----------------------|------------|----------------|----------------------|------------|-----------------------|----------------------|--------------------------------|----------------|-------------------------------|-----------------------|
| Hybrid      | Days to mid-silk (d) | GFP (d)    | Days to PM (d) | Days to mid-silk (d) | GFP (d)    | Days to last harv (d) | Days to mid-silk (d) | GFP (d)                        | Days to PM (d) | GFP (d)                       | Days to last harv (d) |
| A665 x H99  | 99                   | 76         | 175            | 85                   | 66         | 151                   | 114                  | 55                             | 169            | 59                            | 173                   |
| A665 x NZ1A | 97                   | 75         | 172            | 83                   | 64         | 147                   | 110                  | 57                             | 167            | 63                            | 173                   |
| LSD         | ns<br>5.03           | ns<br>1.52 | ns<br>2.80     | ns<br>2.39           | ns<br>2.04 | ns<br>4.58            | ns<br>1.68           | ns<br>1.43                     | ns<br>1.33     | ns<br>2.01                    | -                     |
| Cv (%)      | 2.3                  | 0.9        | 0.4            | 1.3                  | 1.4        | 1.3                   | 0.4                  | 0.7                            | 0.4            | 1.0                           | -                     |

GFP = grain filling period (days).  
PM = physiological maturity.

**Appendix 9.** Vegetative crop growth rate ( $CGR_v$ ) and reproductive crop growth rate ( $CGR_r$ ) of A665 x H99 and A665 x NZ1A under 2 Field and 2 Controlled environments. Rates are estimated by linear regression of dry matter accumulation against time (days).

|             | October<br>planting.                     |                                          | November<br>planting.                    |                                          | Glass<br>House<br>planting.              | Controd<br>environ.<br>28/22C.           | Controd<br>environ.<br>16/6C.            |
|-------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
|             | veg. crop<br>growth<br>rate<br>(g.dwt/d) | rep. crop<br>growth<br>rate<br>(g.dwt/d) | veg. crop<br>growth<br>rate<br>(g.dwt/d) | rep. crop<br>growth<br>rate<br>(g.dwt/d) | veg. crop<br>growth<br>rate<br>(g.dwt/d) | rep. crop<br>growth<br>rate<br>(g.dwt/d) | rep. crop<br>growth<br>rate<br>(g.dwt/d) |
| A665 x H99  | 4.56<br>( $\pm$ 0.05)                    | 9.43<br>( $\pm$ 1.74)                    | 3.05<br>( $\pm$ 0.14)                    | 4.15<br>( $\pm$ 0.08)                    | 0.61<br>( $\pm$ 0.03)                    | 2.10<br>( $\pm$ 0.52)                    | 1.66<br>( $\pm$ 0.54)                    |
| A665 x NZ1A | 4.26<br>( $\pm$ 0.35)                    | 6.86<br>( $\pm$ 1.41)                    | 3.19<br>( $\pm$ 0.01)                    | 3.24<br>( $\pm$ 0.25)                    | 0.54<br>( $\pm$ 0.03)                    | 1.37<br>( $\pm$ 0.18)                    | 1.18<br>( $\pm$ 0.40)                    |

g.dwt/d = gram dry weight per day.  
values in brackets are standard errors.

Appendix 10. Mean cob dry weight and cob moisture content of A665 x H99 and A665 x NZ1A for 2 Field and 2 Controlled environments.

|             | October planting.               |                                       | November planting.              |                                       | Controlled environment at 28/22C. |                                       | Controlled environment at 16/6C. |                                       |
|-------------|---------------------------------|---------------------------------------|---------------------------------|---------------------------------------|-----------------------------------|---------------------------------------|----------------------------------|---------------------------------------|
| Hybrid      | Cob <sup>1</sup> dry weight (g) | Cob <sup>1</sup> moisture content (%) | Cob <sup>2</sup> dry weight (g) | Cob <sup>2</sup> moisture content (%) | Cob <sup>1</sup> dry weight (g)   | Cob <sup>1</sup> moisture content (%) | Cob <sup>2</sup> dry weight (g)  | Cob <sup>2</sup> moisture content (%) |
| A665 x H99  | 157.27                          | 48.90                                 | 86.75                           | 64.34                                 | 101.44                            | 47.60                                 | 95.88                            | 52.50                                 |
| A665 x NZ1A | 146.60                          | 44.00                                 | 82.54                           | 64.37                                 | 68.51                             | 40.70                                 | 65.72                            | 50.30                                 |
| LSD         | ns<br>26.20                     | ns<br>7.16                            | ns<br>11.04                     | ns<br>11.25                           | *<br>22.87                        | ns<br>19.76                           | *<br>27.61                       | ns<br>31.89                           |
| Cv (%)      | 7.7                             | 6.9                                   | 5.8                             | 7.7                                   | 2.1                               | 3.5                                   | 13.4                             | 4.9                                   |

<sup>1</sup> = at physiological maturity.

<sup>2</sup> = at the last sampling.

Statistical differences between hybrid means.

\* = signifcant at P< 0.05.

ns = non significant at P< 0.05.

