# THE GROWTH, DEVELOPMENT AND MODIFICATION OF BARLEY SEED CROPS

by

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**Fig. 31** The effect of nitrogen treatment on ear size distribution (main ears only)

i N1

ii N2

iii N3

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## Abbreviations

| | |
|---|---|
| ai | active ingredient |
| CCC/Chlormequat | (2-Chloroethyl) trimethyl ammonium chloride |
| $CO_2$ | Carbon dioxide |
| CT | coleoptile tiller |
| cv | coefficients of variation |
| D1 (2,3,4) | Density 1 (2,3,4) |
| DAA | Days after anthesis |
| DAS | Days after sowing |
| $day^{-1}$ | per day |
| Df | Degrees of freedom |
| DM | Dry matter |
| DUS | Distinct, uniform and stable |
| EEC | European Economic Community |
| Fh | Harvest index |
| $GA_3$ | Gibberellic acid |
| $GA_7$ | Gibberellin $A_7$ |
| GAI | Green area index |
| ha | hectare |
| hrs | hours |
| HWE | Hot water extract |
| IAA | Indole 3 acetic acid |
| IBA | Indole 3 butyric acid |
| ICI | Imperial Chemical Industries |
| ISTA | International Seed Testing Association |
| J.I. | John Innes |
| $K_2O$ | Dipotassium oxide (Potash) |
| L (e.g. L1) | leaf (e.g. leaf 1) |
| LAD | Leaf area duration |
| LAI | Leaf area index |
| LAR | Leaf area ratio |
| LAS | Leaf appearance stage |
| Leics. | Leicestershire |
| Lincs. | Lincolnshire |
| LWR | Leaf weight ratio |

| | |
|---|---|
| $m^{-2}$ | per square metre |
| MAFF | Ministry of Agriculture, Fisheries and Food |
| mc | moisture content |
| mCi | milli Curie |
| mst | mainstem |
| N | Nitrogen |
| N1 (2,3) | Nitrogen 1 (2,3) |
| NIAB | National Institute of Agricultural Botany |
| no. | number |
| NSCA | North of Scotland College of Agriculture |
| $P_2O_5$ | Phosphorus pentoxide (Phosphate) |
| PGR | Plant growth regulator |
| PP333 | Paclobutrazol |
| ppm | parts per million |
| r | correlation coefficient |
| Rep. | replicate |
| SED | Standard error of the difference between means |
| Sig. | Significance x $p < 0.05$<br>xx $p < 0.01$<br>xxx $p < 0.001$ |
| SLA | Specific leaf area |
| s.w.d. | Soil water deficit |
| T (e.g. T1;T11) | Tiller (e.g. tiller 1; the first secondary tiller on tiller 1) |
| TGW | Thousand grain weight |
| UK | United Kingdom |
| USSR | Union of Soviet Socialist Republics |
| UV | Ultra violet |
| W | Watts |
| WUE | Water use efficiency |
| ZGS | Zadoks growth stage |

Symbols - in order of appearance

| | |
|---|---|
| % | per cent |
| > | Greater than |
| $^{14}C$ | Radioactive labelled carbon |
| < | less than |
| 2nd | second |

## Note

Gibberellins have been supplied to the plant using Berelex (ICI Plant Protection Limited). This contains 90% $GA_3$ plus quantities of $A_1$, $A_4$, $A_7$ and $A_9$. However, for convenience, this mixture of gibberellins will be termed $GA_3$ throughout this thesis.

## ABSTRACT

A series of field and growth room experiments on winter barley (Hordeum vulgare) L. syn. H. sativum Jessen) were undertaken between 1980 and 1983 at the University of Nottingham School of Agriculture, Sutton Bonington. The aim of this study was to attempt to elucidate those factors which influence the suitability of harvested grain for use as seed.

Density, nitrogen fertilizer (both rate and timing) and plant growth regulator applications were used to modify crop growth and development with a view to enhancing the suitability of the grain for seed purposes.

It has been shown that the final grain yield and yield components could be manipulated by the judicious use of the inputs examined. However yield component modification was dependent upon the variety used. Consistent increases in seed yield as a result of the husbandry inputs were not always detectable but where alterations to crop growth and development did occur this occasionally resulted in a reduction in total grain yield. None of the PGRs applied significantly or consistently influenced the suitability of the grain for seed purposes.

All nitrogen trials were conducted on Index O nitrogen sites. However the residual nitrogen may have differed between sites and seasons so confounding the effects of nitrogen treatments. Alterations of both nitrogen rate and timing can be used to modify crop growth patterns.

Alteration of sowing density resulted in a change in the grain yield components. Increased sowing density resulted in an increase in total ear number with a concomitant reduction in mean grain number per ear. As grain yield was shown to be correlated with grain number per unit area the modification of these two components by sowing density did not necessarily influence final grain yield because of yield component compensation.

The seed industry is still divided in its attitude to the desirability or necessity of size graded seeds. However if more emphasis is placed on the production of cereal seed crops the work reported here will help to clarify the possible outcome of desirable modifications to the growth and development of the winter barley crop for seed.

# Chapter 1

# LITERATURE REVIEW

# & INTRODUCTION

## 1.1 Cereal Seed Production

The efficient production of high quality cereal seed is essential in ensuring that the benefits of new and improved varieties of crop are available to the farmer with the minimum delay and that established varieties are correctly maintained.

Current United Kingdom legislation guarantees the seed purchaser that the product is true to variety and meets at least the minimum control standards. All varieties offered for sale within the United Kingdom have been tested for distinctness, uniformity and stability (DUS).

Beginning with the Seeds Act half a century ago and particularly since the introduction of EEC legislation, the UK has had compulsory seed certification which ensures that the seed offered for sale meets the pre-determined standards of seed quality (germination) and freedom from impurities.

Beyond this, the concept of seed quality consists of an amalgamation of many different components. The purchased seed is the fundamental input of the cereal crop and thus should possess high germination capacity and the ability to germinate under adverse conditions (Carver, 1977a). The size grading of purchased seed is of importance, as uniformity in size of the seed sown contributes to the uniformity of growth of the resultant seedlings. High quality seed should also be free from disease and should not contain such items as ergots, bunt balls, seeds of other cultivated species or weed seeds.

Carver (1980) suggested that all farmers in the UK who grow cereal crops were potentially capable of producing cereal seed. The main differences between the grain producer and the seed producer being their facilities for grain production, drying and storage and their attitude towards crop contamination. This differs from the production of vegetable seeds where production is generally in different geographical and climatic areas from the main site of crop production.

Abrol and Mackay (1980) in their survey on plumular abnormality in wheat seeds concluded that although attention was paid to genetic purity and freedom from seed-borne diseases, no special procedures were adopted to ensure high germination. It may be possible that sowing density, which modifies the level of tiller production, may affect the quality of the seed produced. Abrol and Mackay (1980) suggested that seed quality may be lower in a crop with low plant but high tiller numbers than in a crop with high plant numbers, but low numbers of tillers per plant.

Cobbett (1838) suggested that "It is quite useless to prepare land and to incur trouble and expense, without duly, and even very carefully, attending to the seed that we are going to sow". His advice continued: "The sort, the genuineness and the soundness, are all matters to be attended to, if we mean to avoid mortification and loss". Thus since at least 1838 farmers, researchers and government legislators have striven to ensure that only good quality seed is produced and offered for sale (Doling, 1980). The Cereal Seeds Act 1920, the Plant Varieties and Seeds Act 1964 and the Seed Regulations 1974 are all aimed towards this end. Their effectiveness can be judged from the fact that UK farmers obtain approximately 86% of their total cereal seed requirements from the seed trade, the remainder being home saved (Wellington, 1980).

## 1.2 Barley : Its Place in British Agriculture

Cereal crops dominate the arable areas of the world and in Europe wheat and barley together make up approximately 70% of the arable crop area. In the UK (Table 1) barley is the most widely grown cereal and in recent years winter barley has gained area at the expense of spring barley (Table 2). On many farms in East England all cereals are now autumn sown except perhaps after late lifted sugar beet.

## 1.3 Grain Yield Determinants

Grain yield in cereals is determined by four major components. These are plant number per unit area, ear number per plant, grain number per ear and individual grain weight. The factors that influence each of these components will be considered below.

### 1.3.1 Plants per unit area

Seed is the primary input of any cereal crop. A high quality seed is necessary for the production of a viable, disease free and high yielding crop. The ability of the sown seed to germinate and produce a plant

**Table 1** Land allocated for cereal production in the UK ($x10^3$ ha)

| Crop | YEAR | | | | | |
|---|---|---|---|---|---|---|
| | 1970 | 1980 | 1981 | 1982 | 1983 | 1984 |
| Wheat | 1010 | 1441 | 1491 | 1663 | 1695 | 1939 |
| Barley | 2243 | 2330 | 2327 | 2222 | 2143 | 1978 |
| Oats | 376 | 148 | 144 | 129 | 108 | 106 |

Source: MAFF — Agricultural returns for the UK - finals, June (MAFF, 1984)

**Table 2** Land devoted to cereal crops in England ($x\ 10^3$ ha)

| Crop | YEAR | | | | | % change $\frac{1984}{1980}$ |
|---|---|---|---|---|---|---|
| | 1980 | 1981 | 1982 | 1983 | 1984 | |
| Wheat | 1408 | 1482 | 1613 | 1637 | 1854 | +31.6 |
| Winter barley | 710 | 778 | 817 | 826 | 902 | +27.0 |
| Spring barley | 1066 | 1002 | 847 | 770 | 543 | -49.1 |

Source: MAFF — Agricultural returns for England - finals, June (MAFF, 1984) capable of yielding grain in all circumstances is the major consideration in the assessment of quality.

In any seed lot will be found grains of a wide range of sizes and weights. These grain size differences occur between plants, between ears within plants and between grains within ears. Differences in weight between grains within ears have been described by Rawson and Evans (1970), Bremner (1972), Rawson and Ruwali (1972) and Sofield (1976).

The growth of each grain is determined by:

a) Availability of assimilates
b) The grains' intrinsic capacity to accumulate dry matter
c) The resistance within the phloem to the movement of assimilates to the grain (Bremner, 1972).

(Bremner & Rawson, 1978)

The genetic factors determining the final weight of the grain may include such factors as endosperm cell number (Brocklehurst, 1977), amyloplast number (Briarty, Hughes & Evers, 1979), endosperm cell volume (Dunstone & Evans, 1974; Cochrane & Duffus, 1981), the rate of conversion of sucrose to starch (Jenner & Rathjen, 1978) and the duration of grain growth (Asana & Bagga, 1966; Syme, 1967). Varieties have been found to differ in the extent to which grain weight is affected by changes in the environment (Asana & Williams, 1965; Sofield, Evans, Cook & Wardlaw, 1977; Brocklehurst, 1977).

The rate of cereal seedling growth or seedling vigour, which is defined as the relative growth rate during early plant development (Lowe, Ayres & Ries, 1972), is influenced by seed protein content (Evans & Bhatt, 1977), seed size (Kaufmann & McFadden, 1960; Pinthus & Osher, 1966) and genotype.

Many workers have reported positive correlations between seed size and/or seed protein content with final grain yield (Kaufmann & Guitard, 1967; Kaufmann & McFadden, 1963; Lowe & Ries, 1972; 1973). However Kiesselbach (1924) and Holzman (1974) found no relationship between seed protein content and final grain yield or yield components of spring cereal crops.

Jones and Tucker (1926) suggested that factors other than seed size were responsible for the differences in establishment and growth observed in oats grown from seeds produced in different localities. McFadden (1963) concluded that this was due to differences in chemical composition.

A series of experiments by Lowe and Ries and their co-workers (Lowe et al., 1972; Lowe & Ries, 1972; 1973; Ries, Moreno, Meggitt, Schweitzer & Ashkar, 1970; Schweizer & Ries, 1969) have shown that seed protein affects seed vigour. Lopez and Grabe (1971) concluded that differences in seed protein content were mainly confined to the endosperm. Seeds with high protein content ($>$10%) have the ability to absorb water at a faster rate than low protein (6.5%) seeds (Lopez & Grabe, 1973). Mayer and Poljakoff-Mayber (1963) reported that protein was the major seed component that imbibed water. Thus increased water absorption may result in an acceleration of the germination process. This may in turn lead to faster seedling growth and emergence. The acceleration of metabolic processes may result in an increased rate of respiration which has been shown to be correlated with seedling growth and with seedling vigour (Woodstock & Feeley, 1965; Woodstock & Grabe, 1967). Lopez and Grabe (1973) found that high protein seeds have a faster rate of germination. Increased protein contents have also been associated with faster root production (Lopez & Grabe, 1973).

High protein seeds develop into larger seedlings with a higher dry matter (DM) content when grown in nitrogen deficient soils compared to low protein seeds. However in nitrogen enriched soils seed protein content has little effect on seedling growth (Lopez and Grabe, 1971). Thus the beneficial effects of seed protein content are expressed mainly under stress conditions and are more evident when plant growth is dependent on the nutrients available from the endosperm (Welch, 1977).

The application of nitrogen to the parent plant can influence the seed weight and seed protein content of the developing grain (Ries & Everson, 1973). However, based on amino acid analysis, grain quality is unaffected by nitrogen treatments (Hucklesby, Brown, Howell & Hagemann, 1971).

The major factors necessary for ensuring the production of cereals with a high protein content and satisfactory yields are:

a) Availability of nitrogen (Miflin, 1978)
b) Redistribution of nitrogen to the grain within the ear (Cochrane & Duffus, 1981).

Application of nitrogen at the time of sowing has been found to increase grain nitrogen content (Resinauer & Dickson, 1961; Widdowson, Penny & Williams, 1961).

Hence, correct fertilizer management and late spring applications of nitrogen can be used to produce higher grain yields of high protein cereal seeds. However, increasing the nitrogen application rate may result in a decrease in mean seed size. The reduction in size is at the expense of the endosperm. Embryo size and embryo protein content are unaffected by nitrogen applications (Lopez and Grabe, 1971). Protein content of cereal endosperm increases with high nitrogen application, both on an absolute basis and as a percentage of the endosperm.

Seed size has also been shown to influence seedling establishment and grain yield (Austenson & Walton, 1970; Boyd, Gordon & LaCroix, 1971; Kaufmann & Guitard, 1967; Kiesselbach, 1924). However, Demirlicakmak, Kaufmann and Johnson (1963) found that seed size had no effect on seedling emergence. Christian and Gray (1935) recorded that plants grown from large wheat seeds had an advantage in inter-plant competition studies as they were initially more vigorous than the plants produced from small seeds. The plants produced from large seeds have a higher initial seedling weight, partially due to an increase in size of the first two leaves (Kaufmann & McFadden, 1960; Pinthus & Osher, 1966).

Large seeds produce more tillers per plant than those plants grown from small seeds of the same variety (Demirlicakmak et al., 1963; Kaufmann, 1958; McFadden, 1958; Randhawa, Bains & Gill, 1972). Kaufmann and McFadden (1960) found that the yield differences between barley seeds of varying sizes was almost entirely attributable to the difference in the number of ears per plant.

It has been found that cereal plants grown from large seeds are taller, produce a larger number of tillers, an increased number of grains per ear and an increased biomass (Kiesselbach & Helm, 1917; Kiesselbach, 1924; Kaufmann & McFadden, 1960; Pinthus & Osher, 1966).

Growth differences are less pronounced between seeds of varying sizes when they are grown in optimal conditions. Brenchley (1923) found that under normal or unfavourable conditions of growth, the use of well-filled, heavy seeds resulted in an increased crop yield. However, in seasons favourable to the growth of cereals, the yield benefit from large seeds was not always obtained. Black (1959) concluded that in a competitive situation or in a limiting environment, plants from large seeds being larger initially than those from small seeds, compete with each other and become limited by the environment sooner than those from small seeds. Thus the relative advantage of large seeds decreases with time. The importance of length of growing season has been discussed by Currah and Salter (1973) and Austin and Longden (1967).

The mature seed is influenced by all the environmental conditions impinging upon it prior to sowing. However, unless there are extreme variations in the environmental conditions they have very little effect on the viability of most species, as long as the maturation processes are not interrupted by premature harvesting (Austin, 1972). The accurate determination of the optimum date for harvesting is one essential condition for obtaining maximum seed yield from any crop. Viable seeds can be obtained from grains harvested at a very immature stage (Harlan & Pope, 1922; Harlan, 1926). Harlan (1926) showed viability in grains harvested five days post anthesis in barley.

Physiological seed treatments such as priming (Heydecker, 1978) or treatment with plant growth regulators (Thomas & O'Toole, 1980) have been used to improve seed quality (Section 1.5.4.2.4). Improved seed performance may also be achieved by modifying maternal plant morphology by husbandry means or by plant growth regulators (PGRs). Gray (1983) working on carrots found that by increasing plant density, suppression of secondary and tertiary branches was caused. Thus the majority of seeds produced come from the primary umbel which gave lower levels of variation in embryo size. This, in turn, may lead to more accurate timing of harvesting of the seed crop. Jones and Tucker (1926) found a similar situation with oats. They noted that wide spacing of plants resulted in uneven time of maturation of the tillers. Late formed tillers were of no agronomic value as they senesced without producing a viable ear.

Until the attainment of full maturity, that is, the time when no further increase in dry weight occurs, full germination capacity and viability are not attained (Harlan & Pope, 1922).

### 1.3.2 Ears per plant

It has been found that plant establishment and plant winter kill are influenced by sowing density with higher density resulting in decreased percentage plant establishment and increased winter kill (McLaren, 1981; Roebuck & Trenerry, 1978). Ellis, Elliot, Pollard, Cannell and Barnes (1979) reported large variations in plant survival between years and between drilling methods (Ball & O'Sullivan, 1983). However, work by Darwinkel, ten Hag and Kuizenga (1977) showed no effect on plant survival of the number of seeds sown.

The increased plant death at high densities has been attributed to higher inter-plant competition within the rows (Puckridge & Donald, 1967). Roebuck and Trenerry (1978) found that with similar populations inter-plant competition increased at wide row spacings.

Inter- and intra-plant competition can be present throughout the life of the cereal plant. The "excessive" production of tillers by a plant or within a limited area may decrease the grain yield of the resultant crop.

In cereal crops, only one ear is produced per stem. Thus ear number per unit area is dependent upon the number of tillers that are produced and upon the proportion of those tillers that change from being vegetative to being reproductive and are thus potentially capable of producing a viable ear. Tillers which fail to produce an ear may be considered to be antagonistic to the ultimate purpose of the plant. All tillers need water, light and mineral nutrients for their growth which thus deprives the ear producing shoots of essential requirements (Marshall & Wardlaw, 1973; Quinlan & Sagar, 1962; Rawson & Hofstra, 1969).

The general pattern of tillering in cereals has been elucidated (Thorne, 1962; Kirby, 1967; Krishnamurthy, 1963).

Live tiller number peaks in the early spring and then falls to a minimum prior to ear emergence. This viable tiller number is then maintained through until harvest (Bunting & Drennan, 1966; Ong, Marshall & Sagar, 1978). Differences occur between varieties in maximal and final tiller numbers (Watson, Thorne & French, 1958; Kirby, 1967).

Husbandry factors, such as plant density and nitrogen applications, can modify total tiller number and tillering pattern of cereal plants (Kirby, 1967; Colvill, 1978; Cannell, 1969a; Aspinall, 1961; Simmons, Rusmusson & Wiersma, 1982). Increase in plant density decreases the number of tillers emerging on each plant, but initiation of tiller buds is not affected (Kirby & Faris, 1972).

Darwinkel (1978) found that although increasing plant density limited the number of tillers produced per plant, inter-plant competition was more severe and began earlier than in crops sown at low plant densities. Competition in low density stands tends to be intra-plant competition and not inter-plant competition. The emergence of the first primary tillers occurs at approximately the same time in both high and low density crops (Darwinkel, 1978). However, the earlier onset of inter-plant competition at high densities causes tillering to cease earlier (Puckridge & Donald, 1967).

Darwinkel et al. (1977) found that the grain yield of tillers at low plant densities was high, ranging from 4.20 g (main shoot) to 1.86 g DM on late formed tillers. At 25 plants $m^{-2}$, there were 14.6 ears per plant at final harvest. The later emergence of tillers resulted in a decreasing grain number per ear in the late formed ears. However, thousand grain weight was not influenced by tiller age. The decrease in grain number in wheat ears was due to a decreased number of fertile spikelets and also a lower number of grains within the spikelets.

The time of production of tillers is important in determining their ultimate fate. The earlier formed tillers have a greater chance of producing large ears (Bunting & Drennan, 1966; Cannell, 1969a; Krishnamurthy, 1963). Ong (1978) found that the smallest tillers on ryegrass (Lolium perenne L.) were the most likely to die when plants were under stress for light or nutrients. Up to 60% of the tillers produced by a seed crop of ryegrass may die prematurely (Spiertz & Ellen, 1972; Hebblethwaite, 1977). Tiller mortality coincides with the time of stem extension. Death may be caused by competition for the limited supply of nutrients and assimilates (Aspinall, 1961) or by mutual shading (Ong, 1978).

Cannell (1969a; 1969b) noted that the survival of the coleoptile tiller was determined by environmental conditions. Yield advantages have been found in those cultivars in which there was a high frequency of coleoptile tillers. Fletcher & Dale (1974) and Fletcher (1975) found that coleoptile tillers tend to segregate into fast growing or slow growing populations, the latter tending to die.

However, Rawson (1971a) found that grain yield per shoot was not entirely related to the time of production of the tiller. The coleoptile tiller tended to be much less productive than would have been predicted from its time of appearance. Rawson (1971a) also found that the secondary tiller (T11) (Section 2.4.2) gave a lower yield than T3, although they were found to have arisen at similar times. The poor yield of the coleoptile tiller may be due to positional disadvantages for the supply of assimilates from the mainstem and the major primary tillers.

Tillers are nutritionally associated with the expanded lamina immediately above them and not with their subtending leaf. Thus the coleoptile tiller is associated with the coleoptile which has been found to complete its growth within one week of seedling emergence (Fletcher & Dale, 1974). The cessation of growth thus causes a lack of support of assimilates from the coleoptile to its associated tiller. The vascular connections to the developing coleoptile tiller are also poor thus preventing the rapid diffusion of metabolites. After the cessation of growth of the coleoptile, the coleoptile tiller becomes associated with leaf one (L1), which is also the source of assimilated carbon for the rest of the plant including the terminal apices. Thus assimilate competition develops which may be sufficient to inhibit further growth of the coleoptile tiller. The reduction in coleoptile tiller number in high temperature conditions has been reported (Ryle, 1964; Cannell, 1969b; Hamilton, 1948). This decrease in emergence has been explained by Langer (1963), Aspinall and Paleg (1964) and Friend (1965b) as a lack of available nutrient.

Tillers are partially controlled by the nutrient supply. Both the rate and pattern of tillering were influenced by the availability of nutrients in experiments by Aspinall (1961). Cessation of tillering occurs earlier when nutrient supply is low. Senescence of tillers is minimized when nutrients are supplied at frequent intervals throughout the life of the plant with tillers still being produced at maturity of the main stem shoot if nutrients were still freely available (Aspinall, 1961).

Bremner (1969), Cannell (1969a) and Ishag and Taha (1974) have all noted that the application of nitrogenous fertilizers enhance the survival of tillers. Nitrogen deficiency during early stages of tiller production causes a decrease in tiller production and tiller survival. The application of nitrogenous fertilizer has been found to reduce the percentage of main shoots that produce seeds (Power & Alessi, 1978). This has been attributed to the increased inter-tiller competition for the limited resources of water and light (Power & Alessi, 1978).

Nitrogenous fertilizer, by reducing tiller mortality of the higher order tillers, enhances ear production per unit area and results in an increase in grain yield. The application of nitrogen has little effect on grain number per ear or on thousand grain weight (TGW) (Power & Alessi, 1978).

McLaren (1981) found no interaction between plant density and the time of nitrogen application in relation to the number of ears per unit area. This may have been due to the plant distribution within the crop. It has been noted by Evans (1977) that the application of nitrogen increases the tiller death in irregularly spaced plants but decreases tiller death where plant spacial arrangement is regular. Thus McLaren (1981) has suggested that early nitrogen applications may stimulate vegetative tiller production in the thin crop, thus improving the cosmetic appearance of the field, but inducing intra- and inter-plant competition so that the ear number per unit area may not be similarly increased. The application of nitrogen to a dense crop may help to enhance tiller production and survival thus giving rise to increased ear production.

Felippe and Dale (1972), Marshall and Wardlaw (1973) and Rawson and Hofstra (1969) have all shown that tillers are dependent upon the main shoot of a cereal plant for mineral nutrients and assimilates during their intitial growth. During the life of the plant there appears to be continual import and export of assimilates from the tillers to the mainstem and vice versa.

The non ear-producing tiller functions as a temporary sink for assimilates. These stored products may be redistributed wholly or partly to the remaining fertile tillers upon senescence (Thorne, 1962; Rawson & Donald, 1969).

### 1.3.3 Grain number per ear

The importance of ear development to yield was recognised by early workers on cereals such as Engledow and Wadham (1924) and Kiesselbach and Sprague (1926). The process of ear development is vital in determining the grain number per ear of the cereal plant. The number of grains per unit area depends upon the process of tillering and ear development. These two factors have been shown to be important determinants of yield (Sanfaer, Jorgensen & Haahr, 1965; Thorne, 1966; Gallagher, Biscoe & Scott, 1976).

Recently, Baker and Gallagher (1983) noted that in the Gramineae "the changing morphology of the stem apex is the only unequivocal guide to ontogeny and observations of apical development are central to the studies of development of the whole plant". Since the early descriptive work of Engledow and Wadham (1924) and Kiesselbach and Sprague (1926), there have been relatively few investigations into the apical development of cereals. The developmental scales devised by Large (1954) and Zadoks, Chang and Konzak (1974) have assessed cereal crops on a scale based on external morphology and not on apical developmental stage. The apical developmental stages have been used by some workers, e.g. Friend, Fisher and Helson (1963) and Rawson (1970; 1971b), who devised a scale of discrete identifiable stages into which the plant life cycle could be divided. Rawson (1971b), Lucas (1972) and Holmes (1973) have also suggested various methods of following the increase in primordia number during development. The need for a usable scale based upon both the external and internal morphology of the plant has been stressed by Baker and Gallagher (1983).

Investigations into processes occurring during ear formation are hampered by the relatively small size of the developing ear. Gallagher (1978) gives the size of the barley apex to be 3 mm long and 0.5 mg DM at maximum floret number.

The potential number of grains formed per ear is determined by the maximum number of spikelets and the fertility of the spikelets (Kirby, 1974). The percentage grain set can be decreased by adverse conditions prior to and during anthesis through effects of floret development and fertilization and also by interactions between florets at the time of anthesis (Evans, Bingham & Roskams, 1972).

In wheat, there seems always to be an excess of potential grain sites. The maximum number of primordia on the wheat apex is determined by the genotype of the plant. This potential is modified by the interaction of genotype and environment (Lucas, 1972). Spikelet number is varied by plant spacing (Puckridge, 1968), by level of nitrogen (Single, 1964), by daylength (Paleg & Aspinall, 1966), by temperature (Friend, 1965a) and by light intensity (Campbell & Read, 1968; Wardlaw, 1970). The determinants of final grain number have not been completely elucidated (Beveridge, Jarvis & Ridgeman, 1965; Kirby & Faris, 1970), although spikelet death has commonly been associated with competition for insufficient resources (Kirby & Jones, 1977).

Dale and Wilson (1978) investigated the effects of low levels of nitrogen on twenty-one 2-row barleys and nineteen 6-row barleys. The use of low levels of nitrogen (one tenth of the normal rate), gave 40 per cent fewer spikelet positions in 2 row barleys and 60 per cent fewer in 6 row cultivars. The use of low nitrogen applications gave a significant decrease in the number of grain sites filled. However TGW was only slightly reduced by low nitrogen levels in 2 row barleys. Investigations by Spiertz and Ellen (1978) showed that with Lely winter wheat there was an increase in grain yield associated with an increase in nitrogen supply, mainly due to an increased number of grains per ear.

Density has also strongly influenced the percentage of spikelet death (Leakey, 1971). However, Ayravainen and Paatela (1974) found that growth density did not affect the final grain number per ear on two and multi-rowed varieties of barley.

Approximately 40 spikelet nodes form before the apical dome ceases to produce further primordia. The last formed primordia tend to become moribund (Kirby & Faris, 1970; Kirby, 1977). Evans et al. (1972) have recorded that many of the florets that fail to form grains are potentially capable of doing so until about five days after anthesis. It has been suggested that they are prevented from forming grains by the presence of other fully developed florets and their endogenous hormone levels.

In most cereals and grasses the developmentally most advanced spikelet buds are found near the middle of the apex. The gradient of spikelet bud development along the apex is related to differences in growth rates of the primordia (Kirby, 1977). Each primordia initiated has a higher relative growth rate than the previously initiated primordia. There is also an increase in primordia length and diameter of successive primordia initiated until the middle of the ear. The primordia near the apex again decrease in size (Kirby, 1977).

Thus the ear formation phase may be important in determining how grain size varies with position up the ear. In wheats later initiated florets give rise to smaller grains (Kirby, 1974). In barley, Kirby (1977) found that apical dome size at the time a spikelet is initiated is positively correlated with the mean mass per grain at final harvest for that spikelet.

Scott, Appleyard, Fellowes and Kirby (1983) have suggested that relative growth rates are the same for all grain positions within the ear, although grain growth starts from different initial sizes. The grains at different nodes thus maintain the same relative size throughout their growth. Scott et al. (1983) noted that the final dry weight of each grain is closely related to the carpel size before anthesis as over 85 per cent of the dry matter of mature grains is accumulated during the linar phase of grain growth (Riggs & Gothard, 1976; Gallagher et al., 1976).

### 1.3.4 Grain weight

Weight per grain is an important component of grain yield and of grain quality. Environmental factors influence grain weight, but this yield component is also determined genetically (Jenner & Rathjen, 1978). The thousand grain weight of a variety is taken to be relatively stable (European Brewing Convention, 1976; Gallagher, Biscoe & Scott, 1975). The grain position within an ear influences its initial and final weight with the heaviest grains being found in the lower mid-part of the ear. Thus these differences in grain size within the ear contribute to a variable seed size distribution within the grain sample. In barley (Thorne, 1962; Cannell, 1969a) and in spring and winter wheats (Power & Alessi, 1978; Darwinkel, 1978; 1979) main shoots have been found to exceed ear bearing tillers in grain yield. This reduction in yield is a consequence both of decreased grain number and a reduction in mean grain weight (Darwinkel, 1980). Differences between main ears and those produced by later formed tillers can be minimized by the application of nitrogen fertilizers (Power & Alessi, 1978). Thus it is suggested that, by cultural modification, tiller development and subsequent yield and yield uniformity could be increased.

Grain yield is controlled by the size and efficiency of the photosynthetic system (Watson, 1952; Thorne, 1966; 1974). However, there is some evidence that leaf area and the rate of photosynthesis do not limit the supply of assimilates in the early stages of grain growth (Buttrose & May, 1959; Nosberger & Thorne, 1965). Other factors that have been considered that may limit growth are outlined below (Spiertz, 1974):

a) The transport of assimilates through the vascular system (Evans, Dunstone, Rawson & Williams, 1970; Hanif & Langer, 1972)

b) The processes involved in converting sucrose to starch in the endosperm cells (Jenner & Rathjen, 1972; Jenner, 1974)

c) The pattern of grain growth within the ear (Rawson & Evans, 1970; Walpole & Morgan, 1970; Bremner, 1972)

d) The hormonal mechanism regulating the attraction of, and competition for, assimilates within the ear (Wheeler, 1972; Radley, 1976).

Brocklehurst (1977) noted that the final grain weight of cereal crops was mainly dependent upon the rate of accumulation of the dry matter. This, in turn, is governed by the number of endosperm cells formed. Brocklehurst (1977) recorded that the endosperm cell number was regulated by the supply of assimilates available during the first two weeks after anthesis. After fertilization of the ovary coenocytic division of the endosperm occurs. Later cell walls form and further cell division causes the production of up to 150,000 endosperm cells (Brocklehurst, 1977). Thus a plentiful supply of assimilates post anthesis enhances the rate of cell division and hence the potential grain weight (Bingham, 1969).

Scott et al. (1983) have outlined the mechanisms by which potential grain size may be determined. In rice Murata and Matsushima (1975) have proposed that a physical restraint, caused by the attachment of the husk to the developing caryopsis, may inhibit further grain growth. A similar situation may exist in barley.

Littleton (1971) noted that barley awns differed in size within an ear. Walpole and Morgan (1972) proposed that final grain sizes were dependent upon the varying photosynthetic abilities of their component structures. Thus with a lower initial grain size and a smaller subtending awn, the grains at the distal end of the ear receive less photosynthates for growth. Walpole and Morgan (1972) found a positive correlation within the cereal ear between the awn length, the absolute growth rate and the final grain size of each individual grain.

The larger grain size in the basal grains within an ear may be due to their positional ability to capture the limited supply of translocated assimilates from the leaves and the stem (Aspinall, 1965). The supply of photosynthates to the developing plant organs (sinks) depends upon the activity and duration of photosynthesis of the remaining plant structures (sources). Almost invariably, foliar diseases interfere with the activity and duration of photosynthesis and lead to reduced grain weights. Many experiments have been undertaken to assess the source function of the flag leaf, the peduncle and the ear in relation to the sink demand of the developing grains (Stoy, 1965; Carr & Wardlaw, 1965; Lupton, 1972; Evans & Rawson, 1970). However, no clear understanding of the overriding causes of grain weight determination has been forthcoming. Both sink and source confer simultaneous limitations to the grain yield component of grain weight (Bingham, 1971).

## 1.4 Root Production and Growth

Shoot growth is also influenced by root growth. Miller (1939), Watson, Thorne and French (1963) and Connor (1975) have all studied the growth of the wheat root system. Biscoe, Scott and Monteith (1975) investigated the contribution by the roots of the total carbon budget of a cereal crop. However, little detailed work has been recorded on the growth and spatial distribution of roots in a field sown autumn cereal crop (Gregory, McGowan, Biscoe & Hunter, 1978).

Gregory et al. (1978) found that in the winter wheat crop dry weight increased exponentially from sowing until early spring and then linearly until anthesis. Post-anthesis root dry weight was found to remain constant; however other workers have shown a decrease in root weight after anthesis (Troughton, 1962; Welbank, Gibb, Taylor & Williams, 1974). Decrease in root dry weight earlier in the season corresponded to tiller death occurring at the time of stem elongation of the primary tillers. Gregory et al. (1978) found roots present at 2 m below the soil surface, although the length of root in each successive layer decreased with depth. This pattern of distribution has also been noted by Kirby and Rackham (1971) and Welbank et al. (1974).

Welbank et al. (1974) noted that the application of nitrogen fertilizer produced smaller root systems in the early spring with roots being shorter relative to their dry weight. Later, nitrogen application produced larger root systems although it altered the ratio between root and shoot, with the shoot being increased more by nitrogen application.

Kirby and Rackham (1971) reported that in the spring barley crop total root dry weight increased with increasing plant density. However they concluded that root dry weight may have an asymptotic relationship with density as does the shoot weight (Kirby, 1967; 1969).

Sage and Roffey (1981) have indicated that late autumn sowing of winter barley results in decreased autumn growth, low tillering and poor root growth. The development of the barley root system at low temperatures has been investigated by Hay (1976). He concluded that at low soil temperatures roots become thicker and less branched. Low temperatures have also been found to alter the pattern of assimilate distribution and thus alter the root : shoot ratio (Nielson, Halstead, Maclean, Holmes & Bourget, 1960). Low temperature growth has also been associated with alteration of the nitrogen metabolism of the root (Thomason, 1970; Sinclair, 1969), alteration of the balance of endogenous growth substances (Atkin, Barton & Robinson, 1973) and increase in the susceptibility of slow growing roots to pathogens (Hay, 1976). Poor growth of the cereal root system may predispose the root system to the effects of water stress which may cause decreased grain set and poor grain filling (Sage & Roffey, 1981; Aspinall, 1965; Aspinall, Nicholls & May, 1964; Gallagher, Biscoe & Hunter, 1976; Husain & Aspinall, 1970; Salter & Goode, 1967).

## 1.5 Plant Growth Regulation

### 1.5.1 General introduction to plant growth regulators

Austin and Jones (1975) suggested that four main categories could be considered when selecting improved crop varieties. These are:

a) Morphological and anatomical, e.g. crop height, leaf size
b) Compositional, e.g. grain quality, endogenous hormone level
c) Process rates, e.g. photosynthesis, respiration
d) Process controls, e.g. stomatal aperture, enzyme activity.

All these categories have the potential to be modified by the application of specific plant growth regulating substances.

In 1949 P.W. Zimmermann reviewed the uses of "plant hormones in practice". All the listed activities (e.g. rooting, parthenocarpic fruit set, thinning fruit, inhibiting sprouting, inhibiting bud growth, inducing flowering, defoliation, preventing pre-harvest fruit drop and selectively killing weeds) exclusively involved auxins. The identification of five classes of "hormones" active within the plant system has been of considerable importance to all concerned with the manipulation of plant growth. Extensive research has led to an increasing awareness of the ways in which plants can be manipulated. Most aspects of growth and development are now known to be regulated by interacting groups of hormones. The quantitative relationships within the groups are as important for the control of growth as the qualitative composition of the hormone mixture (Elliot, 1977; Pilet, 1978; Lawrence, 1978; Street, Elliot & Fowler, 1978; Wareing, 1978; Chailakhyan & Khryanin, 1980; Fosket, 1980; Pilet & Elliot, 1981).

One major problem with the manipulation of plant growth and development by exogenously applied plant growth regulatory substances is the difficulty of identifying a specific target site within the plant which will respond to chemical application by increasing the crop yield. The recognition of specific developmental and metabolic changes that will improve productivity is an essential element of the research aimed at developing yield enhancing substances. It is only with a complete knowledge of the growth controls normally operating within the plant that we can develop and assess new plant growth regulators (PGRs).

1.5.1.1 Chemosynthetic plant growth regulators Chemosynthetic plant growth regulators have been used to manipulate crop productivity. These either mimic effects of plant hormones so that they can correct endogenous hormone shortages or the applied PGR can disrupt the biosynthesis, translocation or metabolic conversion of the phytohormones (Bruinsma, 1980; 1981). Many of the PGRs developed are for use in horticultural production and in tropical or subtropical crops (e.g. sugar cane [Nickell, 1976]; sunflowers [Lovett & Orchard, 1974]). In Western Europe, the majority of the developmental work on PGRs has been concerned with small grained cereals, grasses, potatoes and oilseed rape. At the present time the major application is to be found in cereal crops where the application of PGRs affects the endogenous balance between gibberellins and ethylene either by inhibiting the biosynthesis of gibberellins or by enhancing ethylene levels.

### 1.5.2 The use of plant growth regulators in cereals

A large number of components of the cereal plant may be improved by the application of PGRs. Austin and Jones (1975) have suggested that the main targets for developmental manipulation are:

a) Leaf area duration:
the matching of the available leaf area to the grain filling period, decreasing senescence

b) Straw length and strength:
decreasing straw length and increasing basal internode strength with the ultimate aim of decreasing lodging

c) Tiller growth:
decreasing "unnecessary" tiller growth, especially in winter cereal varieties

d) Number of floral primordia:
increasing the maximum number of primordia produced and maintaining this number through until harvest

e) Fertility:
Improving the synchrony of flowering events

f) Grain growth:
Manipulation of rate and duration of grain filling to maximize the potential within each grain.

For many years, the manipulation of cereal growth has been primarily concerned with the second of these categories, namely the improvement of straw length and strength.

In wheat plants, the applied PGRs may assist in inhibiting stem elongation and promote the thickening of the culm, the number of vascular bundles and the formation of sclerenchymous tissues (Mayr & Presoly, 1963). This shortening and thickening of the culm assists in lodging prevention.

1.5.2.1 Prevention of lodging in cereals Lodging in small grain cereal crops can cause poor leaf orientation and insufficient nutrient flow to developing grain sites which, in turn, can lead to poor grain filling and subsequently a decrease in yield (Herbert, 1983). Mulder (1954) in a comparison of grain yield between lodged plots and those of supported plants demonstrated a yield reduction of 8 to 20 per cent in barley. The magnitude of seed loss has also been demonstrated in a lodged herbage seed crop (Hebblethwaite, Burbidge & Wright, 1978).

Weibel and Pendleton (1964), Pinthus (1973) and Stanca, Jenkins and Hanson (1979) have reported that the effect of lodging on yield and grain quality is dependent upon its severity and time of onset. Lodging at anthesis is the most detrimental, giving yield reductions over 40 per cent. The malting quality of barley is also adversely influenced by lodging (Day & Dickson, 1958). Lodging of the crop often permits secondary growth to occur. These late tillers do not contribute significantly to grain yield and their presence can cause difficulties during harvesting and drying.

Prevention of lodging in wheat is achieved chemically by the use of (2-Chloroethyl) trimethyl ammonium chloride (CCC, Chlormequat-chloride).

1.5.2.2 The use of chlormequat in cereal production The increased use of chlormequat in recent years has been partially attributed to the greater profitability of cereals which have allowed an increased level of inputs. The development of cereal "systems", in which chlormequat plays an important role, has helped to increase the understanding of the inter-relationships between inputs and their potential contribution towards increasing grain yield. Namokar (1977) in a review of potential agricultural uses of chlormequat estimated that 20 to 25 per cent of the wheat in Germany and Austria was treated as a precaution against lodging. Nickell (1978) estimated the treated area to be over 50 per cent.

The application of chlormequat has been found to influence the growth and development of the cereal crop in many ways:

a) Increase tiller production (Koranteng & Matthews, 1982)
b) Decrease basal internode length and thus plant height
c) Increase chlorophyll content per leaf and per unit fresh weight (Humphries, 1963)
d) Decrease thousand grain weight (TGW) (Humphries, Welbank & Witts, 1965)
e) Increase grain number per ear (Humphries et al., 1965)
f) Delays ear emergence by as much as five days (Linser & Kuhn, 1962)
g) Retards senescence (Jung, 1979)
h) Increases weight of root per ear (Humphries et al., 1965; Sturm & Jung, 1964a; 1964b; Humphries & Bond, 1969)

i) Increases grain yield at apex and collar regions of the ear (Williams, Turner & Sampson, 1982)

j) Reduces eyespot (Pseudocercosporella herpotrichoides) (Williams et al., 1982)

k) Modifies leaf angles (Bruinsma, Vos & Dilz, 1965)

l) Increases winter hardiness when used as a seed treatment (Zadoncev, Pikus & Grincenko, 1977).

Whilst there have been many reports indicating that chlormequat chloride can increase yields in wheat (e.g. Humphries et al., 1965; Pinthus & Rudich, 1967; Matthews & Caldicott, 1981) there have been very few showing a similar response in barley (e.g. Koranteng & Matthews, 1982).

Linser and Kuhn (1962) have shown that spring barley does respond to the application of chlormequat chloride but at a much higher level of application than that used on wheat. The results in terms of height reduction and lodging control were less. Linser, Kuhn and Bohring (1963) observed a shortening of the stem during the early stages of barley growth, but an increase in stem growth post ear emergence, thus resulting in an increased total culm length. Stopik and Cervinka (1967) (cited by Linser, 1968) stated that chlormequat breaks down rapidly within the barley plant, being metabolised and transported to the roots as a quarternary base. Hunt and Baker (1982) have found that $^{14}C$ labelled chlormequat with a surfactant was taken up by wheat leaves to a greater extent than the uptake of barley leaves (30% compared to 15% of applied dose).

The mode of action of plant growth regulators, such as chlormequat has been associated with the inhibition of synthesis or action of the gibberellins. Work has shown that chlormequat blocks gibberellin biosynthesis in the fungus Fusarium moniliforme and in higher plants (Kende, Ninnemann & Lang, 1963; Harada & Lang, 1965). It also interferes with gibberellin utilization (Coolbaugh & Hamilton, 1976) as well as other biochemical processes (Douglas & Paleg, 1978).

### 1.5.3 The use of PGRs in winter barley production

MAFF statistics have shown (MAFF, 1984) the rapid increase in the winter barley hectarage in the last ten years (Section 1.2, Table 2).

This increase is partly attributed to the higher yield potential of winter barley varieties compared to spring sown varieties. Unfortunately the realization of the potential is not always possible due to lodging of the cereal crop prior to maturity. Thus there is a great need for an anti-lodging agent for the barley crop (Woolley, 1980).

In 1979 three new lodging control products for barley were introduced onto the UK market (Table 3).

The usual role for PGRs is as anti-lodging agents and for this reason they have usually been applied relatively late in the life of the crop, usually post Zadoks Growth Stage (ZGS) 31. However, application at this time is unable to modify important developmental components of the crop that have already been determined, e.g. peak tiller number, maximum primordia number and peak floret number (in wheat). Thus the gross morphology of target plants has been little influenced by the application of such regulators as chlormequat.

Many workers have reported yield increases when using chlormequat even in the absence of lodging. Zadoncev (1969) concluded that the application of chlormequat can lead to "growth stimulation". The enhancement of yield by the application of chlormequat on a barley crop has also been reported (Verma & Singh, 1978). The unexplained increases in yield and modification of crop growth have prompted further work into the effects of "early" applications of a range of PGRs.

### 1.5.4 Crop manipulation by PGRs

The application of PGRs to the developing crop are aimed at modifying the following parameters:

a) Apical dominance
b) Plant growth and development
c) Interactions with other inputs.

These factors will be considered briefly in the following section.

1.5.4.1 Apical dominance The growth habit of any plant corresponds to its pattern of meristem production and activity. This is determined by the degree of dominance exerted by the shoot apex on the growth and development of axillary buds and branches. In most cereals and grasses, the development and growth of the tiller buds occurs readily during the

**Table 3** Anti lodging agents for barley

| Product | Cerone | Terpal | Barleyquat |
|---|---|---|---|
| Manufacturer | ICI - Union Carbide | BASF | Mandops (agrochemical specialists) Ltd |
| Active ingredient | 2 Chloroethyl phosphonic acid "Ethephon" (Squires, Breslin & Hill, 1980) | 46% w/v Mepiquat chloride & "Ethephon" | Aqueous solution of Chlormequat and additives |

initial vegetative phase of growth, especially with an adequate level of nutrients, a high temperature and optimum irradiance (Aspinall, 1961; Langer, 1963; Evans, Wardlaw & Williams, 1964). The assimilates necessary for the growth of lateral buds are translocated from the photosynthesizing organs on the mainstem until the tiller reaches a stage where it changes from being a net sink for assimilates to a net source (Quinlan & Sagar, 1962; Bunting & Drennan, 1966; Aufhammer, 1974).

Apical dominance is manifest in at least three ways:

a) by complete or almost complete inhibition of growth in the axillary, or lateral, buds by the presence of the apical bud.
b) by inhibition of the growth of one shoot by the presence of another dominant shoot.
c) in effects of the apical part of the shoot upon orientation and development of lateral organs such as branches, leaves, rhizomes and stolons (Phillips, 1969).

The degree of apical dominance is determined by genetic and environmental factors and is greatly influenced by the physiological age of the plant.

The growth of tiller buds is inhibited by the shoot apex in vegetative plants and by the developing inflorescence and elongating internodes in reproductive plants. Whilst the mechanism of apical dominance is incompletely understood, Sachs and Thimann (1964; 1967) have shown that the phenomenon involves the antagonism between cytokinins and auxins.

An analogous system to the hormonal suppression of tiller buds may occur within the ear of a cereal plant (Aufhammer & Bangerth, 1982). Auxins, and possibly other plant hormones, produced in the growing tissues of the eldest floret are translocated to younger florets and may control their growth and development. There may also be translocation of hormones from central to apical and basal regions of the spike. In response to the alteration of the hormone balance, the younger "grains" are removed from inhibition. If young florets are not released from this suppression, they remain infertile. Nicholls and May (1964) determined that the hormone system starts to exert its influence during early apical initiation, thus the balance of hormones may determine the relative spiklet and floret size until anthesis.

Thus the growth of suppressed tiller buds is stimulated by:

a) Decapitation of the main shoot apex (Leopold, 1949; Hillman, 1970).

b) The application of substances analogous to cytokinins (Jewiss, 1972; Langer, Prasad & Laude, 1973; Clifford & Langer, 1975; Johnston & Jeffcoat, 1977; Sharif & Dale, 1980).

c) Increasing the nutrient supply (Aspinall, 1961; McIntyre, 1965).

The modification of a plant's growth habit by the addition of chemicals which mimic the effects of endogenous hormones or suppress their activity is becoming of major importance in some sectors of the agricultural and horticultural industries. The tillering efficiency of modern cereals is duplicated by the sequential application of gibberellic acid. The early application of $GA_3$ prior to double ridge production on the mainstem apex advances plant development and decreases subsequent tiller production. The tillers already removed from the apical dominance suppression continue to grow and reduce the hierarchy between the developing primary tillers and the mainstem. Those tiller buds inhibited by endogenous plant growth regulating substances remain inhibited (Batch, Hutley-Bull, Schwabe & Joyce, 1980).

1.5.4.2 Plant growth and development The modification of vegetative plant morphology has been divided into seven interdependent sections which are outlined below:

1.5.4.2.1 Ear development It has been found by many workers (Badanova & Levina, 1970; Brian, 1959; Humphries et al., 1965; Hutley-Bull & Schwabe, 1980; Koranteng & Matthews, 1982; Mirghani, 1978; Nicholls, 1978) that the application of a PGR to a cereal plant can modify the plant's development.

The application of $GA_3$ has been found to accelerate plant development due to accelerated cell division in the shoot apices in a number of long day plants (Sachs, Lang, Britz & Roach, 1960; Baldev & Lang, 1965; Jacqmard, 1968; Lin & Loy, 1976).

Nicholls (1978) found that the application of $GA_3$ to barley plants growing under short day conditions resulted in an increased rate of growth of the apical meristem, the earlier appearance of the double ridge state on the mainstem apex and increased rate of growth of both leaf primordia and basal spikelet primordia at the double ridge stage of development.

The addition of exogenous gibberellic acid may lead to supra-optimal levels of gibberellins within the spike, thus suppressing further primordia production (Cottrell, Dale & Jeffcoat, 1982).

Retardant chemicals such as chlormequat generally have the opposite effects to $GA_3$ on such parameters as initiation rate, spikelet differentiation and leaf number (Badanova & Levina, 1970; Tolbert, 1960). The maximum number of spikelet primordia and the final number remaining after degeneration of the distal spikelets are similar in chlormequat treated and non-treated plants (Koranteng & Matthews, 1982).

1.5.4.2.2 Plant structure The major effects on external plant morphology of gibberellic acid and chlormequat are summarized in Table 4.

Gibberellic acid applications increase the apical dominance of the mainstem and primary tillers and thus inhibit the production of secondary or late primary tillers (Batch et al., 1980). Conflicting results have been obtained by Mirghani (1978) and Koranteng and Matthews (1982) who showed that the early application of $GA_3$ significantly increased the mean number of shoots and ears per plant. Batch et al. (1980) indicated that the initial effect of an 'early' $GA_3$ application was to reduce the rate of tiller formation and hence the total tiller number. $GA_3$ advanced the development of the older primary tillers thus "evening up" the hierarchical arrangement between mainstem and tillers. $GA_3$ treated plants exhibited greater tillering efficiency than control plants.

1.5.4.2.3 Root weight and distribution The root system of a cereal plant can be categorized in terms of its component parts in a similar manner to the division of the shoot into component tiller classes. The graminaceous seedling depends on seminal roots arising from the embryo initially. These are rapidly supplemented by adventitious roots arising from the basal nodes of the main stem and tillers (Troughton, 1957).

PGRs can modify the rooting depth and weight of roots in cereals and other crops. Humphries et al. (1965) and Humphries and Bond (1969)

**Table 4** The effects of gibberellic acid and chlormequat on external plant morphology

| | Chlormequat | $GA_3$ |
|---|---|---|
| Tiller number | ↑ | ↓ * |
| Primary tillers | ↓ | ↑ |
| Secondary tillers | ↑ | ↓ |
| Culm length | ↓ | ↑ |
| Length of lower internodes | ↓ | ↑ |
| Leaf number | ↑ * | ↓ |
| Leaf length | ↓ | ↑ |
| Leaf area | (1) ↓ ↑ (2)<br>(1) Per tiller (2) Total | ↑ |
| Dry weight | (1) ↓ ↑ (2)<br>(1) Main stem (2) Total | ↑ * |

* Variable results

found that chlormequat increased root growth in spring wheat in the deeper zones of a sandy loam soil. This enhanced rooting led to an increased yield in a dry year due to an enhanced survival of ear bearing shoots. The higher grain yield in non lodged winter wheat crops after CCC use may, in part, be attributed to the better utilization of water in dry years (Jung, 1979). Hanus (1967) found that chlormequat usually increased the amount of root tissue in all soil depths in a wheat crop.