Appendix 11. Rates of cob and 100-grain growth of A665 x H99 and A665 x NZ1A for 2 Field and 2 Controlled environments. Rates are estimated by linear regression of dry matter accumulation against time during linear growth of the cob and the grains.

|             | October<br>planting                    |                                                  | November<br>planting                   |                                                  | Controlled<br>environment at<br>28/22C. |                                                  | Controlled<br>environment at<br>16/6C. |                                                  |
|-------------|----------------------------------------|--------------------------------------------------|----------------------------------------|--------------------------------------------------|-----------------------------------------|--------------------------------------------------|----------------------------------------|--------------------------------------------------|
| Hybrid      | Cob<br>growth<br>rate<br>(g.dwt<br>/d) | 100-<br>grain<br>growth<br>rate<br>(g.dwt<br>/d) | Cob<br>growth<br>rate<br>(g.dwt<br>/d) | 100-<br>grain<br>growth<br>rate<br>(g.dwt<br>/d) | Cob<br>growth<br>rate<br>(g.dwt<br>/d)  | 100-<br>grain<br>growth<br>rate<br>(g.dwt<br>/d) | Cob<br>growth<br>rate<br>(g.dwt<br>/d) | 100-<br>grain<br>growth<br>rate<br>(g.dwt<br>/d) |
| A665 x H99  | 2.53<br>( $\pm 0.15$ )                 | 0.50<br>( $\pm 0.02$ )                           | 1.61<br>( $\pm 0.07$ )                 | 0.35<br>( $\pm 0.02$ )                           | 2.33<br>( $\pm 0.13$ )                  | 0.79<br>( $\pm 0.02$ )                           | 1.85<br>( $\pm 0.32$ )                 | 0.40<br>( $\pm 0.003$ )                          |
| A665 x NZ1A | 2.20<br>( $\pm 0.09$ )                 | 0.50<br>( $\pm 0.02$ )                           | 1.53<br>( $\pm 0.09$ )                 | 0.40<br>( $\pm 0.03$ )                           | 1.45<br>( $\pm 0.15$ )                  | 0.76<br>( $\pm 0.02$ )                           | 1.03<br>( $\pm 0.17$ )                 | 0.41<br>( $\pm 0.01$ )                           |

g.dwt/d = gram dry weight per day.  
values in brackets are standard errors.

**Appendix 12a.** Mean grain number, 100-grain dry weight, grain moisture content and crop yield of Field grown A665 x H99 and A665 x NZ1A.

|             | October planting.   |                                       |                                         |                                | November planting.  |                                       |                                         |                                |
|-------------|---------------------|---------------------------------------|-----------------------------------------|--------------------------------|---------------------|---------------------------------------|-----------------------------------------|--------------------------------|
| Hybrid      | Grain number (/cob) | 100-grain <sup>1</sup> dry weight (g) | Grain <sup>1</sup> moisture content (%) | crop <sup>2</sup> yield (t/ha) | Grain number (/cob) | 100-grain <sup>1</sup> dry weight (g) | Grain <sup>1</sup> moisture content (%) | crop <sup>2</sup> yield (t/ha) |
| A665 x H99  | 593.90              | 28.37                                 | 45.8                                    | 13.84                          | 509.30              | 14.82                                 | 60.7                                    | 7.05                           |
| A665 x NZ1A | 501.80              | 27.63                                 | 40.6                                    | 12.72                          | 494.30              | 16.09                                 | 59.9                                    | 7.43                           |
| LSD         | *<br>76.93          | ns<br>6.56                            | ns<br>6.87                              | ns<br>1.98                     | ns<br>47.66         | ns<br>1.34                            | ns<br>8.51                              | ns<br>0.96                     |
| Cv (%)      | 11.9                | 10.4                                  | 7.1                                     | 12.6                           | 4.8                 | 3.8                                   | 6.3                                     | 11.2                           |

<sup>1</sup> = at maximum dry weight.

<sup>2</sup> = yield based on 100-grains from the bottom third of the cob.

Statistical differences between hybrid means.

\* = significant at  $p < 0.05$ .

ns = non significant at  $p < 0.05$ .

**Appendix 12b.** Mean grain number, 100-grain dry weight, grain moisture content and crop yield of A665 x H99 and A665 x NZ1A under controlled environmental conditions at 28/22C and 16/6C.

| Hybrid      | Controlled environment<br>28/22C. |                                                    |                                                  |                                      | Controlled environment<br>16/6C. |                                                    |                                                  |                                      |
|-------------|-----------------------------------|----------------------------------------------------|--------------------------------------------------|--------------------------------------|----------------------------------|----------------------------------------------------|--------------------------------------------------|--------------------------------------|
|             | Grain<br>number<br>(/cob)         | 100-<br>grain <sup>1</sup><br>dry<br>weight<br>(g) | Grain <sup>1</sup><br>moisture<br>content<br>(%) | crop <sup>2</sup><br>yield<br>(t/ha) | Grain<br>number<br>(/cob)        | 100-<br>grain <sup>1</sup><br>dry<br>weight<br>(g) | Grain <sup>1</sup><br>moisture<br>content<br>(%) | crop <sup>2</sup><br>yield<br>(t/ha) |
| A665 x H99  | 344.0                             | 29.97                                              | 44.9                                             | 4.46                                 | 344.0                            | 22.02                                              | 50.61                                            | 2.46                                 |
| A665 x NZ1A | 220.7                             | 28.94                                              | 38.52                                            | 3.10                                 | 220.7                            | 23.84                                              | 47.77                                            | 2.28                                 |
| LSD         | **<br>47.66                       | ns<br>1.13                                         | ns<br>28.65                                      | *<br>0.83                            | **<br>47.66                      | ns<br>6.67                                         | ns<br>31.64                                      | *<br>0.06                            |
| Cv (%)      | 8.5                               | 1.1                                                | 5.4                                              | 1.7                                  | 8.5                              | 8.3                                                | 5.1                                              | 0.2                                  |

<sup>1</sup> = at maximum dry weight.

<sup>2</sup> = yield based on 100-grains from the bottom third of the cob.

Statistical differences between hybrid means.

\* = significant at P<0.05.

\*\* = significant at P<0.01.

ns = non significant at P<0.05.