Gibberellic acid application commonly results in a decrease in root dry weight (Lambeth & Das, 1966; Das, 1965; Jung, 1979). $GA_3$ also fails to produce any visible effect on root growth or development when applied hydroponically or as a soil drench (Johnston & Jeffcoat, 1977). Ellis, Graham & Barnes (1980) demonstrated that ethephon plus mepiquat chloride (Terpal) used as a seed dressing for winter barley reduced the root growth at the end of tillering, but did not affect yield.

1.5.4.2.4 Winter hardiness and drought tolerance The application of $GA_3$ to barley decreased the heat resistance and drought tolerance of treated plants. The application of chlormequat used as a soil drench raised the plants' drought hardiness slightly (Badanova & Levina, 1970). It also promoted an increase in the water retaining ability of the leaves and more efficient expenditure of soil moisture by the plant (Kharanyan, 1967).

Humphries and Bond (1969) found that the increased rooting stimulated by chlormequat application resulted in an increase in drought tolerance. In the USSR, the use of chlormequat as a seed dressing aids winter hardiness of wheat seedlings (Zadoncev et al., 1977).

1.5.4.2.5 Chlorophyll content In most reported experiments using $GA_3$, it has been found that the treated plants are lighter in colour than control plants (Batch et al., 1980). Wolf and Haber (1960) have attributed this to either the inhibition by the gibberellins of chlorophyll synthesis or to the failure of the rate of chlorophyll synthesis to keep pace with the high rate of leaf expansion.

The effect of the anti-gibberellin, chlormequat, is to increase the concentration of chlorophyll in the leaves of treated plants (Bokhari & Youngner, 1971), thus making the leaves appear darker.

1.5.4.2.6 Yield components The modification of final yield components by PGRs depends upon the suppression or enhancement of apical dominance, the rate of primordia production and the hierarchical arrangement of surviving tillers.

The application of chlormequat has usually resulted in an increase in ear number per unit area, an increase in grain numbers per ear and a decrease in thousand grain weight (Humphries et al., 1965; Humphries & Bond, 1969; Hutley-Bull & Schwabe, 1982; Jung, 1979; Stevens & Palmer, 1983).

$GA_3$ exerts a variable effect on yield components which depends upon rate and timing of $GA_3$ application. In all cases $GA_3$ advances development and time to ear emergence (Hutley-Bull & Schwabe, 1982; Badanova & Levina, 1970). Ear number per plant is generally reduced (Wheeler, 1980) although it has been shown that ear number per plant can be increased by early $GA_3$ applications which decrease tiller production but increase tiller efficiency (Batch et al., 1980). The reduction of tillering results in an increased uniformity between ears (Koranteng & Matthews, 1982).

1.5.4.2.7 Senescence Senescence can be defined as the sequence of events concerned with cellular disassembly and the mobilization of the materials released during the process. Stoddart (1980) indicated that variations in light, temperature, water status, mineral availability and ambient carbon dioxide ($CO_2$) concentration are all capable of precipitating leaf senescence. The disassembly involved loss of photosynthetic capacity, chloroplast disassembly, changes in cell membrane integrity and increase in respiration.

Gibberellins have been shown to retard senescence in excised leaf tissue of Rumex, Taraxacum and Tropaeolum (Whyte & Luckwill, 1966; Fletcher & Osborne, 1965) and to decrease protein degradation. Senescence can also be delayed by the application of such regulators as chlormequat and Amo-1618 (Halevy, Dilley & Wittwer, 1966) due to their role as general protein biosynthesis inhibitors, not as specific blocking agents for GA synthesis.

### 1.5.4.3 Interactions with other inputs

1.5.4.3.1 Fungicides and herbicides It has been claimed that chlormequat may improve the efficacy of some fungicides and herbicides and thus may allow for a reduction in their use (Williams et al., 1982). Decreased usage of chlormequat by up to 30 per cent when mixed with herbicides has been attributed to the inclusion of wetters with the herbicide (Sandford & Stovell, 1968; Hunt & Baker, 1982).

Bockman (1968) stated that the use of chlormequat decreased lodging in wheat caused by Pseudocercosporella herpotrichoides. The application of chlormequat does not have a direct fungicidal effect on the parasite but the increased stability and stiffness of the straw seems to give effective control and thus prevent lodging (Jung & Sterm, 1966).

1.5.4.3.2 Nitrogen It has been argued that by decreasing the risk of lodging in a given crop situation by the judicious use of a plant growth regulator, it should be possible to increase the nitrogen usage to maximize the yield obtained (Hampton, Clemence & Hebblethwaite, 1983).

There have been conflicting reports of the interactions between the application of PGRs and nitrogen. Results from Humphries et al. (1965) and Hampton et al. (1983) showed no interaction between PGR application and nitrogen level, whereas trials by Alcock, Morgan and Jessop (1966) and the North of Scotland College of Agriculture (NSCA) (1983) have shown variable interactions between inputs.

1.5.4.3.3 Density Koranteng (1981a) noted that although the timing of PGR application may be a crucial factor determining the effectiveness of chlormequat applications, there may also be differences in response due to initial plant population densities and variety. Reports by Batch et al. (1980) have shown a clear relationship between $GA_3$ response and sowing rate in spring wheat, but trials by Humphries and Bond (1969) and Lovett and Kirby (1971) have found no interactions between plant densities and plant growth regulators.

1.5.4.3.4 Variety Batch et al. (1980) found that in winter wheat varieties with a wide range of tillering abilities $GA_3$ reduced tiller production and increased tillering efficiency. However, there was no correlation between the tillering ability of a variety and the yield response to $GA_3$. In trials on many varieties of both wheat and barley no consistent pattern of varietal response has been noted (Koller, 1968; Goodin, McKell & Webb, 1966; Larter, Samii & Sosulski, 1965).

### 1.5.5 The potential role for plant growth regulators

Cereal growth is made up of successive phases which are all initiated in a predetermined sequence but which overlap in time. During each growth period there is a highly complex interrelationship between such factors as environmental conditions, phytohormones and assimilate supply. Although modification of the environment is generally impossible except in controlled enviroment conditions, it is possible to manipulate other factors, which determine the pattern of growth and development. A knowledge of the interrelationships that cause plant changes should enable the plant physiologist to influence plant growth by the manipulation of inputs. The potential role for exogenous PGRs will be summarized in the following sub-sections.

1.5.5.1 Germination In recent years, there has been much interest in enhancing the germination of seeds of crop plants and thus improving plant establishment and crop uniformity with the ultimate aim of increasing the economic yield of the crop.

Large viability differences occur between available batches of seed. Austin (1972) suggested that these differences were due to mineral nutrition, rainfall, temperature and photoperiod during seed development. A seed lot is considered to perform well when it is able to withstand the adverse effects of the environment. Heydecker and Coolbear (1977) have reviewed such techniques as chemical seed soaks, osmotic pretreatments and fluid drilling that have been designed to increase germination and improve the viability of the germinating seed.

Of the endogenous phytohormones $GA_3$ is the most effective germination promoter breaking dormancy in a wide range of species. In the brewing industry, gibberellic acid is used to promote enzyme activity in malting barley (Prentice, Dickinson, Burkhart & Standridge, 1963).

The effect of $GA_3$ on the germination of such seeds as bean, pea, barley and wheat indicate that emergence of seedlings is hastened by 2-4 days but that treated seedlings become elongated. Wittwer and Bukovac (1957) found that the $GA_3$ promoted shoot growth did not give rise to increased grain yield in a field situation. However Verma and Singh (1978) have shown increased grain yields in barley treated with IAA, IBA and $GA_3$.

The promotion of shoot growth at low temperatures has been found with the application of $GA_3$ (Wittwer & Bukovac, 1957). This may be advantageous when growing winter cereals in suboptimal climatic conditions. The disadvantages of using such PGRs as $GA_3$ may be eliminated by using a combination of PGRs with synergistic effects.

Thomas, Biddington and Palevitch (1978) have used combinations of $GA_3$ and $GA_7$ plus daminozide to improve the germination and emergence of celery both in controlled environments and in the field situation. The germination of lettuce seed has been improved by the use of a combination of regulators such as kinetin, $GA_4$, $GA_7$, $GA_3$ and ethylene (Gray & Steckel, 1979; Braun & Khan, 1976).

The treatment of maternal seed-producing plants, either before or during grain production, may be able to influence the quality of the resultant seed. The manipulation of the next generation may be caused by:

a) Incorporation of factors necessary for seed germination
or
b) the indirect modification of existing phytohormones by introduction of other chemicals (Gutterman, Thomas & Heydecker, 1975).

1.5.5.2 <u>Tiller growth</u> The principles behind tiller production have been outlined in previous sections (Sections 1.3.1, 1.3.2, 1.5.4).

The importance of tillering capacity of a cereal plant as a determinant of yield has long been recognized (Engledow & Wadham, 1923). Tillering is important in increasing the number of stems potentially capable of yielding grain. Thus tillering allows maximum utilization of available resources (Fletcher, 1975).

Tillering in graminaceous crops is influenced by:

a) Seed quality (Engledow & Wadham, 1924; Van Dobben, 1966)
b) Soil moisture (Slavik, 1966; Husain & Aspinall, 1970)
c) Mineral nutrition (Evans et al., 1964)
d) Light intensity (Aspinall & Paleg, 1963)
e) Temperature (Friend, 1965b; Cannell, 1969b)
f) Phytohormones (Thorne, 1962; Kirby & Faris, 1970; Section 1.5.4.1)

g) Other factors, e.g. Sowing density (Kirby & Faris, 1970; Section 1.5.4.3.3)
e.g. Depth of planting (Engledow & Wadham, 1924).

The earliest formed tillers, whatever their date of appearance, have a greater chance of becoming fertile tillers than those formed later (Langer & Lambert, 1959; Lupton & Pinthus, 1969; Langer, 1959; Hill & Watkin, 1975; Clemence, 1982). Experiments show that the smallest or youngest tiller irrespective of tiller position tends to die first when the whole plant is under stress (Ong, 1978).

A developing tiller is initially dependent upon the main stem for assimilates (Quinlan & Sagar, 1962). However after formation of adventitious roots and leaves, the tiller becomes independent and can compete with the main culm for resources (Bunting & Drennan, 1966). The vascular connections between the main culm and the tillers are maintained (Dungan, 1931; Clifford, Marshall & Sagar, 1973). At the time of tiller death, mobilization of assimilates from the vegetative tillers to the main culm occurs. This retranslocation is not as efficient as direct production by the mainstem (Lupton & Pinthus, 1969).

Many ideas have been developed for the production of cereals with synchronous tillering, an increased tillering efficiency and decreased inter-plant competition. Donald (1968; 1979) stated that intense inter-plant competition decreased grain yield. Hence, by minimizing inter-plant competition, grain yield could be increased. Donald (1968) concluded that if the competition from tillers was removed, the main culm would produce larger ears and thereby increase the potential for grain production.

Pavlov (1971) suggested that the optimum model for cereal growth would be that of a high tillering variety where tillers may be initiated over a short period of time. With synchronous production would come simultaneous development. This might decrease the mortality of small, late-produced tillers. However, due to sequential development of tiller buds in the axils of the leaves, simultaneous development of tiller buds is unlikely to be wholly possible in cereals (Stoskopf & Fairy, 1975).

Two potential methods of using PGRs to improve tillering efficiency have been discussed (Koranteng, 1981b). Both involve the modification of apical dominance, thus allowing for alteration of the basic tillering pattern.

The use of $GA_3$ early in the growth of the plant may enhance the growth and development of the main culm and the main primary tillers. This increase in apical dominance would thus result in the suppression of lower order primary and secondary tillers. The "removal" of these tillers which compete for resources would allow the first formed culms to survive and maximize their potential (Batch et al., 1980; Koranteng & Matthews, 1982).

Chlormequat and other growth retardants have been used to manipulate tiller production (Koranteng, 1981b; Koranteng & Matthews, 1982). The rate of growth and development of the main shoot and early tillers can be retarded during the early stages of plant development. This reduction in apical dominance allows the lower order primary tillers and secondary tillers to develop and reach a similar growth and developmental stage to the suppressed tillers. Thus growth of the treated plant becomes synchronized. This plant synchrony may produce a more uniform crop in terms of grain number per ear and grain size distribution between and within ears.

1.5.5.3 Ear development and grain filling Attention must be given from ZGS 31 to ensure that growth and development are not restricted by factors which limit assimilate production and distribution (Batch, 1981). Many of the 'traditional' husbandry inputs such as nitrogen top dressing, herbicide applications, elimination of fungal diseases and control of aphids are designed to maintain the potential of the developing plant.

The manipulation by PGRs of the growth of the ear and the division of assimilates within the plant may be possible (Batch, 1981). The alteration of the plant may be achieved by:

a) Increasing the proportion of the total dry matter production of the plant that is found in the harvestable grain (i.e. increasing the harvest index (Fh) (Donald, 1968)
b) Modification of the crop canopy. The change of angle of the flag leaf and penultimate leaf may alter the light distribution within the canopy and improve the amount of radiation intercepted by the lower leaves within the crop stand (Donald, 1979)
c) The application of a PGR to prevent senescence of the leaves which supply assimilates to the developing ear would

lengthen the time available for grain filling (Section 1.5.4.2.7). Hardy (1978) has estimated that delaying the senescence of the flag leaf sheath may lead to a yield increase of approximately 3% $day^{-1}$ in wheat

d) Improvement of photosynthetic efficiency by manipulation of the biochemical pathways of photosynthesis and respiration

e) Improvement of the 'sink' capacity of the ear by increasing the number of grains per ear or the ability of individual grains to acquire photosynthates for further growth (Batch, 1981).

The maximization of potential grain sites during cereal development will be wasted if insufficient assimilates are available to the developing grain sites. Kirby (1974; 1977) has suggested that the death of the distal spikelets and/or florets in cereals may be due to insufficient assimilates being available.

It has been argued (Koranteng, 1981b) that rapid morphogenesis of the apex induced by $GA_3$ application may result in an earlier onset of assimilate competition and hence the earlier degeneration of spikelets. Chlormequat, by suppressing GA synthesis, may lead to a shift of assimilates from shoot to ear growth. It may also induce a modification of the rate of apical development, thus allowing more spikelets to survive and so enhance grain potential (Koranteng, 1981b).

## 1.6 A Barley Ideotype

### 1.6.1 The ideal barley crop for seed production

An ideotype is a biological model which is expected to perform or behave in a particular manner within a defined environment (Donald, 1968). Donald (1968; 1979) has suggested ideotypes for both wheat and barley with the ultimate aim of increasing crop yield. The proposed model for a barley crop for seed production differs slightly from that proposed by Donald (1979). Major features of the proposed model are outlined below.

1.6.1.1 Restricted tillering habit Tillering in any variety is closely related to the number of ears per plant. This yield characteristic shows great variability (Puckridge & Donald, 1967; Kirby & Faris, 1972). Tillering has long been regarded as a major factor in the cereal plant's ability to compensate for early suboptimal conditions such as poor plant establishment or pest attack (Evans, Wardlaw & Fischer, 1975).

As a result of the process of tillering, the plant community is composed of a range of tillers of varying sizes and ages. In many cereals main shoots produce a higher grain yield than that produced by tillers (Cannell, 1969a; Darwinkel, 1978; 1979). Yield reduction is caused by a decrease both in grain number and in individual grain weight. The reduction in tillering by husbandry practices may result in minimizing the variability in grain size between ears.

Unproductive tillers may act either as a drain on available resources required by the plant or as a source of assimilates that can be utilized by the plant in times of stress or as a combination of source and sink depending upon plant growth and environmental conditions. The minimization of secondary and lower order primary tillers may enhance the growth and development of the mainstem and the first formed primary tillers, thus leading to an earlier transition to the reproductive phase and subsequently a higher grain yield potential.

The reduction in tillering ability of the cereal plant may require plant density and thus seed sowing rate to be reconsidered. For optimum resource utilization uniform placement of seeds may be required to allow each to maximize its potential. This may require precision drilling of seeds at a narrower row spacing than is currently employed or broadcasting of the seed to eliminate inter-plant competition within the cereal rows.

Uniformity of tillers as a result of increased plant density and reduced tillering period may result in a narrowing of the ranges of maturities at final harvest. Combine harvesting could thus be timed to optimize the yield and vigour of the seed crop. The complete suppression of tillers on a plant grown in an environment that cannot be regulated may cause decreased yields in suboptimal conditions.

1.6.1.2 Growth habit Monteith (1965) and de Wit (1965) have suggested that during early plant growth, when the leaf area index (LAI) is below 3-4, plants with lax leaves will have a higher photosynthetic rate than those plants with erect leaves. Thus the development of an initially prostrate growth habit may confer advantages on the cereal crop in terms of the accumulation of photosynthates. Also the prostrate growth habit may be advantageous in minimizing the effects of adverse winter weather conditions. After LAI 3-4 erect leaves are advantageous to the growing crop (Innes & Blackwell, 1983) especially under conditions of adequate water supply (Watson & Witt, 1959; Hadfield, 1968; Pendleton, Smith, Winter & Johnston, 1968). In a dense plant community erect leaves permit illumination of a greater area of leaf surface than a canopy of lax leaves (Wardlaw, 1967). Plants with erect leaves are less susceptible to interculm competition at high densities than plants with lax or horizontal leaves (Donald, 1968).

Many modern barley varieties have a small flag leaf. However the flag leaf and the penultimate leaf are major sources of assimilate for the filling grain. Hence a large flag leaf is desirable for the production of photosynthates which can be translocated to the developing ear.

1.6.1.3 Stem length The production of barley varieties with short, strong stems is desirable in that the risk of lodging is reduced. A lodged cereal crop cannot be thoroughly inspected and thus may not be deemed eligible for certification. The reduction of stem height and the strengthening of the culm may allow more nitrogen to be applied to the crop to enhance yields.

The cereal culm can act as a source of assimilates for the developing grains. Pre-anthesis assimilates stored in the stem are retranslocated after anthesis to the grains; greater use being made of pre-anthesis assimilates in times of crop stress, e.g. drought conditions. Hence the reduction of the culm may result in a decrease in the storage capacity. This may thus lead to a reduction in the available assimilates for grain fill.

1.6.1.4 Grain morphology Walpole and Morgan (1972) have shown a positive correlation between awn length, absolute growth rate and final grain weight. The awn contributes a substantial quantity of the post-anthesis photosynthates available to the grain. Poor grain fill of distal grains has been associated with their small initial size and a reduced assimilate contribution from the associated awn. From $^{14}C$ tracer studies it has been found that the majority of the photosynthates fixed by the cereal awn are subsequently found in the grain with which it is associated. Hence increasing awn length or the awn's photosynthetic capacity may thus lead to increased assimilates being translocated to the grain.

Kirby and Rymer (1974) have investigated the development of the vascular system of spring barley. They concluded that terminal spikelet death may be associated with the high resistance within the ear to assimilate transport. This intraspikelet competition develops because of competition from the basal and mid-positioned spikelets of the ear which have an established vascular system. For all the potential grain sites to be fully utilized, no internal competition should prevent the flow of assimilates from photosynthesizing organs or pre-anthesis sources to the developing grains which must themselves be non limiting sinks. The improvement of vascular connections throughout the ear may allow all grain sites to fulfil their potential and thus reduce within ear grain size differences.

1.6.1.5 Senescence Although the assimilates for grain production are from many differing sources, the maintenence of green leaf area is important in allowing assimilates to be moved to the grains during all of the grain filling period. The flag leaf, penultimate leaf and the awns all contribute significantly to the accumulated assimilates within the ear. Extending the time in which these organs were photosynthesizing may lead to an increase in duration of grain fill and thus may ultimately lead to an increase in grain yield.

The elimination of ear and leaf diseases which reduce the photosynthetic ability or the longevity of the plant would result in more assimilates being made available to the grain. The presence of seed-borne diseases, e.g. loose smut (Ustilago nuda), covered smut (Ustilago hordei) and net blotch (Drechslera teres) can cause rejection of the seed crop for certification, due to their detrimental effects on subsequent plant emergence, survival and yield.

1.6.1.6 Seed characteristics The cereal seed produced from the maternal crop should ideally be of a uniform size, with an adequate nitrogen content, without seed-borne diseases and of a high germination capacity under sub-optimal field conditions (i.e. high vigour). This combination of attributes leads to the production of uniform, well established seedlings, well able to withstand the poor environmental conditions that may occur and the ability to yield well at final grain harvest. Furthermore, the grower who purchases seed expects to find a uniform, bold (i.e. well filled) sample.

## 1.7 Introduction to Experiments

The husbandry of the maternal cereal crop has been shown to influence the germination, the seedling growth, the tillering ability and the final yield of the subsequent cereal crop. The differences are often due to an alteration of the seed size or the seed nitrogen content.

Therefore a series of field experiments undertaken from 1980-83, supplemented by studies in controlled environment rooms, was conducted to elucidate the factors which influence such characteristics as thousand seed weight, seed size distribution, seed nitrogen content and germination.

Husbandry inputs of density, nitrogen fertilizer (both rate and timing) and plant growth regulator applications were used with the aim of modifying growth and development in order to produce a crop suited to the production of high quality barley seed.

In addition studies were undertaken to monitor the growth and development of the barley crop from emergence to harvest so that suitable growth parameters for manipulation by husbandry means could be identified.

# Chapter 2

# MATERIALS AND METHODS

## 2.1 General

A series of experiments were carried out between September 1980 and July 1983. Most were conducted on the University of Nottingham Farm, Sutton Bonington, Loughborough, Leics. on a coarse, loamy fluvial drift of the Arrow series overlying Keuper Marl. Similar replicated experiments were also conducted at the trial grounds of Nickerson R.P.B. Ltd., Rothwell, Lincs. on a well-drained, shallow chalky soil.

Experimental details are summarized in Tables 5 and 6.

### 2.1.1 Weather and climatic data

Meteorological data were obtained from the Sutton Bonington micro-meteorological station. This was a maximum distance of 2 kilometres from any trial site at Sutton Bonington.

## 2.2 Growth Analysis Methodology

The stage of apical differentiation (Kirby & Appleyard, 1981) was determined on mainstems of at least five plants from selected treatments at regular intervals during the first 200 days of growth by exposing the apex by dissection and examining under a Nachet binocular microscope. Identification of the stage of apical development gave greater precision and accuracy to the timing of chemical inputs.

At intervals that ranged from monthly in mid-winter to twice weekly post-ear emergence, each plot was sampled by removing two adjacent half metre (2 x ½m) lengths of row from within the inner six rows of the drilled area. Care was taken to minimize any edge effects by ensuring that at least half a metre of crop was left standing between harvest areas.

In the laboratory, plant numbers were counted and a subsample of a known number of plants removed. This number was usually 25 plants per sample.

The subsample was divided into tiller hierarchies which were subsequently split into categories containing dead and senescent material,

**Table 5** *Field trial details — Sutton Bonington*

| *Trial* / Parameter | WB1 | WB5 | PGR1 | PGR2 | WB6 | WB Resown |
|---|---|---|---|---|---|---|
| Location | 24 SB | 10 SB | 10 SB | 2 SB | 25 SB | 10 SB |
| Variety | Tipper<br>Igri | Tipper<br>Igri | Igri<br>Fulmar | Fenella | Tipper | Tipper<br>Igri |
| Drilling date | 18/9/80 | 20/9/81 | 26/9/81 | 1/11/81 | 15/9/82 | 26/9/81 |
| Density seeds $m^{-2}$ | 300,450,650 | 200,300,400,600 | 325 | 200,400,600 | 450 | 400 |
| PGRs applied | - | - | $GA_3$<br>5 C Cycocel | Cerone<br>5 C Cycocel | $GA_3$ → ½A<br>Cycocel → ¼A<br>Cerone → Sp | - |
| Total nitrogen applications | 160 | 80<br>160 | 120 | 100 | 60 | 120 |
| Drill | Øyjord | Øyjord | Øyjord | Øyjord | Øyjord | Øyjord |
| Previous crop | WW | WW | WW | WW | 2nd Early Pots | WW |
| Data collected | 1258 | 1258 | 123578 | 1258 | 12345678 | 258 |

1 = GA data
2 = Final harvest yields
3 = Rooting studies
4 = Neutron probe
5 = Grain nitrogen analysis
6 = Primordia development
7 = Tiller ringing
8 = Seed separation

**Table 6** Field trial details — Rothwell

| Parameter | Trial: RPB 2 | RPB 3 |
|---|---|---|
| Location | Cabourne 8 | Longfield |
| Variety | Tipper<br>Igri | Tipper<br>Igri |
| Drilling date | 29/9/81 | 15/9/82<br>11/11/83 |
| Density seeds $m^{-2}$ | 200,300,400,600 | 330 (15/9), 380 (11/11) |
| Total N application ($kg\ ha^{-1}$) | 105,185,225 | 135 |
| Previous crop | Oil seed rape | Vining peas |
| Protection | Tilt MBC 19/4<br>Tilt 21/5<br>Cleaval 14/4 | Hispor 15/4<br>Tilt 18/5<br>Swipe 7/3<br>Cleaval MCPA 23/5 |
| Data collected | 1,3,4,5,6 | 1,2,3,4,5,6 |

1 = Plant establishment
2 = tiller counts
3 = Yield
4 = Grain nitrogen analysis
5 = Seed separation
6 = Final yield components

leaf blade and stem and/or leaf sheath. From ZGS 37 leaf areas were measured of the flag leaf, the penultimate leaf and remaining green leaf in each tiller category. After ear emergence, ear components were recorded in each hierarchical grouping. No measurements were made of awn area or length after ear emergence.

The number of vegetative and ear bearing tillers present in each category was recorded from ZGS 49 until ZGS 92.

The total green area material in each subsample category was measured using a Paton Industries Limited electronic Planimeter. Where necessary, leaves that had more than 25% senesced tissue were classified as dead (Littleton, 1971; Sergeant, 1978).

All material was dried, as categorized, to constant weight (80°C for 48 hrs). The remainder of the harvested material not used for full analysis was also dried and weighed.

In 1981 all main culms in the subsample were assessed for internode length, internode area and internode weight after ZGS 59. In 1982 selected treatments were monitored for internode area and dry weight from ZGS 49 until ZGS 92. All ears removed from plant samples during grain filling were monitored for their number of grains per ear in each tiller category. Hence the range of grain numbers per ear could be assessed.

All subsample values were mathematically corrected for the whole of the harvested area and subsequently expressed as data per $m^2$ or per plant.

In WB6 from ear emergence until final harvest plants were removed from the inner rows of each plot at 3 or 4 day intervals. Ears from five plants were divided into mainstem, CT, TI and "others". Awns were trimmed from each ear and the rachis removed before each ear category was oven dried and then weighed. No record was made of grain number per ear at each harvest, thus for assessment of mean grain weight at each time it was assumed that the number of grains per ear was equivalent to the mean number found at final harvest.

At the final harvest date plants were also removed from the southernmost row in each plot for mean grain weight determination.

### 2.2.1 Final harvest growth analysis

The fixed tiller sites within each plot were harvested by hand before combining commenced.

In the laboratory, plant numbers were counted. The sample was subdivided with a minimum of twenty plants being retained for full analysis. Total stem numbers and ear numbers were recorded on the remainder. Roots were removed and the straw and ear components dried separately to a constant dry weight.

The working sample was subdivided into tiller categories. Each hierarchy was subdivided into straw and ear components which were oven dried for 48 hours. After weighing, the ear fraction was divided into awns, rachis, unfilled grain and filled grain. These were again oven dried and weighed. Grain numbers were counted from each tiller category using a Decca Mastercount electronic seed counter.

Seed size separation was carried out on oven dried seed samples using Sortimat equipment with slotted sieve sizes of 2.8, 2.5 and 2.2 mm. The grain in each size classification was again weighed then counted.

Thousand grain weight determination was undertaken on replicated samples of at least 3000 seeds. Grain from the combine harvested sample was oven dried then counted. Thousand grain weight values are expressed at 0% moisture content (mc) unless otherwise stated.

### 2.2.2 Grain weight within the ear

In experiment WB1 all mainstem ears from the final harvest assessments and from another replicated harvest site were subdivided into 3 regions; the basal 6 grains (excluding the two grains adjacent to the collar), the apical 6 grains and the mid section of the ear. All grains in each section were removed from the rachis, counted, oven dried and then weighed.

In PGR1 a detailed analysis of grain weights along the ear was undertaken. Paired grains were removed from harvested mainstem ears commencing from the basal region of the ear. Equivalently positioned paired grains from 10 ears were dried and weighed for a mean grain weight in each grain position to be calculated. Variations in the numbers of grains per main ear resulted in unequal numbers of grains being present from each numbered position towards the uppermost regions of the ear. The unequal ear sizes also resulted in pairs of grains being removed from the middle regions of a large ear being pooled with top grains from a small ear.

### 2.2.3 Combine harvested yields

A measured area of each trial plot was used for combining. A Walter & Wintersteiger KG small plot combine harvester was used to give an indication of the total grain yield. The outer rows of each plot were not removed from the harvest area.

After harvest, the collected grain from each plot was sampled to provide approximately 300 g for moisture content determination in the laboratory. The remainder of the grain was placed within a cotton bag, stacked with others and dried. After drying, the grain samples were weighed, subsampled and then cleaned on static equipment.

## 2.3 Fixed Site Analysis

Within one week of drilling, permanent sites were marked out within each plot in all trials. Three one-third of a metre (3 x $\frac{1}{3}$m) adjacent lengths of row were designated as tiller count sites by means of white plastic marker pegs. These sites were monitored regularly throughout the growing season for stem number determination and, immediately prior to harvest, for ear number determination. These marked sites were used as the final harvest growth analysis areas harvested just prior to combining.

Fixed sites within selected treatments of experiments PGR1 and WB6 were used to monitor tiller growth from ZGS 21 until final harvest. Emerging tillers were permanently marked by the use of coloured wire rings that were positioned about the tiller and its subtending leaf. The use of these monitored sites for assessment of tiller production allowed increased reliance to be placed on the growth analysis determination of tiller production and tillering patterns.

### 2.3.1 Tiller development

Plants of the Gramineae are characterized by a set ontogenetic pattern of tillering where, under optimal conditions, tillers are produced in a strict order on the main shoot. Tillers arise from a bud situated at the base of a leaf. Thus the production of leaves directly determines the production of tillers (Mitchell, 1953). Those tillers designated as first order or primary tillers originate from the buds of the main shoot leaves and are termed T1, T2, T3, etc. depending upon the leaf of their origin. The tiller which develops from the axillary bud at the base of the coleoptile is called the coleoptile tiller (CT).

The primary tillers have the potential to produce tillers in the axils of their leaves. These are termed second order or secondary tillers. Thus the tiller arising from the bud in the axil of the prophyll is termed T11, the tiller that develops from the bud in the axil of the first leaf of the first tiller is termed T1(1). As time progresses tertiary and quarternary tillers may be so produced. Within each order each tiller is capable of producing its own progeny thus the resulting group of tillers can be termed a tiller family or hierarchy.

Therefore at any time in the growth and development in a crop, the individual plant is composed of a collection of tillers from several different orders, which thus represent a wide range of tiller ages.

Figure 1 shows the pattern of morphological development. The notation follows that of Mitchell (1953) and of Colvill (1978), except that tertiary tillers bear the notation Xa→z depending upon the leaf from which the tiller arises, e.g. the first tiller of T1(1) (the secondary tiller arising from the first leaf of the first tiller on the mainstem) is termed T1(1)a.

## 2.4 Lodging

Severity of lodging, where present, was quantified by visual assessment of each plot at weekly or more frequent intervals. Lodging scores obtained ranged from 0 (erect) to 10 (uniformly flat).

## 2.5 Row by Row Analysis

In experiment WB6 (Table 5), it was noted that the plants in the outer rows of each plot were dissimilar to those within the drilled plot area. At anthesis, when lodging occurred within the inner rows of the trial plots, the outer rows were still erect.

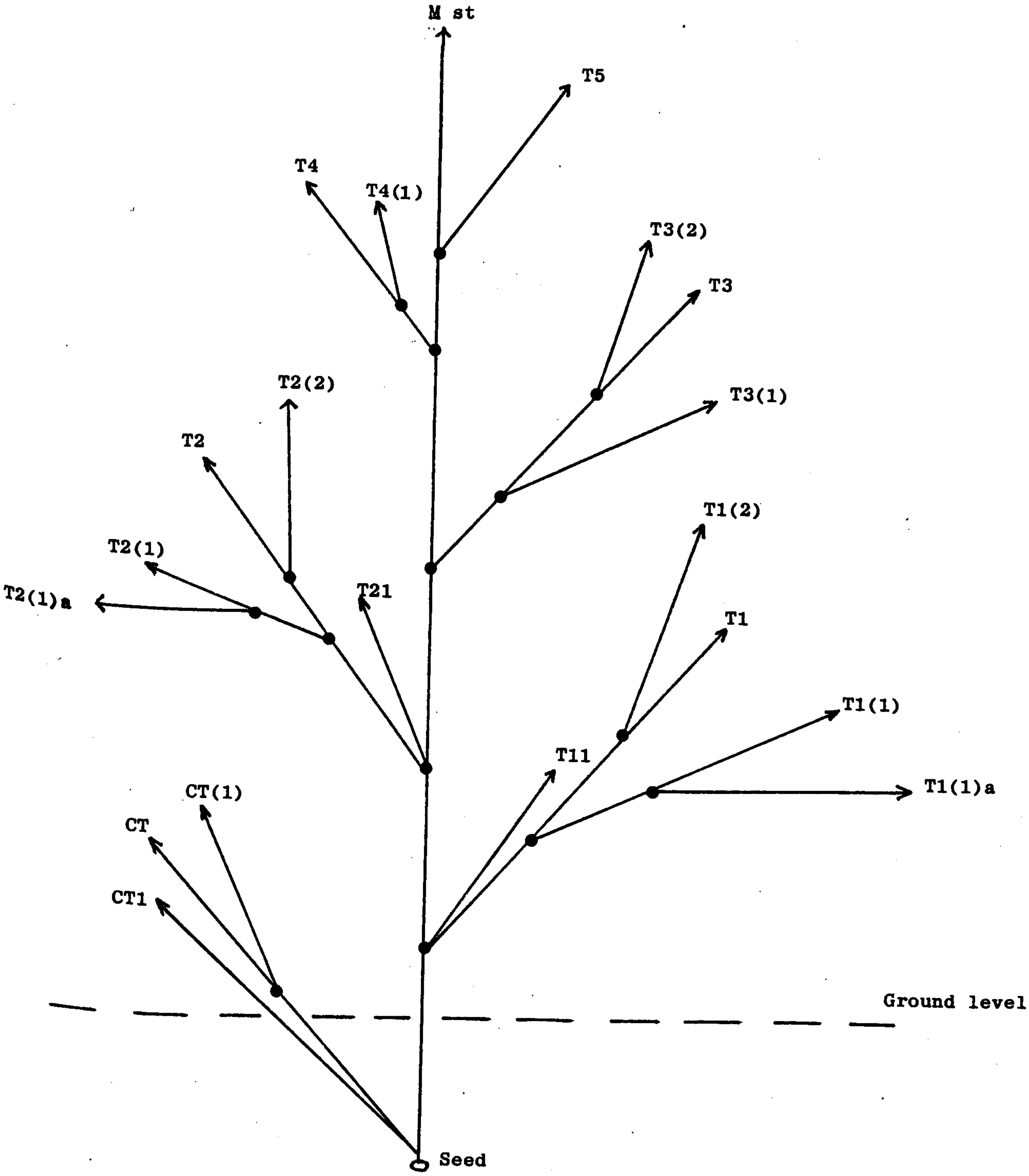
Hence at final harvest, it was decided to harvest adjacent 1 metre lengths of row across each of the three trial discards.

**Fig. 1** The pattern of tiller development in the cereal plant (after Colvill, 1978)

Plants represented with internodes elongated (after Mitchell, 1953)

<u>Key</u>:

| | | |
|---|---|---|
| mst | = | main stem |
| T1 - T5 | = | primary tillers |
| T11 - T41 | = | secondary tillers |
| T1(1)a | = | tertiary tiller |
| CT | = | coleoptile tiller |
| ← | = | tillers |
|  | = | leaf position |


M st
T5
T4
T4(1)
T3(2)
T3
T3(1)
T2(2)
T2
T2(1)
T2(1)a
T21
T1(2)
T1
T1(1)
T11
T1(1)a
CT(1)
CT
CT1
Ground level
Seed

The plant number, tiller number and yield components were obtained for each separate row within each plot. Each discard plot was taken as a block for the purpose of computer analysis of the results. Results and discussion for this investigation are presented in the Appendix.

## 2.6 Root Measurements

### 2.6.1 Root dry weight measurements

Measurements of root dry weights were obtained by taking soil cores from which the roots were subsequently washed. Soil cores were extracted from the trial using 10 cm diameter jarrot auger, supplemented due to excessive stones in a band at 30-60 cm, by a Dutch auger. Samples were taken from experiments PGR1 at 2 weeks post-anthesis of the crop in June 1982. Twenty centimetre depth increments were extracted to a maximum depth of one metre. These samples were stored for a maximum of two months in a 5°C room, prior to extracting the plant roots.

Roots were separated by a combination of filtration and sedimentation to remove extraneous materials. The soil was initially washed through a fine (28 mesh) sieve. The roots, organic debris and larger soil particles being retained. The amount of root washed through the sieve was observed to be negligible. To speed the separation of roots from the clay soils of deep layers, the soil samples were immersed in a solution of "Calgon" (Sodium hexameta phosphate) for 48 hours to disperse the clay particles, thus facilitating the passage of soil through the sieve. Roots from the previous crop and those from the current crop could be distinguished by their appearance (Weaver, 1926); the live roots being lighter in colour and fleshier in texture were retained, the dead roots being darker and more brittle were discarded. Non-root organic material was removed with fine tweezers. Root dry weight was then determined for each 20 cm of the profile.

### 2.6.2 Root staining

Soil cores, to a maximum depth of 50 cm, were taken with a jarrot auger in November 1982 from the WB6 trial. The root samples were taken at a time corresponding to the maximum external changes induced by the applications of gibberellic acid (Batch et al., 1980). Further soil cores to 1 m depth were taken post anthesis.

The soil samples were washed over a fine mesh sieve. Inorganic matter was removed by sedimentation. Large pieces of extraneous organic matter was removed with the use of tweezers. The resulting cleaned root sample was then immersed for 30 minutes in a 5% solution of fluorescein diacetate. After a suitable time for dye uptake, roots were washed on a 200 µm sieve for about 30 seconds. They were then floated onto a 50 x 30 cm pre-flooded tension table (Clement, 1966), which was fitted with a black sugar paper filter. Care was taken to distribute the roots as evenly as possible prior to adding suction pressure. The roots were then examined under ultra violet (UV) lights. The UV light source used was a short-wave (254 nm) low pressure mercury vapour discharge tube (Camlab UVS54 Mineralight). A Photographic record was made of the root distribution.

The length of fluorescent roots recorded on the photographs was estimated by projecting the negative obtained onto a series of parallel lines spaced a known distance apart and counting the number of roots which intersected the lines (Newman, 1966).

For complete details of the fluorescent-dye technique for measuring root length see McGowan, Armstrong and Corrie (1983).

### 2.6.3 Measurement of soil water content

The neutron scattering technique was used to measure the volumetric soil water content at 10 cm increments throughout the soil profile. A modified version of the Wallingford Neutron Probe (Bell, 1969) was used. The probe consists of a source of fast neutrons (50 mCi amercium/beryllium) surrounding a detector of slow neutrons (boron trifluoride). Fast neutrons are slowed down by elastic collisions with atoms of low atomic weight such as hydrogen, which is present in soil water. Thus the density of the slow neutron cloud surrounding the fast neutron source is related to the amount of water present in the soil.

Visvalingham and Tandy (1972) showed that the intensity of the cloud is influenced by the soil water content within 10-20 cm of the emitting source. A boron trifluoride detector is used to measure the slow neutron cloud density. The detector is in turn connected to a rate scaler. The count rate was recorded over a period of 16 seconds.

Aluminium access tubes (4 cm inner diameter, 0.3 cm wall thickness) were placed in the centre of specific plots in early spring. The

1.25 m tube allowed the neutron probe source to be lowered to the required depth in the soil. Care was taken to minimize the disturbance between the inserted tube and the surrounding soil.

## 2.7 Seed Size Separation

Replicated 100 g seed samples were separated by size using a Sortimat automatic seed separator (Sortimat laboratory screening machine, Typek, Franz Pfeuffer Apparateebau).

Sieves were used of slot size 2.8, 2.5 and 2.2 mm. The machine was operated for 4 minutes, thus causing the seeds to be divided by size into 4 size categories. Whole seed numbers and oven dried grain weights were noted for each size classification.

The proportion of large grains in a sample, measured as those retained on a 2.8 mm sieve, is closely related to the thousand grain weight and gives a rough indication of grain filling. As sieving characteristics are influenced by grain moisture content, valid comparisons can only be made when samples are dried to a similar level prior to testing (Bayles, 1976).

## 2.8 Grain Nitrogen and Hot Water Extract (HWE)

The nitrogen content of all grain samples from trials taken through to harvest were assessed using the Technician Industrial Systems Limited "Infralyser" calibrated against samples manually analysed using the Kjeldahl digestion method (Association of Official Agricultural Chemists, 1965). Nitrogen concentration of grain samples from experiment PGR1 were determined by using the Kjeldahl digestion method.

Hot water extract figures for all grain samples were obtained from Nickerson R.P.B. Ltd.

## 2.9 Germination Tests

Germination tests on the combined sample were carried out within six weeks of final harvest and again approximately six months post-harvest.

Replicated samples of 100 seeds from each plot were placed on a sand substrate. The water level used for the tests was 50% of the water holding capacity of the sand which was 21-22%. This was achieved by adding 5785 ml of water to 50 kg of sand, prior to planting of the grain. The grain was evenly positioned onto approximately 13 mm of damp sand and covered with a similar layer of the same material. Each test tray was enclosed within a clear plastic bag. All trays were pre-chilled in darkness at 4°C for 4 days and subsequently moved to a 20°C growth room with a 16 hour photoperiod. After 7 days, the tests were terminated and seedlings classified as normal, abnormal or non-germinating (Abrol, 1978). The oven dried weights of the normal harvested seedlings were then determined.

## 2.10 Resown Trial 1981-1982

After the harvest of WB1 all grain was dried in cotton bags by the forced passage of air. Two kilograms of grain from each replicated plot were pooled together and well mixed. This bulked sample was then subdivided using an Endecott multi-slot sample divider (Endecott, London) until a suitable sized sample was reached. Plot density of 400 seeds $m^{-2}$ , irrespective of year one seed size distribution, were drilled for each of the year one treatment combinations under test.

Øyjord drilled plots were created on 20 September 1981 adjacent to PGR1. All husbandry treatments were similar to those in WB5 with nitrogen treatment N2.

At final harvest two areas each of 3 x $\frac{1}{3}$m lengths of row were taken from each plot. Data was analysed by analysis of variance although due to the lack of replicated blocks accurate error values were unobtainable.

## 2.11 Rothwell

In two of the three years, trials were conducted at the experimental ground of Nickerson R.P.B. Ltd. Experimental details can be found in Table 6. All field operations were undertaken by staff of Nickerson R.P.B. Ltd. No growth analysis sampling was possible due to the limited plot size. At final harvests in 1982 and 1983, the tiller count areas were removed and final harvest yield components determined in the laboratory.

### 2.11.1 Meterological data

All meterological data pertaining to the experiments at Rothwell were obtained from Binbrook RAF Station, a maximum distance of 8 kilometres from the field sites. The climatic data obtained from Binbrook may not accurately portray the Rothwell field conditions, as the similarity in aspect and elevation between the meterological site and the field site was limited.

# Chapter 3

# THE EFFECTS OF VARIETY, DENSITY AND NITROGEN TREATMENT ON THE GROWTH AND DEVELOPMENT OF THE WINTER BARLEY SEED CROP

## 3.1 Introduction

The initial experiment WB1 was undertaken to investigate the use of various husbandry practices as means of crop manipulation with the aim of optimizing seed production from winter barley. The growing crop was also used to quantify growth and development.

### 3.1.1 Experimental design and procedure

This factorial experiment with inputs of variety, density and nitrogen timings was replicated 3 times in a randomized block design. Further trial details are as in Table 5. The nitrogen treatments, all with an applied nitrogen total of 150 kg $ha^{-1}$ N, are outlined in Table 7.

The crops were monitored at frequent intervals. The time between harvests ranged from monthly in mid winter to every 7-10 days in the summer. From 225 DAS only one nitrogen regime was monitored (N2). The middle density plots (initial seed rate of 450 seeds $m^{-2}$) were not monitored from 225 DAS to allow maximum data to be obtained on the extreme density treatments.

All harvested samples, except harvest 1 where all plants were analysed, were subsampled on a plant number basis with usually 25 plants being taken as the working sample. This thus resulted in a lower percentage of the high density plants sample being analysed compared to the low density samples.

## 3.2 The Effects of Variety

Two winter barley varieties were monitored in WB1. These were Igri, a well established, high yielding, 2 row feed barley, and Tipper, a relatively new 2 row barley with moderately good malting quality. Both varieties received additional inputs at similar times irrespective of their differences in growth habit. Timing of inputs depended upon the growth of the more advanced variety or upon the need to prevent a build-up of disease or pest infestation within the crop.

**Table 7** Nitrogen treatments used for experiment WB1 (kg $ha^{-1}$)

| kg $ha^{-1}$ | Seedbed | 27/1/1981 | 6/4/1981 |
|---|---|---|---|
| N1 | 40 | 30 | 80 |
| N2 | 0 | 100 | 50 |
| N3 | 0 | 50 | 100 |

### 3.2.1 The effect of variety on tiller hierarchies

The number of stems present per plant varied with time and with variety. Igri reached a maximum of 6.95 stems per plant at 191 DAS (16 February 1981) whereas Tipper reached its maximum value of 3.9 stems per plant as early as 48 DAS (5 November 1980) (Fig. 2). Igri lost nearly 50% of its stems before maturity at which time it had 3.7 stems per plant. Tipper maintained the majority of its stems through until harvest with 3.20 stems per plant being present at the final count.

The categories of tillers that contributed to this number are summarized in Fig. 3(i) and Fig. 3(ii) for Tipper and Igri respectively. These figures are for individual varieties but for pooled densities. The interactions between variety and density are outlined in section 3.3.2.

Throughout growth the T1 tiller predominated in both varieties with over 90% of plants having this primary tiller. Significant differences occurred between varieties in all other monitored tiller categories. However the large amount of early and mid season production of tiller categories CT, T11, T21 and T4 in Igri resulted in small amounts of these tillers being present at final harvest.

Prior to maturity Tipper had a higher proportion of plants with the CT tiller. Throughout growth approximately 45% of plants possessed this tiller although at final harvest less than 25% of the plants present had the CT. The percentage of mature Igri plants with the CT was similar but the percentage of plants prior to maturity with a CT was less than that of Tipper.

The only secondary tiller to have been present in large numbers in both varieties was T11. Tiller T21 was noted in approximately 25% of the plants in the variety Igri but was seldom present in Tipper. At least the first four main primary tillers were present at peak tillering in Igri on more than 75% of all plants. However in Tipper at a similar time after sowing (151 DAS) no T4 tillers were present and less than 10% of plants possessed a T3 tiller.

### 3.2.2 The effect of variety on leaf area index

The varieties did not differ in their total green area indices (GAI) pattern over time. The variety Igri showed later maturity with the variety

**Fig. 2** The varietal difference in stem number per plant (WB1)

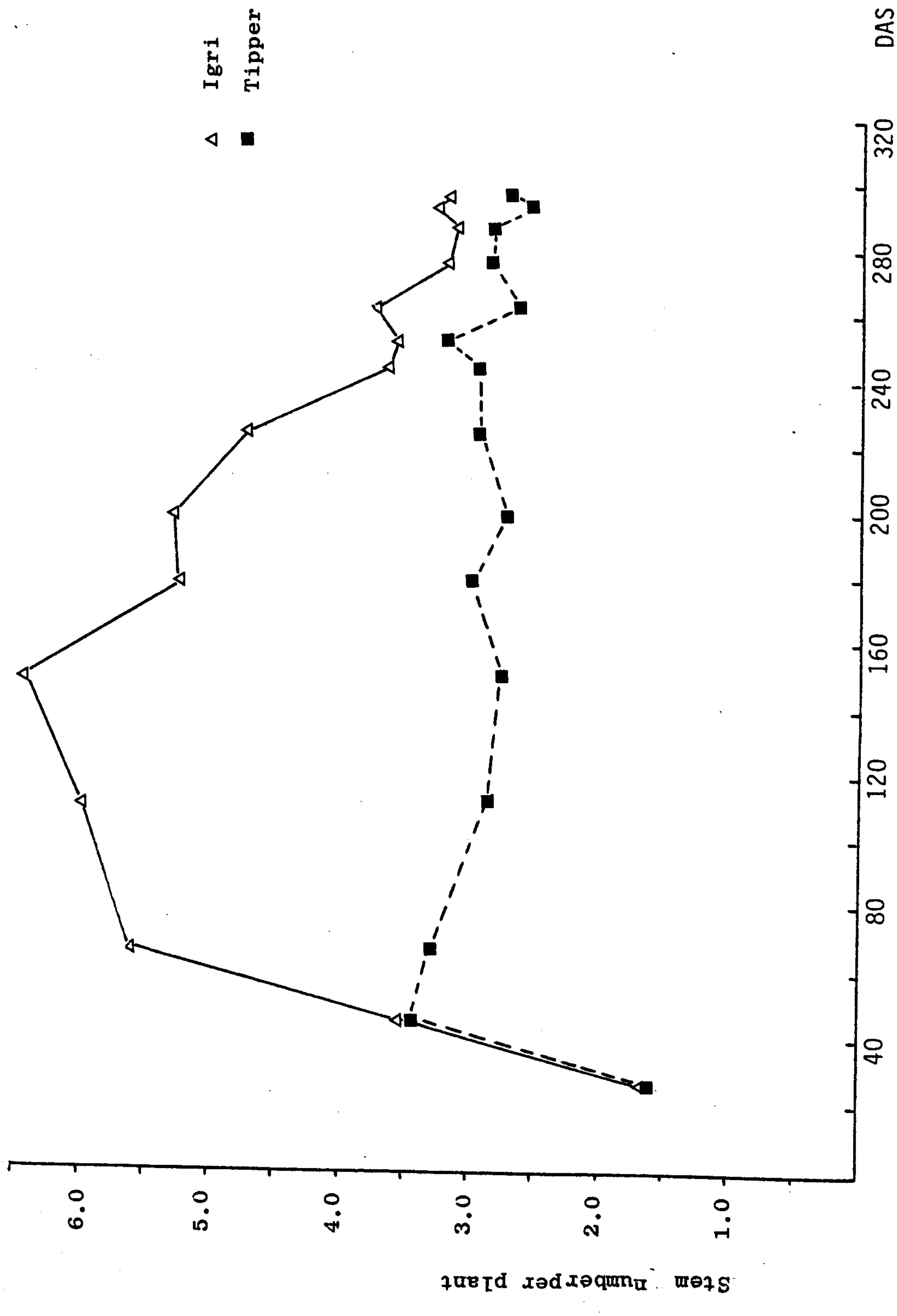
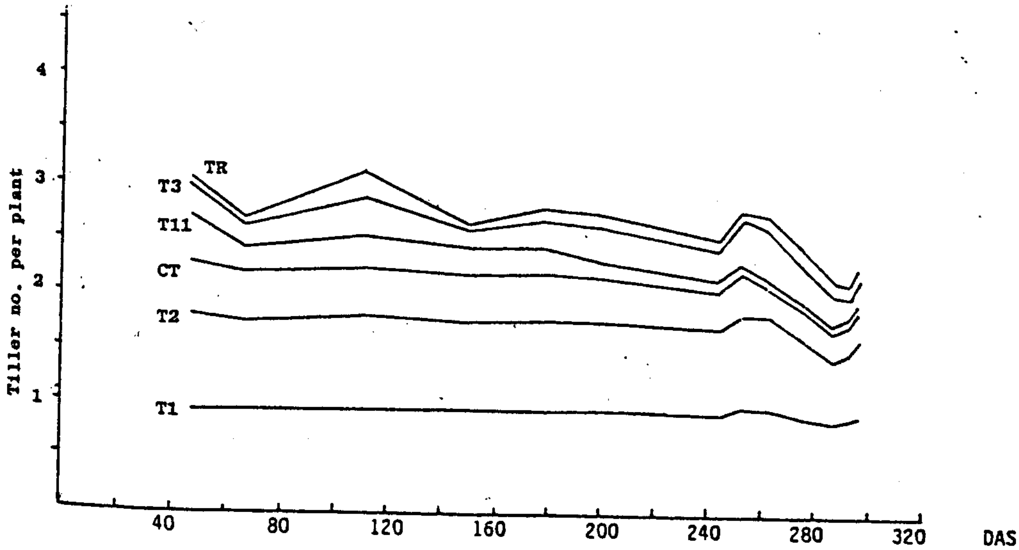

Stem numberper plant
6.0
5.0
4.0
3.0
2.0
1.0
40
80
120
160
200
240
280
320
DAS
Igri
Tipper

**Fig. 3** The contribution of individual tiller categories to total tiller number

i Tipper

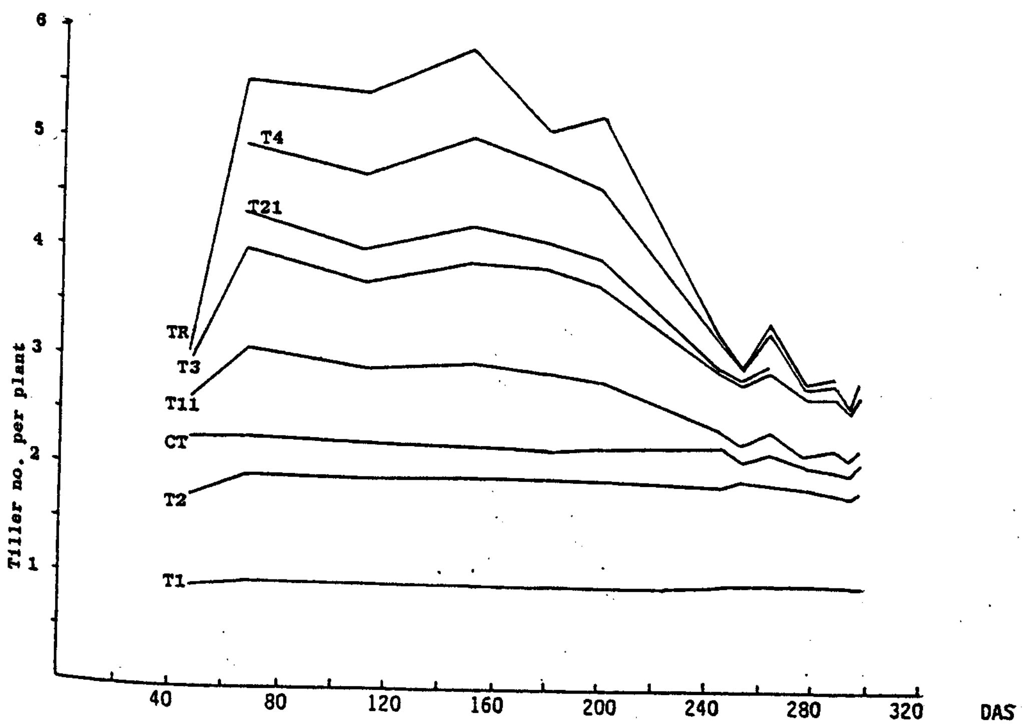
ii Igri

i)



Tiller no. per plant
4
3
2
1
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
320
DAS


ii)



Tiller no. per plant
6
5
4
3
2
1
T4
T21
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
320
DAS

having a GAI of 3.7 and Tipper a GAI of 1.8 at 277 DAS, 28 days before combine harvesting (Fig. 4). Tipper commenced stem extension prior to Igri with an increased GAI at 151 DAS (16/2/81) and 179 DAS (16/3/81) due to the advanced growth. Although not significant the peak GAI and LAI were smaller in Tipper than in Igri (Fig. 4). Both varieties reached a LAI of 1 within one month of crop emergence and maintained a LAI of below 3 throughout the winter (until 151 DAS) after which time the spring production of leaves and stem extension caused a rapid increase in both LAI and GAI (data not presented).

The contribution of various tiller categories to total plant green area are outlined in Fig. 5. The contribution of the main stem to total crop area differed between varieties. The main stem (mst) of Igri contributed approximately 30% of the plant's green area during most of its growth. Within the variety Tipper over the same period of time the contribution varied from 45% to 32% of the total green area. The T1 tillers increased in percentage contribution upon the onset of senescence of the mainstem. In Igri the T1 contribution ranged from 21% to 30% depending upon the stage of plant growth. The varieties differed in the contribution by late primary and secondary tillers to the total green area with Igri having a high level of dependence on these later formed tillers. In both varieties rapid senescence of the mainstem occurred prior to the senescence of the primary tillers and thus its percentage contribution to the measured green area decreased.

The leaf area ratio (LAR), the specific leaf area (SLA) and the leaf weight ratio (LWR) were assessed throughout the plants' growth. LAR is defined as the ratio of total leaf area to whole plant dry weight. Thus LAR represents the ratio of photosynthesizing to respiring material within the plant. Specific leaf area (SLA) is the mean area of leaf displayed per unit of leaf weight. LWR is an index of the leafiness of a plant on a weight basis. Both the LAR and SLA figures (Fig. 6) (data for LAR only presented) show variability throughout the season. The highest LAR values for both varieties were obtained in November less than 70 days after drilling. Thus the area of the plants was increasing but the total plant weight increase was not at the same rate. LAR decreased from this peak to a level of approximately 100 cm $g^{-1}$ by mid February corresponding to the onset of stem elongation. Post ZGS 31 the LAR increased again reaching a second

**Fig. 4** Green area index (GAI) — varietal differences

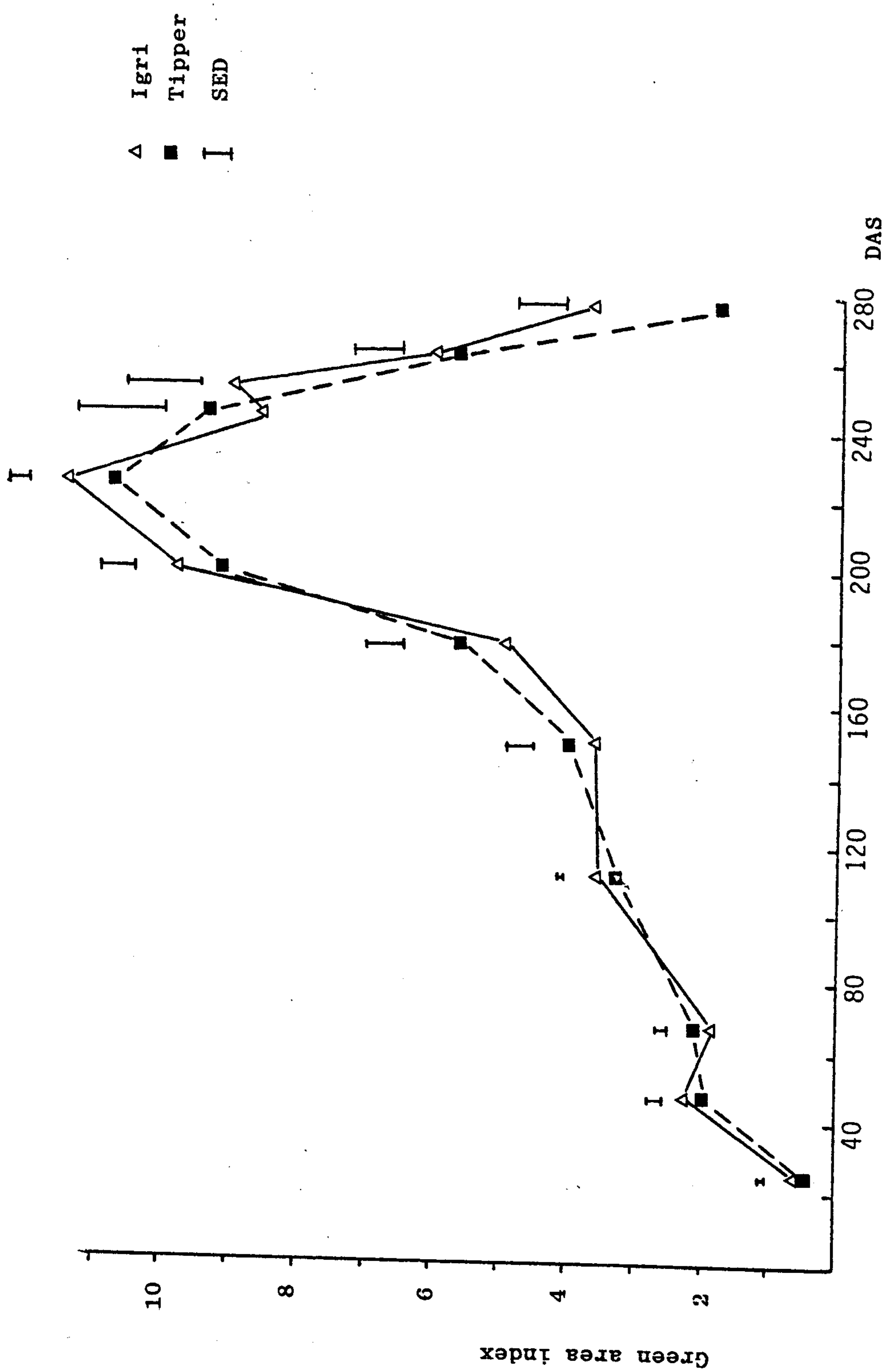
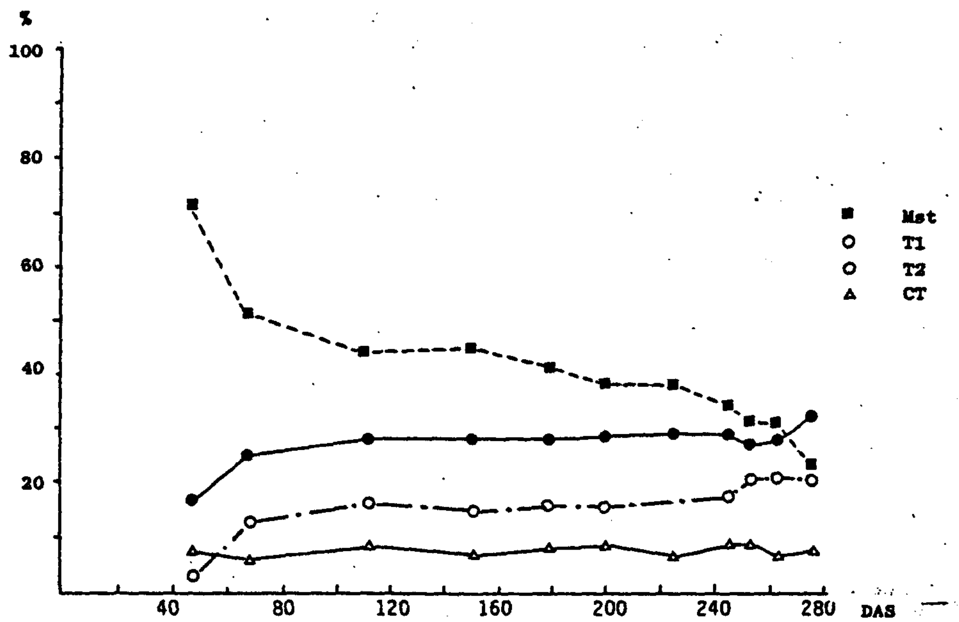

Igri
Tipper
SED
Green area index
2
4
6
8
10
DAS
40
80
120
160
200
240
280

**Fig. 5** The contribution by various tiller categories to total plant area

i Tipper

ii Igri

(i)


%
100
80
60
40
20
40
80
120
160
200
240
280
DAS
Mst
T1
T2
CT

(ii)

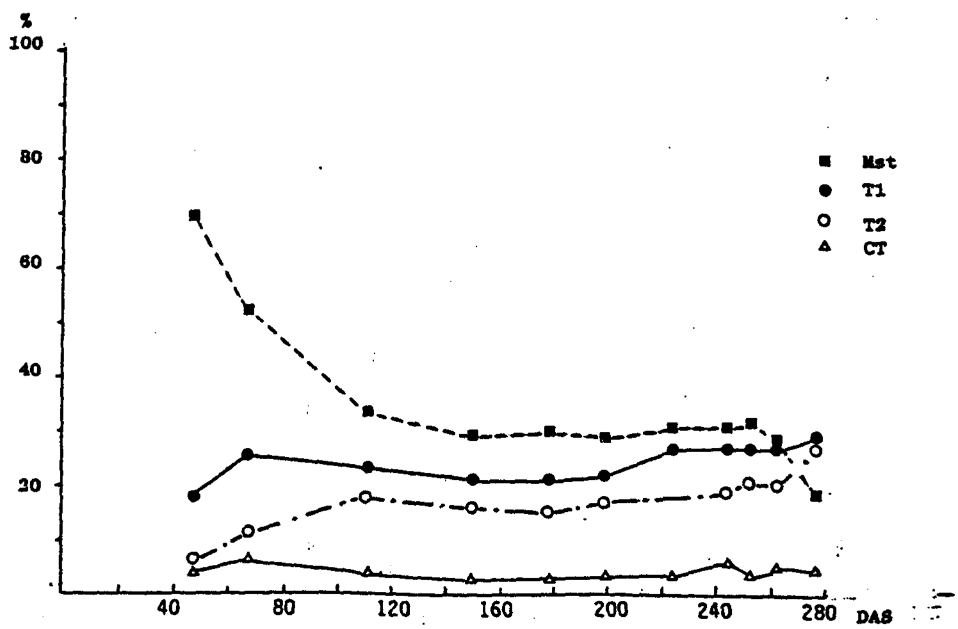
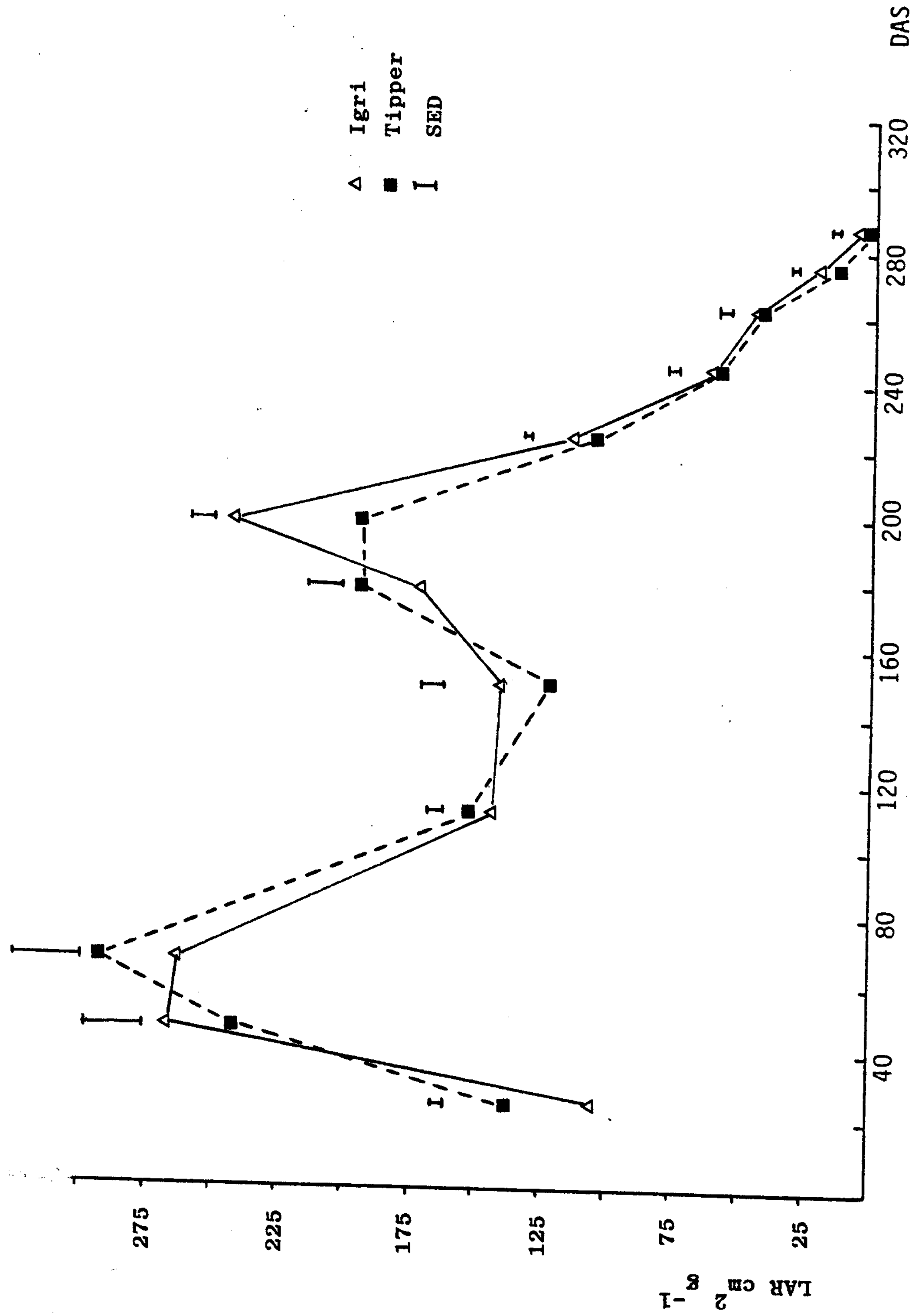

%
100
80
60
40
20
40
80
120
160
200
240
280
DAS
Mst
T1
T2
CT

**Fig. 6** The influence of variety on leaf area ratio


Igri
Tipper
SED
DAS
40
80
120
160
200
240
280
320
LAR cm2 g-1
275
225
175
125
75
25

peak value of 244 cm $g^{-1}$ for Igri and 196 cm $g^{-1}$ for Tipper at 200 DAS (6/4/81). After this date the LAR decreased at a similar rate for both varieties due to the onset of senescence. LAR for both varieties reached zero by 280 DAS.

SLA followed a similar pattern to that of LAR. SLA peaked at 68 and 225 DAS for both varieties and decreased to a minimum value at 151 DAS. The varieties did not react similarly to environmental conditions post ZGS 31 (151 DAS). Here Tipper had significantly higher SLA values than Igri until 253 DAS when both varieties had decreasing SLA values.

The decline in LAR occurred before the decline in LAI. Thus LAR decline may have been due to an increase in dry matter in plant parts and not a decrease in green area of the leaves. Hunt (1981) suggested that SLA is sensitive to environmental change and prone to ontogenetic drifting. The reasons for the reduced values for SLA at 151 DAS were difficult to elucidate. Some increase in leaf weight may have occurred due to increased nutrient uptake with the onset of spring growth or the translocation of assimilates from the senescing leaves at the base of the crop canopy to the leaves still acting as sinks for assimilates prior to the commencement of their active spring growth.

### 3.2.3 The effect of variety on biomass

Igri and Tipper differed significantly in their final biomass yields with Igri having a higher yield (Fig. 7). However the biomass values of the two tested varieties were not significantly different for the majority of the plants' growth. From 277 DAS until final harvest at 297 DAS the biomass yield of Igri was above that of Tipper but this difference was not always significant. The biomass dry weight loss of over 2.5 t $ha^{-1}$ (Igri) and 2.4 t $ha^{-1}$ (Tipper) may have been attributable to the non harvesting of dead and shattered leaves and tillers, the loss of awns upon senescing and the removal of grains by birds. The accurate partitioning of this loss into loss of vegetative structures and grain was difficult. Table 8 gives an indication of the estimated weight of the grains lost. This value assumes no compensatory growth or increase in weight of the remaining grains on the ear. The estimated grain weight loss from Tipper was greater than 900 kg $ha^{-1}$. The higher value for this variety may have been due to its earlier maturity and thus its earlier attack by birds. Tipper also had large

**Fig. 7** Above ground biomass — the effect of variety

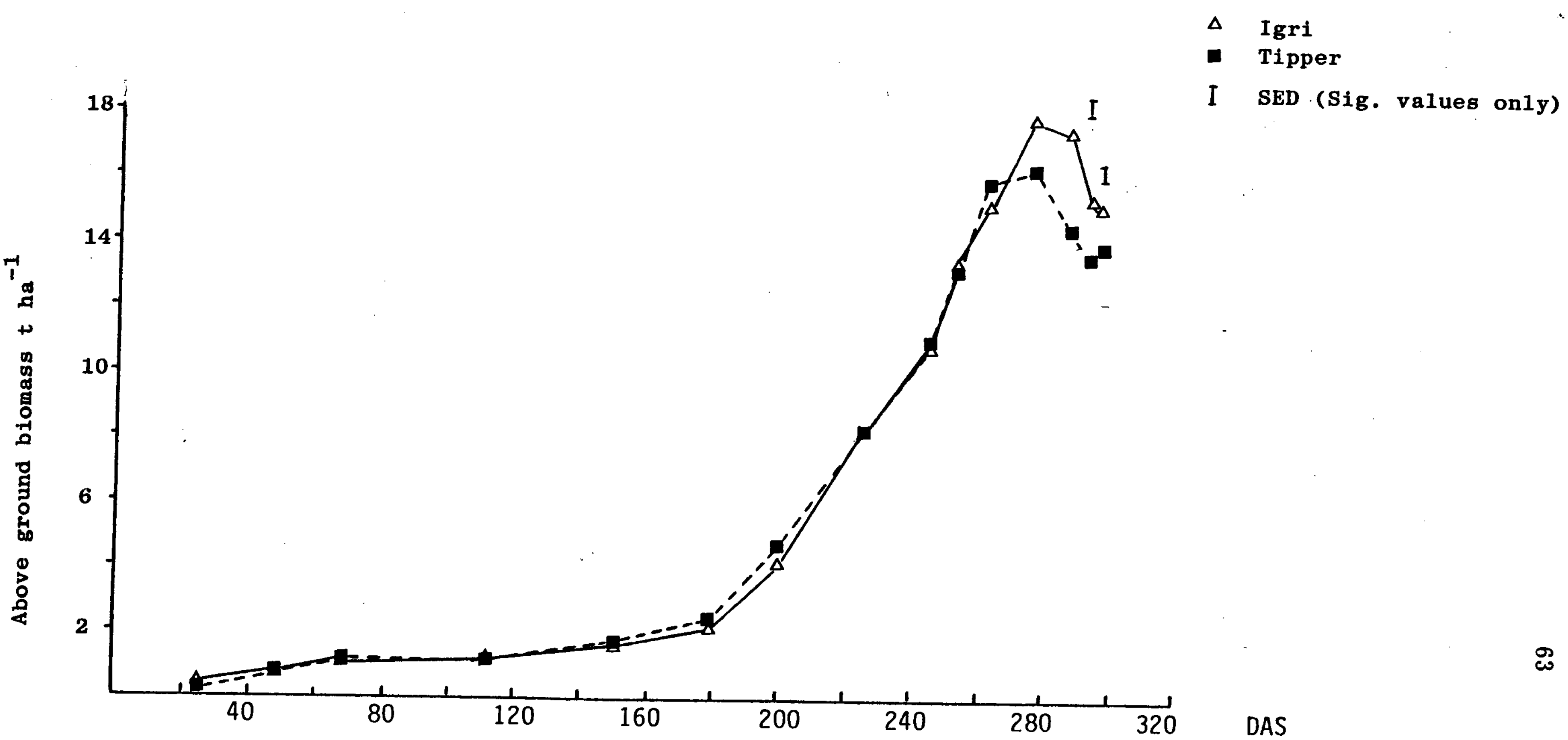

Above ground biomass t ha$^{-1}$
18
14
10
6
2
40
80
120
160
200
240
280
320
DAS
Igri
Tipper
SED (Sig. values only)

**Table 8** Estimated grain weight lost by missing grains

Effects of i) Variety ii) Density iii) Nitrogen

i)

| | Variety | | SED | Sig |
|---|---|---|---|---|
| | Igri | Tipper | | |
| Estimated grain weight loss kg $ha^{-1}$ | 776 | 908 | 81.6 | ns |

ii)

| | Density - seeds sown $m^{-2}$ | | | SED | Sig |
|---|---|---|---|---|---|
| | 350 | 450 | 650 | | |
| Estimated grain weight loss kg $ha^{-1}$ | 950 | 785 | 791 | 100 | ns |

iii)

| | Nitrogen treatments | | | SED | Sig |
|---|---|---|---|---|---|
| | N1 | N2 | N3 | | |
| Estimated grain weight loss kg $ha^{-1}$ | 978 | 776 | 772 | 100 | ns |

numbers of non-fertile grains. The reasons for this are not clear but the low mean weekly temperatures during late April and early May may have caused abnormalities in pollen or stigma formation which may have subsequently influenced grain fertilization.

Individual tiller categories contributed differing amounts to the total crop weight (Fig. 8). In both varieties the mst contributed most to the total crop weight. The amounts contributed depended upon the period of growth of each variety. During early growth (25/11/1980) the mainstem of both varieties contributed approximately 45% of the total plant weight. At final harvest the percentage contributions were 37% for Tipper and 35% for Igri. Tillers similarly varied in their contributions depending upon the variety and the period of growth.

A higher proportion of the total plant weight of Igri comes from late primary tillers and secondary tillers compared to the variety Tipper. In both Igri and Tipper the contribution of the coleoptile tiller to total plant weight was below 10% throughout growth. The percentage contribution to total plant weight at 151 DAS showed significant differences between the varieties when Igri had over 13% of its total weight contributed by lower order primary and secondary tillers whereas the contribution by these tillers in the variety Tipper was below 2%. After the onset of tiller death and stem extension at approximately 150 DAS the percentage contribution to total dry weight by the tiller categories T1 and T2 increased in Igri where tiller death was more acute.

### 3.2.4 The effect of variety on grain yield and yield components

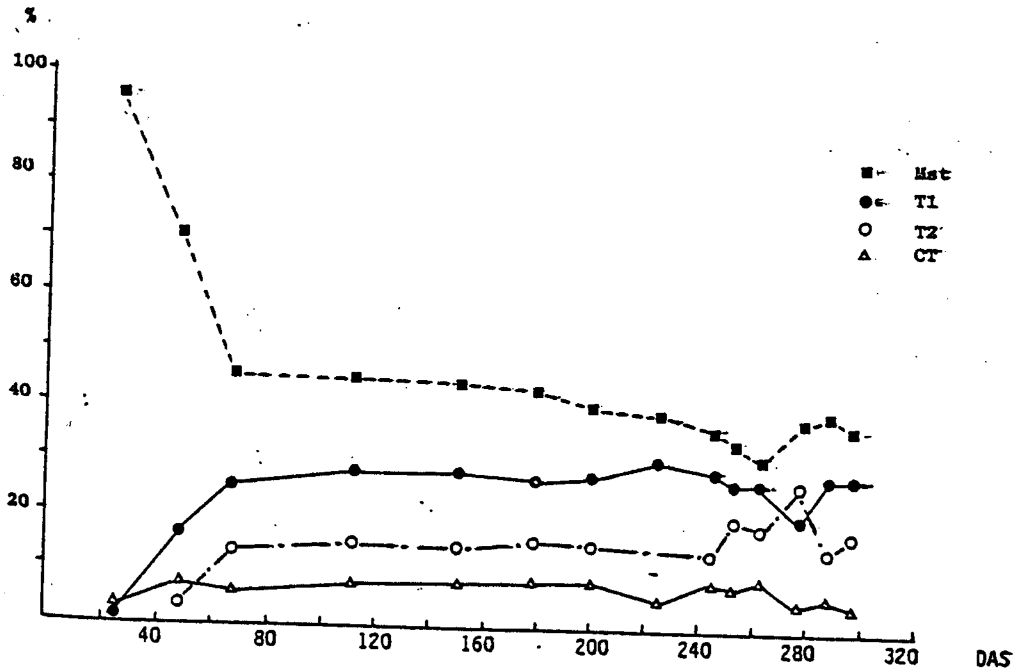
The tested varieties differed significantly in their harvested grain yield with Igri yielding over 1 t ha$^{-1}$ more grain than Tipper (Table 9). The components of yield also differed between varieties with Igri having more ears per unit area and a higher TGW but a lower potential number of grain sites per ear (Table 9). The value for potential grain number was estimated from the number of filled grains per ear plus the number of infertile or unfilled grains per ear plus the grain sites remaining from grain that had been removed. This value for the potential is not equivalent to the potential grain number estimated by apical dissection of the developing apex prior to commencement of floret death. Tipper had a higher number of possible grain sites within the emerged ear but also a lower TGW of those grains remaining.

**Fig. 8** The contribution by various tiller categories to total plant dry weight

i Tipper

ii Igri

(i)


%
100
80
60
40
20
40
80
120
160
200
240
280
320
DAS
Mst
T1
T2
CT

(ii)

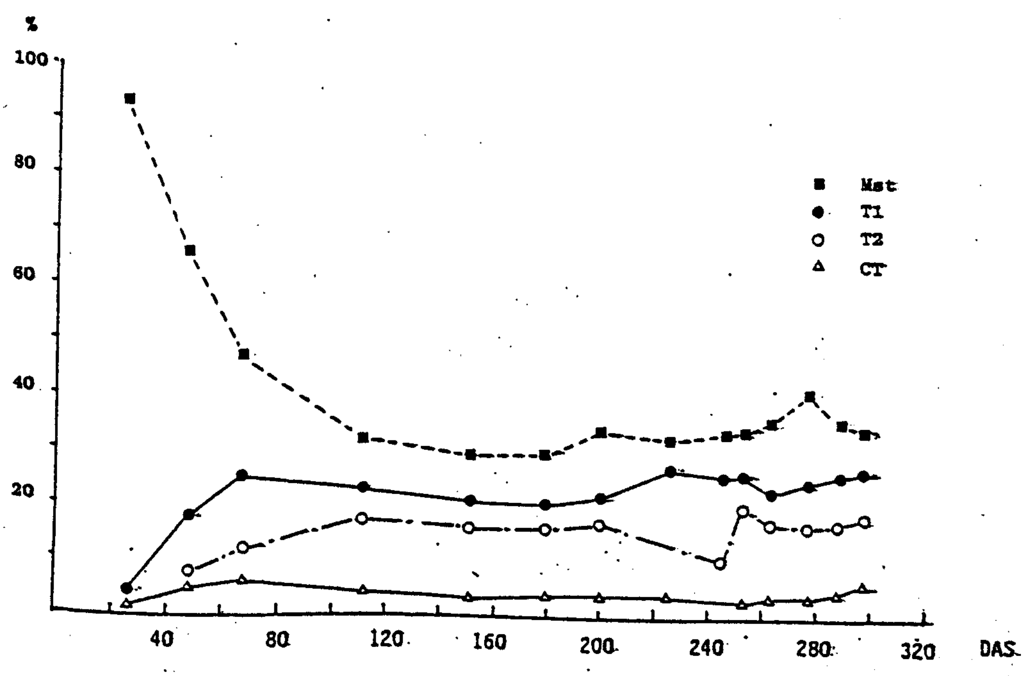

%
100
80
60
40
20
40
80
120
160
200
240
280
320
DAS
Mst
T1
T2
CT

**Table 9** The effect of variety on grain yield and yield components

| | Igri | Tipper | SED | Sig |
|---|---|---|---|---|
| Yield t $ha^{-1}$ 14% MC (combine wt.) | 8.58 | 7.38 | 0.205 | xxx |
| Ears per $m^{-2}$ | 981 | 842 | 35.3 | xxx |
| 'Potential' grain number $ear^{-1}$ | 24.31 | 30.53 | 0.651 | xxx |
| TGW 0% MC (combine sample) | 43.56 | 36.50 | 0.354 | xxx |
| Tillers per plant | 3.690 | 3.189 | 0.1045 | xxx |
| Biomass kg $ha^{-1}$ DM | 15291 | 13955 | 529.4 | x |

The number of filled grains per ear present on 270 main ears of each variety was noted. The proportion of the total number falling into each seed number category is shown in Fig. 9. The majority (75.4%) of the ears of the variety Igri have between 16 and 25 grains present. In Tipper a large range of grain numbers was present with 18% of ears having less than 10 filled grains present. The majority (58.3%) of the ears of this variety had more than 21 filled grains present.

Similar differences between varieties occurred in the T1 tiller ears (Fig. 9). In both varieties the proportion of ears with less than 10 grains per ear present was higher in the T1 tiller category than in the main ear and conversely the proportion of large ears, that is those with more than 25 grains per ear present, was lower in the T1 tiller.

The significant relationships between combine harvested grain yield and final harvest yield components are shown in the correlation matrix (Table 10). A diagrammatic representation of the relationships between components is shown in Fig. 10.

As has previously been found by many workers, improved grain yield was associated with improved above ground biomass yields. The variability of grain yield decreased with increases in final plant numbers (Fig. 11(ii)). Unlike the other experiments reported within this thesis there was no significant relationship between grain number $m^{-2}$ and grain yield. Here grain yield was strongly influenced by grain number per ear and mean grain weight.

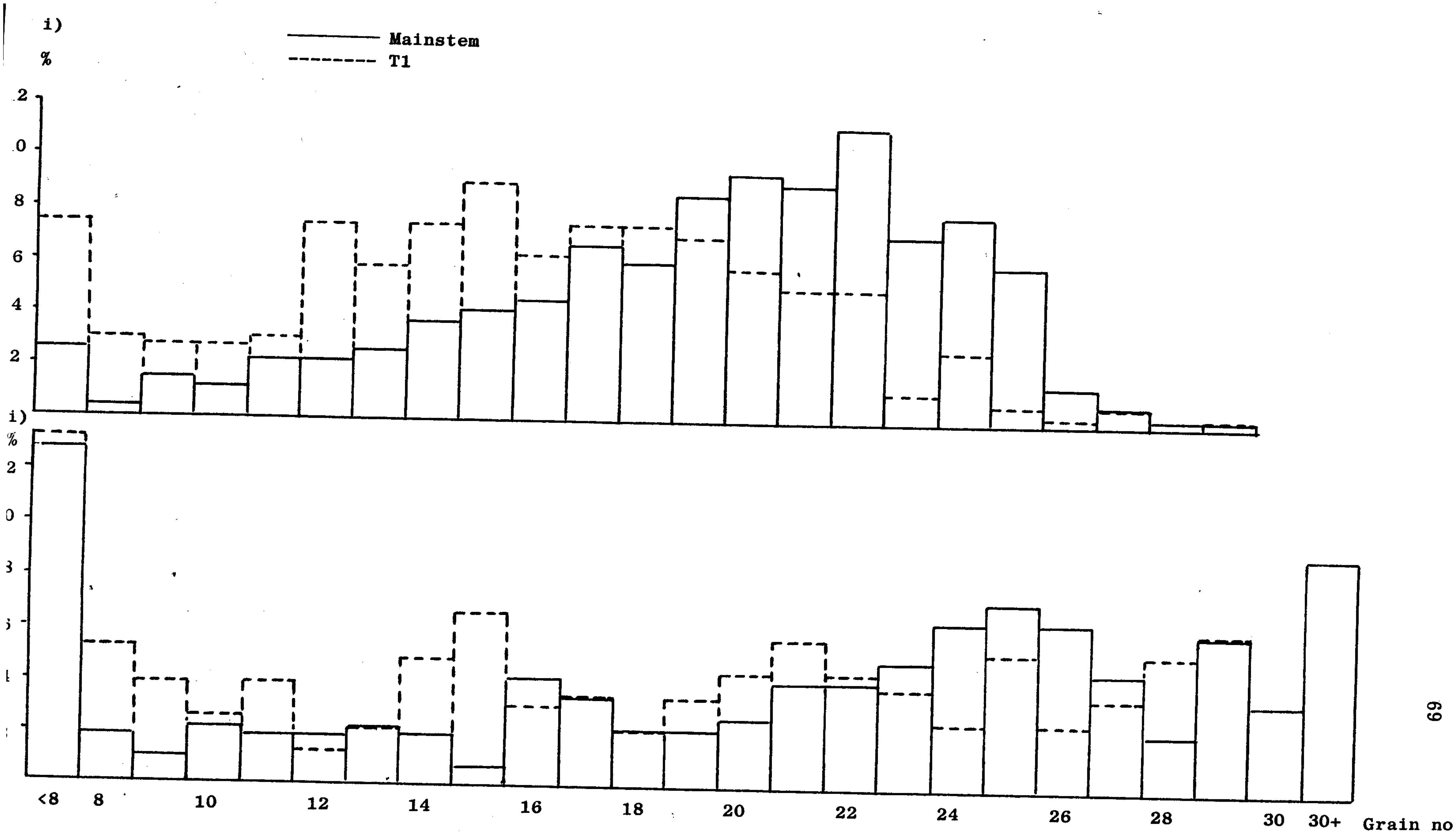
Previous work by McLaren (1981) showed that within any one environment there was little evidence that thousand grain weight was associated with yield other than through a genotype effect. Sergeant (1978) showed that in a range of wheat varieties there was a trend for the lower yielding crops to have slightly lighter grains. Kirby (1974) has demonstrated that a relationship exists between ovary size at fertilization and final grain weight. Thus if ovary size is influenced by crop growth then a crop which shows poor pre-anthesis crop growth will have smaller ovaries and hence lighter grain (Sergeant, 1978).

The mean grain weight of grains off the main culm is usually greater than the mean grain weight of grains from tiller ears (Darwinkel, 1978). At high plant densities a higher proportion of the ears present at

**Fig. 9** The distribution of grain number per ear as influenced by variety

i Igri

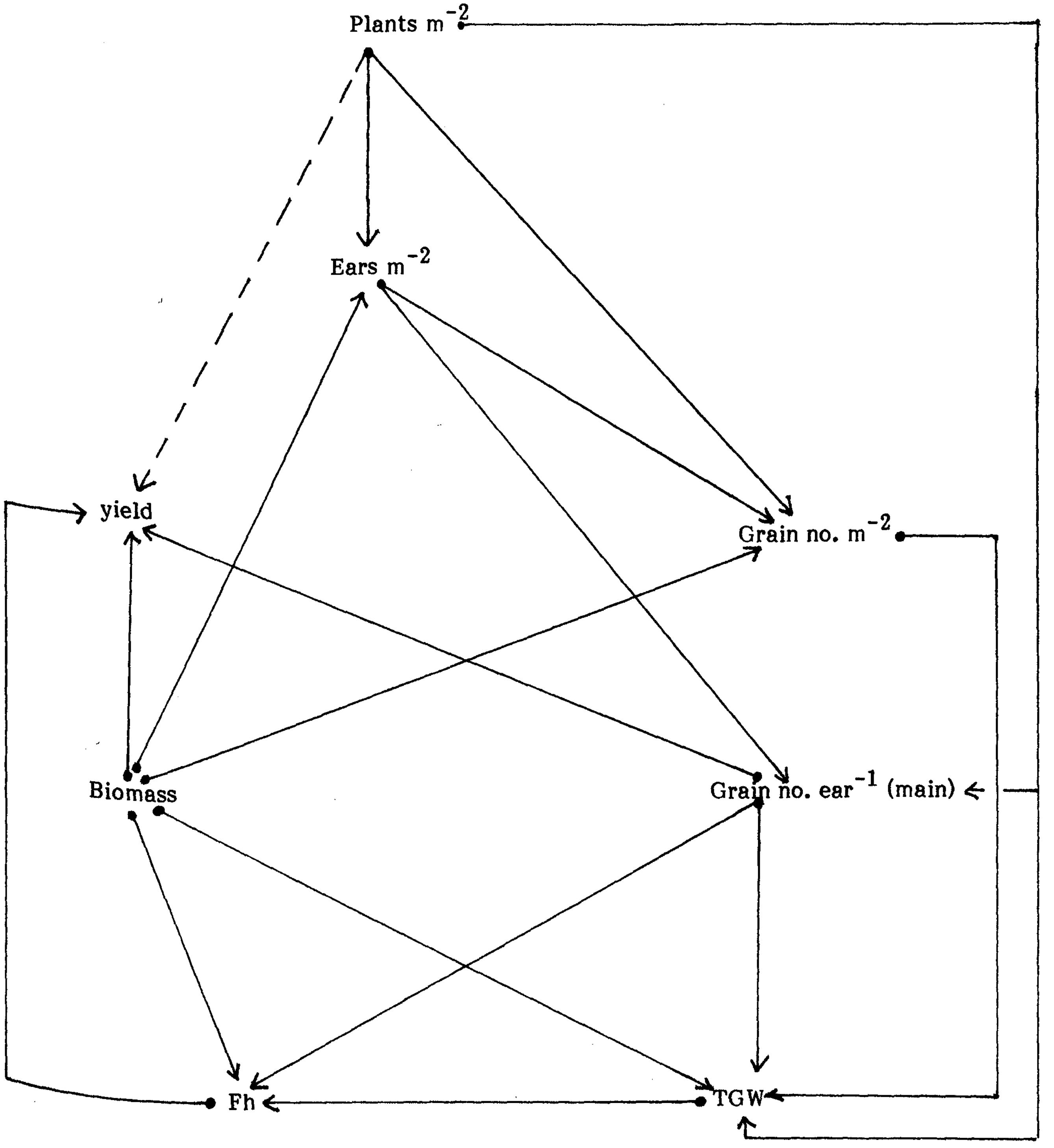
ii Tipper



i)
%
Mainstem
T1
.2
.0
8
6
4
2
i)
%
2
<8
8
10
12
14
16
18
20
22
24
26
28
30
30+
Grain no.

**Fig. 10** The relationship between grain yield components and grain yield

**Fig. 10**


Plants m$^{-2}$
Ears m$^{-2}$
yield
Grain no. m$^{-2}$
Biomass
Grain no. ear$^{-1}$ (main)
Fh
TGW

KEY

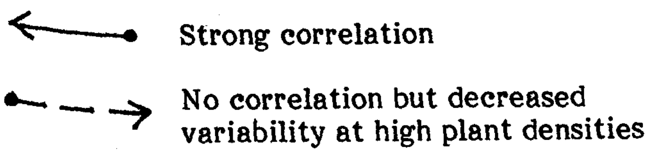

Strong correlation
No correlation but decreased variability at high plant densities

**Fig. 11**

i The relationship between final plant number and above ground biomass

ii The relationship between final plant number and combine harvested grain yield

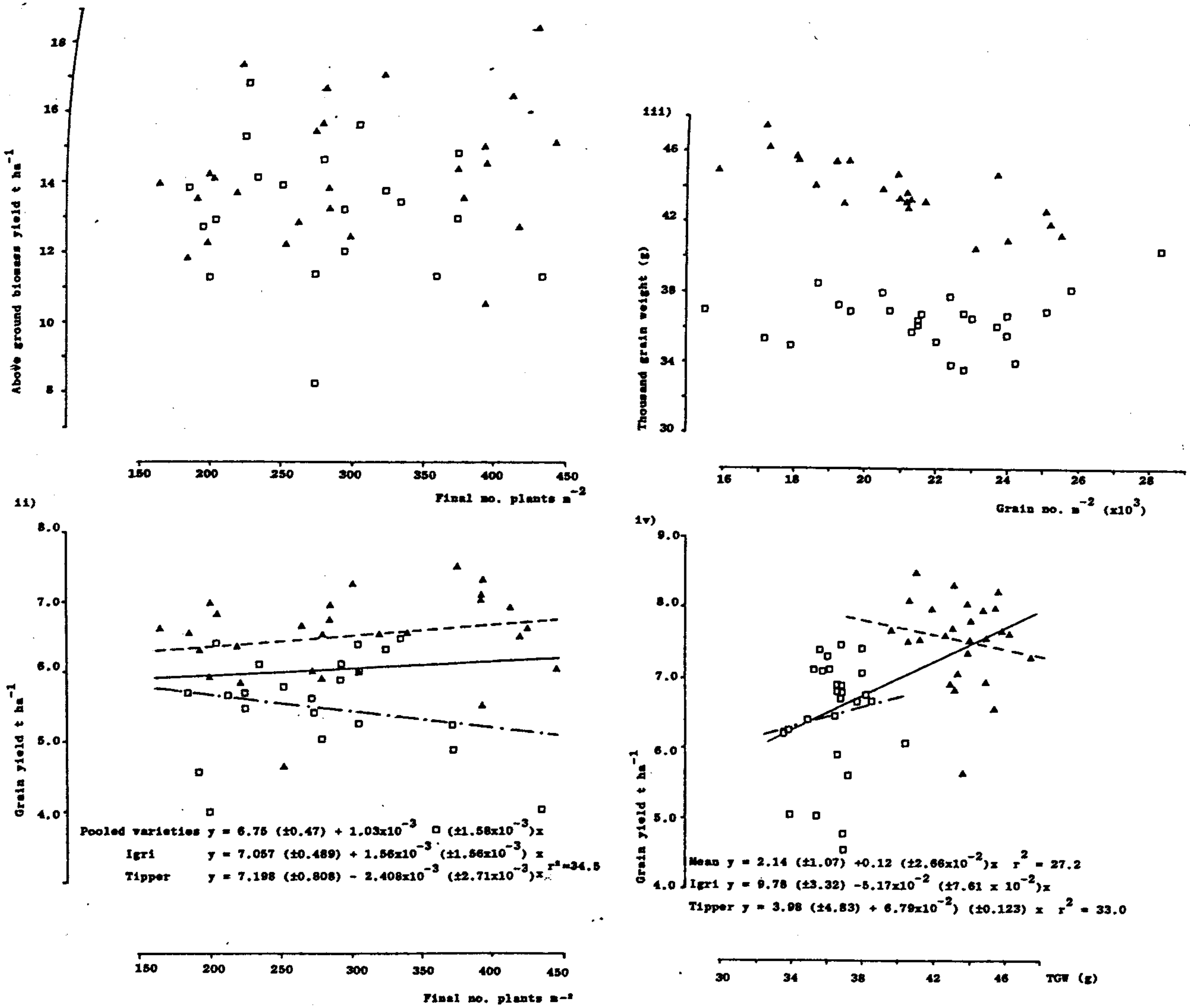
iii The relationship between grain number $m^{-2}$ and thousand grain weight

iv The relationship between thousand grain weight and grain yield

Key:

▲- - -▲ = Igri

□—· —□ = Tipper



Above ground biomass yield t ha-1
Final no. plants m-2
ii)
Grain yield t ha-1
Pooled varieties y = 6.75 (±0.47) + 1.03x10-3 □ (±1.58x10-3)x
Igri y = 7.057 (±0.489) + 1.56x10-3 (±1.56x10-3) x
Tipper y = 7.198 (±0.808) - 2.408x10-3 (±2.71x10-3)x r²=34.5
Final no. plants m-2
iii)
Thousand grain weight (g)
Grain no. m-2 (x10³)
iv)
Grain yield t ha-1
Mean y = 2.14 (±1.07) +0.12 (±2.66x10-2)x r2 = 27.2
Igri y = 9.78 (±3.32) -5.17x10-2 (±7.61 x 10-2)x
Tipper y = 3.98 (±4.83) + 6.79x10-2) (±0.123) x r2 = 33.0
TGW (g)

**Table 10** *Correlation matrix WB1*

| | No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fh (main) | 1 | - | | | | | | | | | | | | |
| Yield t $ha^{-1}$ | 2 | xxx 0.6945 | - | | | | | | | | | | | |
| Ears $m^{-2}$ | 3 | ns 0.2399 | ns 0.2437 | - | | | | | | | | | | |
| Grains $ear^{-1}$ (main) | 4 | x -0.3492 | x -0.3366 | xxx -0.4949 | - | | | | | | | | | |
| Ave. grains $ear^{-1}$ | 5 | x -0.3686 | x -0.3253 | xxx -0.5445 | xxx 0.9290 | - | | | | | | | | |
| Grain no. $m^{-2}$ | 6 | ns -0.0854 | ns -0.0281 | xxx 0.6219 | ns -0.2878 | x 0.3061 | - | | | | | | | |
| TGW (ex combine) | 7 | xxx 0.6366 | xxx 0.5614 | ns 0.1761 | xxx -0.5706 | xxx -0.6130 | x -0.3632 | - | | | | | | |
| Grain wt. $m^{-2}$ | 8 | x 0.3080 | x 0.3203 | xxx 0.7659 | ns -0.0731 | ns -0.0802 | xxx 0.8052 | ns 0.2552 | - | | | | | |
| Wt. per main ear | 9 | xxx 0.6586 | x 0.3784 | ns -0.2741 | ns 0.2818 | ns 0.2564 | ns -0.1011 | ns 0.2742 | ns 0.0596 | - | | | | |
| Plants $m^{-2}$ | 10 | ns -0.0456 | ns 0.0838 | xxx 0.8570 | xx -0.3953 | xx -0.4748 | xxx 0.5141 | ns -0.1215 | xx 0.4589 | xxx -0.4948 | - | | | |
| Tillers $m^{-2}$ | 11 | ns 0.2684 | x 0.3267 | xxx 0.9405 | xxx -0.5583 | xxx -0.6073 | xx 0.4865 | x 0.3264 | xxx 0.7211 | ns -0.2198 | xxx 0.7699 | - | | |
| Tillers $plant^{-1}$ | 12 | ns 0.2644 | ns 0.1259 | xx -0.4890 | ns 0.0863 | ns 0.1663 | xx -0.3974 | xxx 0.4922 | ns -0.1039 | xxx 0.5147 | xxx -0.8108 | ns -0.2843 | - | |
| Biomass | 13 | xxx 0.5266 | x 0.3564 | xx 0.4812 | ns -0.0483 | ns 0.0126 | xxx 0.5425 | ns 0.2628 | xxx 0.7255 | xxx 0.4841 | ns 0.1514 | xxx 0.5149 | ns 0.2027 | - |
| | No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

Df = 41 ns = not significant x = $p < 0.05$ xx = $p < 0.01$ xxx = $p < 0.001$

final harvest are main culm ears. Thus it would be expected that these would have higher mean grain weights than grains from tiller ears. As decreased grain yield variability results from increased plant density this was partially due to the increased contribution to the total grain yield by grains from main stem ears with higher mean grain weights.

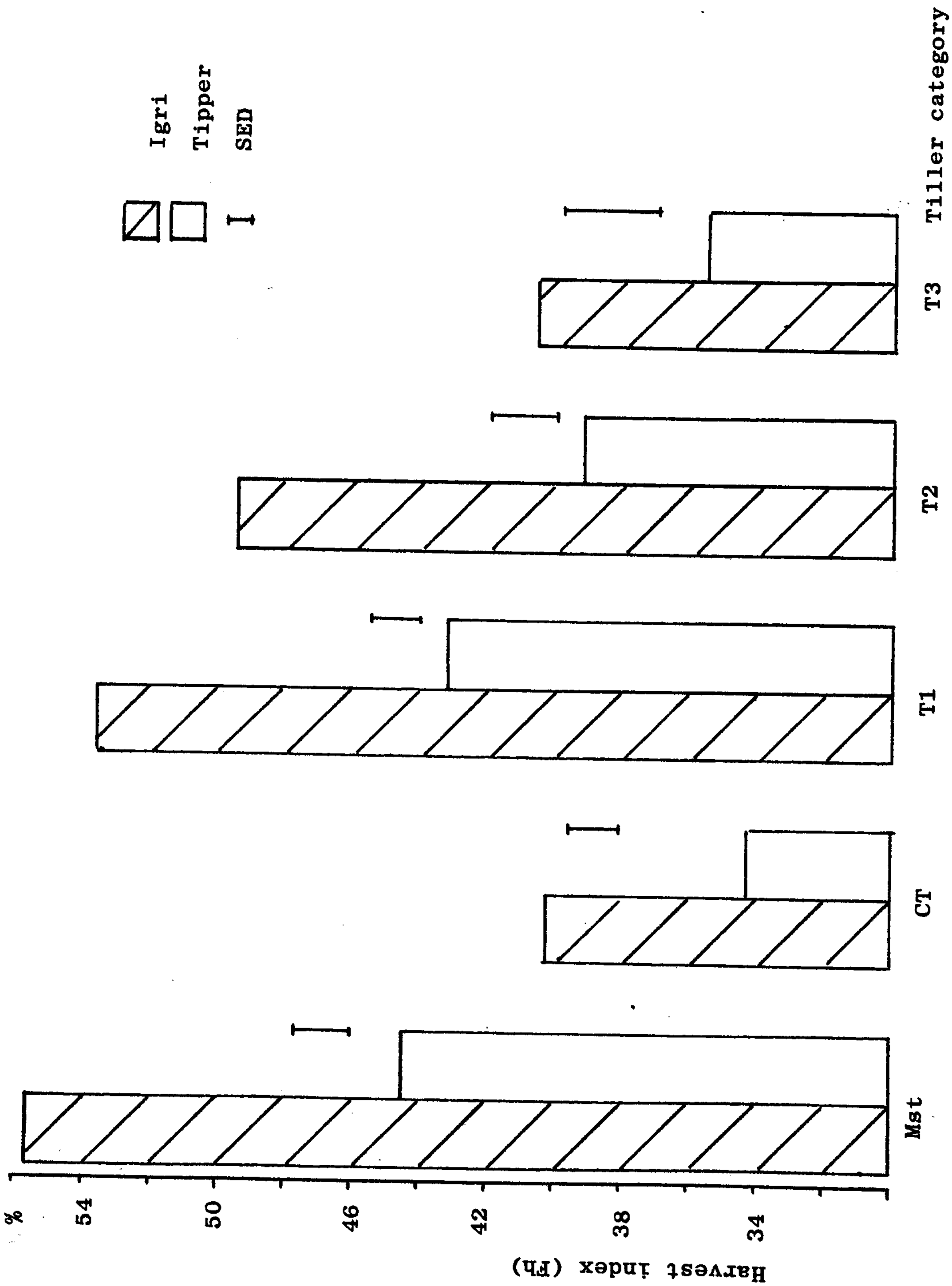
If plant density is increased dramatically a value for plant density is reached after which grain yield decreases. This optimum plant density depends upon species, variety and environment. As plant density is increased above its optimum less space is available per culm. This in turn results in decreased grain yield per ear due to a fall in grain number per ear, a decrease in TGW and a reduction in Fh (Darwinkel, 1978).

An increase in plant density (at least up to 450 plants $m^{-2}$) resulted in an increase in total above ground biomass which enhanced ear number $m^{-2}$ and grain number $ear^{-1}$. This increase in biomass thus resulted in both an increase in source and in sink capacity. This increase in source capacity was capable of meeting the assimilate demands of the larger sink, i.e. more grains. This resulted in more grains approaching their maximum potential size, i.e. larger grains with a higher TGW.

At final harvest the harvest indices of tiller categories were assessed. Tipper had significantly lower values for Fh than Igri for all tiller categories measured. The ranking for harvest indices for both varieties was mst, T1, T2, T3, CT. Thus although the CT emerged at a similar time to the T1 tiller it differed significantly in its harvest index from that of the T1 tiller (Fig. 12).

The harvest index values were taken from above ground dry matter. No attempt was made to include an estimate of root dry weight per unit area. It has been estimated (Sylvester-Bradly, personal communication 1984) that the root length of a winter cereal crop can be as much as 23 km $m^{-2}$ and the quantity of nitrogen in the roots can be up to 50 kg $ha^{-1}$. Thus any estimates of harvest indices obtained when root values are not included must necessarily be inaccurate estimates of the actual harvest indices. There was a significant variety nitrogen treatment interaction in the harvest indices obtained. Within Igri the N2 treatment depressed Fh but in Tipper this treatment enhanced Fh. In Tipper the lowest Fh (37.6%) was obtained with N1 treatments.

**Fig. 12** The effect of variety and tiller category on harvest index


Igri
Tipper
SED
Harvest index (Fh)
%
54
50
46
42
38
34
Mst
CT
T1
T2
T3
Tiller category

### 3.2.5 The effect of variety on seed size distribution

The varieties differed in their relative proportions of seed in varying size categories. These differences were present when the grain distribution was assessed by number and by weight (Fig. 13).

The TGW of each size category was dependent upon the variety with Igri having a significantly higher TGW in all size categories (Fig. 14). This TGW difference ranged from over 5 g in those grains above 2.8 mm in size to 1.31 g for grains below 2.2 mm in size.

This method of separation of grain samples into size categories has several disadvantages:

a) Another sieve size above that of 2.8 mm could have been used to advantage so that full size separation of large seeds could have been achieved.

b) Discrepancies may have arisen when the samples were subdivided and analysed on a percentage number basis. The material in the less than 2 mm sieve size may not have been whole grains. Thus thorough cleaning of the sample would eliminate any errors that may have arisen from the inclusion of non grain material or partial grains within the separated sample.

### 3.2.6 The effect of variety on grain characteristics

The grain nitrogen content was influenced by variety with Tipper having a significantly lower grain nitrogen content (Table 11). The varieties also differed in their hot water extract values with Tipper having an improved HWE (Table 11).

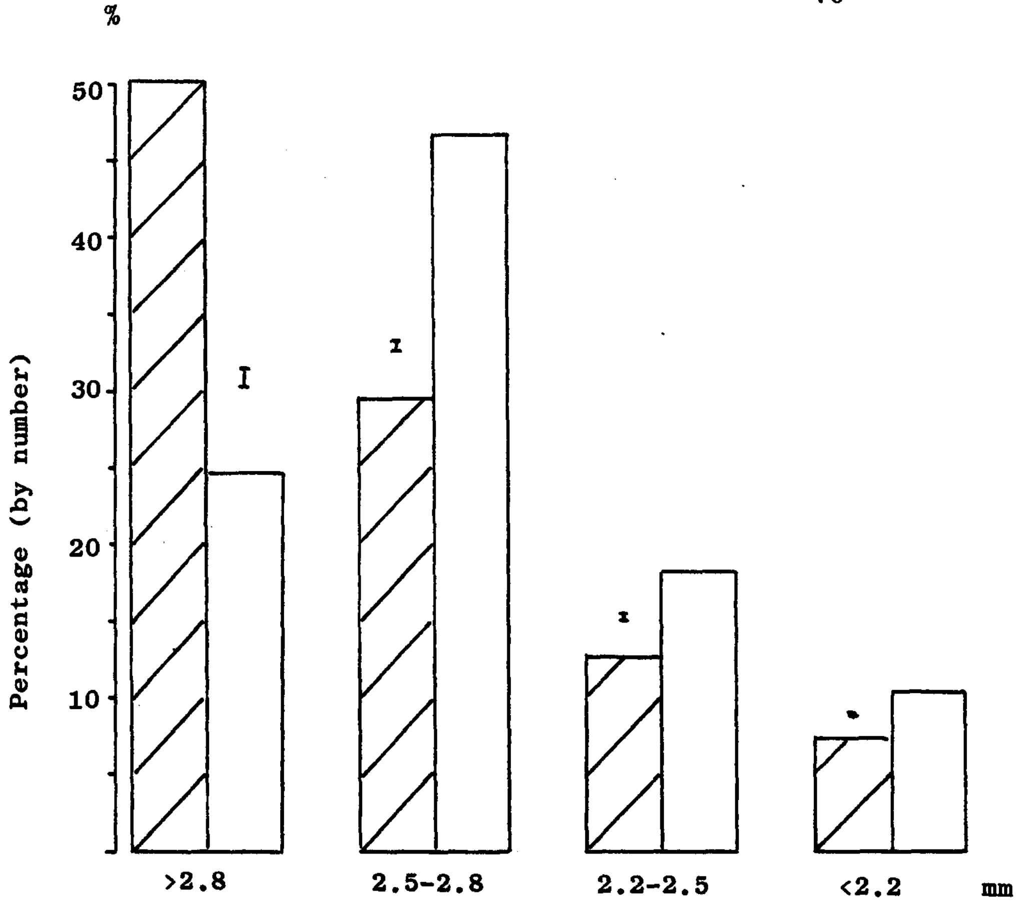
The varieties did not differ significantly in their germination percentages (original and angularly transformed data) when first tested (September 1981) or after long term storage in non sealed containers at room temperature and humidity (Table 11). The germination percentage of those seeds greater than 2.8 mm did not differ between varieties. However the seeds of Tipper below 2.2 mm in size had significantly lower germination percentages than equivalent sized seeds of Igri (Table 11). There were no interactions between variety, density or nitrogen in the

**Fig. 13** The effect of variety on seed size distribution

i by number

ii by weight

i)


%
50
40
30
20
10
Percentage (by number)
>2.8
2.5-2.8
2.2-2.5
<2.2
mm

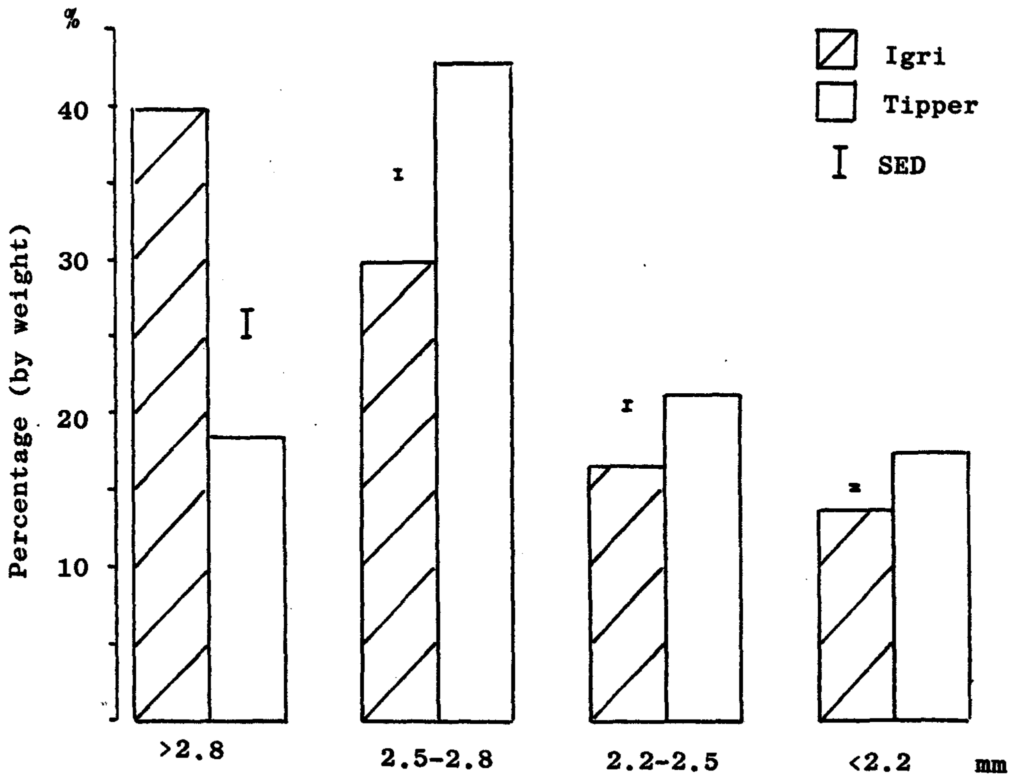

%
40
30
20
10
Percentage (by weight)
>2.8
2.5-2.8
2.2-2.5
<2.2
mm
Igri
Tipper
SED

**Fig. 14** The effect of variety and seed size category on TGW

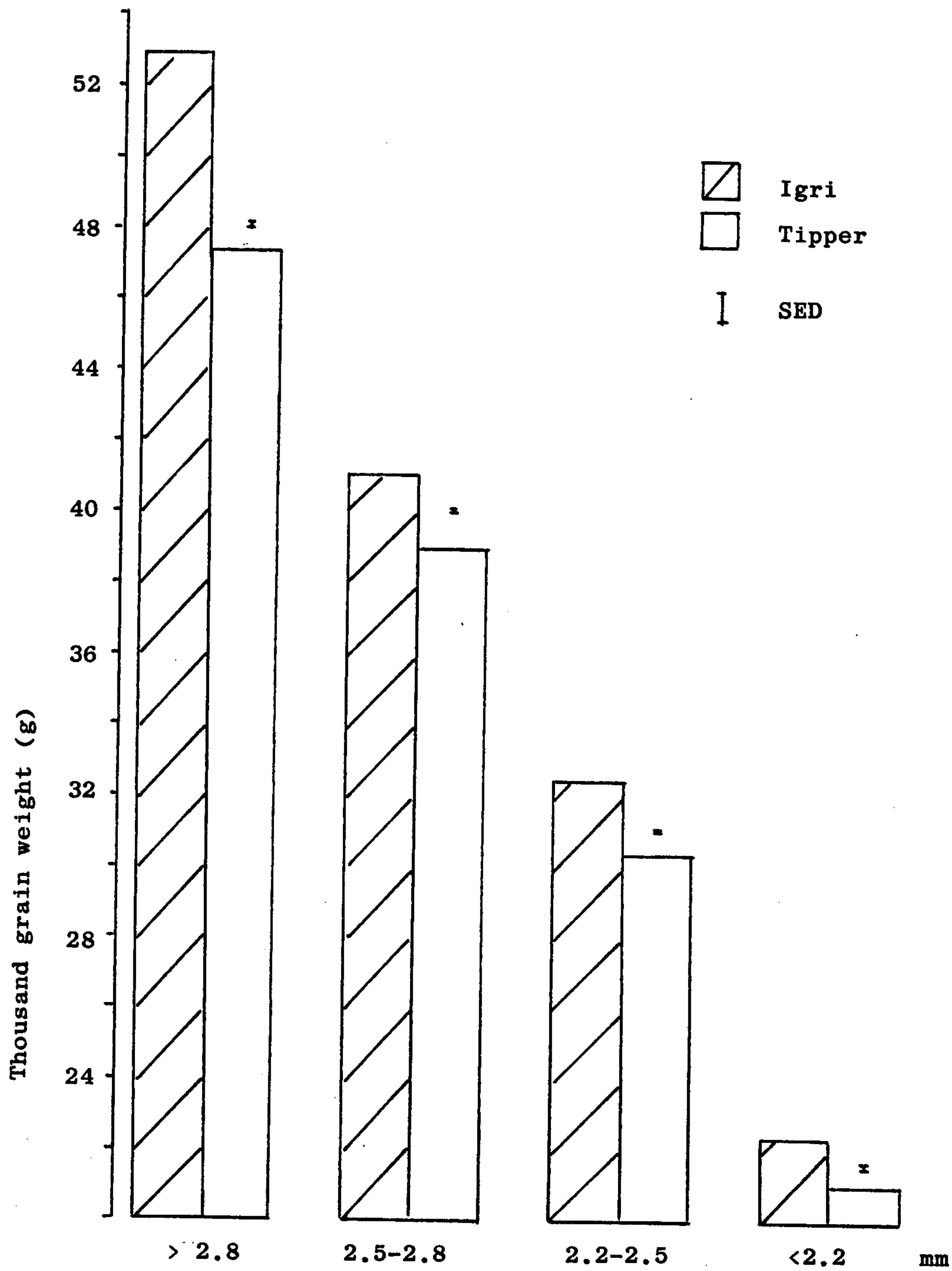

Igri
Tipper
SED
Thousand grain weight (g)
52
48
44
40
36
32
28
24
> 2.8
2.5-2.8
2.2-2.5
<2.2
mm

**Table 11** The effect of variety on grain nitrogen content, grain hot water extract and germination percentages

i) 1981 ii) 1983

i)

| | Igri | Tipper | SED | Sig |
|---|---|---|---|---|
| N% | 1.978 | 1.934 | 0.0094 | x |
| HWE | 281.23 | 288.60 | 0.704 | xx |
| Total sample Sept 1981 | 98.76 | 97.22 | 0.757 | ns |
| Total sample June 1983 | 98.22 | 96.68 | 0.593 | ns |
| Seeds > 2.8 mm Sept 1981 | 98.96 | 97.97 | 0.396 | ns |
| Seeds < 2.2 mm Sept 1981 | 97.75 | 95.59 | 0.176 | xx |

ii)

Total sample June 1983 - The effects of nitrogen on germination percentages

| | N1 | N2 | N3 | SED | Sig |
|---|---|---|---|---|---|
| Igri | 98.25 | 98.42 | 97.99 | 0.763 | x |
| Tipper | 97.36 | 97.64 | 95.03 | | |

germination percentages of the whole sample tested in September 1981 or in the largest and smallest size categories tested at this time. However in June 1983, 23 months after harvest of the grain, there was a significant reduction in germination percentage with the N3 nitrogen treatments (Table 11).

## 3.3 The Influence of Density

### 3.3.1 Introduction

Three seed densities were established. These consisted of 300, 450 and 650 seeds sown per square metre (seeds $m^{-2}$). Full experimental details are presented in Table 5 and Section 3.1.1. Stem numbers were monitored at regular intervals throughout the life of the crop at the fixed positions within each plot, care being taken to minimize the disturbance to the crop which may have influenced plant morphology and ultimately yield components and yield.

At each growth analysis total plant numbers were counted in the harvested sample. The number of tillers in each tiller category was noted and total tiller and stem numbers recorded.

### 3.3.2 The effect of plant density on tiller hierarchies

The initial percentage establishment differed between densities with the highest density having a lower percentage establishment. At final harvest the percentage establishment ranged from 87% for the low density treatments to 71% for the high density treatments.

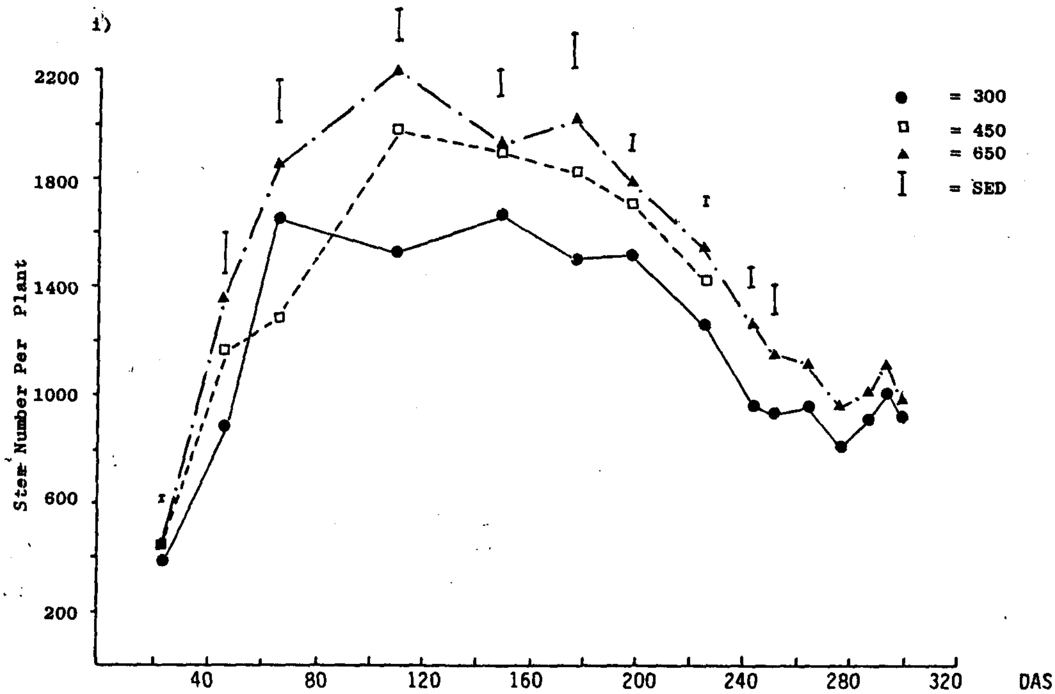
The densities differed in their total number of stems $m^{-2}$ (Fig. 15(i)) and in the number of stems per plant (Fig. 15(ii)). The high density treatments had a high number of stems per unit area but a low number of stems per plant. Peak number of stems per plant occurred at 151 DAS for the low density treatments but at higher initial plant densities peak tiller number occurred before this date (68 DAS for 650 seeds $m^{-2}$ and 112 DAS for 450 seeds $m^{-2}$). From their respective peak values all density treatments declined in tiller numbers so that at final harvest the numbers of stems per plant were 4.20 (300 seeds $m^{-2}$), 3.40 (450 seeds $m^{-2}$) and 2.75 (650 seeds $m^{-2}$). Thus in all density treatments the number of stems $m^{-2}$ at final harvest was between 900 and 1000. The slight increase

**Fig. 15** The effect of density on

i stem number $m^{-2}$

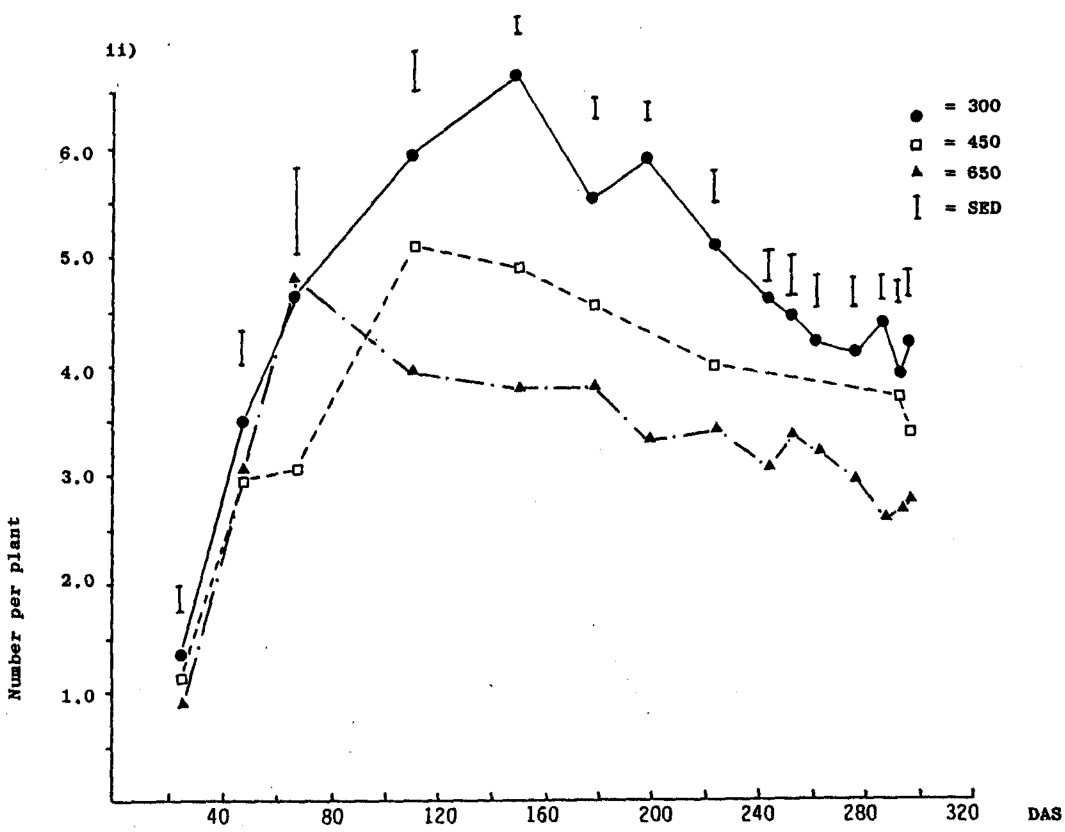
ii stem number $plant^{-1}$

i)



2200
1800
1400
1000
600
200
Stem Number Per Plant
40
80
120
160
200
240
280
320
DAS
= 300
= 450
= 650
= SED


ii)



6.0
5.0
4.0
3.0
2.0
1.0
Number per plant
40
80
120
160
200
240
280
320
DAS
= 300
= 450
= 650
= SED

in stem number per plant and stem number $m^{-2}$ from 278 DAS until final harvest occurred due to the presence of late, non productive green tillers.

Fig. 16 indicates the contribtion to total tiller number of each density by each monitored tiller category. In all three densities the T1 tiller was present in more than 90% of the plants. However the proportion of plants with all other tiller categories differed with the density treatment. The T2 tiller was present during the majority of the growth of the low density plants on more than 90% of those plants present. However on the high density treatments (650 seeds $m^{-2}$) only approximately 70% possessed a T2 tiller. Later formed primary tillers and secondary tillers were less common in high density treatment. The contribution of the CT tiller both at peak tillering (taken as peak tillering of the high density plots) and at final harvest differed between density treatments. Density treatments also influenced the tillering efficiency of each tillering category. Tillering efficiency was calculated as the proportion of the maximum tiller number of a specific tiller category taken through to final harvest. Tiller categories varied in their tillering efficiencies with the efficiency of tillering of T1 being greater than 90% in all density treatments. The tillering efficiency for the CT tiller was below that of the other three main primary tillers. Tillering efficiencies decreased from the first formed primary tiller to the T4 tiller, the latest emerged tiller that was generally present at final harvest. T11, the most frequently occurring secondary tiller, usually had a tillering efficiency lower than the T3 tiller although the T11 tiller usually emerged before the T3 tiller.

Fig. 16 illustrated the differences in tillering patterns caused by various initial sowing densities. However the two varieties tested reacted differently to changes in their initial sowing densities. Fig. 17 indicates the differences in overall tillering patterns and in individual tiller category contribution to the final stem number between Tipper and Igri with an initial sowing density of 650 seeds $m^{-2}$. Peak stem number for Igri at this density occurred at 112 DAS and reached a maximum of 6.1 stems per plant. In Tipper the initial stem assessment at 48 DAS showed the highest number of stems per plant (4.97). From this time stem number declined throughout growth until a peak of late, green unproductive tillers arose at approximately 250 DAS.

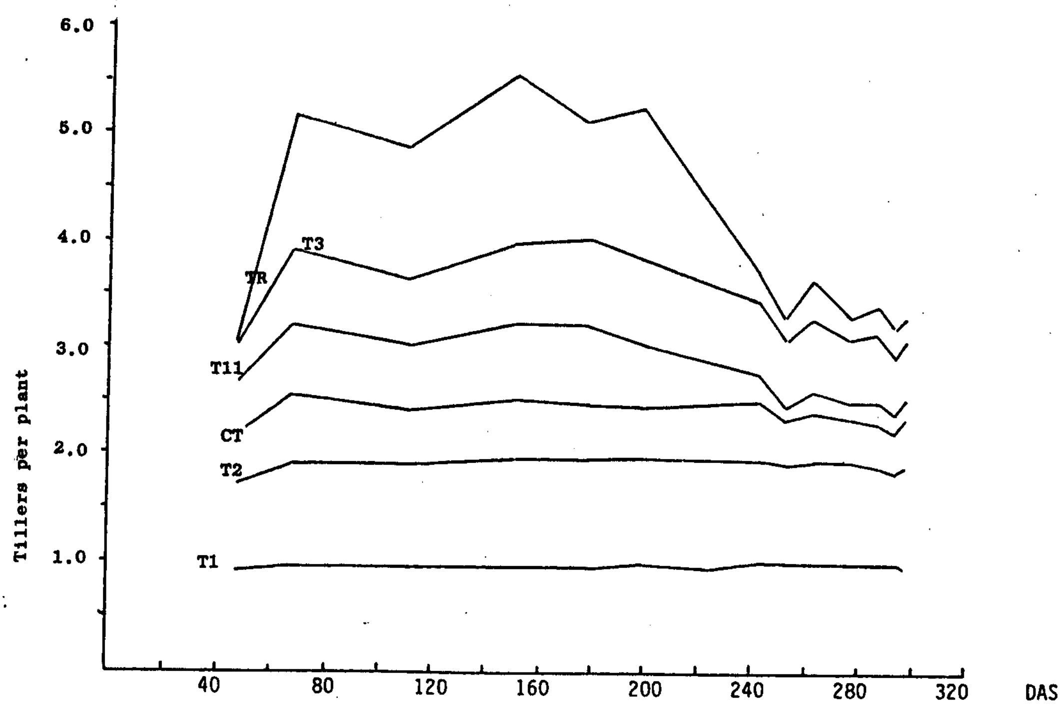
**Fig. 16** The effect of density on tillering patterns

i 300 seeds $m^{-2}$

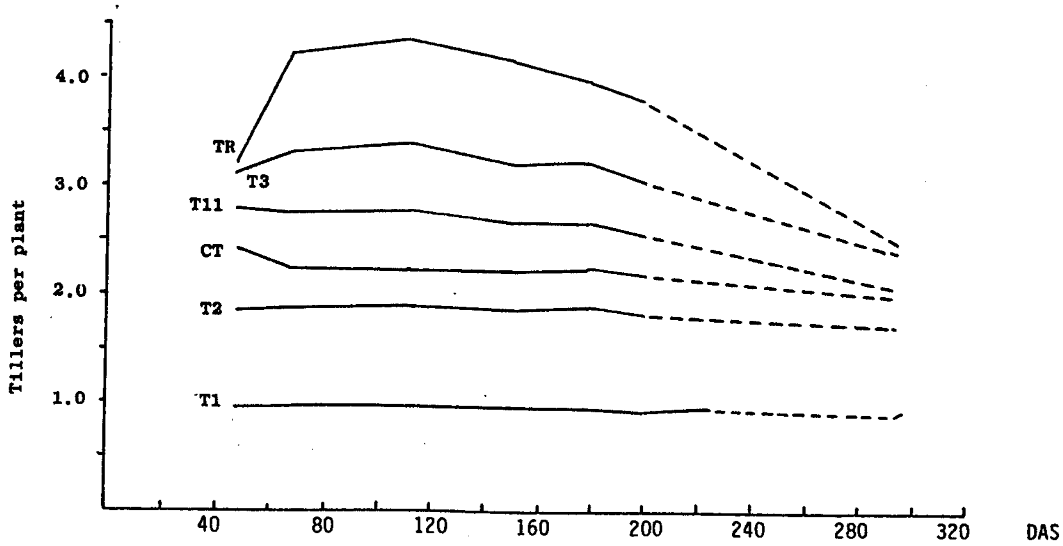
ii 450 seeds $m^{-2}$

iii 650 seeds $m^{-2}$

i)


6.0
5.0
4.0
3.0
2.0
1.0
Tillers per plant
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
320
DAS

ii)


4.0
3.0
2.0
1.0
Tillers per plant
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
320
DAS

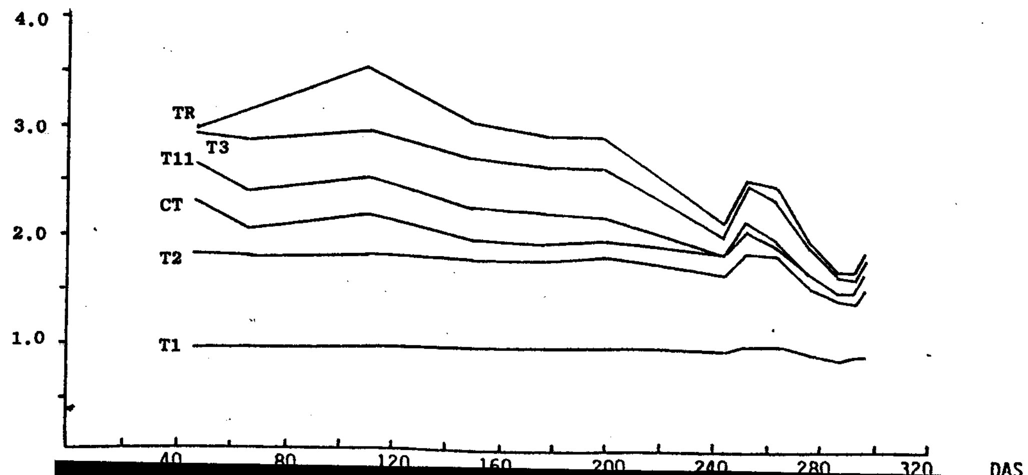

4.0
3.0
2.0
1.0
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
320
DAS

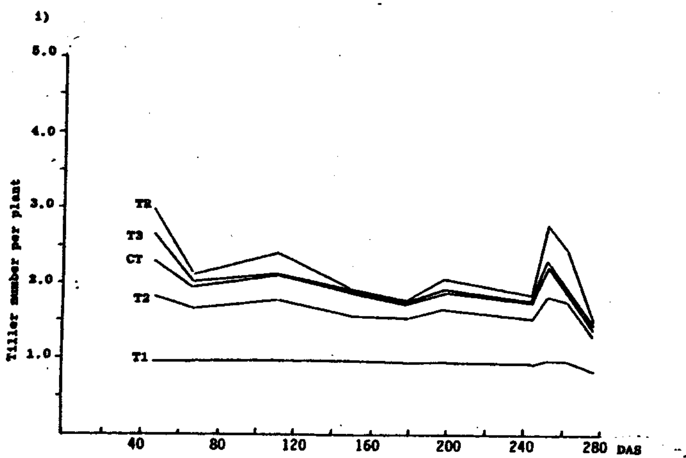
**Fig. 17** The interaction between density and variety in the modification of tillerings

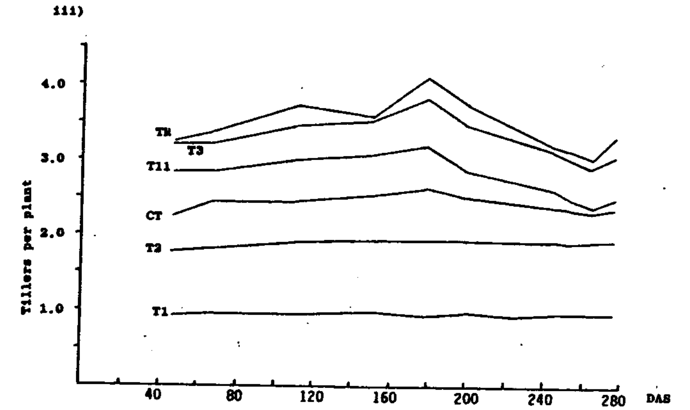
i 650 seeds $m^{-2}$ Tipper

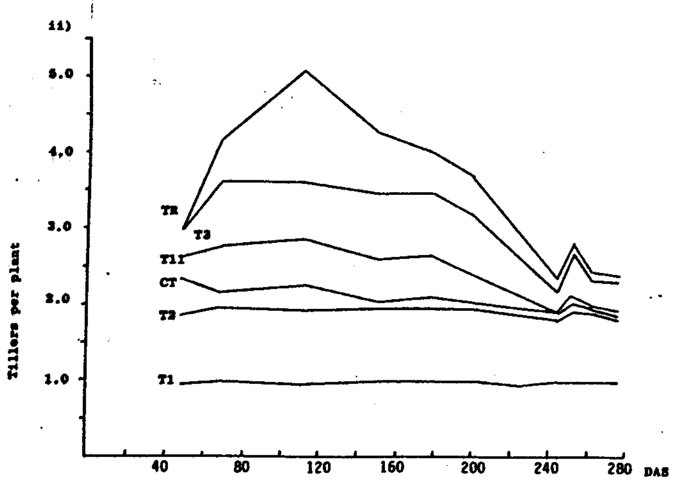
ii 650 seeds $m^{-2}$ Igri

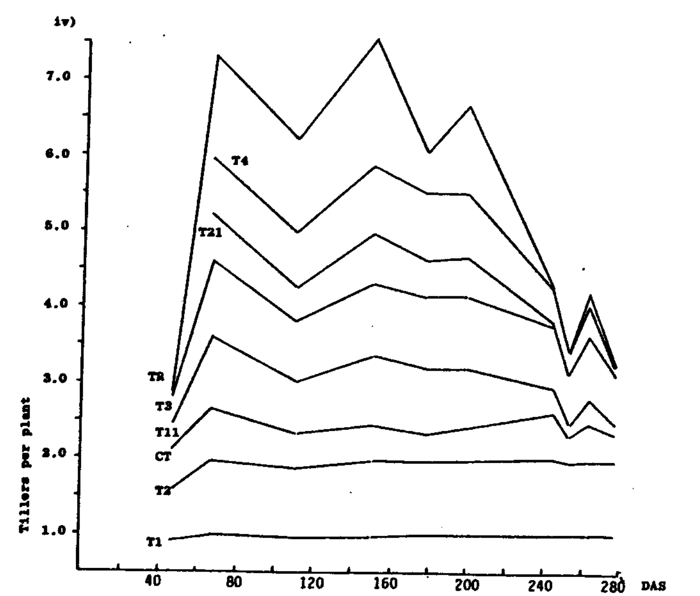
iii 300 seeds $m^{-2}$ Tipper

iv 300 seeds $m^{-2}$ Igri


i)
Tiller number per plant
5.0
4.0
3.0
2.0
1.0
TR
T3
CT
T2
T1
40
80
120
160
200
240
280
DAS


iii)
Tillers per plant
4.0
3.0
2.0
1.0
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
DAS


ii)
Tillers per plant
5.0
4.0
3.0
2.0
1.0
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
DAS


iv)
Tillers per plant
7.0
6.0
5.0
4.0
3.0
2.0
1.0
T4
T21
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
DAS

The total tillering efficiency for Tipper was greater than that of Igri mainly due to the lower production of late primary tillers and secondary tillers. The tillering efficiencies of all tiller categories monitored, excluding the CT tiller, had lower efficiencies associated with the variety Tipper.

The varietal differences between Igri and Tipper at 300 seeds $m^{-2}$ are shown in Figs 17(i) and (ii). At low initial seed densities both varieties increased the number of tillers per plant above that achieved at high initial plant densities. Tipper reached its peak value for tillers per plant later than the peak for Igri. Igri produced large numbers of secondary tillers and some late (i.e. T5 and later) primary tillers; at peak tillering these accounted for 1.7 stems per plant. In Tipper only 0.05 stems per plant at peak tillering were late primary tillers or secondary tillers. The tillering efficiencies of each tiller category at low initial seed densities are outlined in Table 12.

In each tiller category the tillering efficiencies at high densities were below those at low densities (Table 12).

The varieties and densities did not differ in the number of tillers per plant at the first time of recording (48 DAS). At this time all treatments had approximately 3 tillers per plant. Thus it was only after this time that environmental factors and inter- and intra-plant competition occurred and caused a modification of the tiller numbers present. At low densities both varieties had approximately 3.25 tillers per plant at final harvest although the relative contributions of various tiller categories differed. At high densities the final number of tillers per plant differed between varieties with Tipper producing 0.9 tillers per plant less than Igri at final harvest.

### 3.3.3 The effect of density on leaf area indices

GAI and LAI were influenced by density with high density treatments usually having higher GAI and LAI values than the lower tested densities although the differences were not always significant (Fig. 18). From emergence until peak LAI and GAI at 225 DAS higher values were obtained for both parameters with increasing initial plant densities. Post peak LAI the two monitored densities did not differ significantly in their GAI or LAI values.

**Table 12** The interaction between variety and density on tillering efficiencies of varying tiller categories

i) Initial density 650 seeds $m^{-2}$

| | Variety | |
|---|---|---|
| | Igri | Tipper |
| Total | 47.6 | 51.2 |
| CT | 17.2 | 23.4 |
| T1 | 100 | 86.7 |
| T11 | 5.3 | 4.7 |
| T2 | 82.7 | 50.5 |
| T3 | 46.7 | 7.9 |
| T4 | 13.8 | - * |

ii) Initial density 300 seeds $m^{-2}$

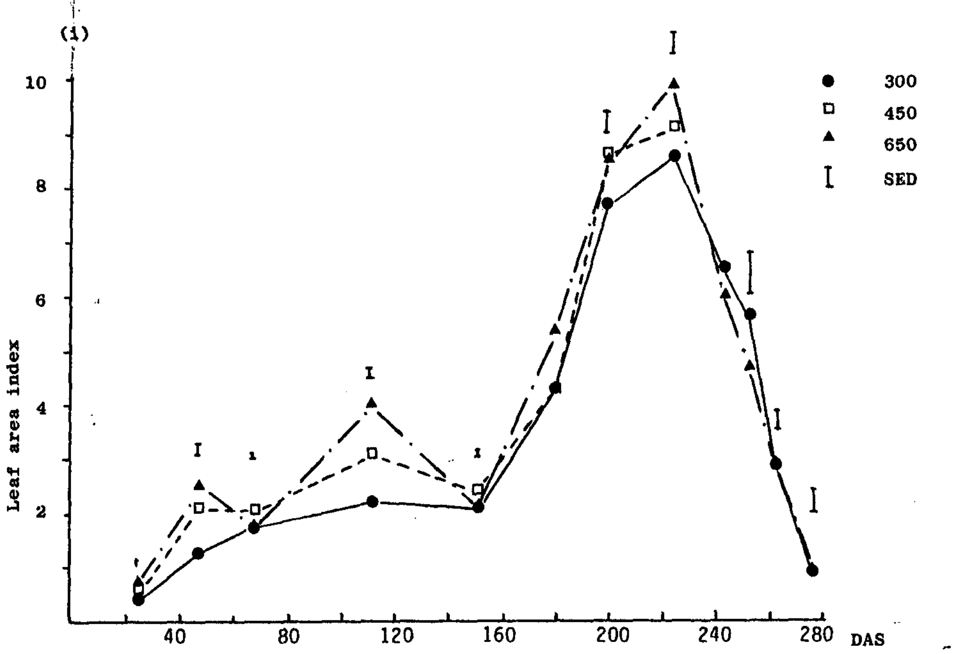
| | Variety | |
|---|---|---|
| | Igri | Tipper |
| Total | 43.0 | 81.2 |
| CT | 64.4 | 49.7 |
| T1 | 100 | 100 |
| T11 | 21.8 | 17.4 |
| T2 | 96.0 | 98.3 |
| T3 | 87.6 | 61.7 |
| T4 | 91.0 | 12.9 |

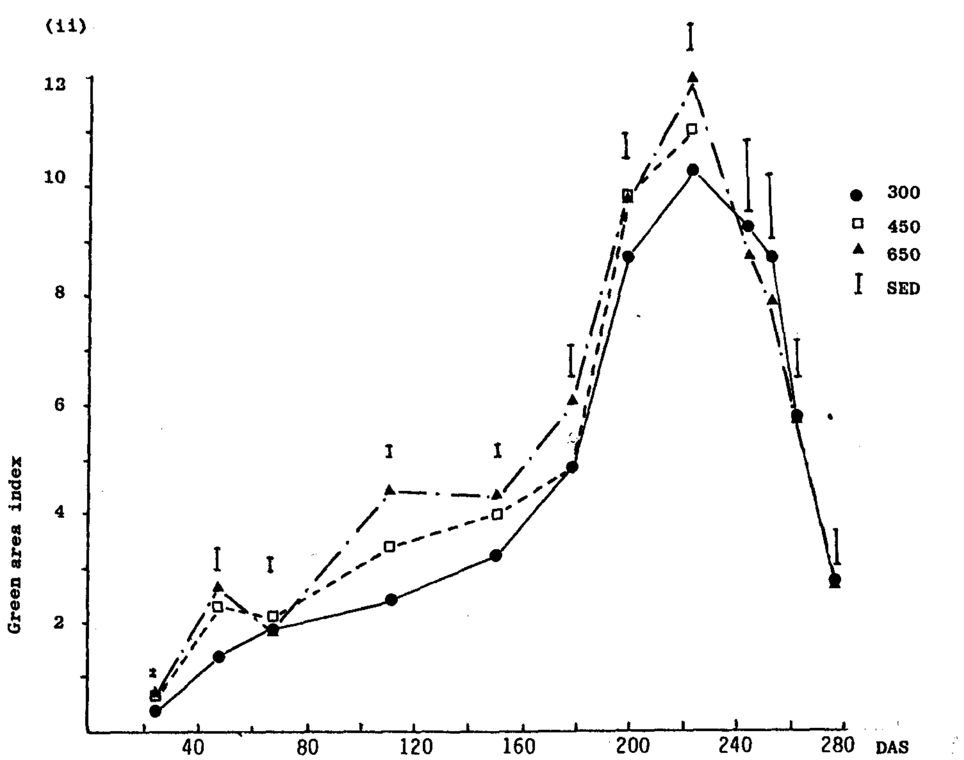
* Insufficient data available

**Fig. 18**

i The effect of density on LAI

ii The effect of density on GAI


(i)
Leaf area index
DAS
300
450
650
SED


(ii)
Green area index
DAS
300
450
650
SED

The maximum LAI for the high density treatments was 9.85 whilst that of the low density treatment was 8.60. In all cases the LAI approached or just exceeded the estimated optimum LAI of 9 for spring barley.

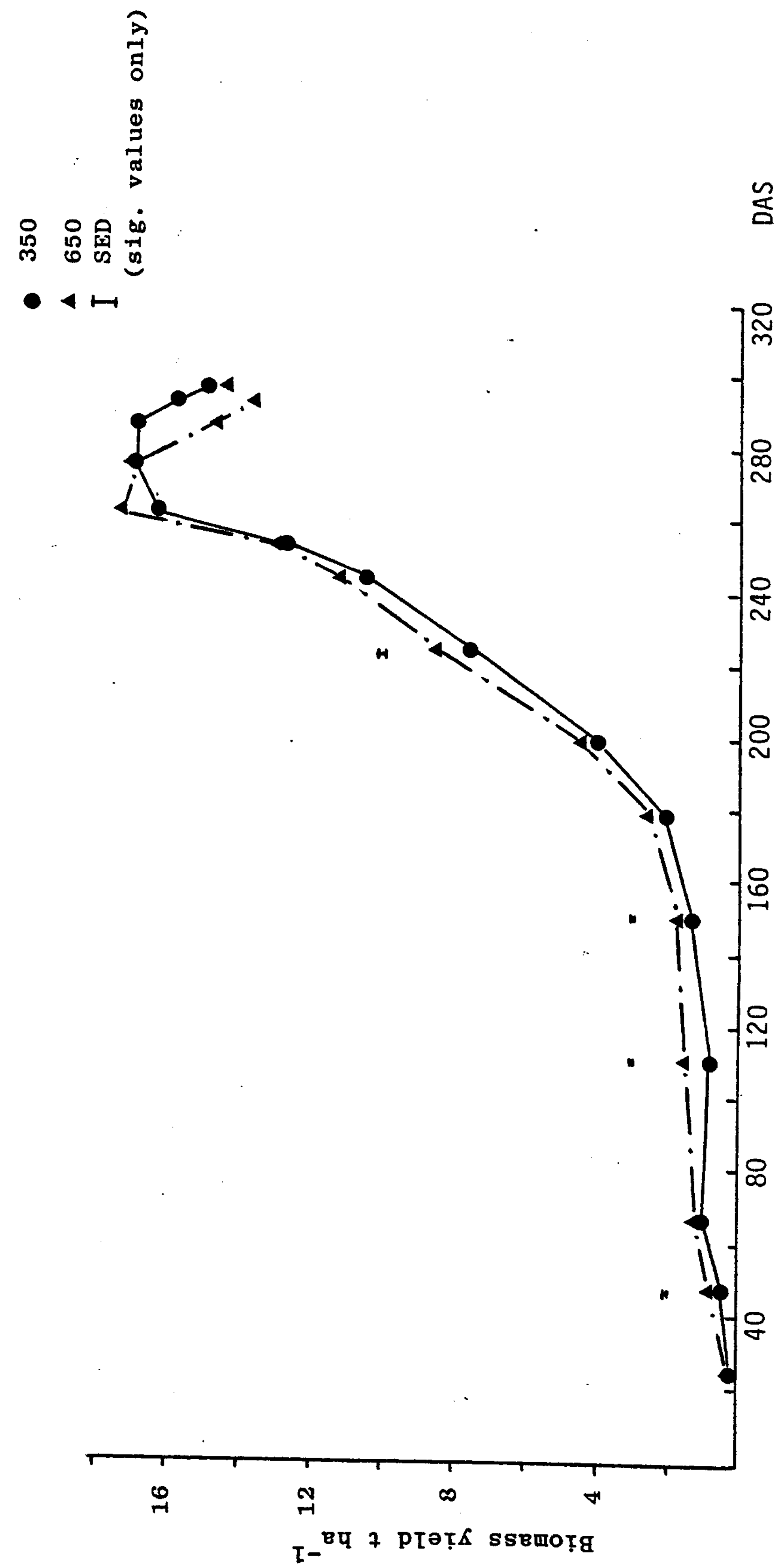
### 3.3.4 The effect of density on crop biomass

Densities differed in their total dry matter accumulated per unit area (Fig. 19). High density plots had a higher dry matter per hectare value than low density plots until 263 DAS. After this biomass peak of 17.4 t $ha^{-1}$ values declined so that by final harvest the biomass yield was 14.6 t $ha^{-1}$ for high density plots. Peak biomass for low density treatments occurred later, at 277 DAS, with a maximum value of 17.0 t $ha^{-1}$ DM being obtained. Biomass on these plots declined to reach 15.1 t $ha^{-1}$ at final harvest. Table 8 indicated the amount of grain estimated to have been lost prior to harvesting. There were no significant differences between densities in the estimated grain loss.

The contributions to total weight (excluding roots) per unit area of each monitored tiller category are shown in Fig. 20. Within high density treatments a higher proportion of the total plant weight was contributed by main stems. In high density treatments during most of the crop's growth this value was approximately 45%, whereas at low plant densities main stems contribute less than 30% of the total crop dry weight. The small decline in percentage contribution by the main stem between 240 and 280 DAS in the high density plots may have been associated with the decline in plant numbers harvested per unit area. Thus as every plant can only have one mainstem a decline in total plant number is associated with a concomitant decrease in main stem number. A decline in plant number per unit area is usually matched by an increase in stem number per plant. Thus between 240 and 280 DAS when harvested samples showed a decline in plant numbers the percentage of weight attributable to tillers rose. In low density plots harvested plant numbers increased at 263 and 277 DAS. This was matched by an increase in the percentage weight contribution by the main stem on these dates.

The percentage weight contribution of the CT tiller to total weight significantly differed between densities with high density plots having usually less than 5% of their total weight contributed by this tiller.

**Fig. 19** Biomass — the effect of density



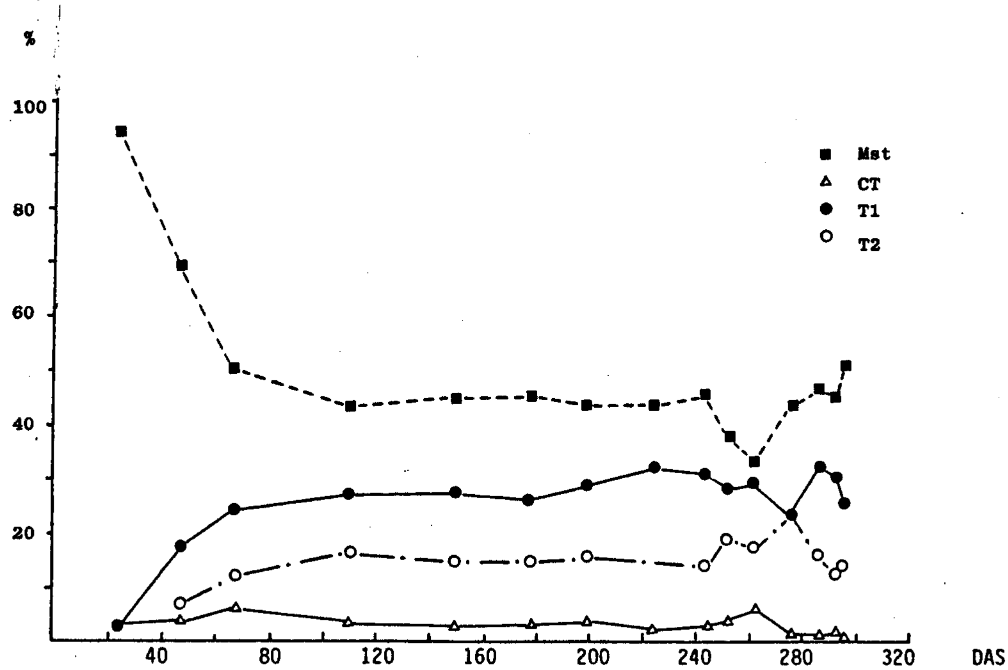
350
650
SED
(sig. values only)
DAS
Biomass yield t ha-1
4
8
12
16
40
80
120
160
200
240
280
320

**Fig. 20** The effect of density on the proportion of total weight contributed by tiller categories

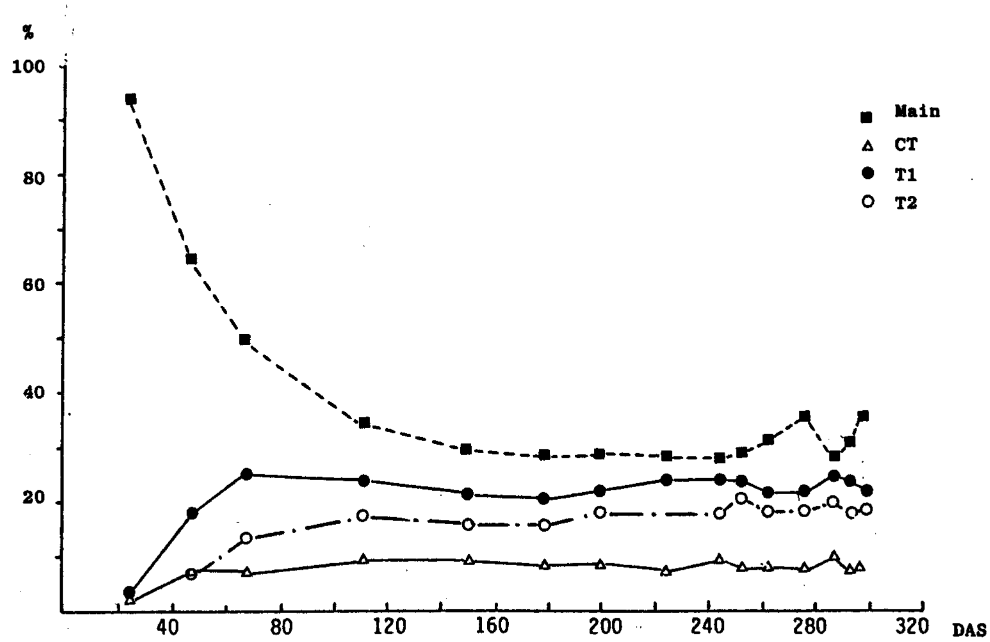
i 650 seeds $m^{-2}$

ii 300 seeds $m^{-2}$

i)


%
100
80
60
40
20
40
80
120
160
200
240
280
320
DAS
Mst
CT
T1
T2

ii)


%
100
80
60
40
20
40
80
120
160
200
240
280
320
DAS
Main
CT
T1
T2

The weight contributions of T1 and T2 were below that of the mainstem and ranged from 14.5% (T2, high density) to 32.5% (T1, high density). The differences between T1 and T2 in their weight contributions was greater in the high density treatments.

The proportion of the total ear weights contributed by each ear category differed between densities (Fig. 23). The high density treatment had a significantly greater percentage of its total ear weight contributed by the mainstem and T1 and a significantly lower proportion contributed by the CT, T3, T4 and secondary tillers.

### 3.3.5 The effect of plant density on yield components and on grain yield

Grain yield did not differ significantly between densities (Fig. 21). However yield components varied. High density treatments had a higher number of ears per unit area but a lower grain number per ear (Fig. 21) and a lower thousand grain weight (Fig. 21). The number of filled grains per ear on over one thousand ears was noted. The proportion of the total number within each grain number classification and within specific number categories are outlined in Fig. 22 for the mainstem ears and the T1 tiller ears.

Within the main ears increasing density resulted in an increased proportion of ears with below 10 grains per ear present. Within all three densities the majority of the ears had between 16 and 25 grains per ear present.

Within the T1 tiller category density influenced the proportion of ears in any size classification. At the lowest density (D1) the majority of ears had between 16 and 25 grains present whereas at the higher density (D3) the majority of the ears had less than 15 grains per ear present.

The TGW of grains from specific areas within the ear are recorded in Table 13. In all cases the grains from the mid region of the ear were greater than those from the basal region (this was taken to be the basal six grains upon the ear), which, in turn, were greater than the grains from the distal regions of the ear. In almost all cases no significant differences occurred between densities in the TGW obtained within each section. The exceptions to this were the mid region of the mainstem and the T3 basal section. In these cases the TGWs of grain from high density

**Fig. 21** The influence of density on

i Grain yield

ii Grain number per main ear

iii TGW % MC

iv Tillers $m^{-2}$

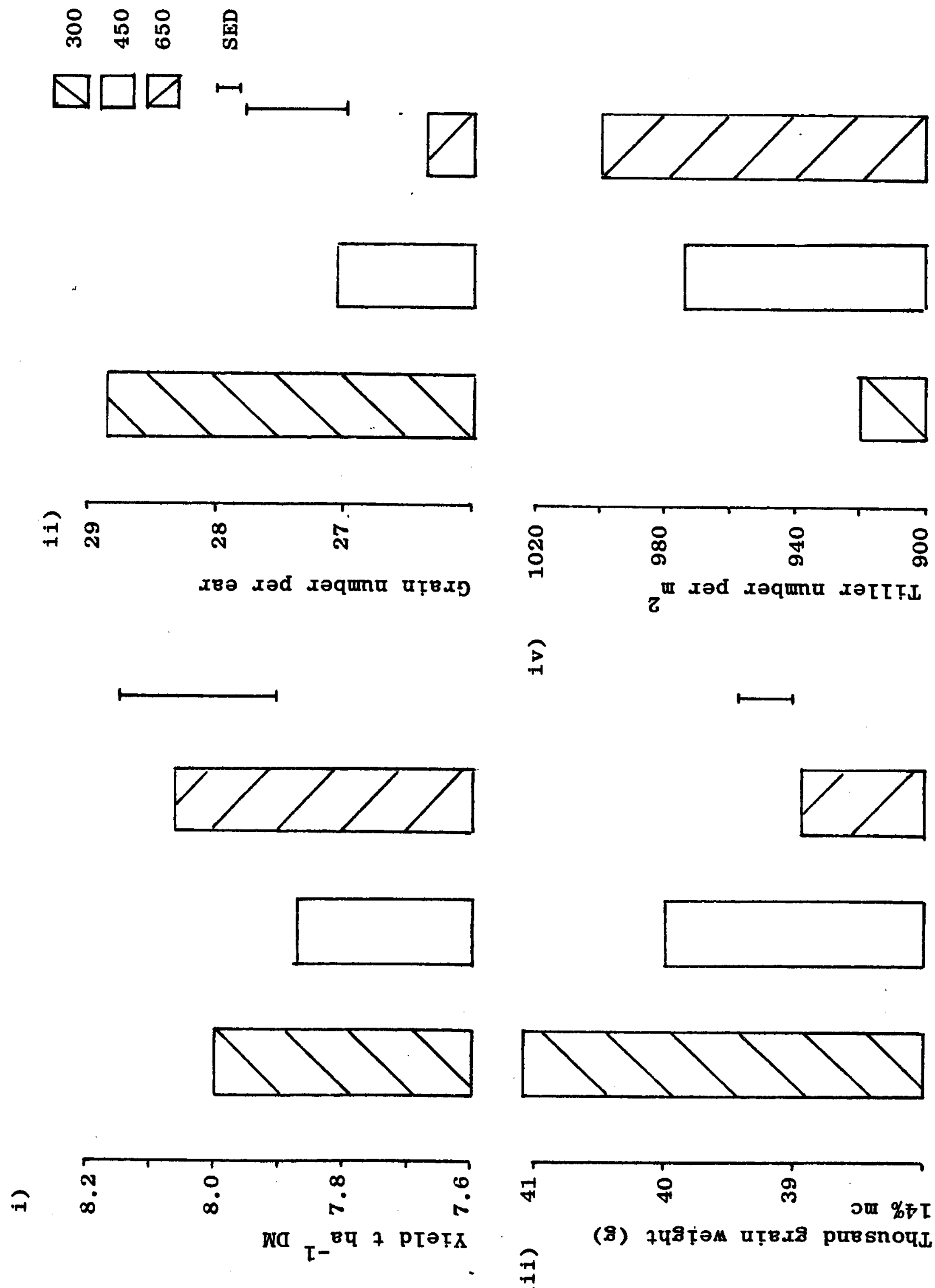

300
450
650
SED
i)
Yield t ha$^{-1}$ DM
8.2
8.0
7.8
7.6
ii)
Grain number per ear
29
28
27
iii)
Thousand grain weight (g) 14% mc
41
40
39
iv)
Tiller number per m$^2$
1020
980
940
900

**Fig. 22** The effect of density on the distribution of ear sizes as measured by grain number per ear

A) Mainstem

B) T1

i 300 seeds $m^{-2}$

ii 450 seeds $m^{-2}$

iii 650 seeds $m^{-2}$

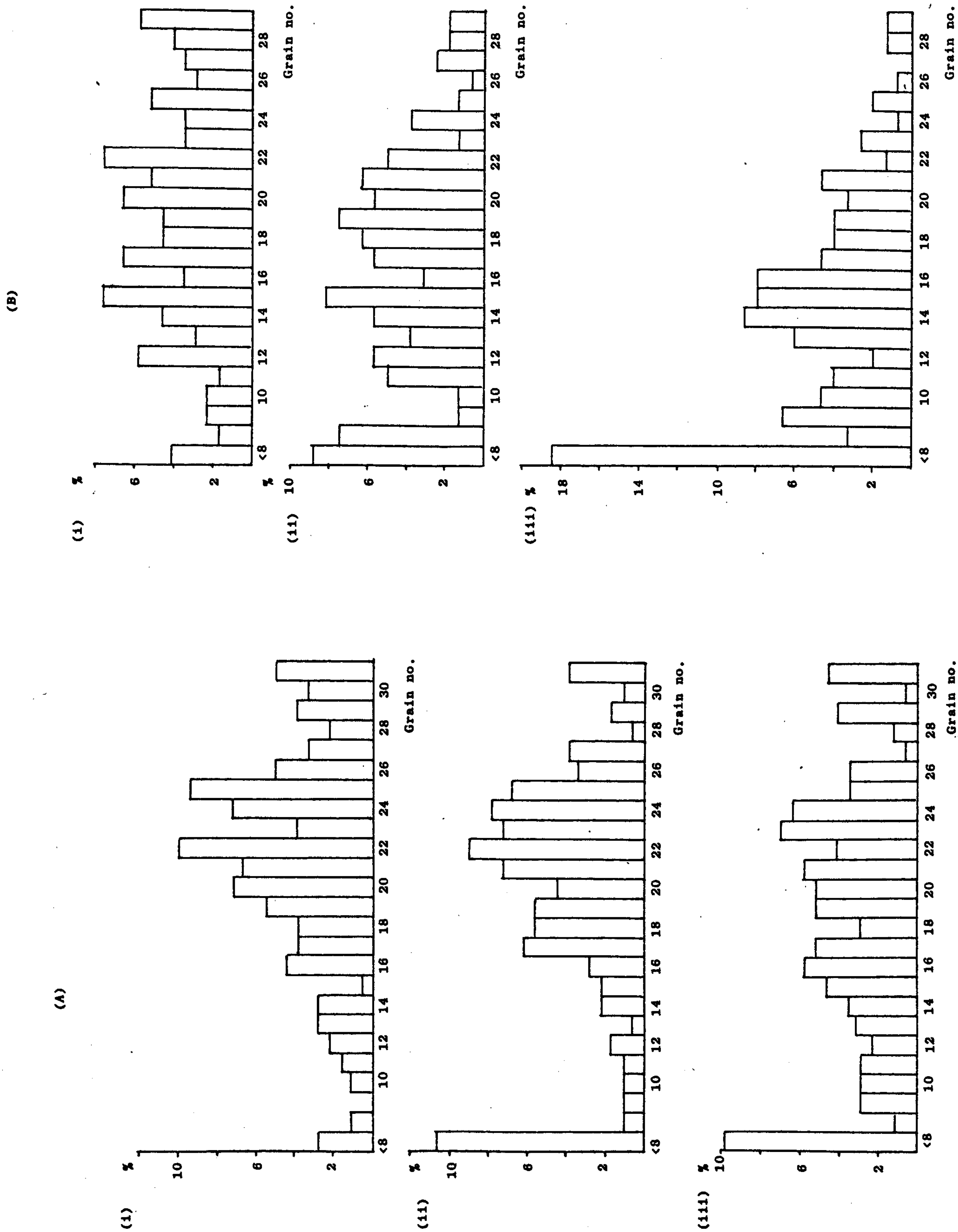
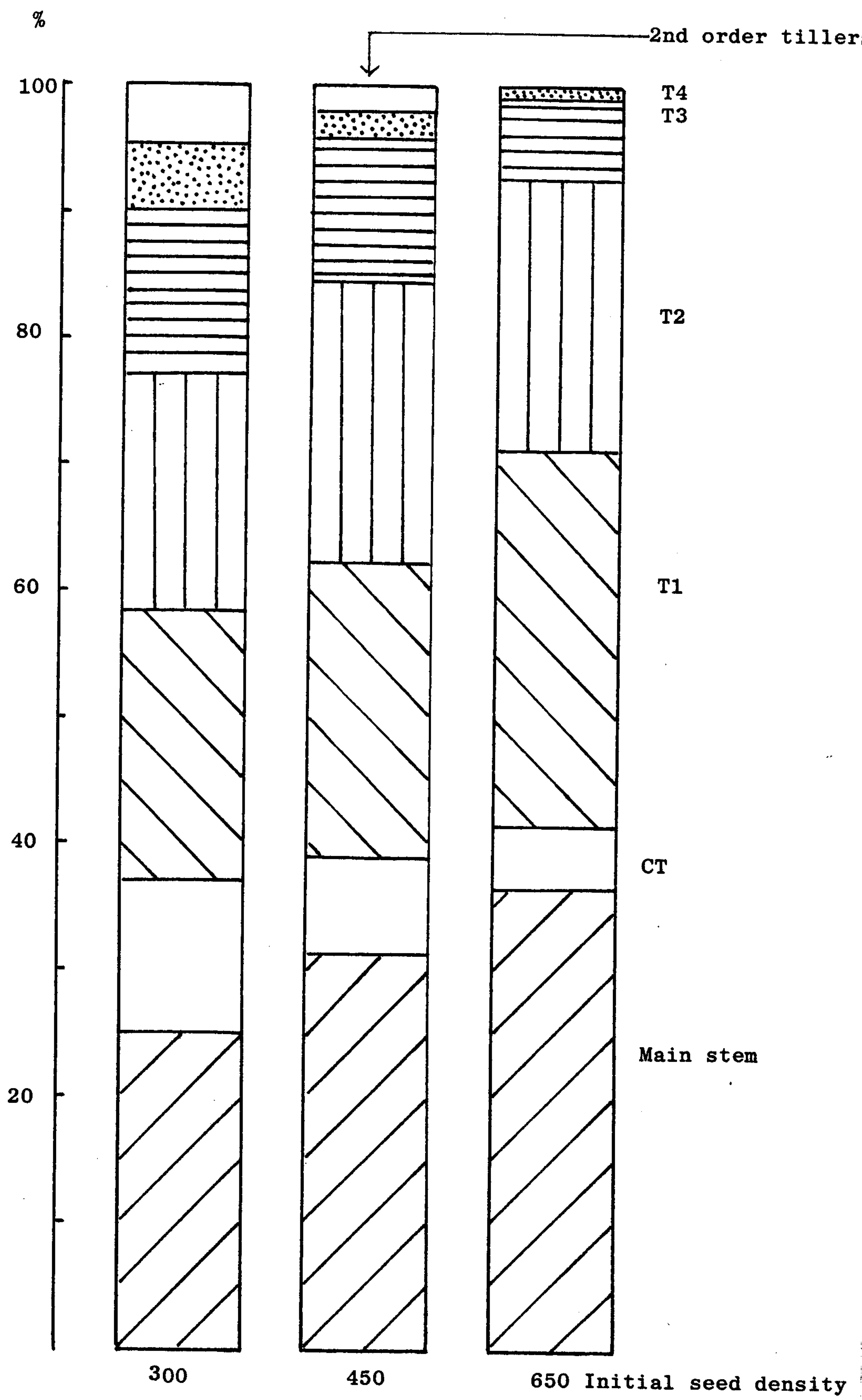

(A)
(B)
(i)
(ii)
(iii)
%
Grain no.
<8
10
12
14
16
18
20
22
24
26
28
30
2
6
10
14
18

**Table 13** Thousand grain weight of hand harvested samples

| | TOP | | | | | MID | | | | | BASE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 300 | 450 | 650 | SED (8Df) | Sig | 300 | 450 | 650 | SED (8Df) | Sig | 300 | 450 | 650 | SED (8Df) | Sig |
| Main | 28.27 | 29.03 | 26.24 | 1.102 | ns | 39.91 | 39.87 | 36.70 | 1.053 | x | 38.18 | 38.78 | 35.95 | 1.113 | ns |
| CT | 25.20 | 26.97 | 26.48 | 1.626 | ns | 35.63 | 37.03 | 34.57 | 2.228 | ns | 33.59 | 34.26 | 32.10 | 2.065 | ns |
| T1 | 28.09 | 27.59 | 26.42 | 1.367 | ns | 39.00 | 37.01 | 36.65 | 1.369 | ns | 37.67 | 35.79 | 34.36 | 2.008 | ns |
| T2 | 28.46 | 28.14 | 24.87 | 1.653 | ns | 39.3 | 37.1 | 36.23 | 1.69 | ns | 37.70 | 35.75 | 32.78 | 1.810 | ns |
| T3 | 24.77 | 28.22 | 23.75 | 1.989 | ns | 35.7 | 35.2 | 31.9 | 8.47 | ns | 34.30 | 33.68 | 29.30 | 1.537 | x |

**Fig. 23** The proportion of total ear weights contributed by each ear category

| Category | SED (30Df) | Sig |
|---|---|---|
| Main | 1.577 | xxx |
| CT | 1.329 | xxx |
| T1 | 1.275 | xxx |
| T2 | 1.454 | ns |
| T3 | 1.298 | xxx |
| T4 | 0.655 | xxx |
| 2nd order tillers | 0.742 | xxx |


%
100
80
60
40
20
2nd order tillers
T4
T3
T2
T1
CT
Main stem
300
450
650 Initial seed density

treatments was significantly lower than those obtained from lower density initial seed rates.

Harvest indices of each tiller category differed in each density (Fig. 24) although high variability caused significant levels to be reached infrequently. The Fhs of high density treatments were lower than those achieved at low sowing densities.

### 3.3.6 The effect of density on seed size distribution

Significant differences occurred between densities in seed size distribution by weight and by number (Fig. 25). High density treatments reduced the proportion of grain in the largest size category (>2.8 mm) but increased the proportion of grain below 2.5 mm compared to the grain distribution of low density treatments. There were no interactions between variety and density in the proportion of seed in each size category.

TGW estimated from the sieved samples showed significant differences between densities with high density treatments having lower TGWs (data not presented). These estimated values for TGW were higher than those obtained when separately calculated from grain samples extracted from the cleaned grain ex-combine harvester. The differences may have occurred because of the selectivity of the Decca seed counter which tended to reject large seeds when transporting the seeds to the region of the counter. Thus the seed weight estimated when using the counter was lower than the true value. This error was minimized in subsequent experiments by counting all grains within a subsample and not selectively counting a predetermined number. Accuracy of grain weight determination was increased during seed size separation procedures by thoroughly cleaning the grain and removing any broken grains from the sample.

### 3.3.7 The effect of density on grain characteristics

Grain nitrogen content and grain HWE were not significantly affected by density changes (Table 14). However increasing densities tended to have increasing grain nitrogen content and decreasing HWE values.

Germination percentages (original and angularly transformed data) were not affected by original drilling densities (Table 14). No

**Fig. 24** Harvest indices of various tiller categories as influenced by density

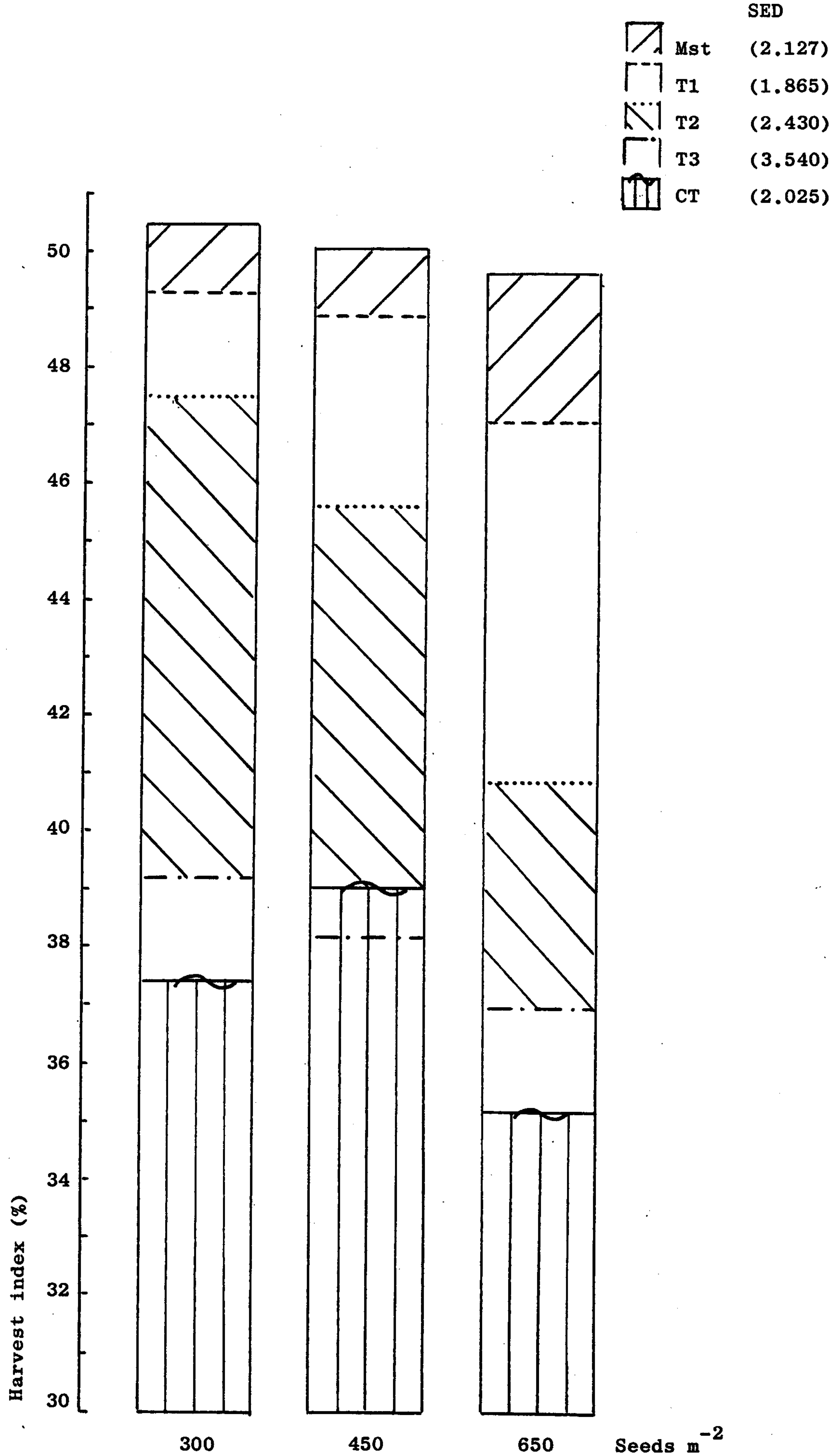
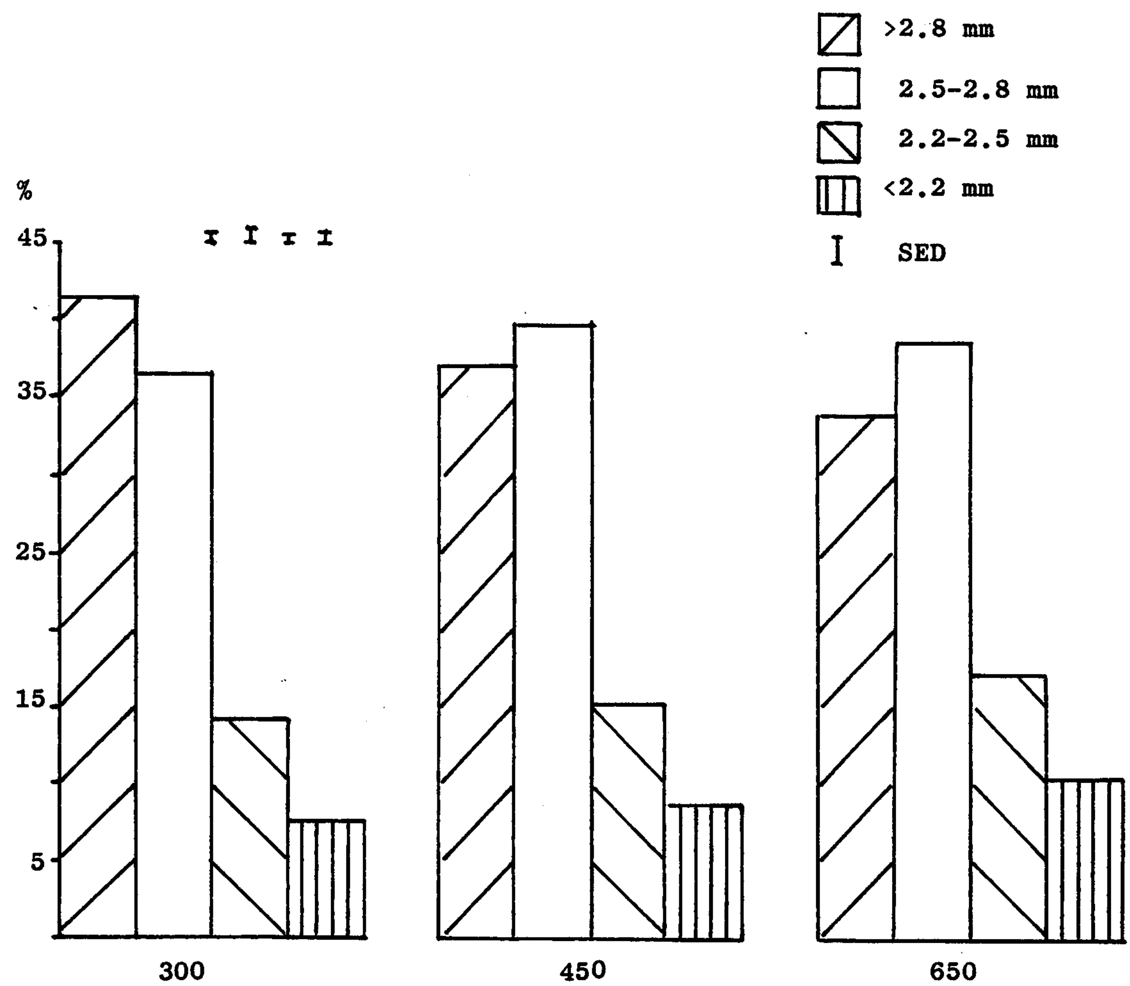

SED
Mst (2.127)
T1 (1.865)
T2 (2.430)
T3 (3.540)
CT (2.025)
50
48
46
44
42
40
38
36
34
32
30
Harvest index (%)
300
450
650
Seeds m-2

**Fig. 25** Seed size distribution — the effects of density

i percentage distribution by weight

ii percentage distribution by number

(i)




(ii)

Key as above

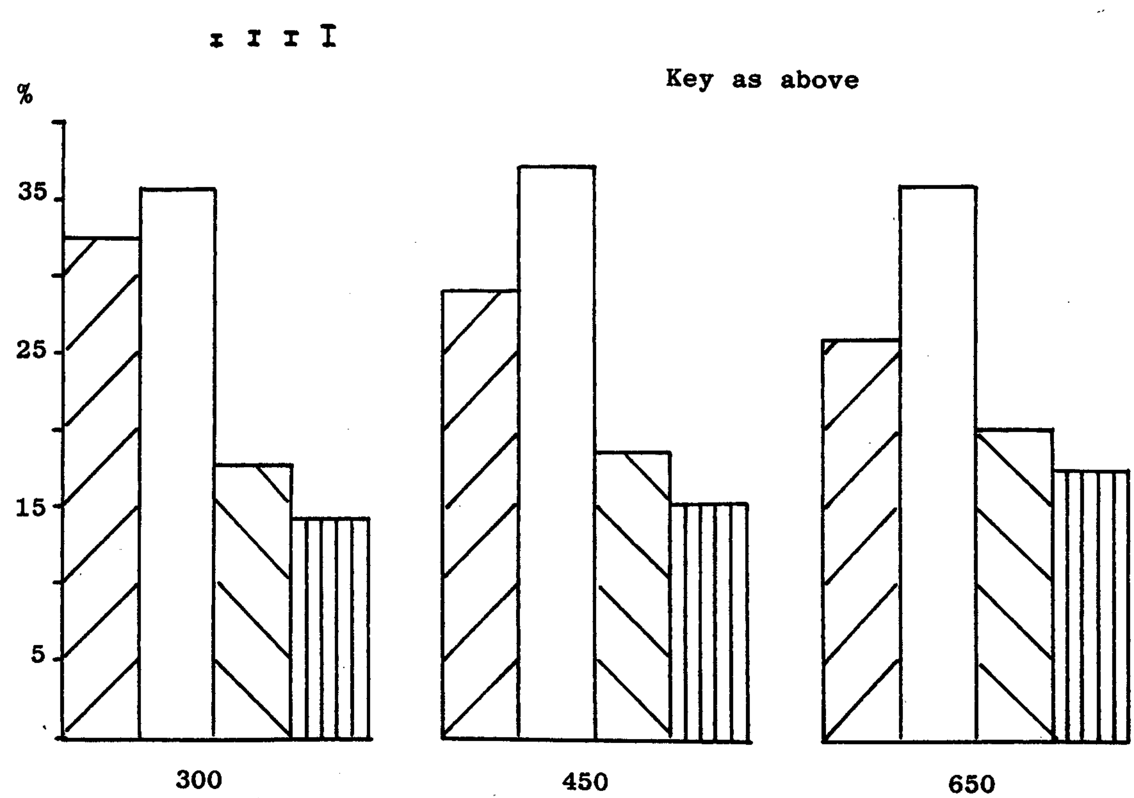


**Table 14** The effect of density on grain nitrogen content and grain HWE

Germination percentages as influenced by density

| | Density | | | SED | Sig |
|---|---|---|---|---|---|
| | 300 | 450 | 650 | | |
| Grain Nitrogen % | 1.931 | 1.958 | 1.978 | 0.195 | ns |
| HWE | 285.41 | 284.74 | 284.59 | 0.855 | ns |
| Total sample Sept 1981 | 98.00 | 98.17 | 97.81 | 0.410 | ns |
| Total sample June 1983 | 97.20 | 97.83 | 97.32 | 0.409 | ns |
| Seeds > 2.8 mm Sept 1981 | 98.64 | 98.46 | 98.30 | 0.294 | ns |
| Seeds < 2.2 mm Sept 1981 | 96.74 | 96.95 | 96.31 | 0.960 | ns |

differences were evident when grain samples were tested after a short storage period or after prolonged storage (June, 1983). No differences were present between densities in the germination percentages of seeds above 2.8 mm or below 2.2 mm.

## 3.4 The Effect of Nitrogen Treatments

### 3.4.1 Introduction

One aim of experiment WB1 was to investigate the extent to which crops could be modified by the timing of nitrogen applications. Full trial details are outlined in Section 3.1.1 and specific details pertaining to the nitrogen treatments are noted below (Section 3.4.2).

### 3.4.2 Experimental design and procedure

Three nitrogen treatments were established. These are outlined in Table 7. All treatments totalled 150 kg $ha^{-1}$ nitrogen applied. From 225 DAS only treatment N2 was monitored, but the grand mean of a measured component was taken to be equivalent to the average N2 value which is thus used in the following data presentation. The first top dressing of nitrogen (27 January 1981) was applied by hand as the ground was not suitable to use a tractor mounted fertilizer spreader. The second top dressing (6 April 1981) was applied from a tractor mounted spreader. All nitrogen was applied as Nitram (ICI) which contained 34.5% N.

### 3.4.3 The effect of nitrogen treatment on tillering

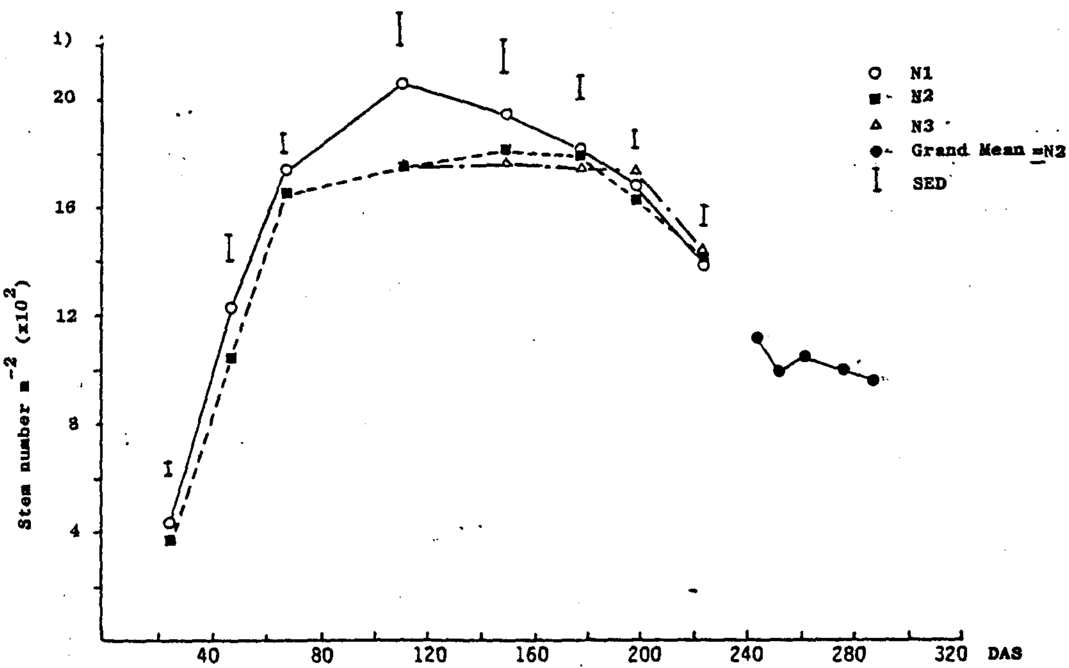
Seedbed nitrogen (40 kg $ha^{-1}$) initially increased the number of tillers per plant (Fig. 26(i)) and the number of stems $m^{-2}$ (Fig. 26(ii)). Significant differences occurred between treatments in peak tiller numbers obtained and the time of occurrence of peak tiller number. The N1 treatment reached peak tiller number at 112 DAS (8 January) with N2 and N3 reaching their lower peak values at 151 DAS (16 February).

The application of N at 131 DAS stimulated the production of tillers in N2 and N3, higher application rates resulting in an increased tiller population. This first top dressing was applied too late to increase peak tiller number of the N1 treatment. The highest nitrogen application rates at the second top dressing (6 April) slowed the decline of tiller numbers.

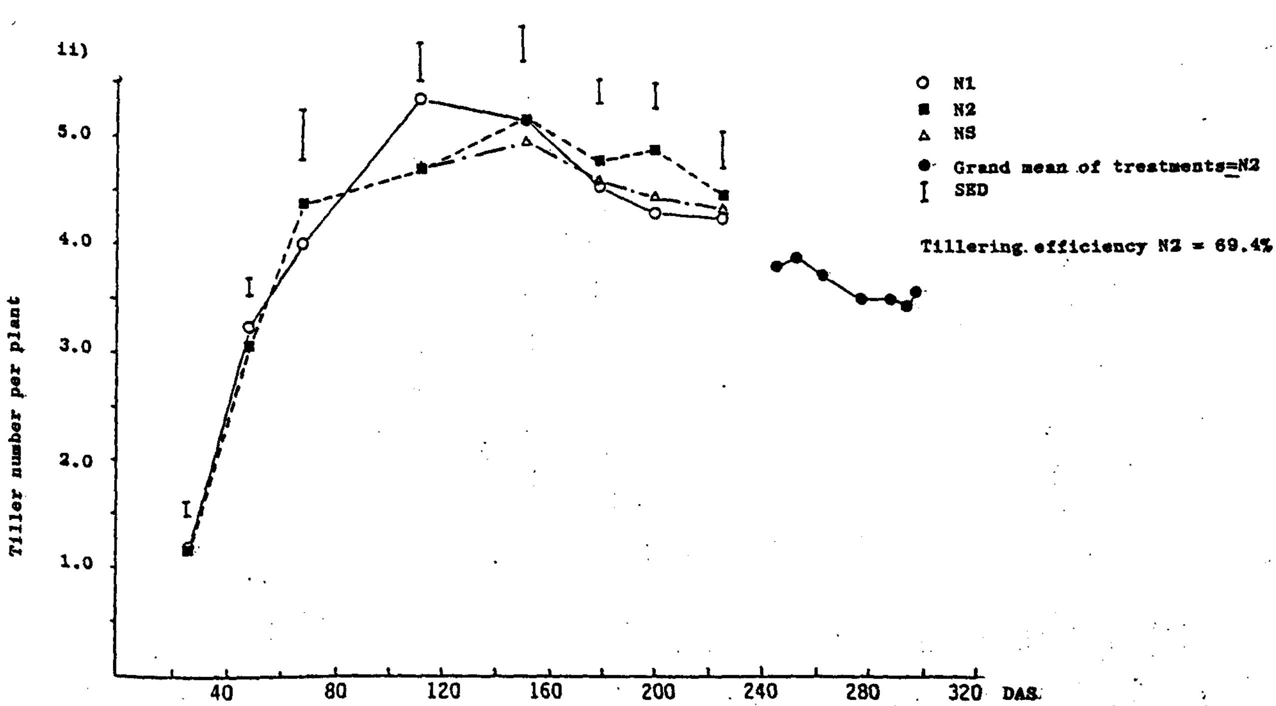
**Fig. 26**

i The effect of nitrogen treatment on the number of stems $m^{-2}$

ii and on the number of tillers per plant



i)
Stem number m$^{-2}$ (x10$^2$)
4
8
12
16
20
40
80
120
160
200
240
280
320
DAS
N1
N2
N3
Grand Mean =N2
SED

ii)
Tiller number per plant
1.0
2.0
3.0
4.0
5.0
40
80
120
160
200
240
280
320
DAS
N1
N2
NS
Grand mean of treatments=N2
SED
Tillering efficiency N2 = 69.4%

The estimated tillering efficiency of the N2 treatments was 69.4% when assessed using the values for the number of tillers per plant.

### 3.4.4 The effect of nitrogen treatment on leaf area indices

Seed bed nitrogen increased the LAI of the crop above those obtained without seedbed nitrogen until 180 DAS (Fig. 27). However the peak LAI was significantly lower than that of other treatments. The treatment with large amounts of N in the second top dressing produced the highest LAI. No estimates could be made of the leaf area duration (LAD) post peak LAI or post anthesis.

GAI showed a similar pattern to that of LAI with the GAI of N1 being significantly higher than that of N2 prior to 180 DAS. However after this time the GAI of N3 exceeded that of N1.

SLA until 225 DAS was not consistently modified by varying nitrogen treatments although during the autumn and early winter growth the SLA of crops with additional seedbed nitrogen was increased (data not presented).

LAR (Fig. 28) was significantly influenced by nitrogen treatments after 151 DAS. N1 treatments had significantly lower LARs than those obtained by the N2 treatment. This onset of significant modification of the LAR was coincident with the start of stem elongation. The N1 treatment showed no significant modification of above ground biomass yields from 180 DAS but did have lower values for LAI. Thus there was less leaf area per unit dry weight of the whole plant, i.e. LAR was lower.

### 3.4.5 Effect of nitrogen treatment on biomass

Prior to 180 DAS the addition of nitrogen to the seedbed increased plant above ground biomass above that obtained when seedbed nitrogen was not applied although on only two occasions (8/1/1981 and 16/2/1981) was the difference significant (Fig. 29). This early increase in biomass was as a result of the increased production of tillers by the N1 treatments. By 151 DAS there was no significant difference between nitrogen treatments in the stem number per unit area or in the tiller number per plant.

From the onset of spring growth no significant differences occurred between nitrogen treatments in their biomass yields.

**Fig. 27** The effect of nitrogen treatment on LAI

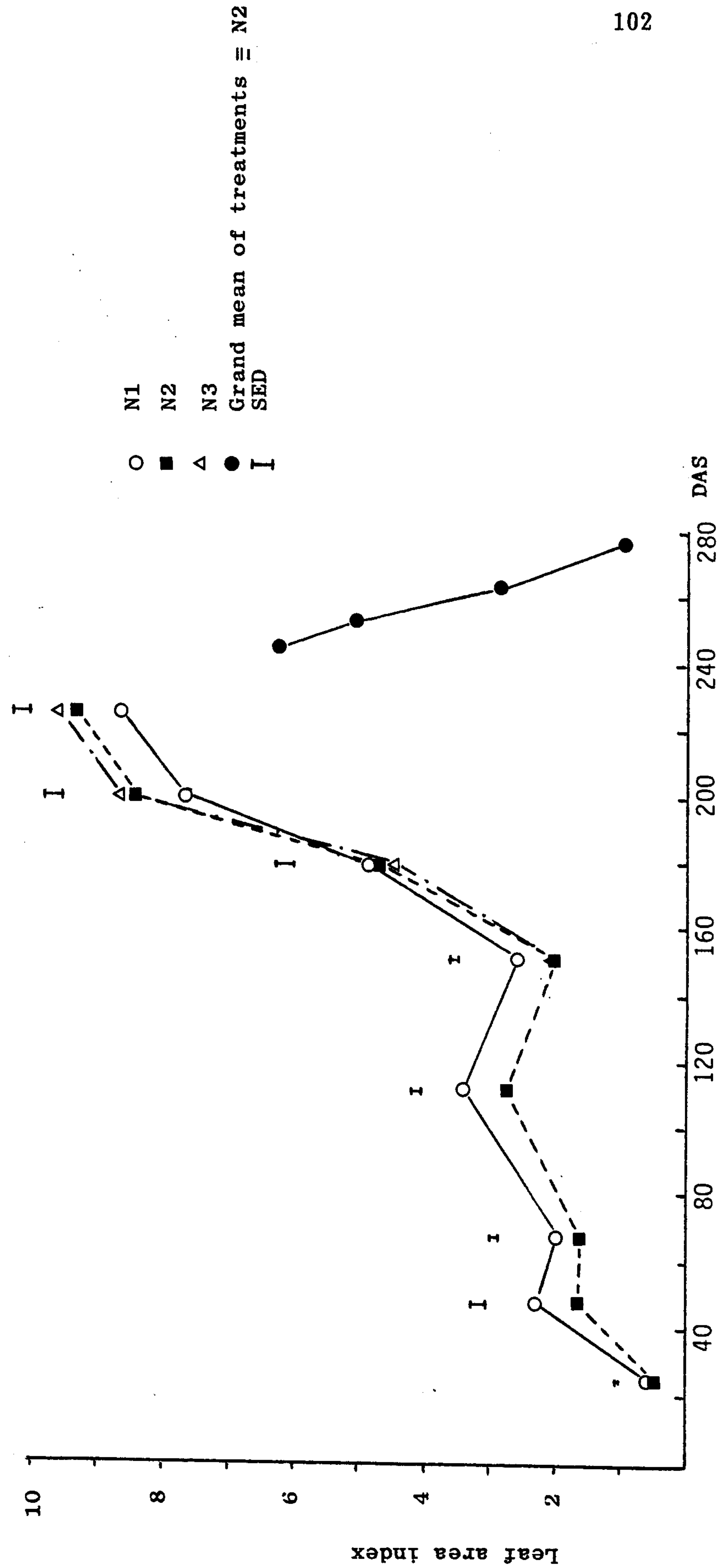

N1
N2
N3
Grand mean of treatments ≡ N2
SED
Leaf area index
10
8
6
4
2
40
80
120
160
200
240
280
DAS

**Fig. 28** The effect of nitrogen regimes on LAR

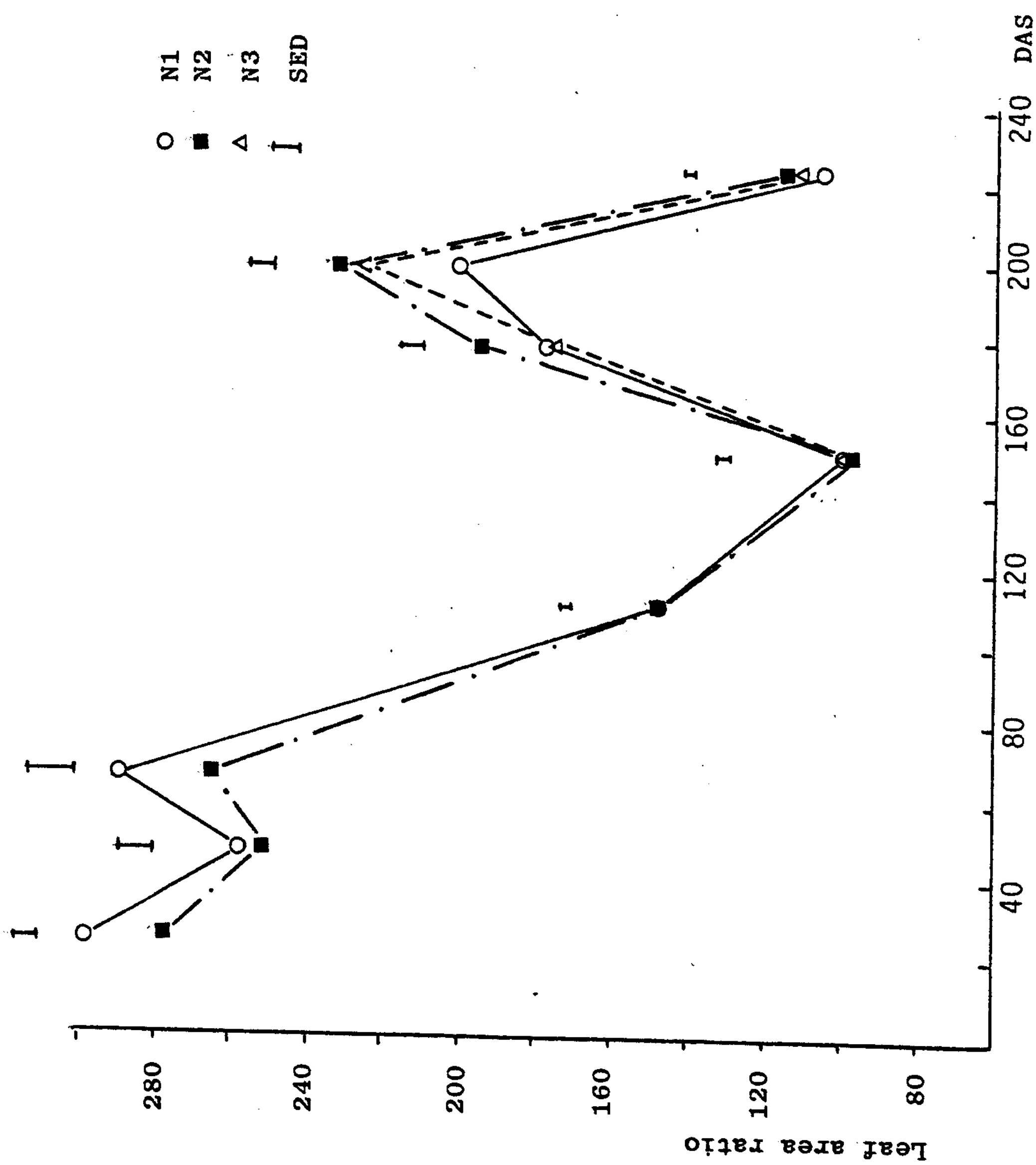
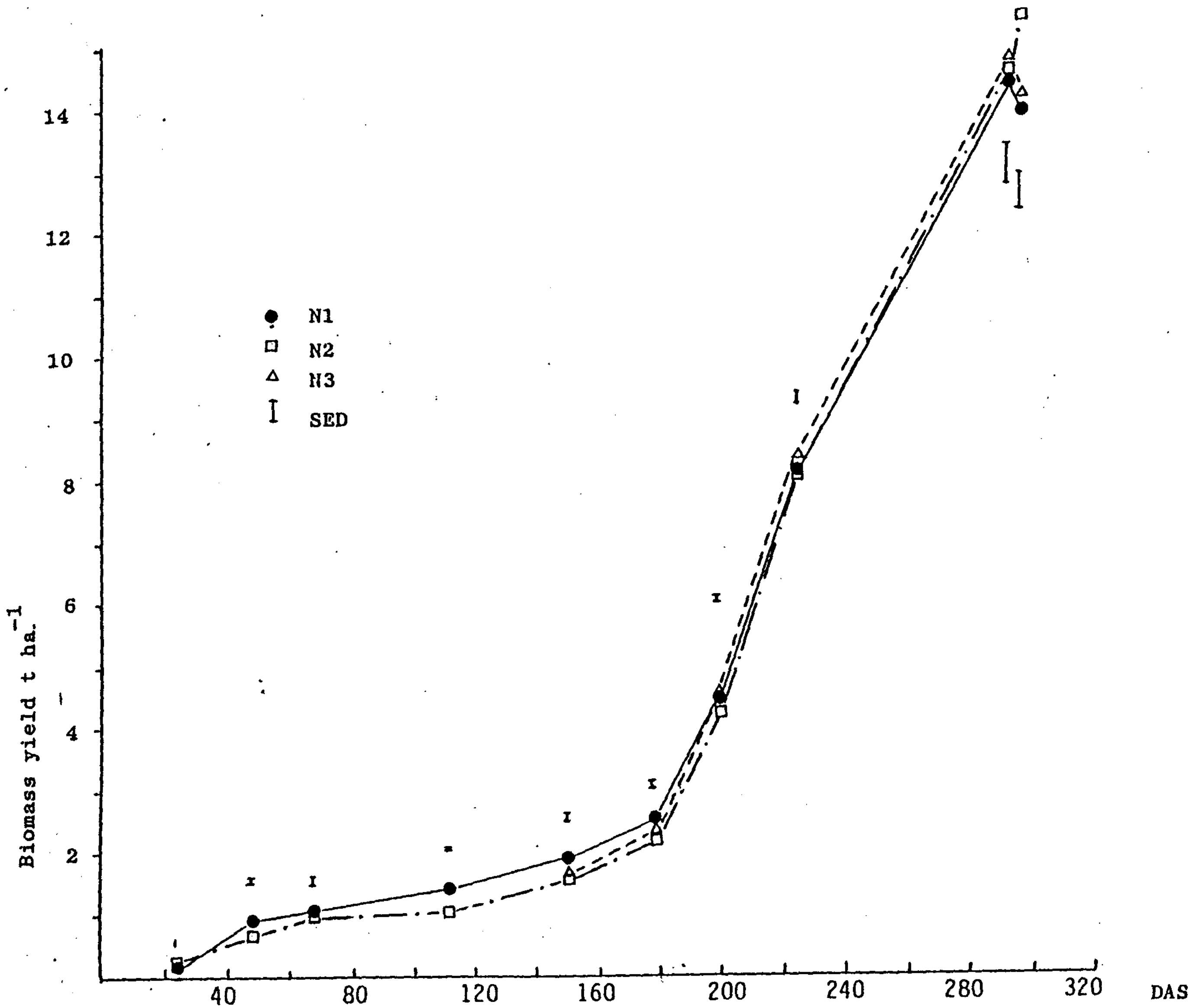

N1
N2
N3
SED
Leaf area ratio
280
240
200
160
120
80
DAS
40
80
120
160
200
240

**Fig. 29** The modification of crop biomass by nitrogen


N1
N2
N3
SED
Biomass yield t ha.$^{-1}$
DAS
14
12
10
8
6
4
2
40
80
120
160
200
240
280
320

### 3.4.6 Effect of nitrogen treatment on harvest index (Fh)

At final harvest there were no significant differences between treatments in their total yield of straw and also no significant differences in their grain yield when calculated from hand harvested samples. However the estimated values for harvest indices of each tiller were dependent both on the tiller category and on the nitrogen treatment. The Fh values of the majority of the tiller categories were increased by the N3 treatment, however this increase was not always statistically significant.

Tiller categories differed in their harvest indices with the ranking, in descending order, being mainstem, T1, T2, T3, CT. This order was not markedly altered by nitrogen treatments (Fig. 30).

### 3.4.7 The effect of nitrogen treatments on grain yield and on yield components

Combine harvested grain yield was significantly reduced by the N1 treatment, i.e. where over 25% of the total nitrogen applied was received in the seedbed. However the nitrogen treatments did not significantly influence any yield component (Table 15).

The nitrogen treatments did not significantly influence the proportion of total ear weight contributed by each ear category (Table 16).

Applied nitrogen treatments did not significantly affect TGW (ex combine) (Table 17). There were no significant differences between treatments in the number of grains $m^{-2}$. This value was calculated from the derived ear number $m^{-2}$ and the estimated value for the average grain number per ear. However the grain yield $m^{-2}$ which depended both on TGW and on grain number showed significant differences between treatments with the N2 treatment having a greater grain yield per unit area. These values differed from those obtained from the combine harvested samples, in each case the derived values being greater.

The higher grain number per unit area in the N2 treatment was also shown in the higher potential number of grain sites per ear present upon ear emergence.

The effects of nitrogen treatment on the number of filled grains per main stem ear are outlined in Fig. 31. Treatment N2 had a lower percentage of ears with less than 10 grains per ear but a higher percentage

**Table 15** The effects of nitrogen treatment on grain yield and yield components

| | N1 | N2 | N3 | SED (34Df) | Sig |
|---|---|---|---|---|---|
| Yield t $ha^{-1}$ 14% MC | 7.47 | 8.11 | 8.35 | 0.251 | x |
| Ears per $m^{-2}$ | 919 | 952 | 863 | 43.2 | ns |
| Potential grain no. ear (main) | 26.66 | 28.14 | 27.46 | 0.795 | ns |
| TGW 0% MC (combine) | 39.98 | 39.75 | 40.36 | 0.434 | ns |
| Tillers per plant | 3.364 | 3.522 | 3.432 | 0.1279 | ns |
| Biomass kg $ha^{-1}$ | 14082 | 15573 | 14213 | 648.4 | ns |

**Table 16** The proportion of total ear weight contributed by each ear category — the influence of nitrogen treatment

| Category | N1 | N2 | N3 | SED (30Df) | Sig |
|---|---|---|---|---|---|
| Main | 31.33 | 29.52 | 31.80 | 1.577 | ns |
| CT | 7.66 | 7.89 | 9.25 | 1.329 | ns |
| T1 | 25.18 | 25.22 | 24.02 | 1.275 | ns |
| T2 | 21.04 | 20.74 | 20.89 | 1.454 | ns |
| T3 | 9.92 | 10.47 | 10.09 | 1.298 | ns |
| T4 | 2.19 | 3.10 | 1.83 | 0.655 | ns |
| 2nd order tillers | 2.69 | 3.06 | 2.15 | 0.742 | ns |

**Table 17** The modification of seed characteristics

| | Nitrogen treatment | | | SED (34Df) | Sig |
|---|---|---|---|---|---|
| | N1 | N2 | N3 | | |
| TGW 0% MC | 39.98 | 39.75 | 40.36 | 0.43 | ns |
| Grain wt. $m^{-2}$(g) | 788 | 879 | 785 | 40.5 | x |
| Grain no. $m^{-2}$ | 19721 | 22188 | 19593 | 1037 | ns |

**Fig. 30** The effect of nitrogen on Fh of tiller categories

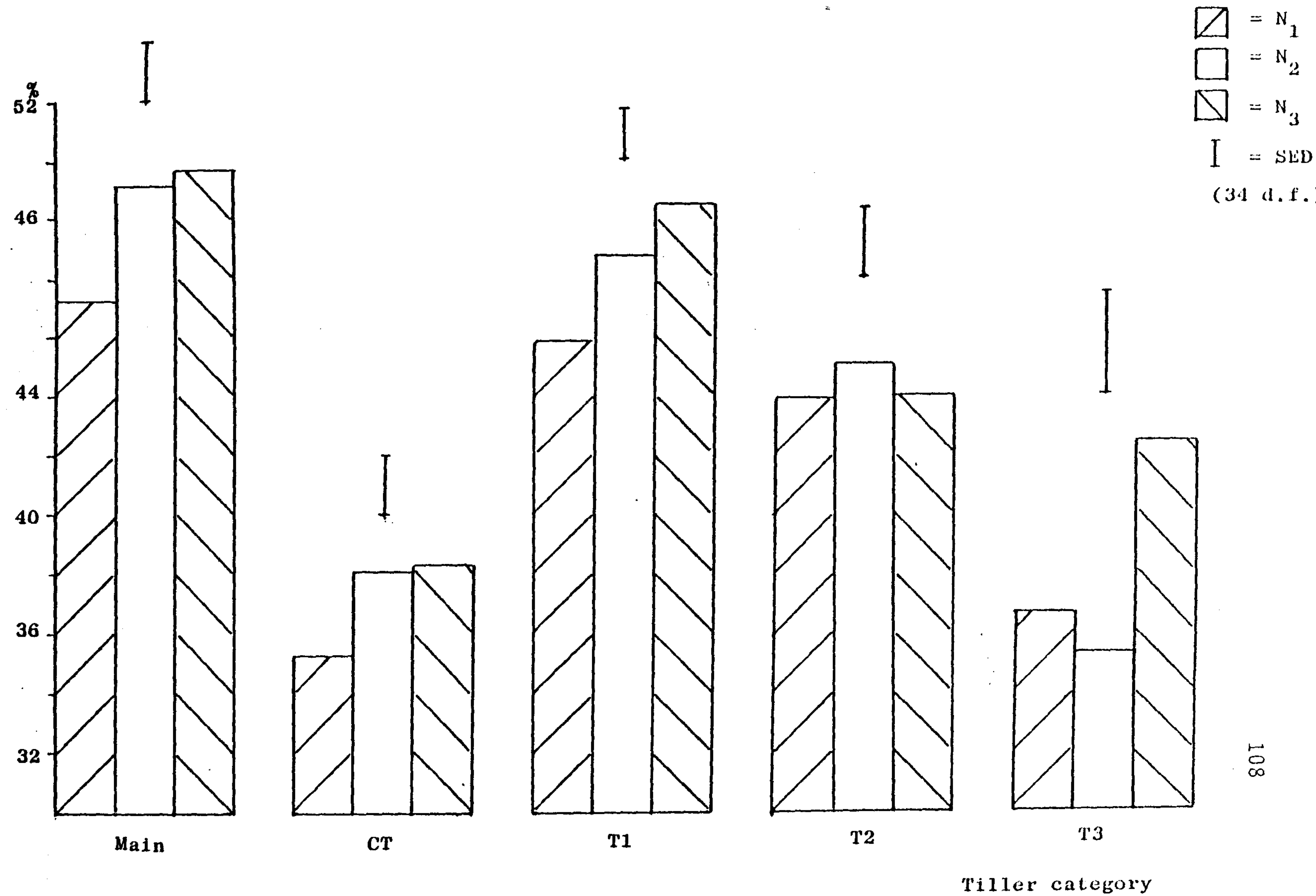
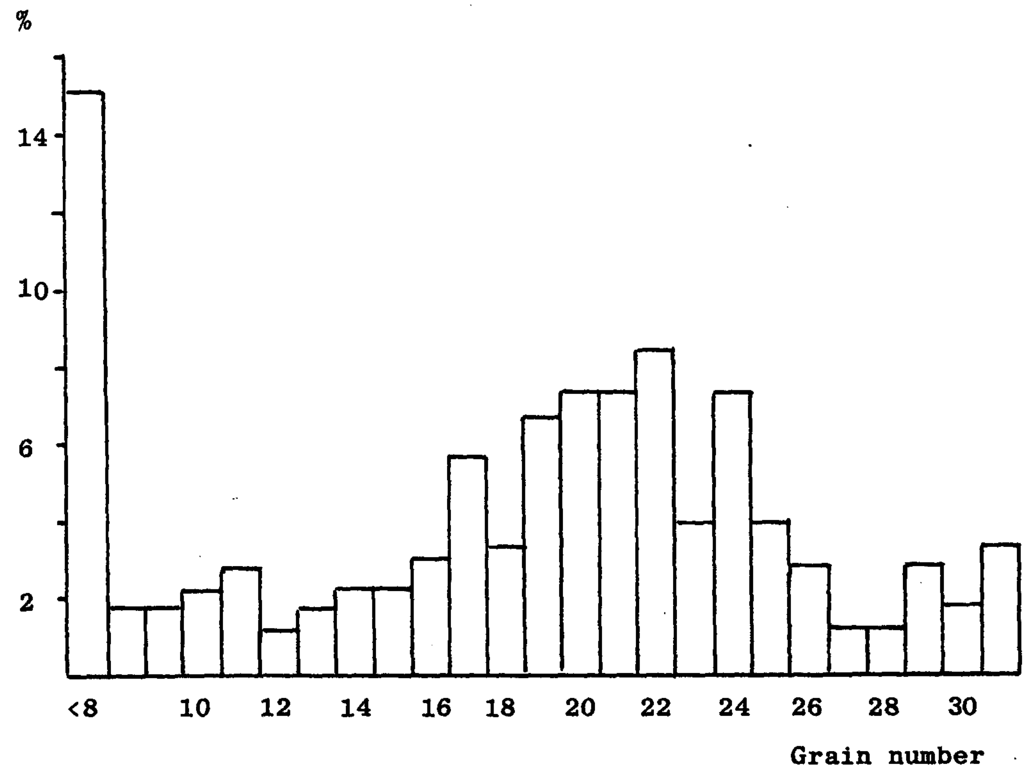

%
52
46
44
40
36
32
Main
CT
T1
T2
T3
Tiller category
= N1
= N2
= N3
= SED
(34 d.f.)

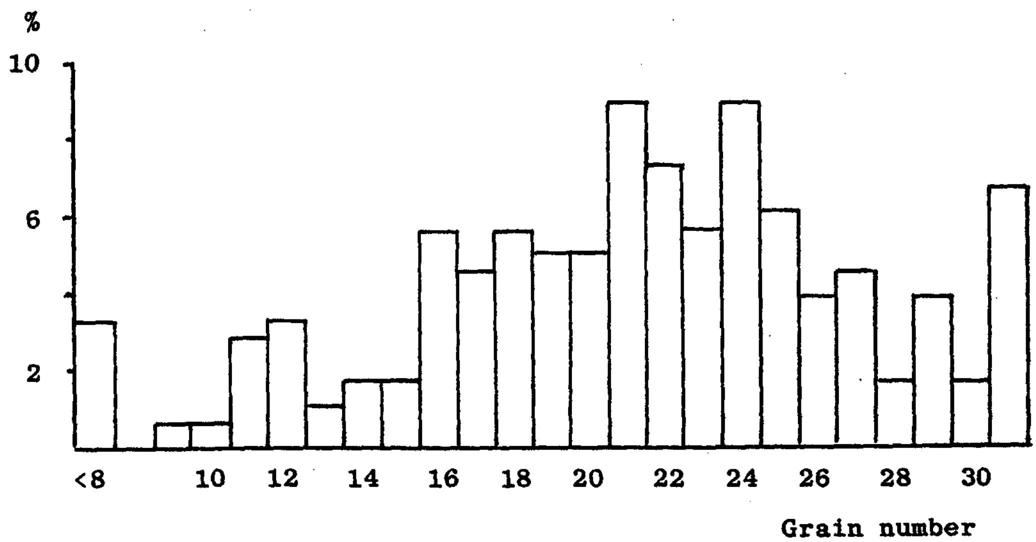
**Fig. 31** The effect of nitrogen treatment on ear size distribution (main ears only)

| | |
|---|---|
| i | N1 |
| ii | N2 |
| iii | N3 |

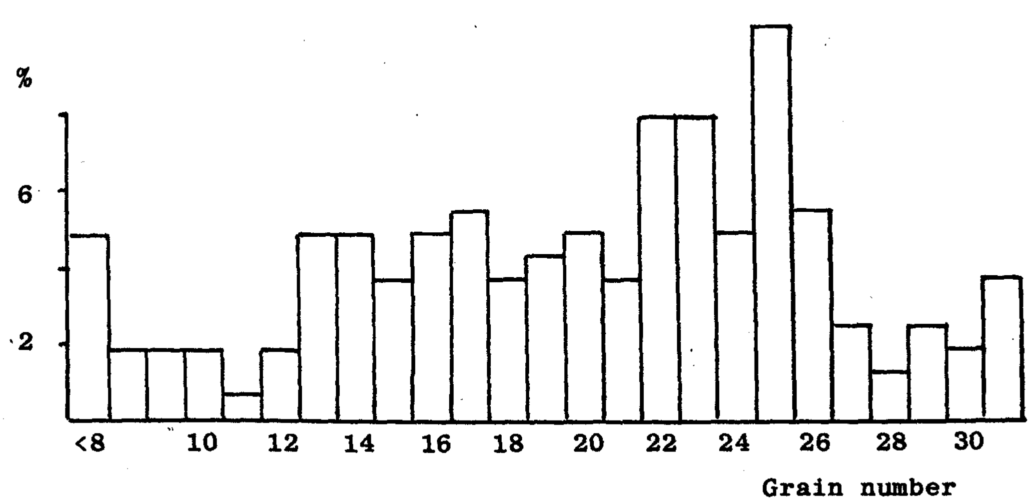
(i)


%
14
10
6
2
<8
10
12
14
16
18
20
22
24
26
28
30
Grain number

(ii)


%
10
6
2
<8
10
12
14
16
18
20
22
24
26
28
30
Grain number

(iii)


%
6
2
<8
10
12
14
16
18
20
22
24
26
28
30
Grain number

of ears with more than 21 grains per ear than the other nitrogen treatments.

The application of autumn nitrogen, treatment N1, produced a large proportion of ears with less than 10 grains per ear present.

The higher proportion of ears with grain numbers above 16 per ear in the N2 treatment is in agreement with the higher potential number of grain sites per ear present upon ear emergence of the N2 treated plants.

The thousand grain weights of grains from the hand harvested sample is outlined in Table 18. Those grains classified as top and base are the uppermost and basal six grains from each ear taken for analysis. In the basal region this excludes the final two grains on each ear which are barren. Nitrogen treatments do not significantly alter TGW of any part of the ear in any tiller category except in T3 where large amounts of late nitrogen significantly increased TGW. However this anomaly may have been caused by the small number of grains used for the analysis.

Tillers differed in the recorded TGW of their grains with the TGW of grains from the middle of the ear being lower in later emerging tiller categories. Infrequent interactions occurred between nitrogen and density and between nitrogen and variety when considering thousand grain weights of grains harvested from specific regions of the ear.

### 3.4.8 The effect of nitrogen treatments on seed characteristics

3.4.8.1 Seed size distribution Nitrogen treatments had no significant effect on the proportion of grains within each size classification when assessed by number or by weight (Fig. 32). In all three nitrogen treatments over 35% of the grains were between 2.5-2.8 mm in size. Those grains below 2.2 mm accounted for over 15% of total seed number and over 7% of total seed weight in each nitrogen treatment.

However there was a significant variety/nitrogen interaction in the proportion of seeds in each size category (Fig. 33). Igri had a larger proportion of seeds in the size category above 2.8 mm whereas the largest percentage of the Tipper seeds were between 2.5-2.8 mm in each nitrogen treatment. The varieties differed significantly in their response to the N2 treatment. The N2 treatment increased the proportion of the seeds greater than 2.8 mm in size but decreased those between 2.5-2.8 mm in Tipper. Within Igri the reverse was true.

**Table 18** Thousand grain weight of hand harvested samples

| | TOP | | | | | MID | | | | | BASE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N1 | N2 | N3 | SED (24Df) | Sig | N1 | N2 | N3 | SED (24Df) | Sig | N1 | N2 | N3 | SED (24Df) | Sig |
| Main | 28.60 | 26.70 | 28.23 | 1.056 | ns<br>- | 38.48 | 38.43 | 39.57 | 1.206 | ns<br>(VN) | 37.01 | 37.79 | 38.12 | 1.236 | ns<br>(VN) |
| CT | 27.37 | 24.38 | 26.91 | 1.910 | ns<br>- | 34.47 | 36.39 | 36.37 | 2.048 | ns<br>- | 33.84 | 31.63 | 34.49 | 2.094 | ns<br>- |
| T1 | 28.06 | 26.72 | 27.31 | 1.069 | ns<br>(DN) | 37.40 | 37.60 | 37.66 | 1.161 | ns<br>(VN) | 36.12 | 36.68 | 35.01 | 1.646 | ns<br>- |
| T2 | 27.59 | 27.00 | 26.88 | 1.294 | ns<br>- | 37.00 | 37.20 | 35.80 | 2.62 | ns<br>- | 34.81 | 35.76 | 35.67 | 1.662 | ns<br>- |
| T3 | 25.67 | 25.50 | 25.56 | 2.115 | ns<br>- | 33.0 | 27.4 | 42.4 | 4.85 | x<br>(DN)<br>(VDN) | 31.88 | 32.47 | 32.94 | 2.415 | ns<br>- |

**Fig. 32** The distribution of harvested grains within four size categories. The proportions determined by:

i number

ii weight

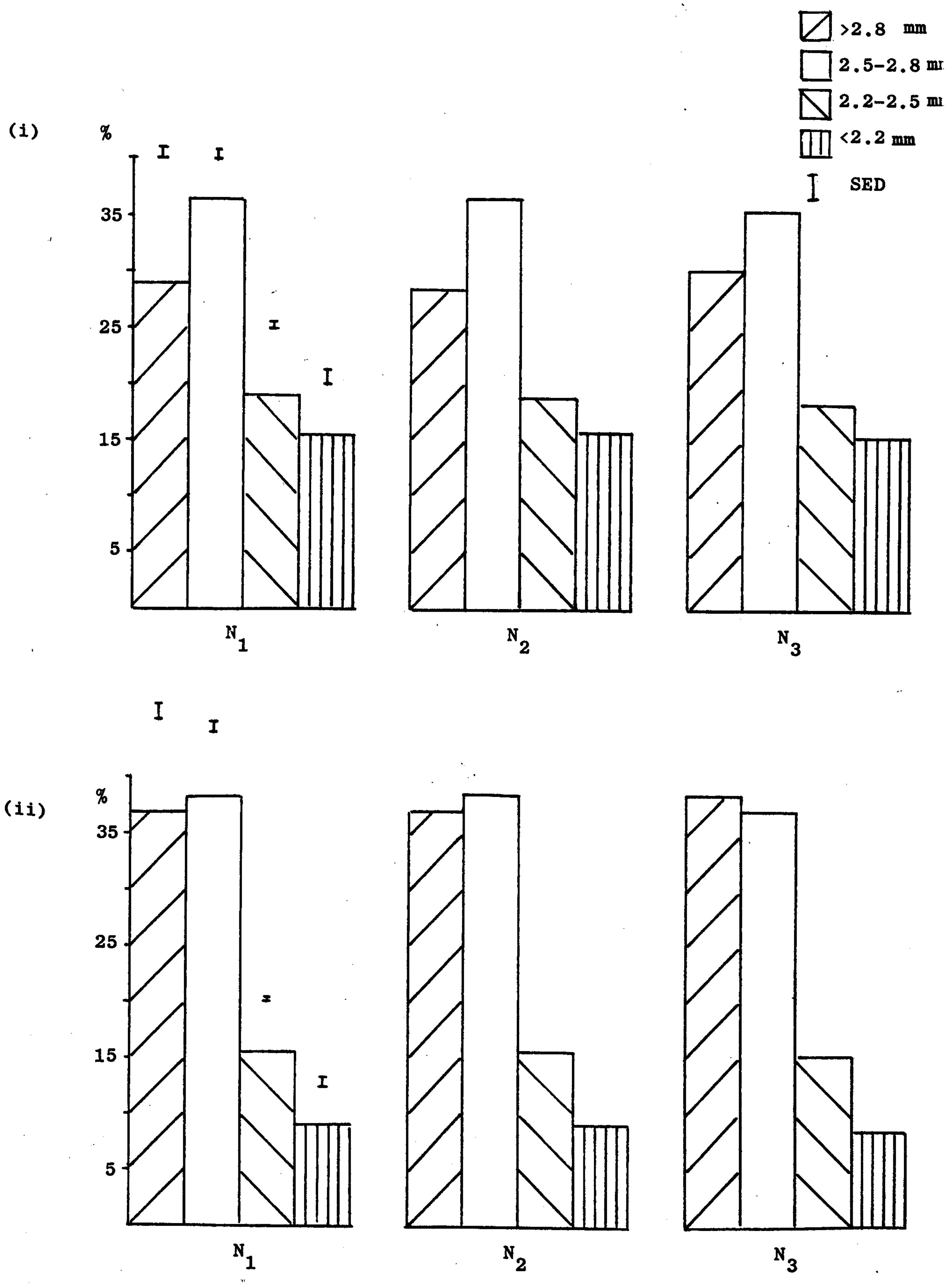
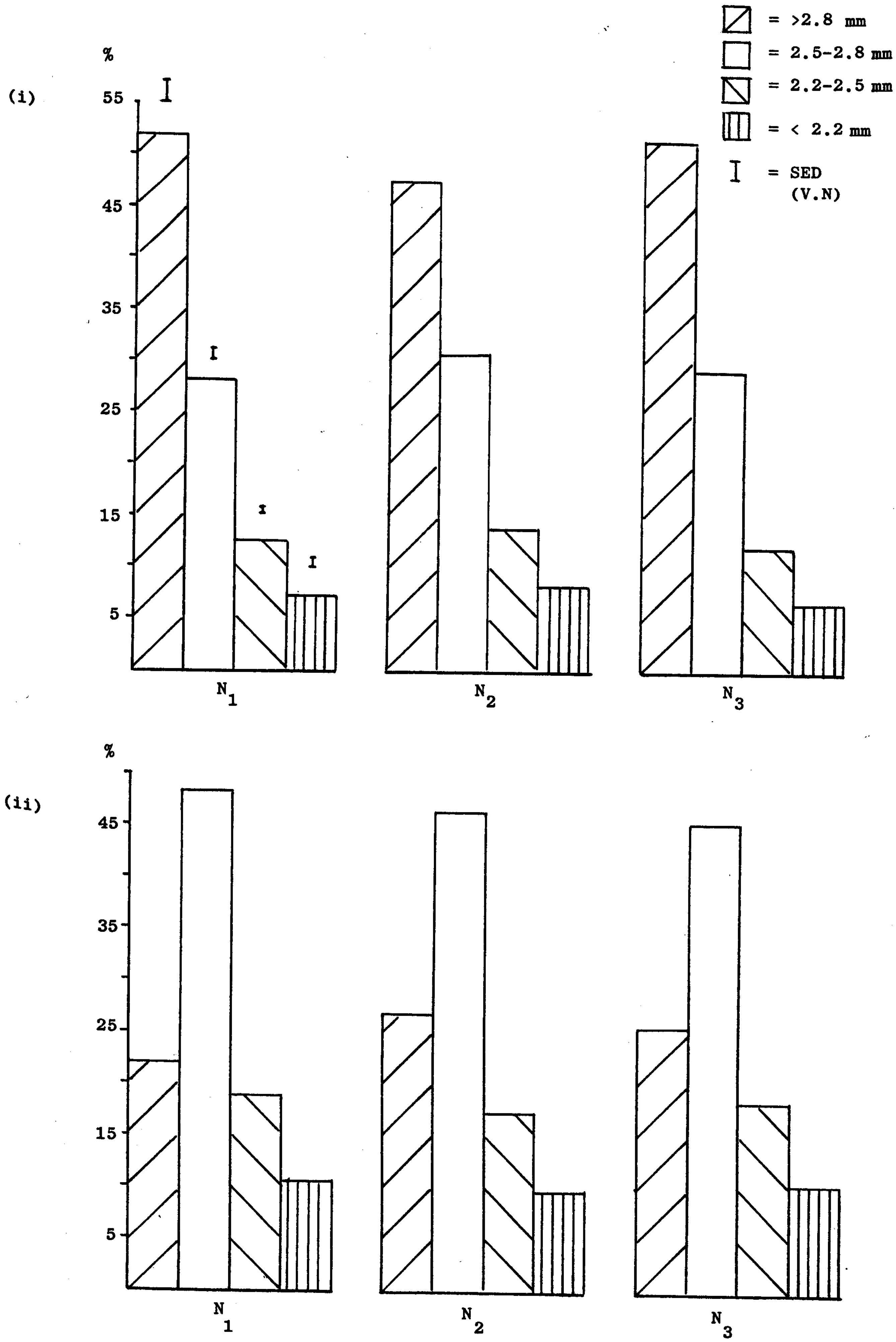

>2.8 mm
2.5-2.8 mm
2.2-2.5 mm
<2.2 mm
SED
(i)
%
35
25
15
5
N1
N2
N3
(ii)
%
35
25
15
5
N1
N2
N3

**Fig. 33** The effect of nitrogen on two varieties of winter barley — seed distribution by weight

i Igri

ii Tipper


= >2.8 mm
= 2.5-2.8 mm
= 2.2-2.5 mm
= < 2.2 mm
= SED
(V.N)
(i)
%
55
45
35
25
15
5
N1
N2
N3
(ii)
%
45
35
25
15
5
N1
N2
N3

3.4.8.2 Grain nitrogen The nitrogen treatments influenced the proportion of nitrogen within the grain with the N3 treatment having a significantly higher grain nitrogen content than that obtained with other nitrogen treatments (Table 19).

3.4.8.3 Hot water extract The nitrogen treatments had no significant effect on the obtained HWE estimates (Table 19).

3.4.8.4 Germination There were no significant differences between nitrogen treatments in the germinations recorded in September 1981 when expressed as a percentage or as arc-sine transformed data (Table 19). No differences were recorded between nitrogen treatments in the percentage germination of the seeds greater than 2.8 mm or below 2.2 mm at this time. In germination tests conducted in June 1983 the N3 treatment significantly reduced the germination percentage recorded although the germination percentage was still above 96%.

**Table 19** The effect of nitrogen treatment on grain nitrogen content and HWE

| | Nitrogen | | | SED | Sig |
|---|---|---|---|---|---|
| | N1 | N2 | N3 | | |
| Grain Nitrogen % | 1.937 | 1.928 | 2.002 | 0.019 | xxx |
| HWE | 285.28 | 285.44 | 284.02 | 0.837 | ns |
| Total sample Sept 1981 | 98.25 | 97.75 | 97.97 | 0.409 | ns |
| Total sample June 1983 | 97.81 | 98.03 | 96.51 | 0.416 | xx |
| Seeds >2.8 mm Sept 1981 | 98.52 | 98.61 | 98.26 | 0.346 | ns |
| Seeds <2.2 mm Sept 1981 | 96.46 | 97.42 | 96.11 | 0.590 | ns |

# Chapter 4

## THE MODIFICATION OF THE BARLEY SEED CROP BY VARIETY, DENSITY AND NITROGEN TREATMENTS

## 4.1 General Introduction

Experiment WB5 was conducted in field 9 of the University farm. The trial was on a freely drained soil of the Arrow series, overlying Keuper Marl at a varying depth across the site (Bourn, 1983).

### 4.1.1 Experimental design and procedure

Two varieties of winter barley were investigated, namely Igri and Tipper (Section 3.2). These were sown at four seed densities; 200, 300, 400 and 600 seeds sown $m^{-2}$. All plots received 60 kg $ha^{-1}$ of both $P_2O_5$ and $K_2O$ in the seedbed and 40 kg $ha^{-1}$ N applied as a top dressing within three days of drilling. Succeeding nitrogen treatments are outlined in Table 20. Full trial details are shown in Table 5.

All treatments were replicated three times in a randomized block design. All plots were drilled with an Øyjord drill giving a plot width of 1.5 m with 10 rows per plot; plot lengths being 20 m. Due to the size of the experimental trial area the subsequent whole trial field operations of spraying were conducted across all plots, not over each individual plot. Thus within each plot a set of wheelings were created. These were established at the time of the first nitrogen application and were used at each subsequent operation. No growth analysis samples were taken from within 1 m of these wheelings and no estimates were taken of the yield effects of these wheelings.

Immediately prior to combine harvesting all plot lengths were reduced to approximately 14 m in length by mowing out a 0.5 m wide strip at the plot ends. Any remaining growing crop not required for combine harvester yield analysis was removed. Individual plot lengths were measured and recorded. From within the remaining areas the fixed tiller count sites were harvested by hand and removed for analysis. Plots were harvested using a Walter and Wintersteiger small plot combine harvester. All harvested grain was collected and dried prior to analysis.

Throughout the experiment only two density treatments were monitored, these being the 300 and 600 seeds $m^{-2}$ densities. Two nitrogen treatments were fully investigated (N1 and N2).

**Table 20** Nitrogen treatments WB5 (kg $ha^{-1}$)

| Nitrogen Treatment | Application time | | | |
|---|---|---|---|---|
| | Seedbed | 5/11/1981 | 2/2/1982 | 4/4/1982 |
| N1 | 40 | 0 | 40 | 0 |
| N2 | 40 | 40 | 40 | 40 |
| N3 | 40 | 40 | 0 | 80 |

All growth analysis samples were subdivided on a plant number basis with a known number of plants being taken from each sample for full analysis. All results are expressed on a per harvested area or on a per $m^2$ basis with the figures for conversion from recorded data being derived from the subsample proportional dry weight of the whole harvested sample.

### 4.1.2 Meteorological data

Mean weekly temperature fell to below -2°C for a period of five weeks in December and January. Throughout the major part of the crop's growth rainfall was below the long term average (Table 21) although in June the rainfall recorded was three times more than the average for that month. The month of July was extremely dry with only 4.2 mm of rainfall recorded.

## 4.2 The Effects of Variety

### 4.2.1 General introduction

Igri and Tipper were again used to investigate the growth of the winter barley seed crop. As in WB1 basic seed of both varieties was obtained from Rothwell Plant Breeders Ltd. The TGW of the sown seed being 44.9 g for Tipper and 49.0 g for Igri. Both varieties were drilled on 20 September 1981 into a well prepared seedbed.

Estimates were made daily of crop emergence and full emergence was estimated to have occurred on 12 October 1981.

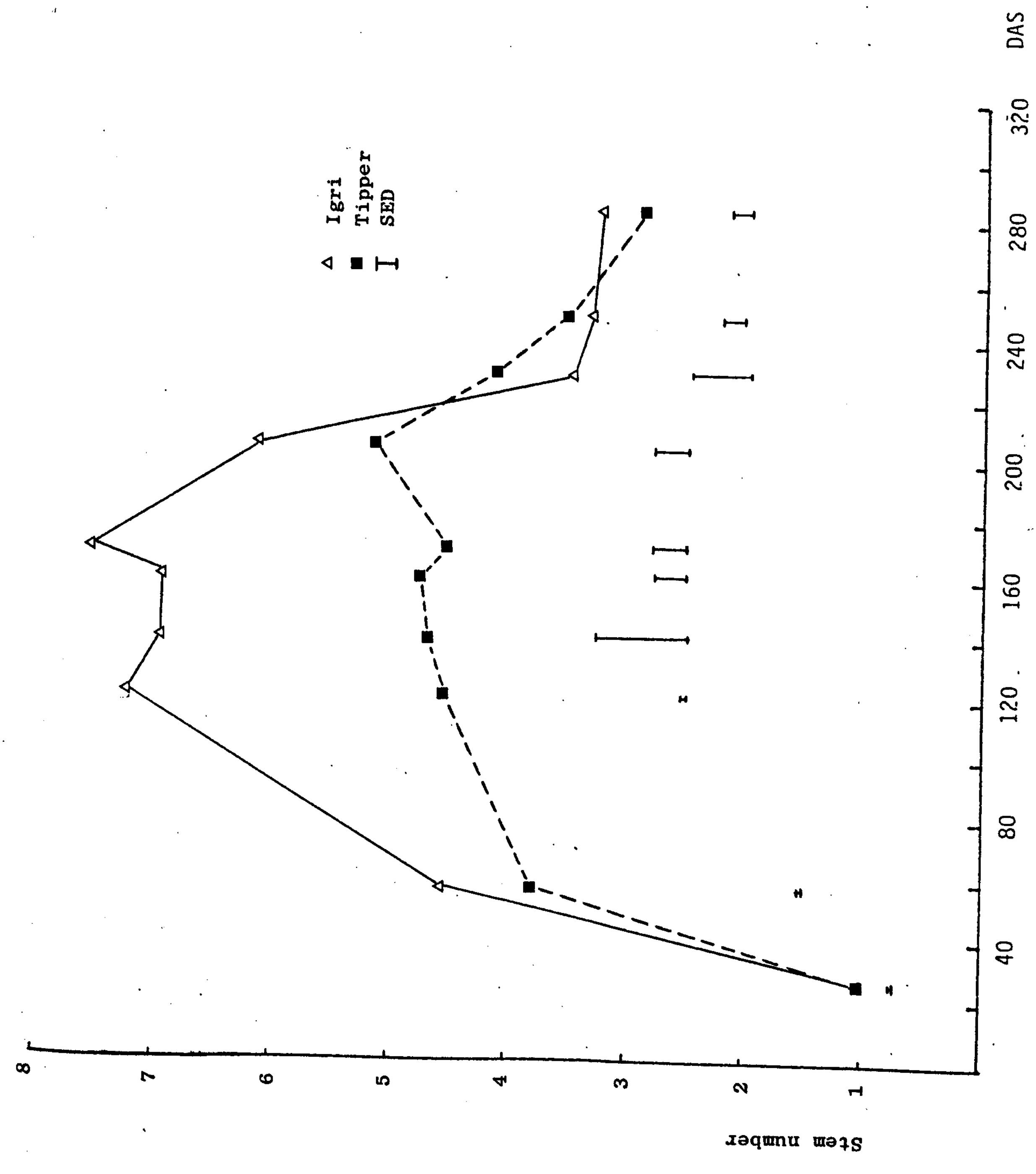
### 4.2.2 Tillering

Fig. 34 illustrates the pattern of tillering of both tested varieties. Igri again produced many more stems per plant than Tipper throughout, reaching its peak stem number of just over 7.5 stems per plant on 171 DAS (9 March 1981). Tipper attained its peak stem number slightly later at 206 DAS (14 April 1981) but only 5.2 stems per plant were produced. Final stem numbers per plant were not significantly different between varieties. The efficiencies of stem production were thus 43.4% for Igri and 56.3% for Tipper.

**Table 21** Rainfall data summary 1981-1983 compared with the long term average for Sutton Bonington

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Total |
|---|---|---|---|---|---|---|---|---|---|
| Rainfall (mm) | 1981 | 29.6 | 44.1 | 76.3 | 62.5 | 50.2 | 23.2 | 28.9 | 314.8 |
| | 1982 | 32.3 | 27.0 | 72.1 | 28.5 | 20.1 | 141.7 | 4.2 | 325.9 |
| | 1983 | 58.9 | 27.0 | 32.9 | 87.7 | 107.7 | 8.4 | 28.6 | 351.2 |
| Long term average rainfall (mm) (1916-1981) | | 50.0 | 41.0 | 45.0 | 39.0 | 49.0 | 48.0 | 51.0 | 323.0 |

**Fig. 34** The effect of winter barley variety on the number of stems per plant throughout the growing season



Igri
Tipper
SED
Stem number
1
2
3
4
5
6
7
8
DAS
40
80
120
160
200
240
280
320

4.2.2.1 Contributions by tiller categories to total tiller number As in WB1 (Section 3.2.1) the varieties differed in the contribution to total tiller number by different tiller categories as shown in Fig. 35. Over 95% of the plants of both varieties possessed a T1 tiller throughout their growth. Differences occurred in the proportion of plants with tillers in other tiller categories. Tipper had less than 10% of plants with T4 or T21 tillers whilst Igri possessed over 50% of plants with the T4 tiller and over 25% of plants with the T21 tiller at peak tillering. At the peak tillering of Igri (171 DAS) this variety had over 1.5 late primary or secondary tillers per plant but Tipper had only 0.3 tillers per plant in this category.

### 4.2.3 The effect of variety on LAI and GAI

Throughout growth leaf area indices and green area indices were measured. Both LAI and GAI were low for all treatments, possibly due to the below average rainfall for the majority of the spring and early summer period of growth. Until approximately 206 DAS Igri had a higher LAI than Tipper although its peak LAI at 230 DAS was significantly lower than that obtained by Tipper (Fig. 36).

In neither variety was the measured LAI reduced significantly from mid November until the end of January although appreciable, but not measured, amounts of leaf tip death occurred on the variety Tipper immediately after the period of below zero average weekly temperatures. During winter and early spring the variety Tipper exhibited signs of stress with the whole crop appearing yellow. This yellowing was increased after frost damage to the uppermost parts of the erect plants. However the presence of a covering of snow shielded the lower portions of the plants and the prostrate plant types.

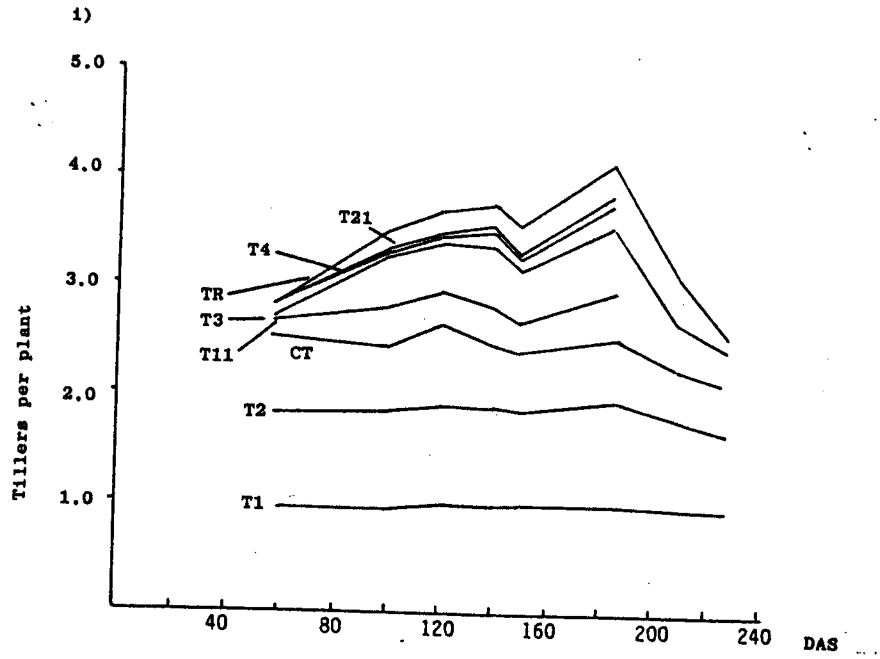
Stem extension commenced about 170 DAS - the beginning of March. Green area indices increased to a peak value of between 6.2 and 6.6 on 230 DAS (3 May 1982).

4.2.3.1 The proportion of the total area accounted for by each tiller category The varieties differed in the contribution by their tillers to the total photosynthetic area of the plant stand (Fig. 37). Data is presented for the mainstem and the first three tillers usually formed. During the early spring and summer growth the contribution by

**Fig. 35** The effect of variety on tillering patterns

i Tipper

ii Igri


i)
5.0
4.0
3.0
2.0
1.0
Tillers per plant
T21
T4
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
DAS

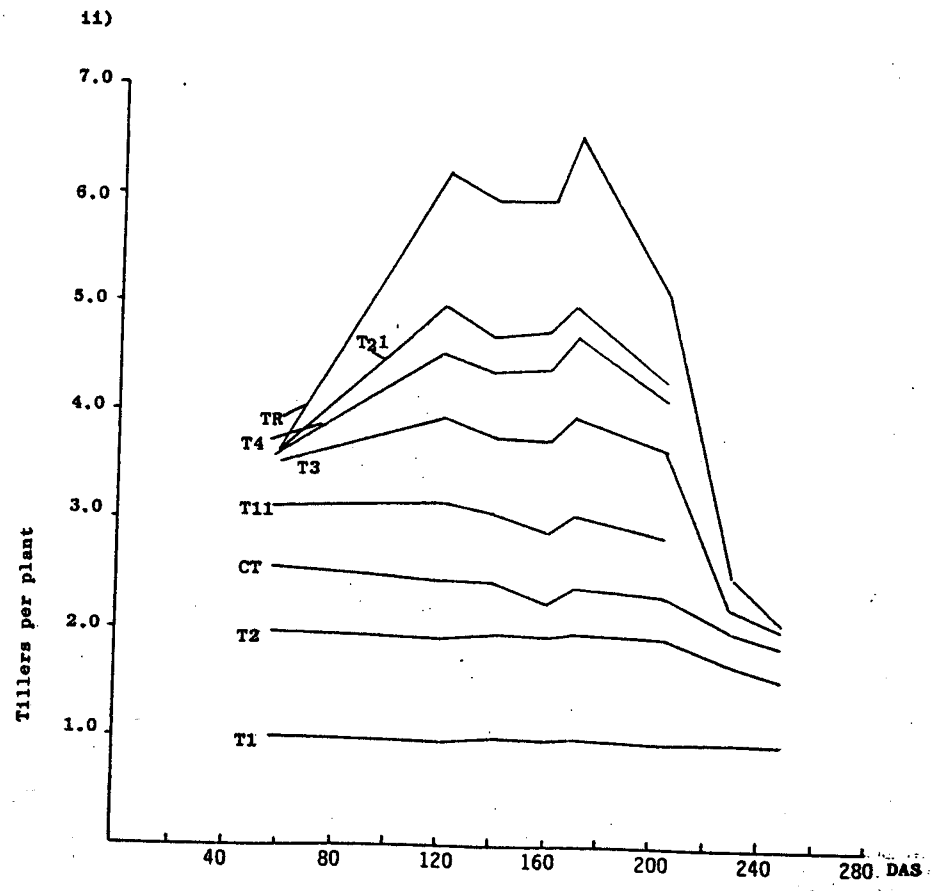
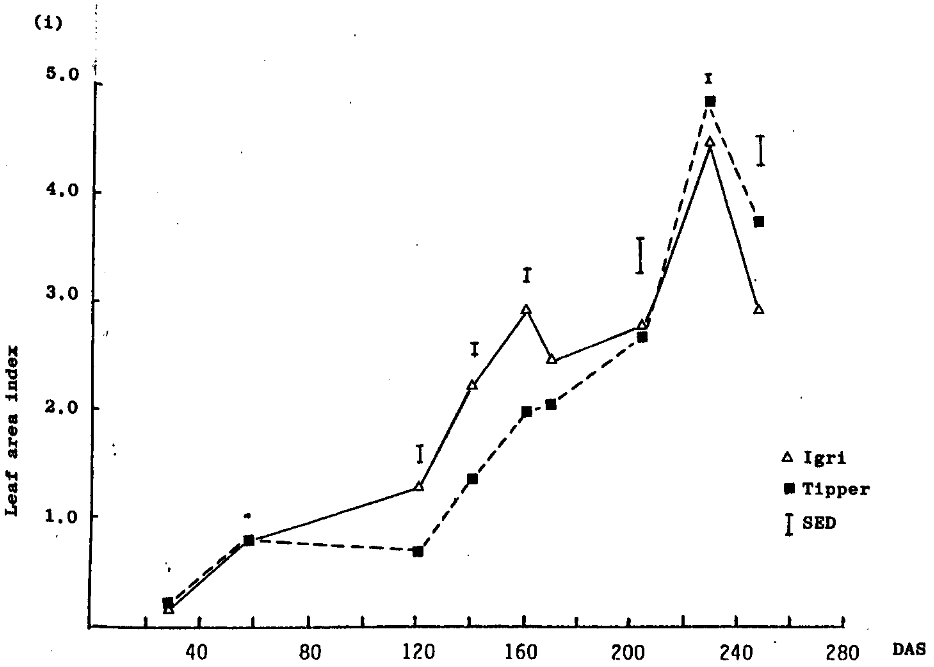

ii)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Tillers per plant
T21
TR
T4
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
DAS

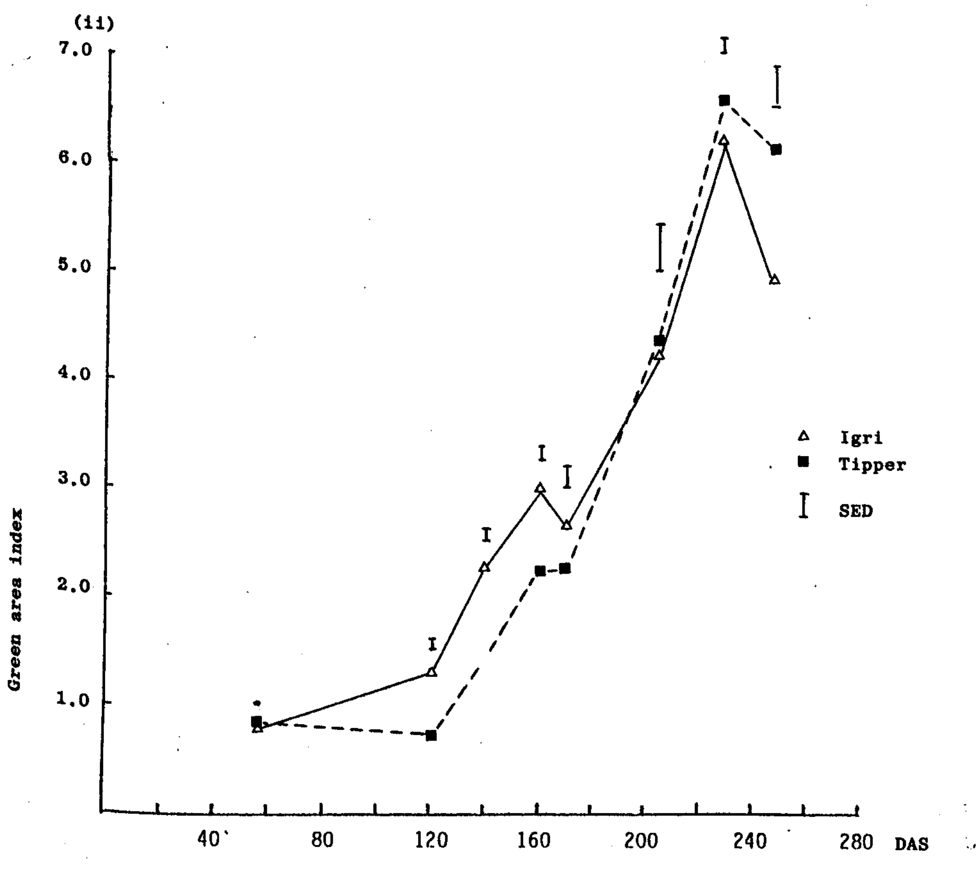
**Fig. 36** The effect of variety on

i LAI

ii GAI



(i)
Leaf area index
5.0
4.0
3.0
2.0
1.0
40
80
120
160
200
240
280
DAS
Igri
Tipper
SED

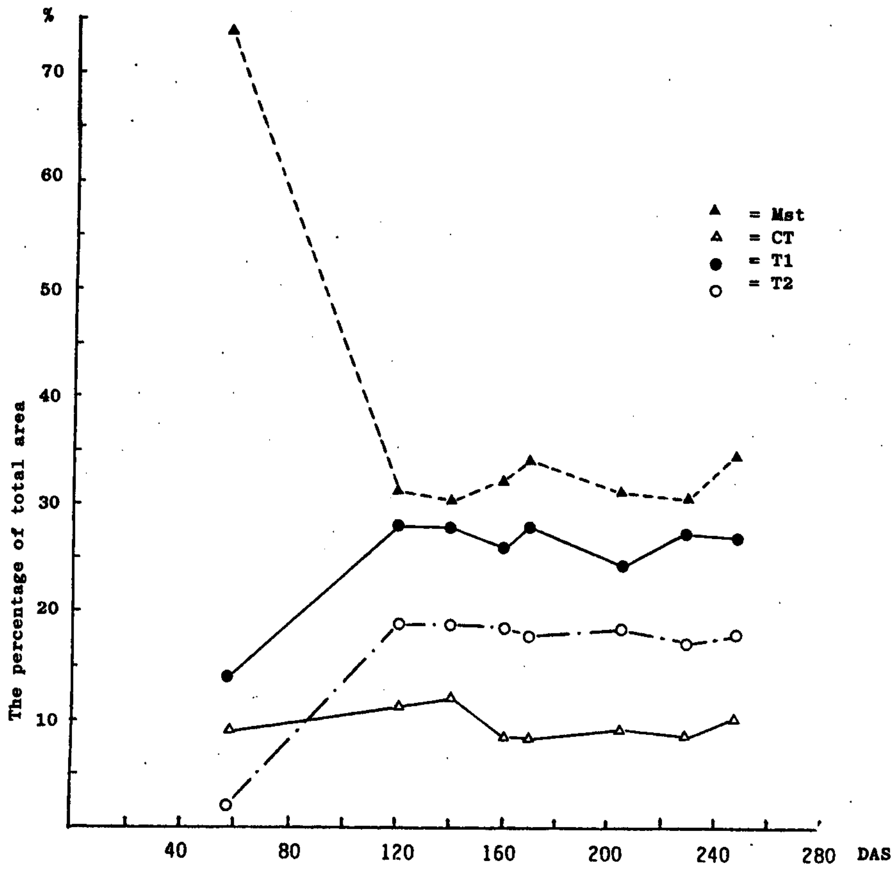



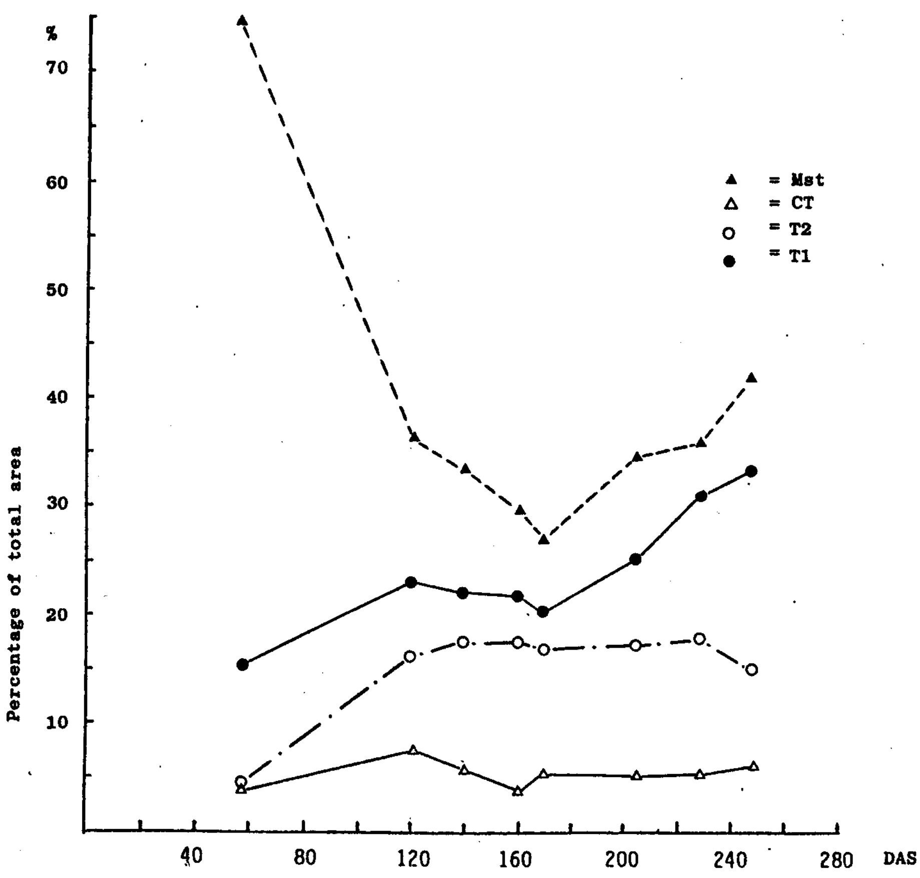
(ii)
Green area index
7.0
6.0
5.0
4.0
3.0
2.0
1.0
40
80
120
160
200
240
280
DAS
Igri
Tipper
SED

**Fig. 37** The proportion of total area accounted for by each tiller category

i Tipper

ii Igri


%
70
60
50
40
30
20
10
The percentage of total area
▲ = Mst
△ = CT
● = T1
○ = T2
40
80
120
160
200
240
280
DAS


%
70
60
50
40
30
20
10
Percentage of total area
▲ = Mst
△ = CT
○ = T2
● = T1
40
80
120
160
200
240
280
DAS

the mainstem to the total photosynthetic area of the plant of the variety Tipper was between 30 and 35% but within Igri the mainstem contribution fluctuated from a minimum percentage contribution of 27% at 171 DAS (peak tillering) to a maximum of 42% at 250 DAS (the end of May). Similar differences occurred with the T1 tiller albeit to a lesser extent. The proportional contribution of the T2 tiller was similar in both varieties.

### 4.2.4 The effects of variety on total above ground biomass

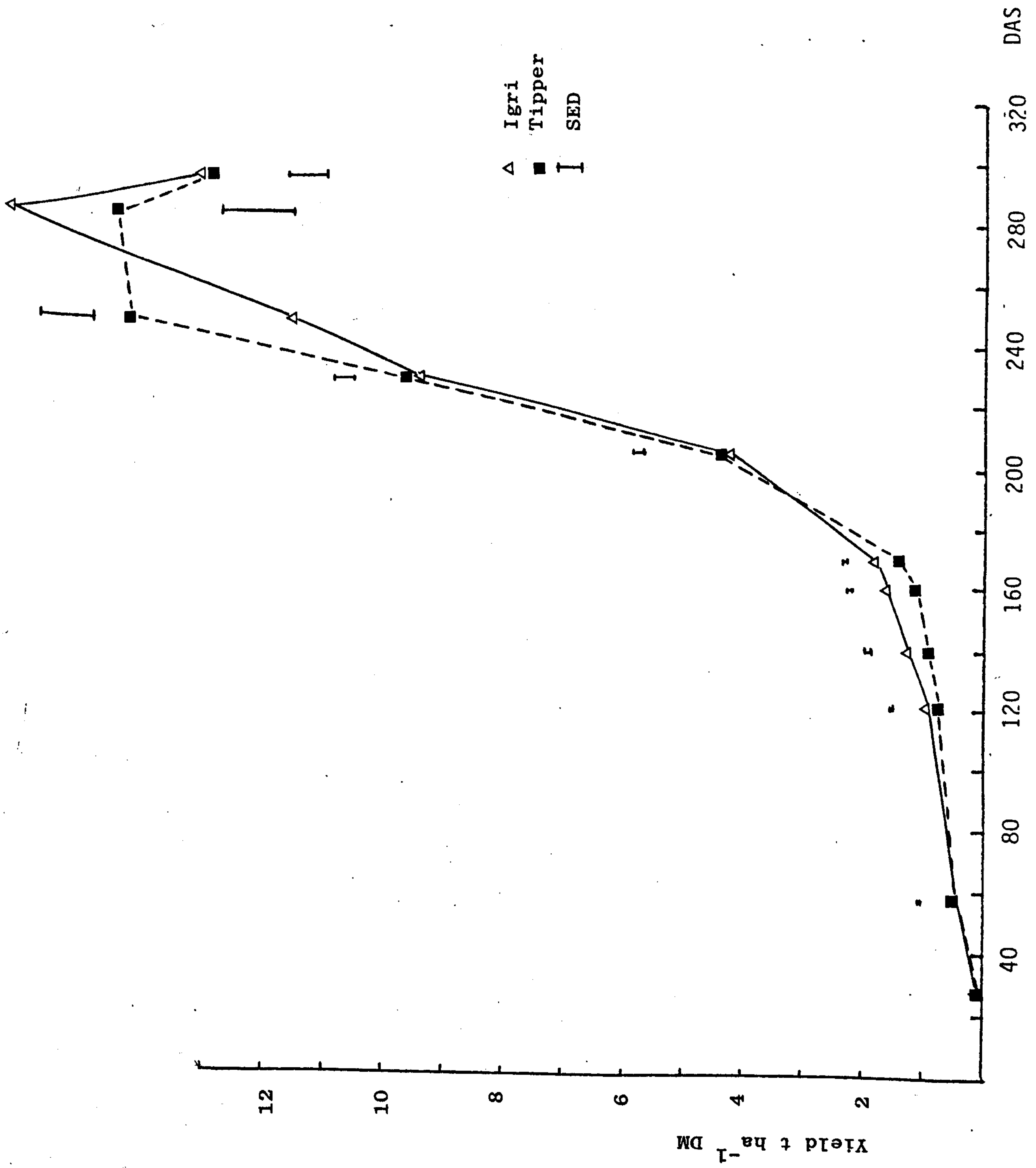
Crop above ground biomass increased slowly until 171 DAS at which time the biomass yield was 1.8 t $ha^{-1}$ DM for the variety Igri and 1.4 t $ha^{-1}$ DM for Tipper (Fig. 38). Thereafter biomass yield increased rapidly with Tipper reaching a biomass plateau of approximately 14.5 t $ha^{-1}$ DM by 250 DAS (28 May 1982). Igri reached its peak biomass yield of 16.3 t $ha^{-1}$ DM at the beginning of July (284 DAS). From their respective peak values the biomass yields of both varieties declined, both reaching approximately 13 t $ha^{-1}$ DM by 296 DAS (final harvest). Thus in both varieties there was a large decline in total crop biomass, amounting to approximately 3 t $ha^{-1}$ DM in the variety Igri. This was similar to the biomass fall of the same variety experienced in WB1 (Section 3.2.3).

4.2.4.1 <u>The proportional contribution to total crop weight</u> The variety Tipper had a greater proportion of its total above ground weight contributed by newly emerged tillers earlier in the growing season than Igri. In both varieties the mainstem contribution fluctuated between 30 and 40% of the total plant weight. At all times during the growth of the plants the percentage weight contribution by the CT tiller was greater in Tipper than in Igri amounting to approximately 9%.

### 4.2.5 Grain characteristics

Igri and Tipper differed in the proportions of seeds within each size classification (Fig. 39). Igri had a higher proportion of its grains in the largest size classification than Tipper; the majority of the grain of Tipper being between 2.5 and 2.8 mm in size. The differences in proportional distribution occurred when considering the seed sample by weight or by number of seeds present. In all cases the proportion of seeds smaller than 2.2 mm in size was less than 3% of the total weight or number. Seed size

**Fig. 38** The effect of variety on above ground biomass yield



Igri
Tipper
SED
DAS
Yield t ha-1 DM
40
80
120
160
200
240
280
320
2
4
6
8
10
12

**Fig. 39** Seed size distribution — by variety

i by weight

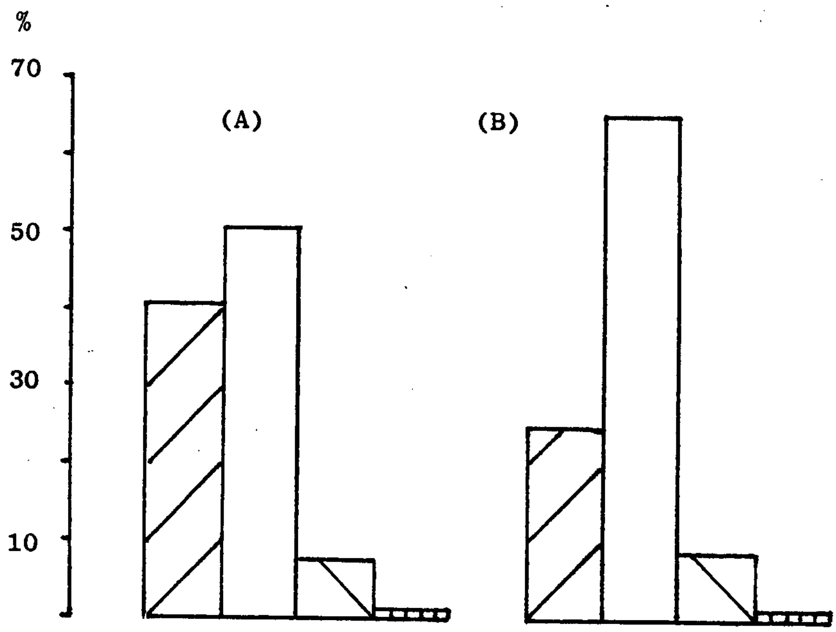
ii by number

A = Igri

B = Tipper

| | | S.E.D. |
|---|---|---|
| ▨ | = >2.8 mm | 1.156 |
| □ | = 2.5-2.8 mm | 0.995 |
| ▧ | = 2.2-2.5 mm | 0.490 |
| ▥ | = <2.2 mm | 0.071 |

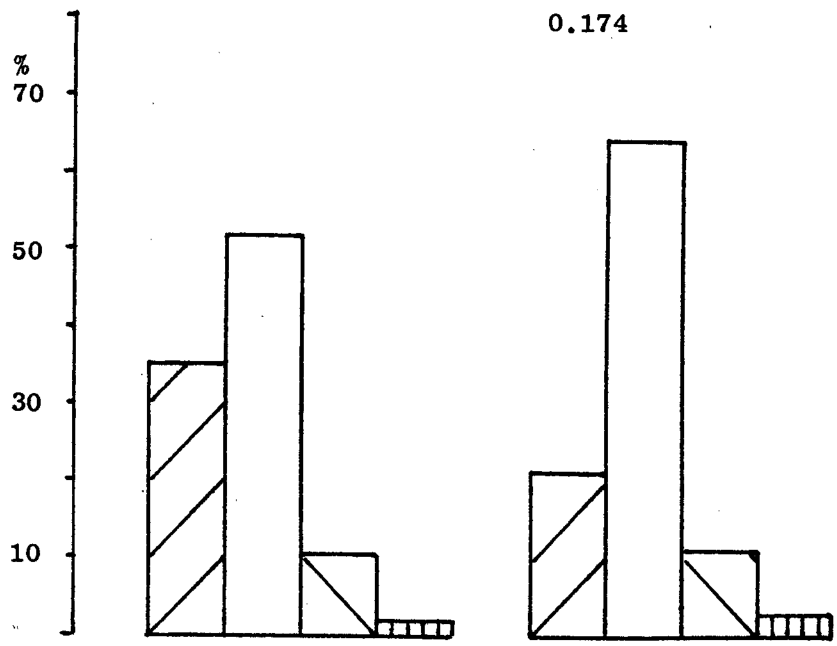
(i)




Key as above

| S.E.D. |
|---|
| 0.787 |
| 1.088 |
| 0.695 |
| 0.174 |

(ii)



influenced TGW as was expected. However there were significant differences between the varieties in the TGWs of seeds in any one size classification (Table 22). This was possibly caused by the differences in seed shape and/or density restricting the movement of specific shaped seeds through the slotted sieves. In this experiment no estimates were made of seed density.

The thousand grain weight of the combine harvested grain significantly differed between varieties with Tipper having the lowest TGW (38.87 g). In both cases the TGW of the harvested seed was below that of the drilled seed (Table 22). There was no significant difference between the varieties in the nitrogen content of the grain or in the estimated hot water extract values (Table 22).

### 4.2.6 Yield and yield components

4.2.6.1 Yield There was no significant difference between the varieties in the grain yields obtained by combine harvesting. However the varieties differed in their final yield components albeit not all significantly (Table 23).

4.2.6.2 Yield components The thousand grain weight from both the hand harvested samples and from grain removed from the combine harvested sample was lower in Tipper than in Igri. However Tipper had a higher number of grains on the main stem ear and in the remainder ears, which were composed of both main stem ears and tiller ears, than the variety Igri (Table 23). There was a significantly lower total ear number per unit area in the variety Tipper than in Igri.

### 4.2.7 The effects of seed size selection on seed yield

The 'economic' yield of the cereal seed crop is dependent upon the required grain sizes. Thus the screening out of specific grain size categories will alter the yield of seed corn produced. Removal of all grains except those between 2.2 mm and 2.8 mm in size, gave a higher yield for the variety Tipper than for Igri. However selecting seeds above 2.5 mm in size produced a higher yield of uniform Igri seeds (Table 24).

**Table 22** The effects of seed size on thousand grain weight, grain nitrogen content and hot water extract

| | Igri | Tipper | SED | Sig |
|---|---|---|---|---|
| Seed size | | | | |
| > 2.8 mm | 52.45 | 46.10 | 0.38 | xx |
| 2.5-2.8 mm | 43.67 | 39.18 | 0.54 | x |
| 2.2-2.5 mm | 32.69 | 29.66 | 0.85 | ns |
| < 2.2 mm | 22.19 | 18.83 | 0.26 | ns |
| Grain Characteristics | | | | |
| TGW Total | 44.87 | 38.87 | 0.25 | xx |
| N% | 1.895 | 1.881 | 0.036 | ns |
| HWE | 298.20 | 300.82 | 2.483 | ns |

**Table 23** The effect of variety on grain yield and yield components

| | Igri | Tipper | SED | Sig |
|---|---|---|---|---|
| Yield $t\ ha^{-1}$ 0% MC | 7.6 | 7.56 | 0.15 | ns |
| TGW 0% MC (Hand harvested) | 40.77 | 35.91 | 1.327 | ns |
| Ears per $m^2$ | 1190 | 961 | 49.6 | x |
| Grain no. per ear (main) | 23.88 | 30.10 | 0.61 | xx |
| Grain no. per remainder ear | 22.16 | 27.61 | 0.535 | xx |
| Biomass $kg\ ha^{-1}$ DM | 13145 | 12900 | 650.3 | ns |
| Harvest index (hand harvested)* | 52.8 | 50.8 | 1.3 | ns |

$$* \quad \frac{\text{Ear weight}}{\text{Ear weight + straw weight}} \times 100$$

**Table 24** The grain yield obtained by selection of specific size categories of grain (t $ha^{-1}$) – division by weight

| Size category (mm) | Igri | Tipper |
|---|---|---|
| > 2.8 | 3.11 | 1.86 |
| 2.5 + | 6.97 | 6.78 |
| 2.2-2.8 | 4.45 | 5.54 |
| Screenings < 2.2 | 0.09 | 0.11 |

### 4.2.8 Harvest indices

There was no significant difference between the varieties in the harvest indices which ranged from 50.8% to 52.8% for the main stem. These values differed from those obtained in WB1 (Section 3.2.4, Fig. 12).

### 4.2.9 The relationship between some yield components and grain yield of winter barley

4.2.9.1 Preamble Variation in grain yield can be examined by dividing yield into its components and seeing if any component is more closely correlated than the others with yield. If so the environmental and husbandry factors which influence that component would be important in determining yield (Gales, 1983).

It should be recognized that the components of yield are not always measured independently. For example the number of grains per unit area is often calculated from other measured components. Thus it is possible that sampling errors and random variations in the measured components could combine to make the estimated component more variable than it would be in reality.

4.2.9.2 Results Table 25 illustrates the correlation matrix between grain yield and various measured and calculated components from final harvest. Those correlations indicated are discussed later in this section.

In experiment WB5 a linear relationship was found between the total number of ears $m^{-2}$ and the final plant density, with the variance accounted for being 71.1% (Fig. 40). Irrespective of variety higher grain yields were associated with greater ear populations.

There was also a significant negative linear relationship between the number of plants $m^{-2}$ and the number of ears per plant; the variance accounted for being approximately 55% when varieties were considered separately (Fig. 40).

The total number of ears per unit area is composed of the number of mainstem ears plus the number of tiller ears. There was a significant linear relationship between the final number of plants and the number of tiller ears per unit area (Fig. 40), the percentage variance accounted for by the pooled varieties being under 35%, thus indicating that plant density had less effect on tiller ear numbers than on total ear numbers per unit area.

**Table 25** *Correlation matrix WB5*

| Component | No. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ears per plant | 1 | 1.0000 | | | | | | | | | |
| Ears per $m^{-2}$ | 2 | -0.1668 ns | 1.0000 | | | | | | | | |
| Plants $m^{-2}$ | 3 | -0.6404 ● x | 0.8425 ● xxx | 1.0000 | | | | | | | |
| Yield $m^{-2}$ | 4 | 0.1972 ns | 0.4799 xxx | 0.2112 ● ns | 1.0000 | | | | | | |
| Biomass $m^{-2}$ | 5 | 0.0361 ns | 0.6867 ● xxx | 0.4691 xxx | 0.5399 ● xxx | 1.0000 | | | | | |
| TGW | 6 | 0.2409 x | 0.1966 ns | 0.0104 ns | 0.0783 ns | 0.0493 ns | 1.0000 | | | | |
| Grain no. $m^{-2}$ | 7 | -0.0218 ns | 0.2356 x | 0.1551 ● ns | 0.7375 ● xxx | 0.3975 ● xxx | -0.6020 ● xxx | 1.0000 | | | |
| Ave grain no. | 8 | 0.1611 ns | 0.3820 xxx | -0.3762 xx | 0.1942 ns | 0.0875 ns | -0.3176 xx | 0.3923 xxx | 1.0000 | | |
| Tiller ears $m^{-2}$ | 9 | 0.0952 ns | 0.8707 xxx | 0.5970 ● xxx | 0.4894 xxx | 0.8027 xxx | 0.2185 ns | 0.2280 ns | -0.2933 x | 1.0000 | |
| Fh | 10 | 0.3682 xx | 0.1654 ns | -0.0718 ns | 0.4727 ● xxx | 0.0524 ns | 0.1251 ns | 0.2659 x | 0.1519 ns | 0.1406 ns | 1.0000 |
| | No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Df = 12

Asterisks signify significance of correlation (xxx, $P < 0.001$; xx, $P < 0.01$; x, $P < 0.05$; ns = not significant

● indicates illustrated relationships

**Fig. 40**

i The effects of actual post winter plant populations on the number of ears $m^{-2}$

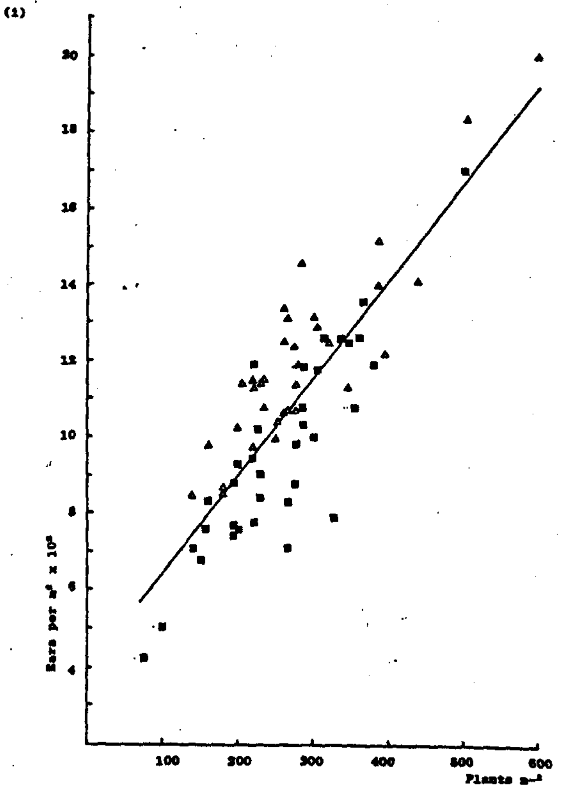
ii The influence of plant number $m^{-2}$ on ear number per plant

iii The influence of plant number $m^{-2}$ on total number of tiller ears $m^{-2}$

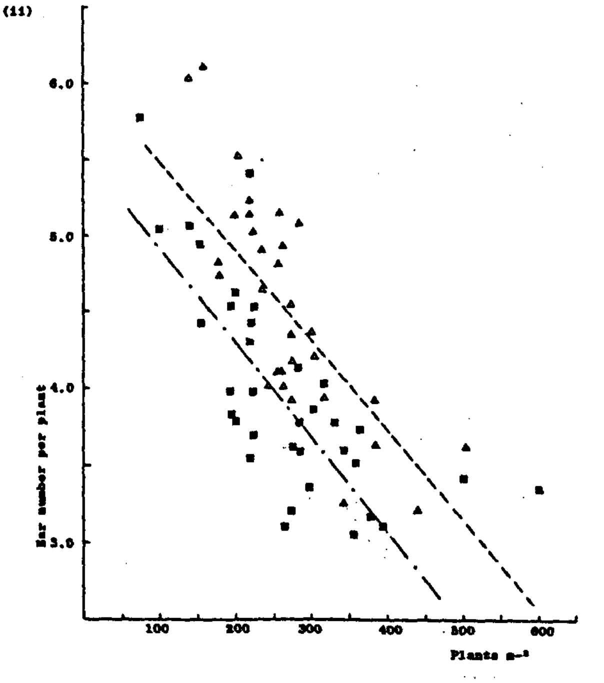
iv The effect of nitrogen treatment on the relationship between final plant density and ear number $m^{-2}$

Mean y = 390.1 ( ±35.80) + 2.56 (±0.30) x
Igri = 538.7 (± 67.07) + 2.32 (±0.22) x
Tipper = 306.7 (± 96.43) + 2.87 (±0.33) x

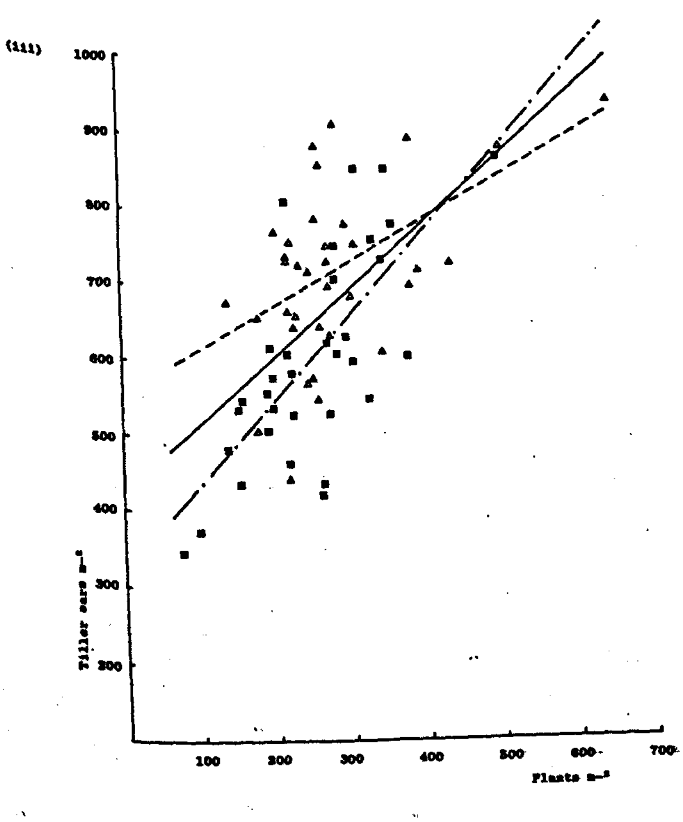
% Variable accounted for 71.1




y = 5.69 (±0.22) - 5.57 x 10⁻³ (±8.04 x 10⁻⁴) x
% variance accounted for 40.6
Igri y = 6.09 (±0.28) - 5.8 x 10⁻³ (±9.6 x 10⁻⁴) x
Tipper y = 5.55 (±0.40) - 6.25 x 10⁻³ (±1.4 x 10⁻³) x
% variance accounted for 54.9



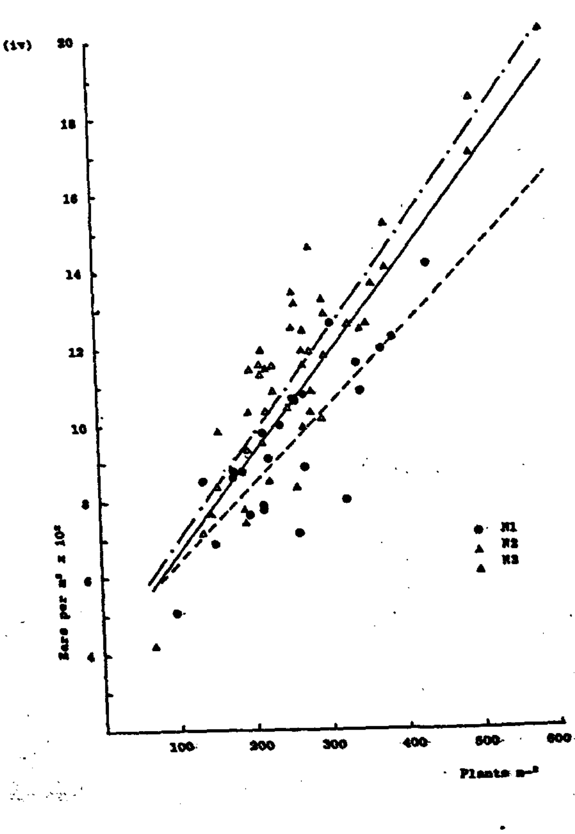

y = 423.3 (±40.4) + 0.889 (±0.14) x
% variance accounted for 34.4
Igri y = 557.3 (±51.8) + 0.54 (±0.17) x
Tipper y = 220.0 (±73.0) ± 1.10 (±0.26) x




y = 390.1 (±33.39) + 2.56 (±0.19) x
% variance accounted for 71.1

$N_1$ = 422.98 (±86.51) + 2.03 (±0.33) x (- - -)
$N_2$ = 402.93 (±123.81) + 2.71 (±0.45) x (-.-.-.)
$N_3$ = 421.31 (±116.59) + 2.66 (±0.42) x

lines not significantly different



There were significant differences between applied nitrogen treatments in the relationship between final plant number and total ear number per unit area (Fig. 40). Nitrogen treatments N2 and N3 differed significantly from N1 in the number of extra ears expected for a specified increase in plant density with the expected increase (≡ slope) being lower at the reduced nitrogen rate.

Figure 41 indicates the poor relationship between final plant number $m^{-2}$ and grain yield (t $ha^{-1}$ DM). However the variation in grain yield was much higher at the low and medium plant densities . Both Igri and Tipper produced grain dry weights ranging from 8.85 to 5.82 t $ha^{-1}$ at plant densities below 250 plants $m^{-2}$ whilst at higher plant densities, up to 600 plants $m^{-2}$, grain yields tended to be more consistent with yields of between 8.2 and 8.6 t $ha^{-1}$ DM above 500 plants $m^{-2}$. McLaren (1981) suggested that this variation in grain yield with plant density was caused by the effects of plant density on the number of grains $m^{-2}$. Fig. 41 shows that at lower plant densities the number of grains produced was more variable than at higher plant densities.

There was a linear relationship between grain yield and the number of grains $m^{-2}$ which differed significantly between varieties (Fig. 41). From this graph estimates of TGW were 28.6 ($\pm$ 3.07) g for Tipper and 19.4 ($\pm$ 4.29) g for Igri. Estimates differ from those presented in Section 4.2.5, Table 22. In this estimate grain yield values of the dependable variable were those obtained from the combine harvested sample while the independent variable (grain number per unit area) was obtained from hand harvested samples. In WB5 the linear relationship between grain yield and the number of grains $m^{-2}$ accounted for 90% of the variance. Grain nitrogen application significantly influenced the relationship between grain yield and grain numbers $m^{-2}$ (Fig. 42).

Other workers have shown strong correlations between grain numbers per unit area and yield, e.g. for wheat (Gales, 1983; Biscoe & Gallagher, 1977; Spiertz, 1979) and for spring barley (Dyson, 1977; Gallagher et al., 1975). Fischbeck (1982) demonstrated the close relationship between grain yield and grain numbers per unit area but also noted that this close correlation decreased with higher yield levels. In experiment WB5 grain yield appeared to reach a maximum of approximately 850 g $m^{-2}$ by 23,000 grains $m^{-2}$ and did not increase linearly with further increases in grain number.

**Fig. 41**

i The effect of actual post winter plant density on total grain dry weight

ii The relationship between combine harvested grain yield and total above ground dry matter

iii The relationship between total above ground biomass (g $m^{-2}$) and grain number $m^{-2}$

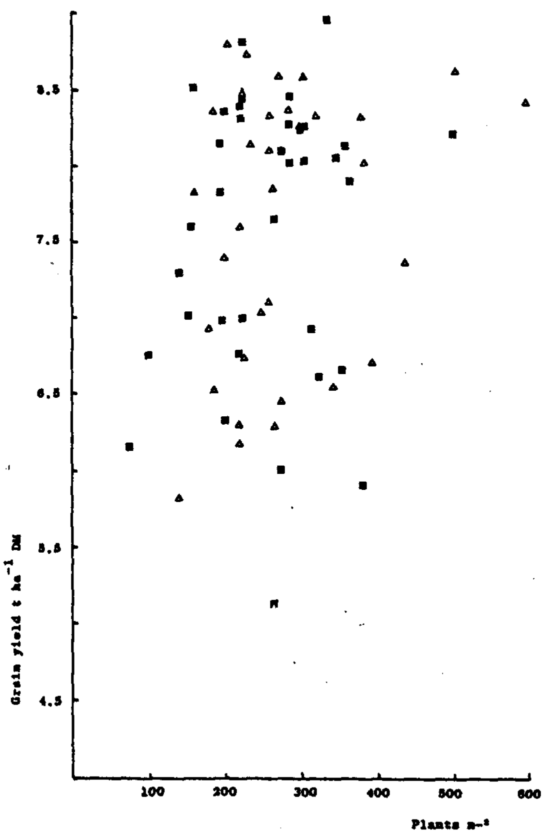
iv The relationship between above ground biomass and ear number $m^{-2}$

Intercept = 7.07 (±0.32)
Slope = 2.02 x 10-³ (±1.16 x 10-³)

% variance accounted for = 2.9
NS difference between varieties

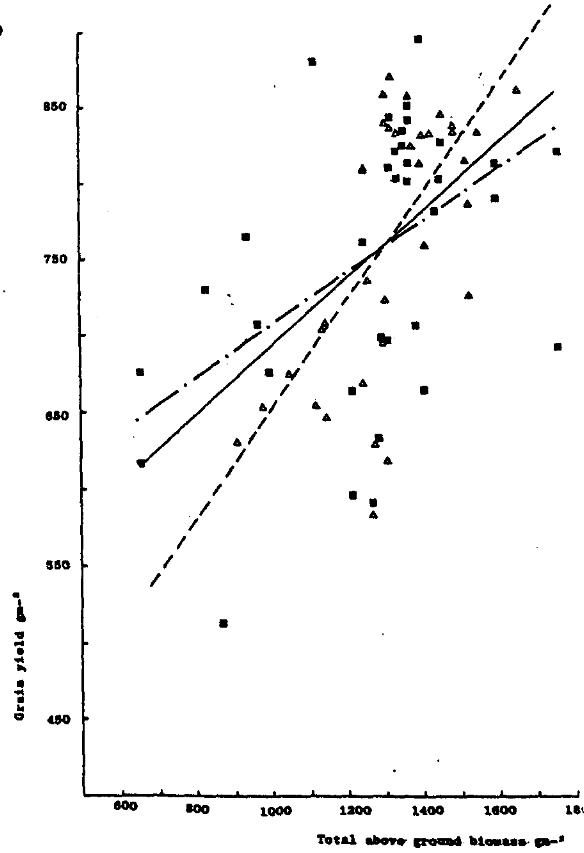
△ Igri
■ Tipper

(i)




y = 473 (±54.6) + 0.22 (±0.04) x (——) % variance accounted for 30.1
Igri 297 (±104.6) + 0.35 (±0.06) x (——)
Tipper 536 ±(122.0) + 0.17 (±0.09) x (-.-)

(ii)

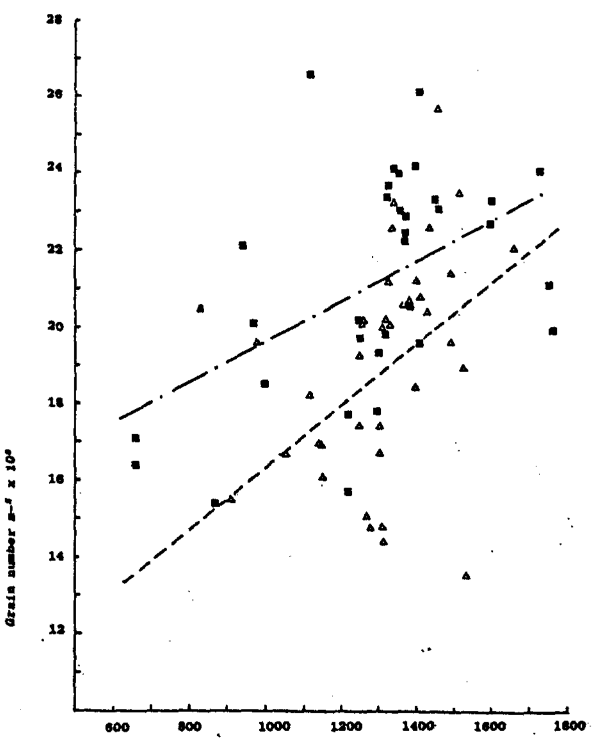



y = 12636 (±2081) + 5.68 (±1.55) x % variance accounted for 15.1
Igri = 6262 (± 3640) + 9.06 (±2.74) x (- -) % variance accounted
Tipper = 14306 (±4.247) + 5.30 (±3.20) x (-.-) for = 29.0

y = 0.86 (±0.11) x - 42.03 (±146.36) % variance accounted for 48.4
Igri y = 0.92 (±0.19) x - 33.93 (±251.87) % variance accounted
Tipper y = 0.78 (±0.22) x - 45.80 (±294.02) for 57.7

Slopes ns diff.

(iii)




(iv)

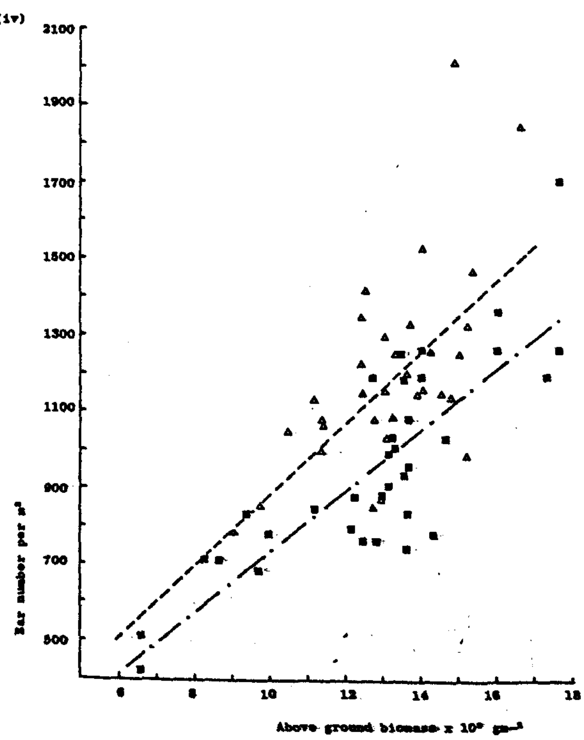


**Fig. 42**

i The relationship between grain yield and grain number $m^{-2}$

ii The relationship between grain yield and grain number $m^{-2}$ – the influence of nitrogen

iii The effect of grain number $m^{-2}$ on TGW

iv The relationship between the average number of grains per ear and TGW (% MC)

% variance accounted for 53.0

Igri $394.18\ (\pm 59.23) + 1.94 \times 10^{-2}\ (\pm 3.07) \times 10^{-3})\ x$ (——)
Tipper $149.81\ (\pm 87.31) + 2.86 \times 10^{-2}\ (\pm 4.29 \times 10^{-3})\ x$ (-.-.)

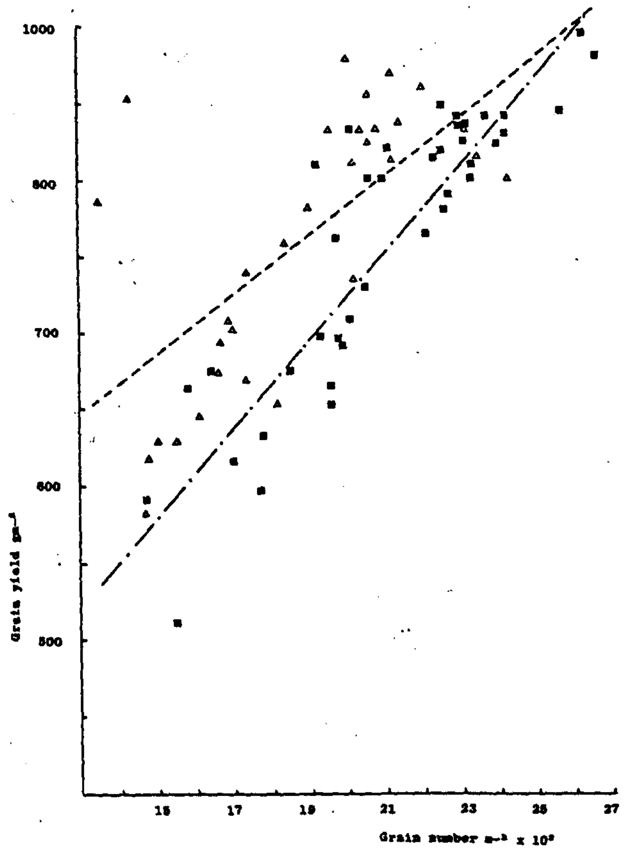
lines are significantly different in slope & intercept
% variance accounted for 64.5

$y = 339.16\ (\pm 47.36) + 0.02\ (\pm 0.0023)\ x$
% variance accounted for 53.0

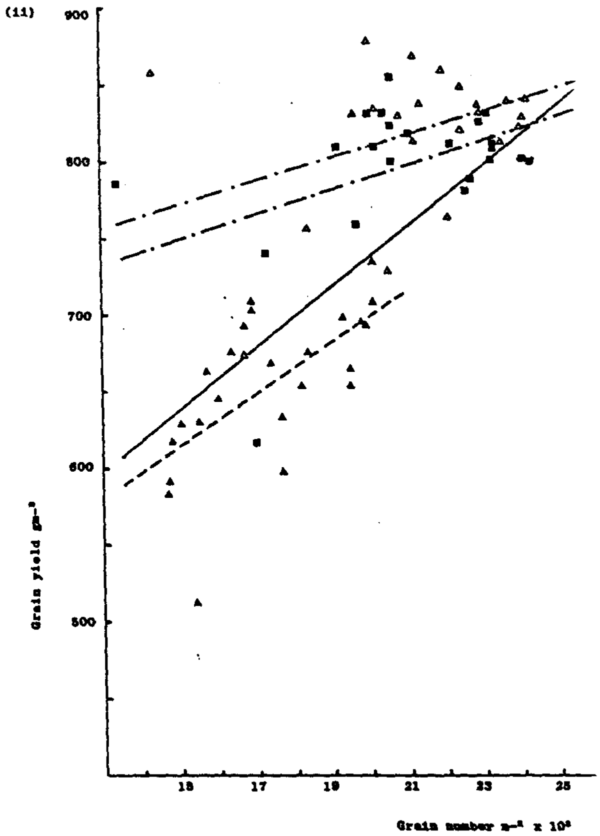
$N_1$ $y = 631\ (\pm 81.7) + 1.69 \times 10^{-2}\ (\pm 4.67 \times 10^{-3})\ x$
$N_2$ $y = 624\ (\pm 107) + 8.29 \times 10^{-3}\ (\pm 5.69 \times 10^{-3})\ x$
$N_3$ $y = 653.7\ (\pm 107) + 7.93 \times 10^{-3}\ (\pm 5.67 \times 10^{-3})\ x$

% variance accounted for 77.5

(i)




(ii)




$y = 56.77\ (\pm 2.88) - 9.19 \times 10^{-4}\ (\pm 1.41 \times 10^{-4})\ x$
% variance accounted for 36.7

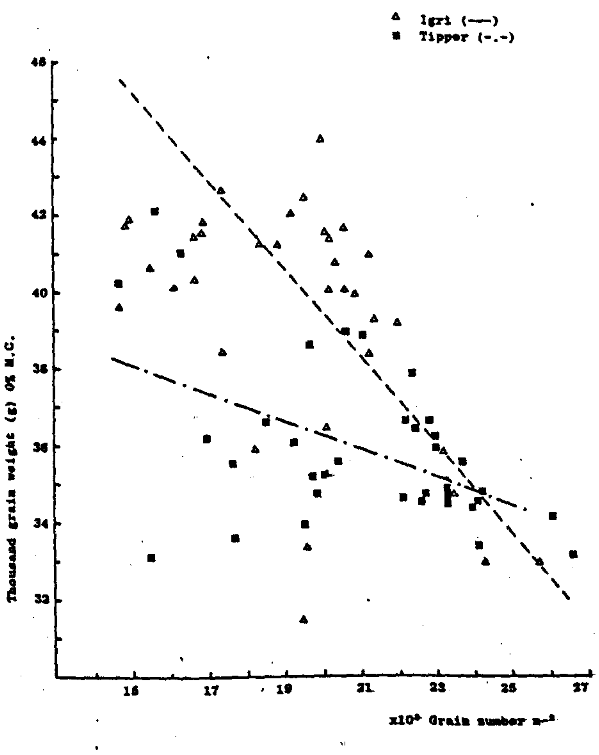
Igri $= 62.53\ (\pm 3.60) - 1.14 \times 10^{-3}\ (\pm 1.56 \times 10^{-4})\ x$
Tipper $= 43.63\ (\pm 5.31) - 3.65 \times 10^{-4}\ (\pm 2.61 \times 10^{-4})\ x$

(i) $y = 48.80\ (\pm 3.62) - 0.39\ (\pm 0.13)\ x$
% variance accounted for 9.7

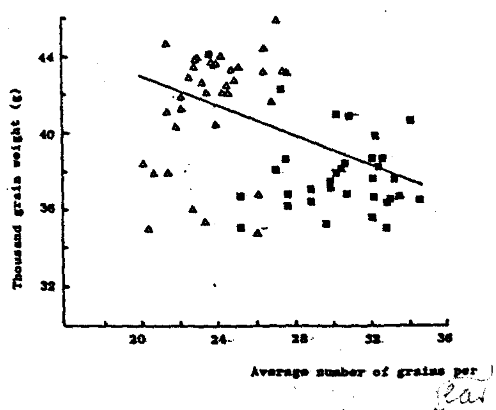
(ii) mean grain weight $= 3.5 \times 10^{-2}\ (\pm 2.25 \times 10^{-3}) + 2.93 \times 10^{-6}\ (\pm 2.02 \times 10^{-6})$ Ears per m²

% variance accounted for 1.6
(data not presented)

(iii)




(iv)



When numbers of grains per unit area was divided into its components, i.e. number of ears and grain number per ear, yield was correlated with both but more closely with ear number per unit area (Fig. 43).

No significant differences occurred between nitrogen treatments N2 and N3 in the relationship between grain number $m^{-2}$ and yield but these treatments differed significantly from the N1 nitrogen treatment with higher grain numbers increasing the yield of N1 treated plots more than those of N2 or N3 plots due to the higher TGW of N1 grains.

There was a poor relationship between the average number of grains per ear (estimated from the final growth analysis) and the thousand grain weight (as estimated from samples removed from the combine harvested grain) (Fig. 42). However if grain number $m^{-2}$ was considered there was a significant negative linear relationship between grain number $m^{-2}$ and TGW (Fig. 42). The varieties differed significantly with Tipper maintaining a more stable TGW over a range of plant densities. The reduction in TGW of Igri was approximately 1.14 g per thousand grains compared to 0.36 g per thousand grains for the variety Tipper. This agrees with the work of Fischbeck (1982) who demonstrated that in some varieties negative correlations could occur between numbers of grains per unit area and individual grain weight and that varieties might differ in the optimum range for number of grains per unit area.

The range of TGW for both varieties was relatively small with only 8.3% of the Tipper samples being outside the range 33-39 g per thousand seeds (0% MC). In Igri 19.4% of seeds exceeded the limits of 38-44 g per thousand seeds. Thus again illustrating the TGW stability of the variety Tipper.

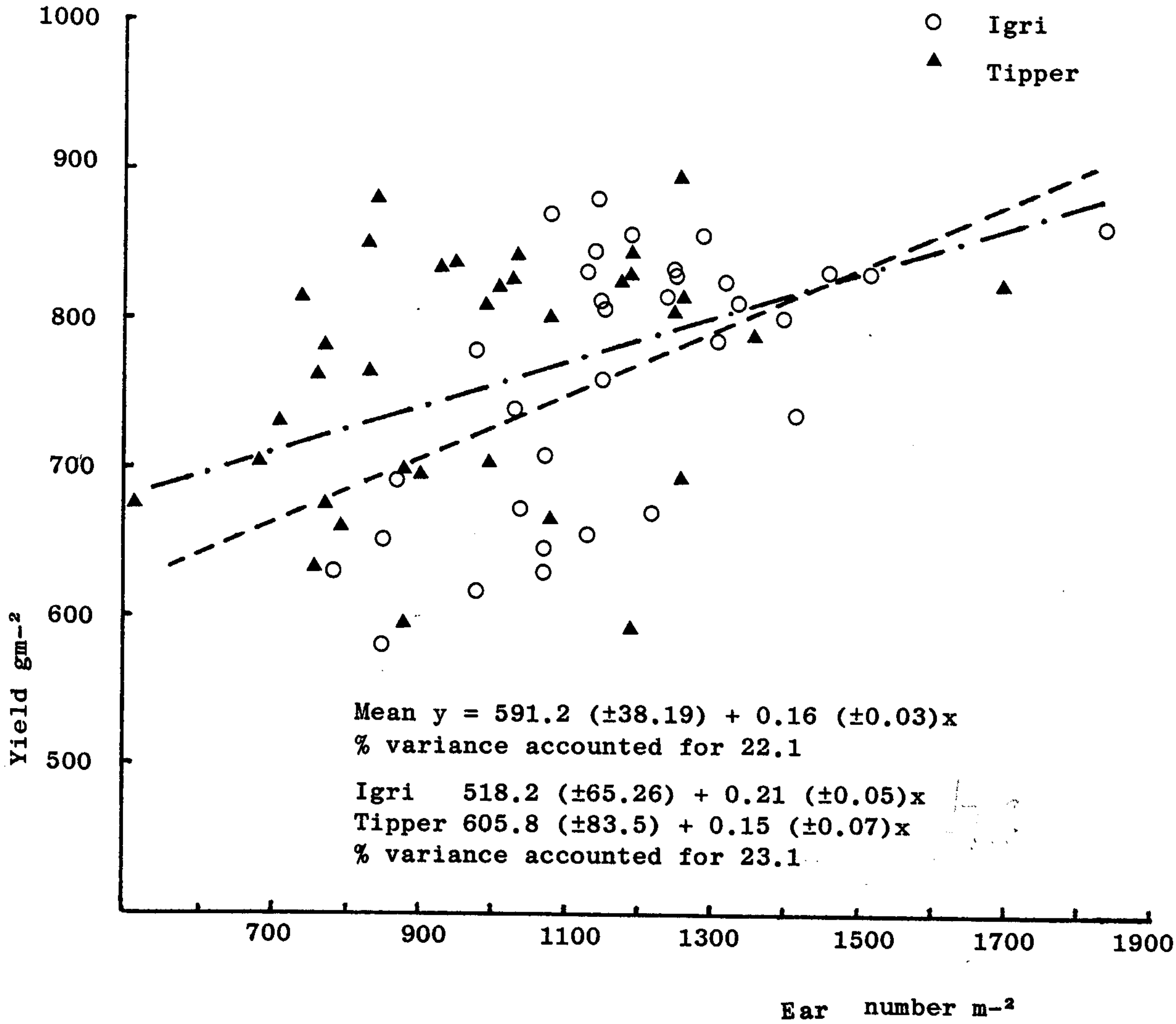
Figure 41 shows that for the range of yields obtained from 5.12 to 8.96 t $ha^{-1}$ DM there was a linear relationship between total combine harvested grain yields and total above ground biomass yields. Igri with its slightly higher harvest indices (Section 4.2.8) partitioned more of its total biomass into the production of grain. Thus for an increase of 1000 g $m^{-2}$ biomass the yield of Igri was increased by 350 g. For Tipper the corresponding figure was 170 g. The slope of the line should correspond to the harvest index figures obtained (Section 4.2.8). Differences will have occurred due to the use of combine harvested grain yields as the

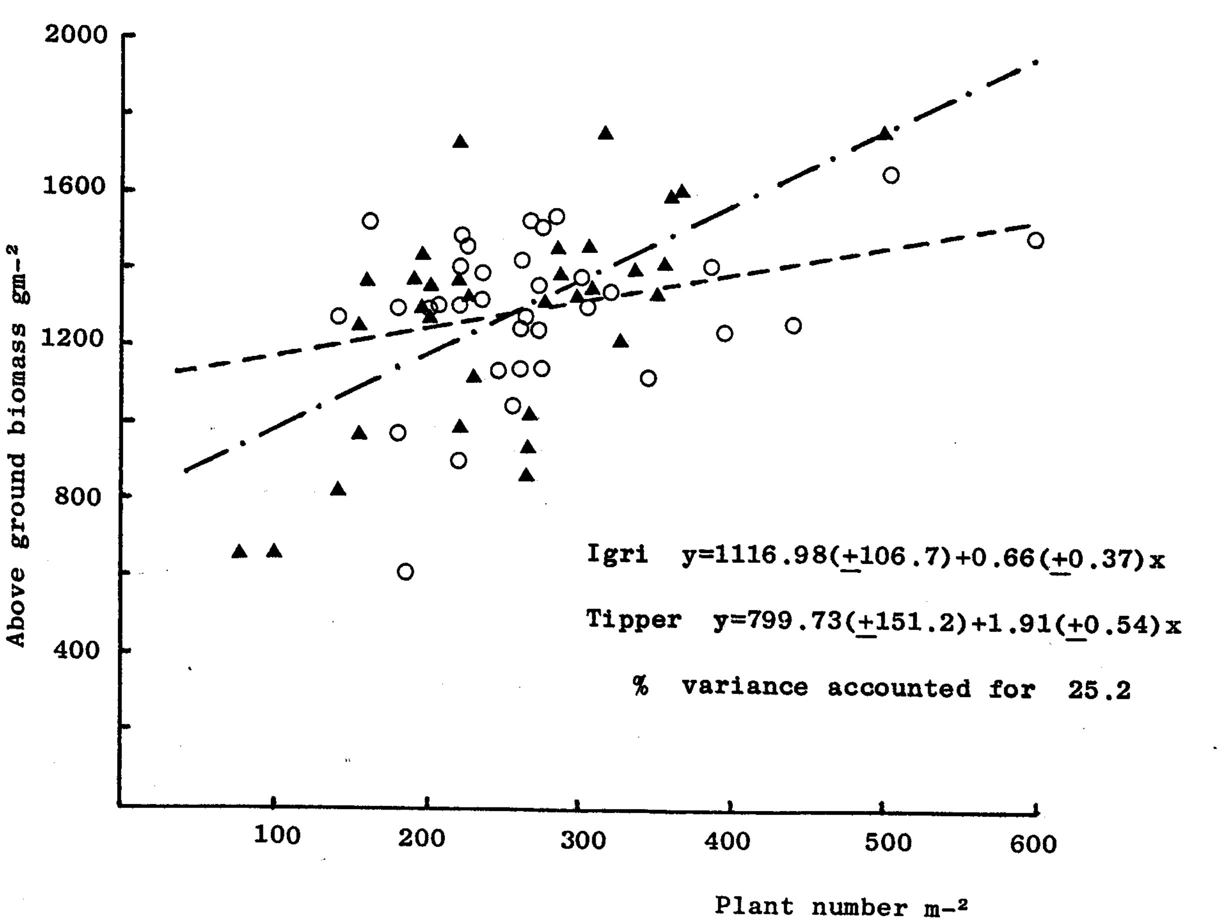
**Fig. 43**

i The relationship between ear number $m^{-2}$ and grain yield

ii The relationship between plant number $m^{-2}$ and above ground biomass

(i)


Igri
Tipper
1000
900
800
700
600
500
Yield gm-2
700
900
1100
1300
1500
1700
1900
Ear number m-2
Mean y = 591.2 (±38.19) + 0.16 (±0.03)x
% variance accounted for 22.1
Igri 518.2 (±65.26) + 0.21 (±0.05)x
Tipper 605.8 (±83.5) + 0.15 (±0.07)x
% variance accounted for 23.1


2000
1600
1200
800
400
Above ground biomass gm-2
100
200
300
400
500
600
Plant number m-2
Igri y=1116.98(±106.7)+0.66(±0.37)x
Tipper y=799.73(±151.2)+1.91(±0.54)x
% variance accounted for 25.2

indeterminate variable and hand harvested biomass figures as the determinate variable.

Thus as grain yield was related to both total above ground biomass and the number of grains $m^{-2}$ then the relationship between grain number $m^{-2}$ and total above ground biomass was shown to be significantly linear with Igri producing a greater number of grains for every unit increase in biomass (Fig. 41). However the variance accounted for was less than 30%. Thus although the experimental treatments influence the number of grains $m^{-2}$ the responses were confounded with the influence of total dry matter production on the number of grains produced and the effects of treatments on total dry matter production (Fig. 41).

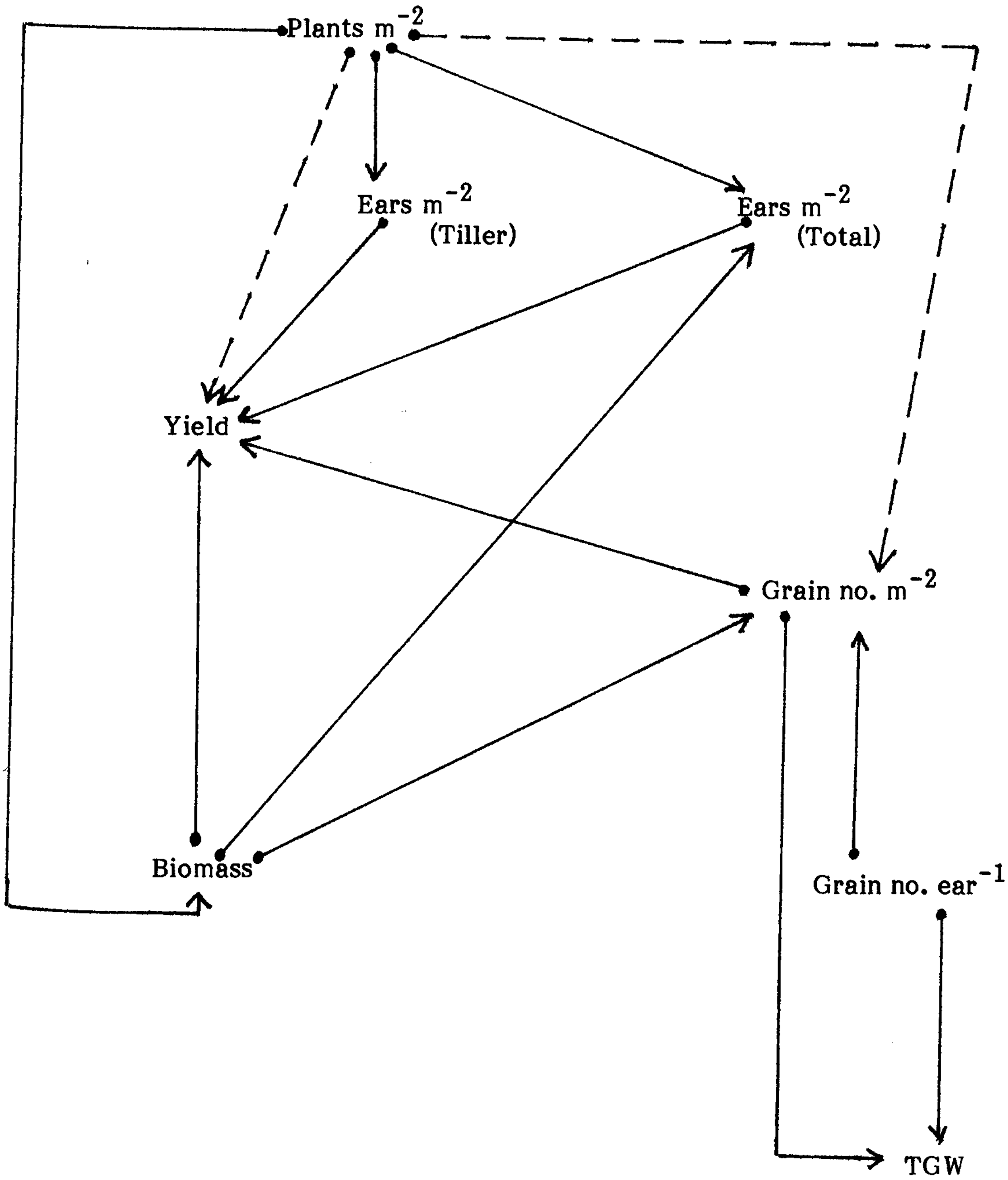
Daniels, Alcock and Scarisbrick (1982) noted that low yields were consistent with low numbers of grains per unit area and conversely higher yields with high numbers of grains. This suggests "that a high source potential during the entire reproductive phase is essential to the achievement of high yields, initially to ensure that a large number of grains are set and later to ensure that this sink capacity is fully satisfied" (Daniels et al., 1982).

Grain yield can be considered as the proportion of the total above ground biomass that is partitioned to the grain — the harvest index. Total dry matter is a result of growth processes, i.e. the increase in size of a crop as it passes through the growing season, while harvest index is largely a product of development which leads to an accumulation of morphological structures termed yield components (Green, 1984). Green (1984) noted that for a range of winter wheats the variations in harvest indices were small and not systematically related to grain yield. McLaren (1981) showed that Fh was affected by variety and plant density. However the magnitude of the differences in Fh caused by the imposed experimental treatments was less than 10%. In this experiment over 95% of the harvest indices for both varieties were between 49.0% and 57.5%. For similar Fh values the grain yield $m^{-2}$ ranged from 512 to 880 g. Thus there was no significant systematic relationship between grain yield and harvest index.

A simple flow diagram of the influences of various yield components on yield is given in Fig. 44.

**Fig. 44** A schematic representation of the relationship between grain yield and grain yield components

**Fig. 44**




**Key**

Strong correlation

No correlation but decreased variability at high plant densities

## 4.3 The Effect of Density

### 4.3.1 Introduction

To investigate the effects of density on the growth of the winter barley seed crop four density treatments were imposed in experiment WB5. These initial seed densities were 200, 300, 400 and 600 seeds sown $m^{-2}$. These densities were chosen to extend the range of densities tested in WB1 (Section 3.3.1). Only two densities were monitored throughout growth and development of the crop. These were the 300 and 600 seeds sown $m^{-2}$ treatments hereafter referred to as D2 and D4.

### 4.3.2 Plant establishment

The percentage of sown seeds that were present as plants at full establishment did not differ significantly between densities. The range of established densities was from 173 to 476 plants $m^{-2}$. However the proportion of sown seeds that were present as plants at final harvest depended upon the initial sowing density. The greater the initial sowing density the lower the percentage of seeds forming plants at final harvest. Thus final plant numbers ranged from 179 to 378 plants $m^{-2}$.

### 4.3.3 The effect of density on stem number per plant

The stem number per plant was dependent upon initial sowing density with high density treatment plants having significantly less stems per plant than low density treatments (Fig. 45). Peak stem number per plant was reached at a similar time for both monitored densities (160 DAS).

4.3.3.1 The contribution by tiller categories to total stem number The contribution by different tiller categories differed between density treatments (Fig. 46). In D2 a large number of lower order primary tillers and secondary tillers were produced. In plants at this density over 95% contained a T1 tiller and over 80% a T2 tiller. The contribution of the CT tiller at 250 DAS amounted to 0.55 CT tillers per plant. At peak tiller number the number of unclassified tillers amounted to approximately 2 per plant. However in the high density plots this situation was significantly different. Here the production of lower order primary tillers and secondary tillers was limited, reaching a maximum of only 0.5 tillers per

**Fig. 45** The influence of density on stem numbers per plant

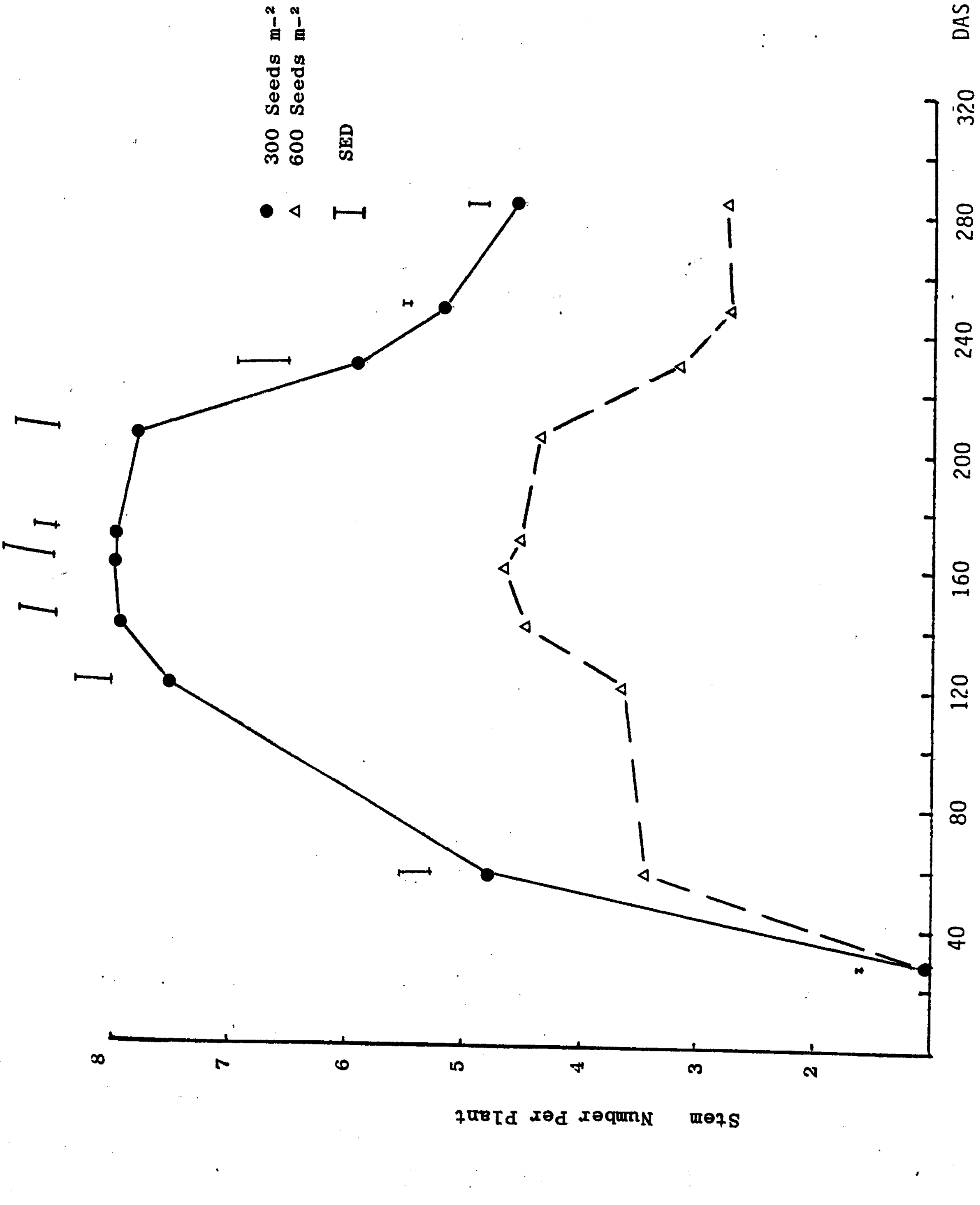
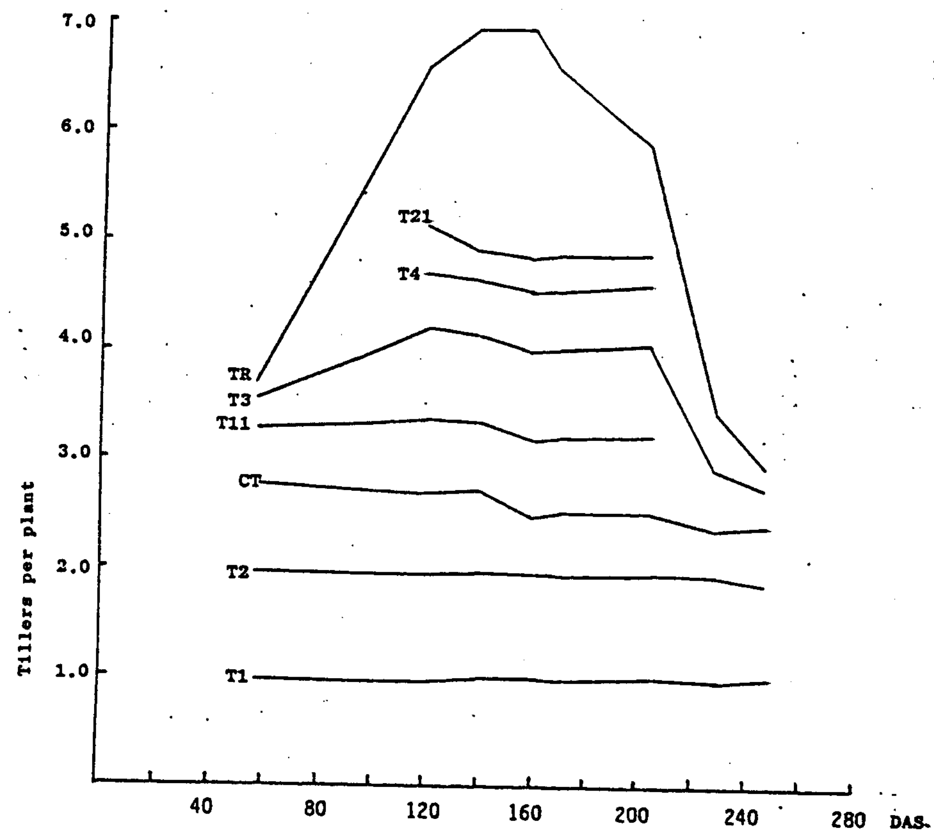

300 Seeds m-2
600 Seeds m-2
SED
Stem Number Per Plant
DAS
8
7
6
5
4
3
2
40
80
120
160
200
240
280
320

**Fig. 46** The influence of density on tillering patterns

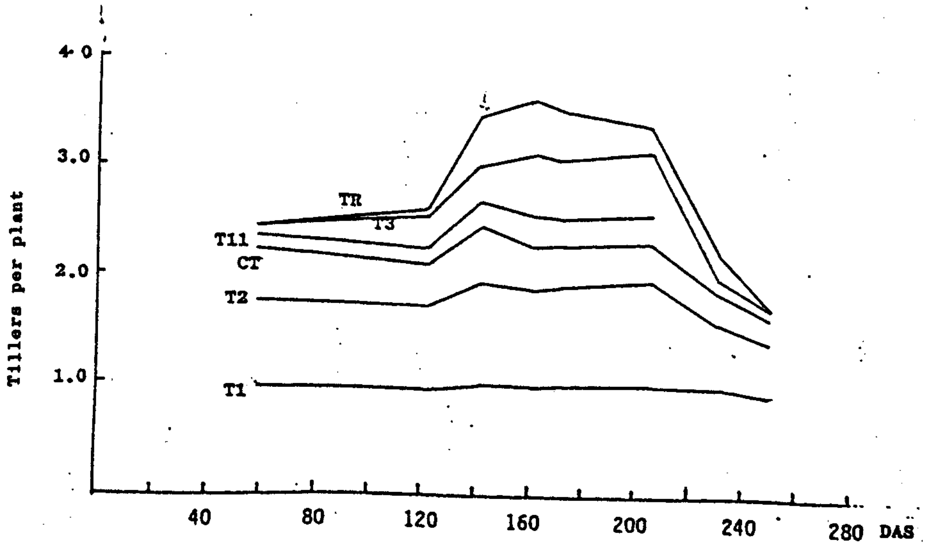
i 300 seeds sown $m^{-2}$

ii 600 seeds sown $m^{-2}$

(i)


7.0
6.0
5.0
4.0
3.0
2.0
1.0
Tillers per plant
T21
T4
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
DAS.

(ii)


4.0
3.0
2.0
1.0
Tillers per plant
TR
T3
T11
CT
T2
T1
40
80
120
160
200
240
280
DAS

plant at peak tillering. However this value includes the values for T4 and T21 which were included as separate tiller categories in the low density treatment. At 250 DAS, the last date of full recording of tiller categories, the major tiller on each plant was the T1 tiller, with over 90% of plants having a T1 tiller present. However the T2 tiller was present in 50% of the plants. The rest of the tillers present were CT, approximately 20% of plants, T3 (10% of plants) and T4 ($<$ 5% of plants).

### 4.3.4 The effects of density on LAI and GAI

Throughout growth the LAI of the high density treatment D4 was greater than that of D2 albeit not always significantly different (Fig. 47). Densities were significantly different in their peak LAI values at 230 DAS with D4 reaching an LAI of 5.1 and D2 of only 4.15.

The GAI was also higher for D4 than D2 during growth reaching a significantly higher peak GAI of 6.95 at 230 DAS (3 May).

Stem extension commenced at approximately 170 DAS (8 March) for both densities.

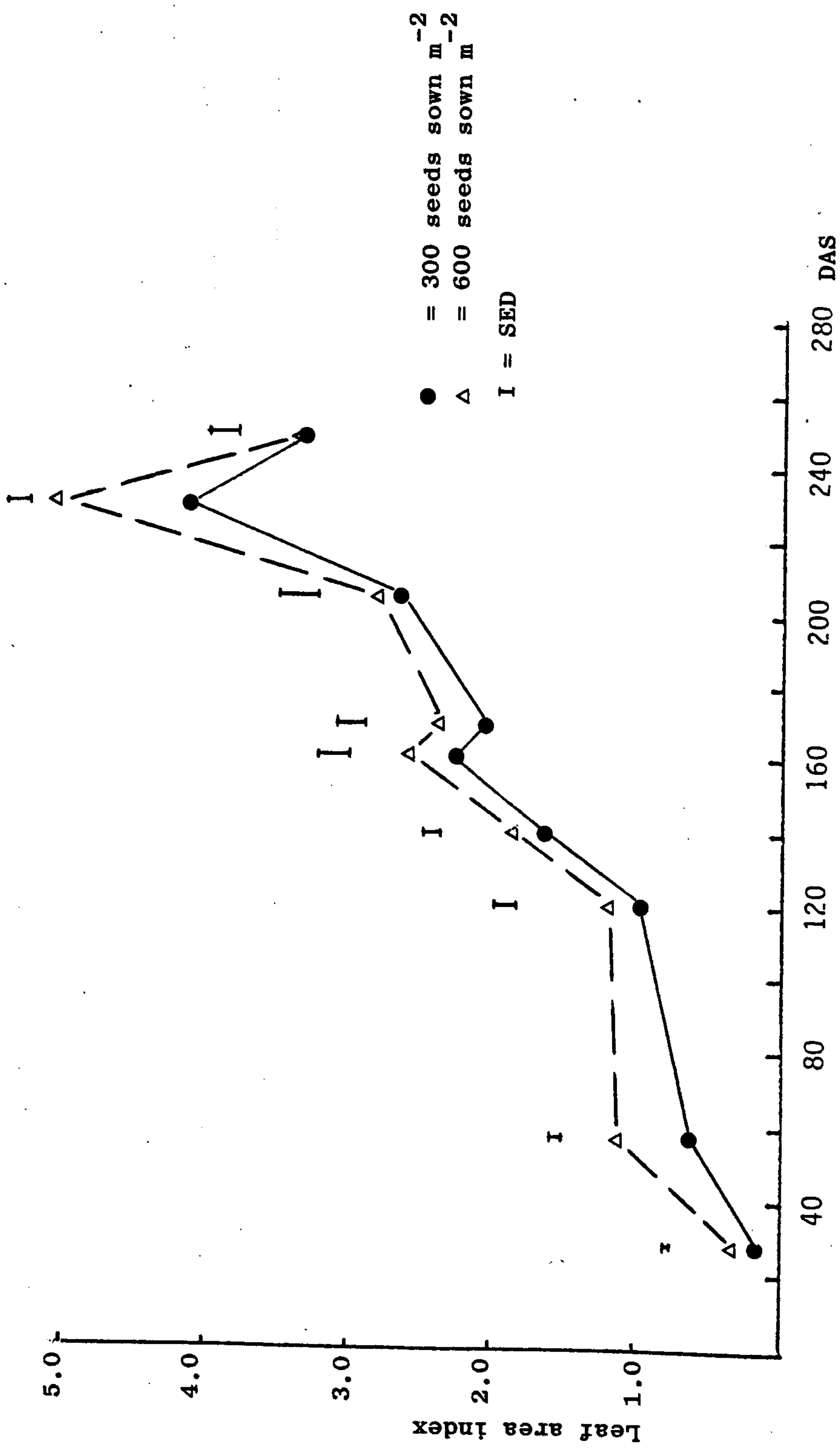
### 4.3.5 Above ground biomass – the influence of density

Total above ground biomass was significantly different between the densities at the first three harvest dates (14/10/1981, 17/11/1981 and 20/1/1982) with the high density plots having a greater DM yield per unit area (Fig. 48). Thereafter no significant differences were recorded between densities.

Biomass yields prior to 170 DAS were below 2 t $ha^{-1}$ DM. However upon stem extension which occurred at this time biomass yields increased rapidly. There was a decline in total crop biomass yield of between 2 and 3 t $ha^{-1}$ DM from peak biomass to final biomass yields.

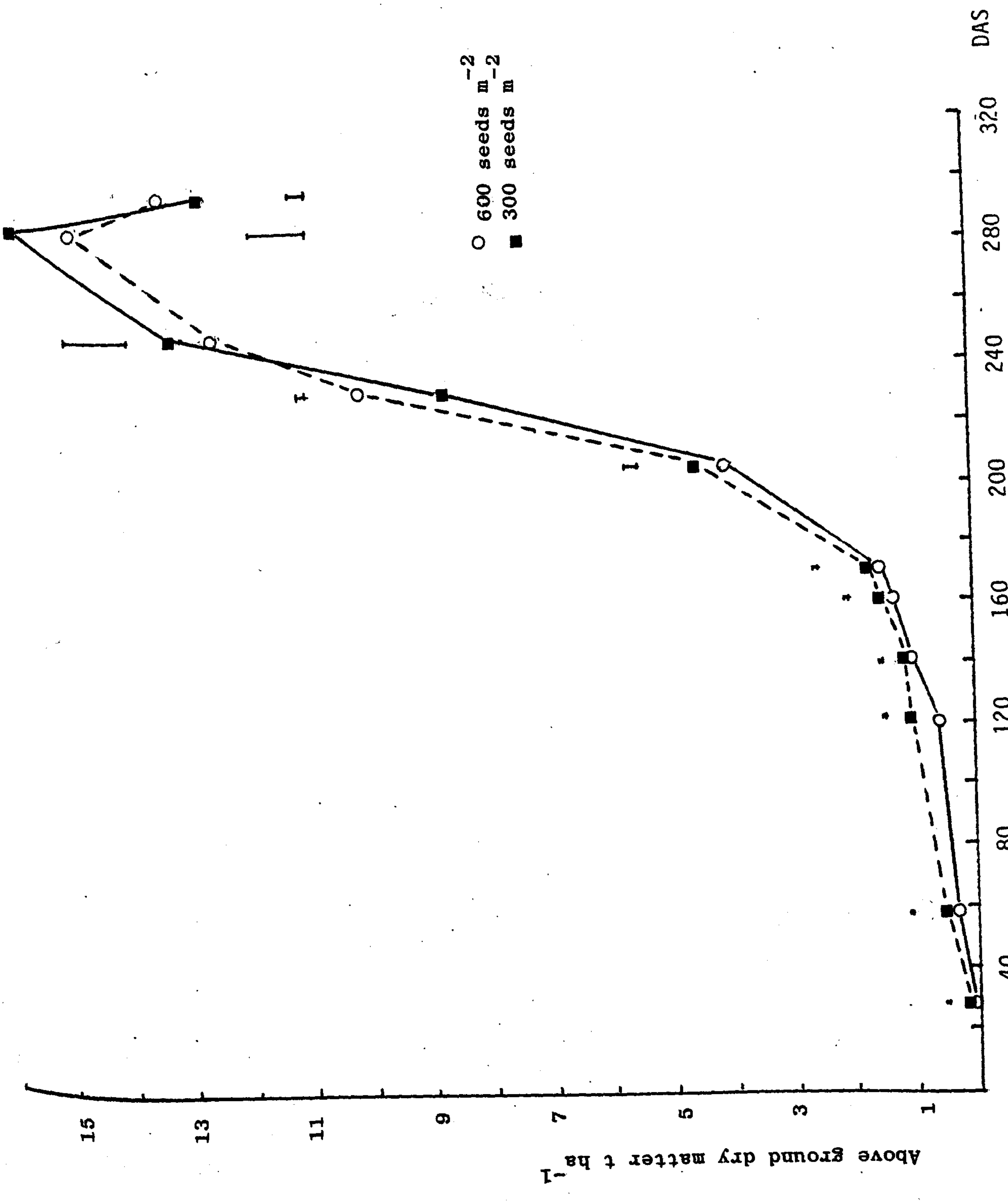
4.3.5.1 <u>The contribution to total plant weight of tiller categories</u> During crop growth the percentage contribution to total plant weight by each tiller category varied with density (Fig. 49). In D4 a higher proportion of the total plant weight was contributed by the mainstem than that contributed within D2. The percentage contribution to total weight by tiller categories is outlined in Fig. 49.

**Fig. 47** The effects of density on LAI



● = 300 seeds sown $m^{-2}$
△ = 600 seeds sown $m^{-2}$
I = SED
Leaf area index
5.0
4.0
3.0
2.0
1.0
40
80
120
160
200
240
280
DAS

**Fig. 48** The effect of initial seed density on above ground biomass yields



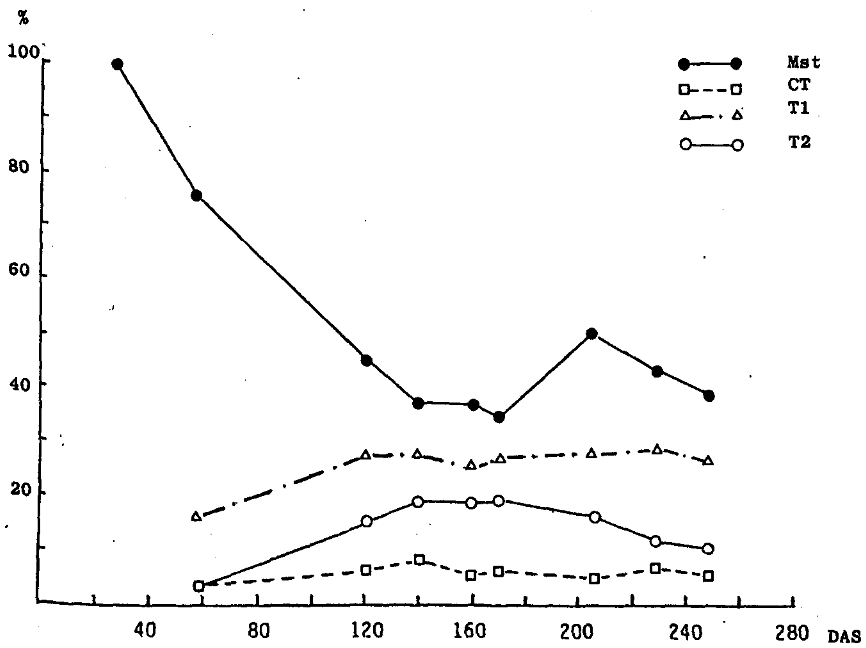
600 seeds m-2
300 seeds m-2
Above ground dry matter t ha-1
DAS
1
3
5
7
9
11
13
15
40
80
120
160
200
240
280
320

**Fig. 49** The proportional contribution to total plant weight by tiller categories

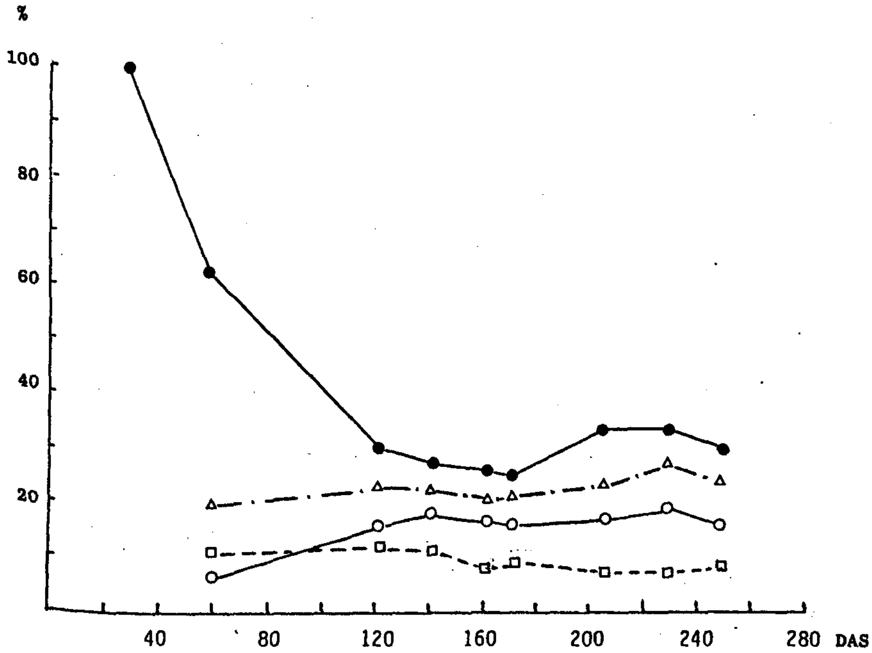
i 300 seeds sown $m^{-2}$

ii 600 seeds sown $m^{-2}$

i)


%
100
80
60
40
20
Mst
CT
T1
T2
40
80
120
160
200
240
280
DAS

ii)


%
100
80
60
40
20
40
80
120
160
200
240
280
DAS

The rise in percentage contribution by the mainstem in both D2 and D4 corresponds to the peak in tiller numbers and their subsequent steady decline. This decline is concurrent with the rapid increase in biomass caused by the onset of spring growth and the commencement of stem extension. The increase in the proportion of the total weight contributed by the mainstem was matched by a decline in contribution by late primary and secondary tillers and by a decline in the weight contribution of the T2 tiller.

The percentage contribution by the CT tiller to total plant weight was higher in the D2 treatment than in the D4 although in neither case was the percentage contribution greater than 10%.

### 4.3.6 Grain characteristics

The proportion of seeds within each size classification depended upon the initial sowing density imposed (Fig. 50). Increased sowing density resulted in a decreased proportion of the harvested seeds being over 2.8 mm. However there was a concomitant increase in the percentage of seeds within the seed category 2.5 to 2.8 mm.

These alterations in seed size distribution were similar when the samples were assessed by number or by weight.

Table 26 shows the yield of seeds within specific seed size categories. Highest yields of seeds between 2.2 and 2.8 mm were obtained at high initial seed densities. Maximum yield of seeds above 2.5 mm in size were obtained at D2 density. Highest yields of seeds greater than 2.8 mm in size were obtained by the lowest tested seed sowing density of 200 seeds $m^{-2}$.

Thus the sowing density could be adjusted depending upon the seed size spectrum required.

As shown in WB1 (Section 3.3.6), increasing initial sowing density from 200 to 600 seeds $m^{-2}$ significantly lowered the thousand grain weight of the harvested grain although there were no significant differences between the densities in the nitrogen content of the grain or in the hot water extract values (Table 27).

### 4.3.7 Yield and yield components

4.3.7.1 Yield Final harvest grain yield (ex-combine harvester) was not significantly different between treatments with yields ranging from 7.4 to

**Fig. 50** The effects of density on seed size distribution

i by weight

ii by number

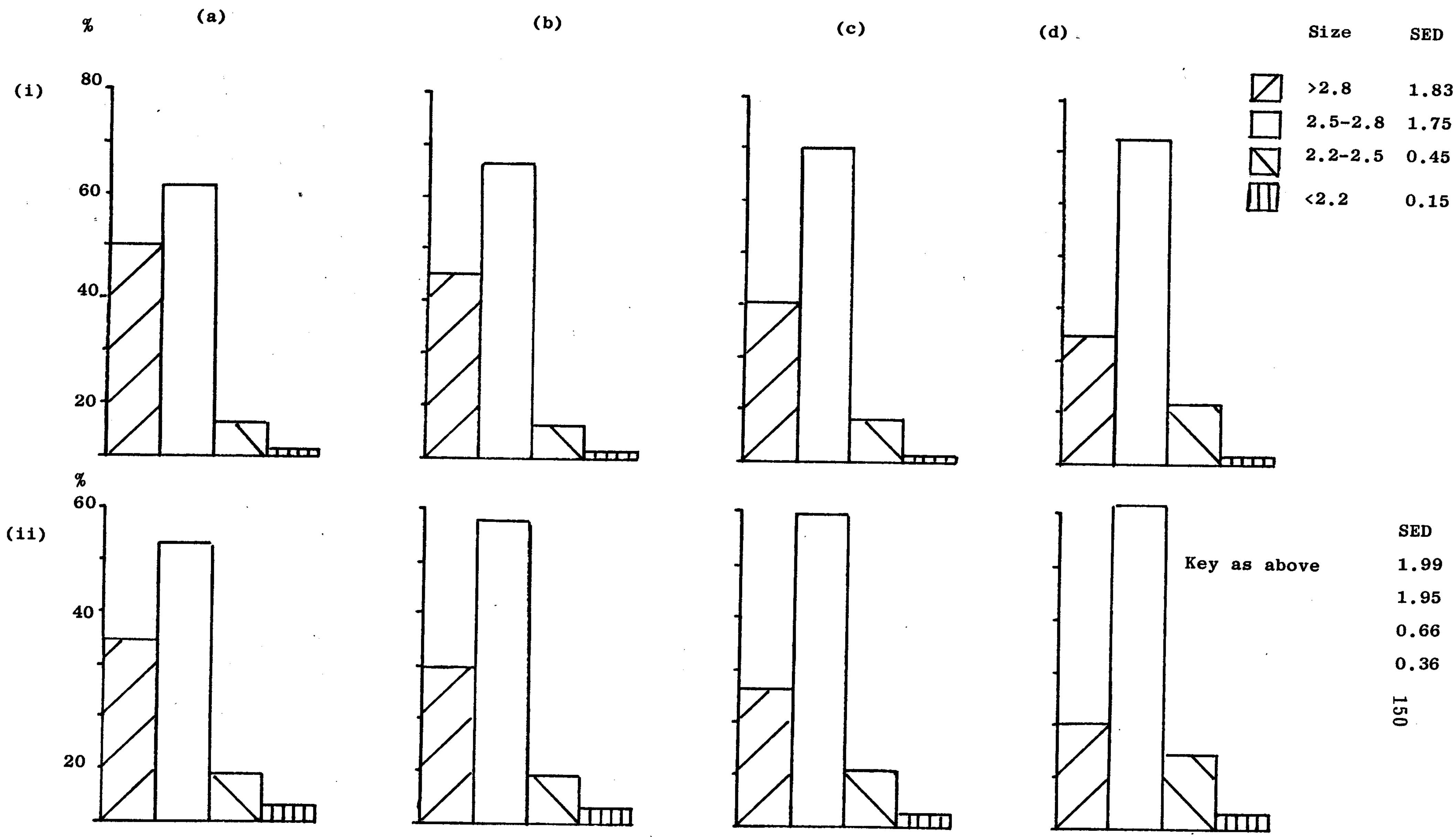
Key:

a = 200 seeds sown $m^{-2}$

b = 300 seeds sown $m^{-2}$

c = 400 seeds sown $m^{-2}$

d = 600 seeds sown $m^{-2}$



%
(a)
(b)
(c)
(d)
Size
SED
(i)
80
60
40
20
>2.8 1.83
2.5-2.8 1.75
2.2-2.5 0.45
<2.2 0.15
%
(ii)
60
40
20
Key as above
SED
1.99
1.95
0.66
0.36

**Table 26** The yield of seeds obtained within specific seed size classifications

| Size (mm) | 200 | 300 | 400 | 600 |
|---|---|---|---|---|
| > 2.8 | 3.00 | 2.69 | 2.34 | 1.87 |
| 2.5 + | 6.86 | 7.03 | 6.96 | 6.63 |
| 2.2-2.8 | 4.34 | 4.86 | 5.26 | 5.65 |
| Screenings < 2.2 | 0.09 | 0.10 | 0.09 | 0.12 |

**Table 27** Grain characteristics WB5

| | 200 | 300 | 400 | 600 | SED | Sig |
|---|---|---|---|---|---|---|
| TGW (g) | 43.41 | 42.64 | 41.77 | 39.66 | 0.650 | xxx |
| N% | 1.911 | 1.900 | 1.905 | 1.836 | 0.035 | ns |
| HWE | 300.23 | 298.42 | 300.02 | 299.36 | 1.715 | ns |

7.7 t $ha^{-1}$ for the D1 and D3 treatments respectively (Fig. 51). Final crop biomass values were similarly not affected by initial sowing densities (Fig. 48). However in both yield and biomass the lowest density exhibited the lowest values for these components, highest values being obtained at intermediate or high densities (D3 or D4).

4.3.7.2 Yield components There were significant differences between the initial sowing densities in the TGW of the resultant grain (Fig. 51). The TGW of seeds removed from D1 and D3 was significantly higher than the TGW of D2 and D4 grain. These differences are hard to attribute to any measured component or environmental factor.

Significant differences were evident in the effects of density on the number of grains present per ear (Fig. 51). In both main culm ears and in tiller ears the number of grains per ear was greater in the plants from low initial seed densities.

The number of tillers $m^{-2}$ was significantly different between the density treatments with low initial sowing densities having a lower number of tillers per unit area (Fig. 51). The number of tillers present ranged from 800 (D1) to 1100 (D4) tillers $m^{-2}$. The number of ears per unit area showed a similar pattern with a greater number of ears being produced at high densities. The proportion of tillers present at final harvest that were ear bearing declined with increasing sowing densities (Table 28). Hence a greater proportion of the total ears present at final harvest of the high density plots came from mainstem ears.

### 4.3.8 Harvest indices

The harvest estimates made from hand harvested samples showed significant differences between D1 and D4 with the lowest initial seed density giving the highest harvest index (data not presented).

## 4.4 The Effect of Nitrogen Rate and Timing

### 4.4.1 Introduction

In experiment WB5 three nitrogen treatments were employed. Full details of rates and timings can be found in Table 20. Although dates of application of nitrogen can be found in Table 20 the time of availability

**Fig. 51** The effect of density on:

- i Grain yield t $ha^{-1}$
- ii TGW 0% MC
- iii Tillers $m^{-2}$
- iv Grain number per main ear
- v Above ground biomass yield
- vi Fh

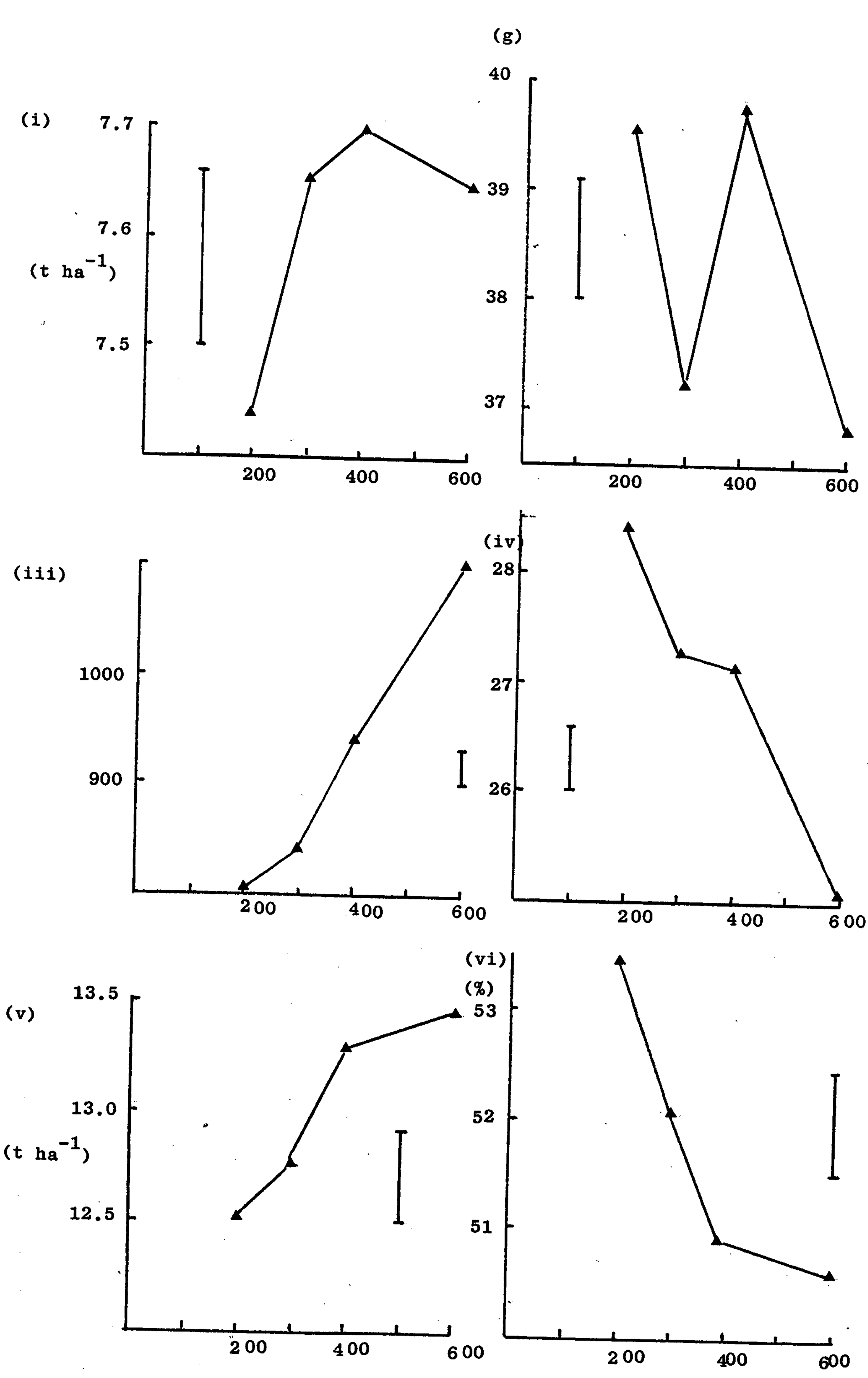

(i)
7.7
7.6
(t ha$^{-1}$)
7.5
200
400
600
(ii)
(g)
40
39
38
37
200
400
600
(iii)
1000
900
200
400
600
(iv)
28
27
26
200
400
600
(v)
13.5
13.0
(t ha$^{-1}$)
12.5
200
400
600
(vi)
(%)
53
52
51
200
400
600

**Table 28** The effect of density on ear numbers

| | 200 | 300 | 400 | 600 | SED | Sig |
|---|---|---|---|---|---|---|
| Tillers $m^{-2}$ | 805 | 841 | 941 | 1101 | 34.8 | xxx |
| % Tillers with ears | 88.89 | 90.26 | 86.29 | 84.49 | 1.748 | x |
| Ears $m^{-2}$ | 901 | 995 | 1091 | 1315 | 88.9 | xxx |

of the nitrogen may be dissimilar due to the atypical pattern of rainfall during the growing season.

### 4.4.2 The effect of nitrogen treatment on the number of stems per plant

Throughout growth the number of stems per plant was dependent upon the nitrogen treatment imposed with N1 always having fewer stems per plant albeit not always significantly fewer (Fig. 52). Peak stem number was reached earlier on the N1 treatments (122 DAS) than in the N2 treatment (170 DAS).

Stem number decline occurred concurrent with the onset of stem elongation in the N2 treatments but prior to stem elongation in the N1 nitrogen treatments.

### 4.4.3 The effects of nitrogen on LAI and GAI

Until 170 DAS nitrogen treatments made no significant differences to the LAI (Fig. 53). At the onset of stem elongation significant differences were evident with the N2 treatment producing significantly higher LAI values at 171 and 206 DAS than the N1 treatment. The peak LAI values were obtained at similar times, that is at 230 DAS. The values at peak LAI for N2 being greater than those for N1 albeit not significantly different.

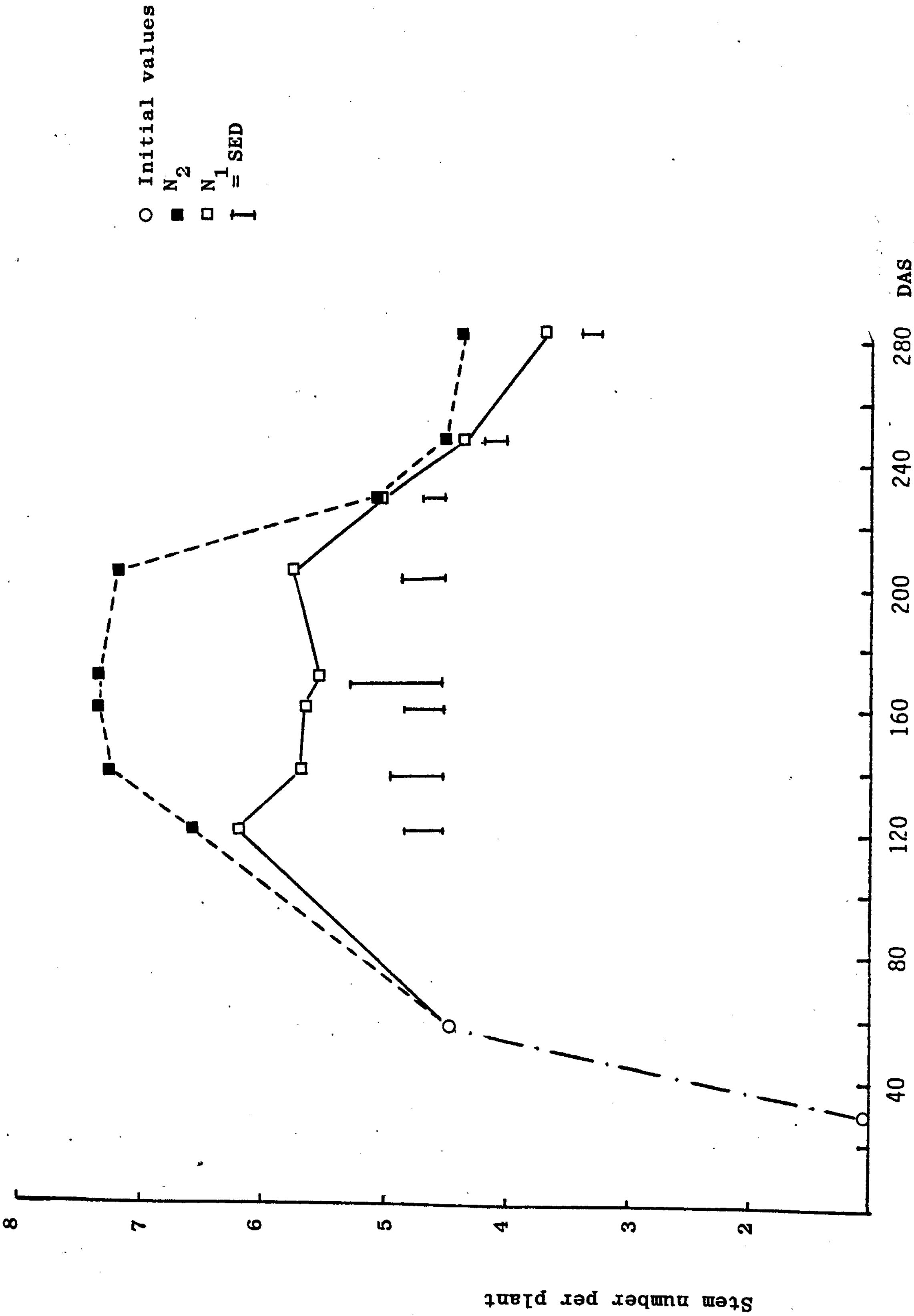
Until 206 DAS (14 April) there were no significant differences between the nitrogen treatments in their GAI. From this time the N2 treatment gave higher, although not always significantly higher, GAI estimates. Peak GAI values for N1 being 6.75 and for N2 approximately 7.0.

There was no difference between the nitrogen treatments in the time of onset of stem extension as estimated by the rapid increase in GAI and biomass occurring during early March.

In both nitrogen treatments LAI reached unity at 120 DAS, thus throughout the autumn and early winter full ground cover was not achieved.

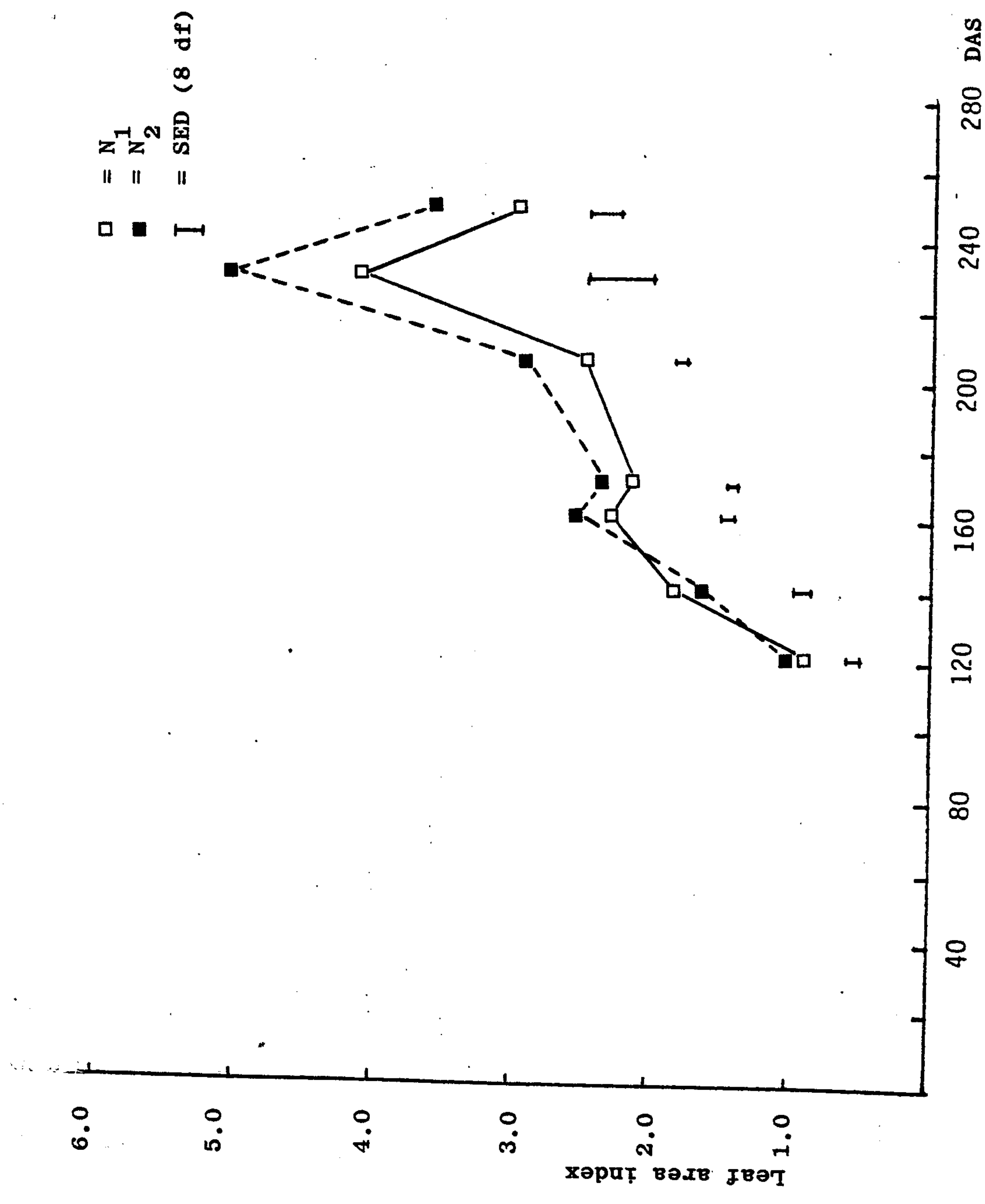
4.4.3.1 <u>The proportion of the total area accounted for by each tiller category</u> There was a constant contribution in treatment N1 from the mainstem to the total plant area from peak

**Fig. 52** The influence of nitrogen on stem numbers per plant



Initial values
$N_2$
$N_1$
= SED
Stem number per plant
DAS
8
7
6
5
4
3
2
40
80
120
160
200
240
280

**Fig. 53** The effect of nitrogen on LAI


= $N_1$
= $N_2$
= SED (8 df)
Leaf area index
6.0
5.0
4.0
3.0
2.0
1.0
40
80
120
160
200
240
280
DAS

tillering until 171 DAS at which time stem extension was commencing. From this time the proportional contribution from the mainstem increased to reach a peak contribution of 40%.

In N2 the mainstem proportional contribution to plant area declined from 120 until 162 DAS at which time the peak tiller number for the N2 treatment had been reached. After this time the contribution of the mainstem increased reaching a maximum contribution of approximately 36.5%.

### 4.4.4 The effect of nitrogen on total above ground biomass

Nitrogen treatments had significant effects on total above ground biomass of the crop at its peak value and at final harvest (Fig. 54). In both cases the N2 treatment gave significantly higher biomass yields, the differences being approximately 2.5 t $ha^{-1}$ DM at peak biomass and 1.7 t $ha^{-1}$ at final harvest.

Prior to peak biomass there were no significant differences between the nitrogen treatments in the biomass yields obtained.

### 4.4.5 Grain characteristics

Nitrogen treatments significantly altered the seed size distribution of the grain samples obtained (Fig. 55). There were significantly more seeds greater than 2.8 mm in size in the N3 treatment and also significantly less seeds in the range 2.5-2.8 mm than in the N1 treatment. In all nitrogen regimes the proportion of grains less than 2.2 mm in size was under 4% by number.

There was a significant interaction between variety and nitrogen in the percentage of seeds falling into each size classification. Within the variety Igri the N2 treatment produced the lowest percentage of seeds above 2.8 mm in size but the highest percentage of seeds between 2.5 and 2.8 mm. However in Tipper this distribution was evident in the N3 treatment.

The yield of grain of specific size categories depended upon the nitrogen treatment imposed (Table 29). The optimum nitrogen treatment for yield of grain within specified size restrictions depended upon the size of grains required, the highest yields of very large (>2.8 mm) or large (2.5 mm plus) seeds being obtained with the N3 nitrogen treatment when

**Fig. 54** Above ground biomass yields as influenced by nitrogen treatments

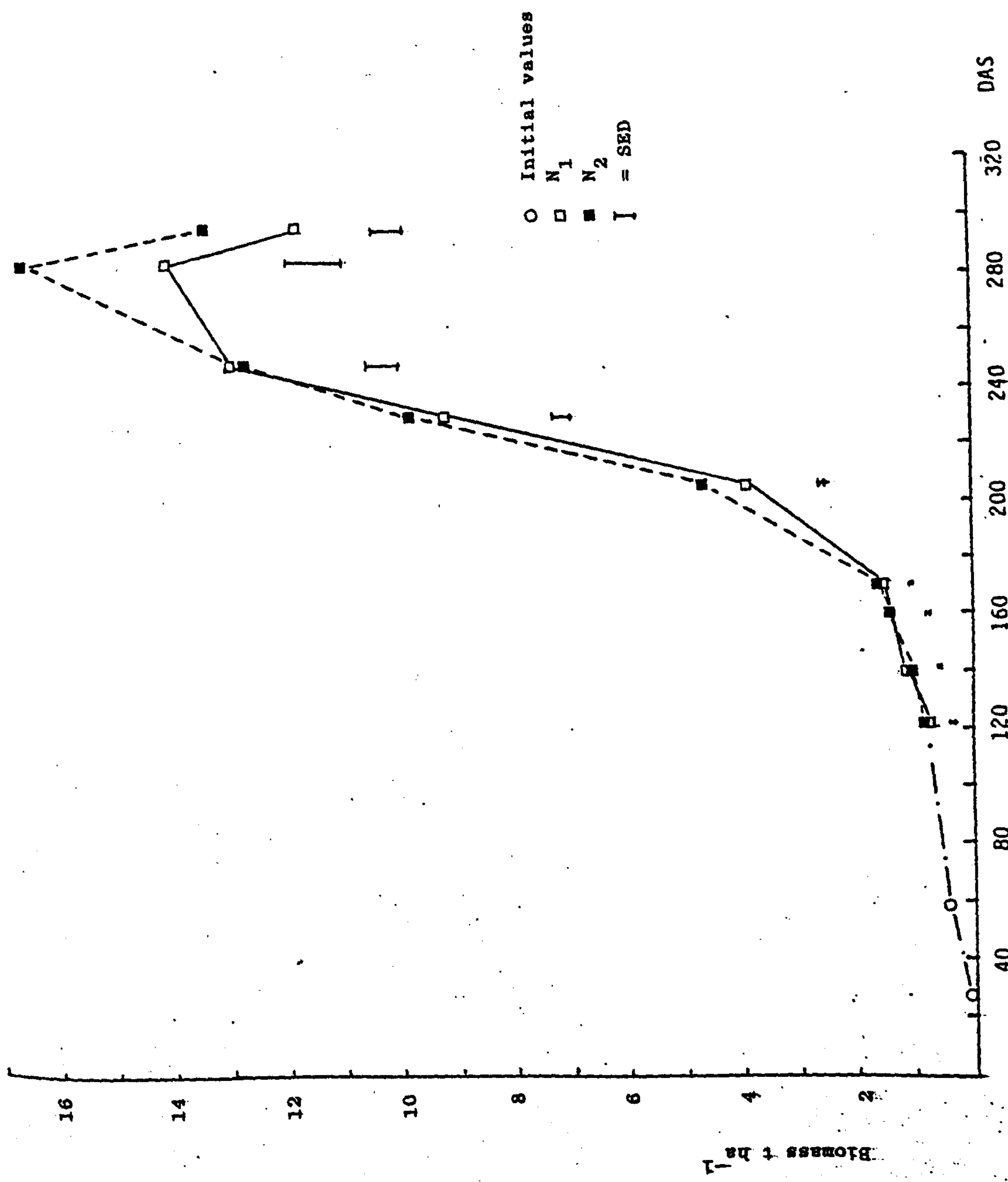

Initial values
N1
N2
= SED
DAS
40
80
120
160
200
240
280
320
Biomass t ha-1
2
4
6
8
10
12
14
16

**Fig. 55** Seed size distribution

i by weight

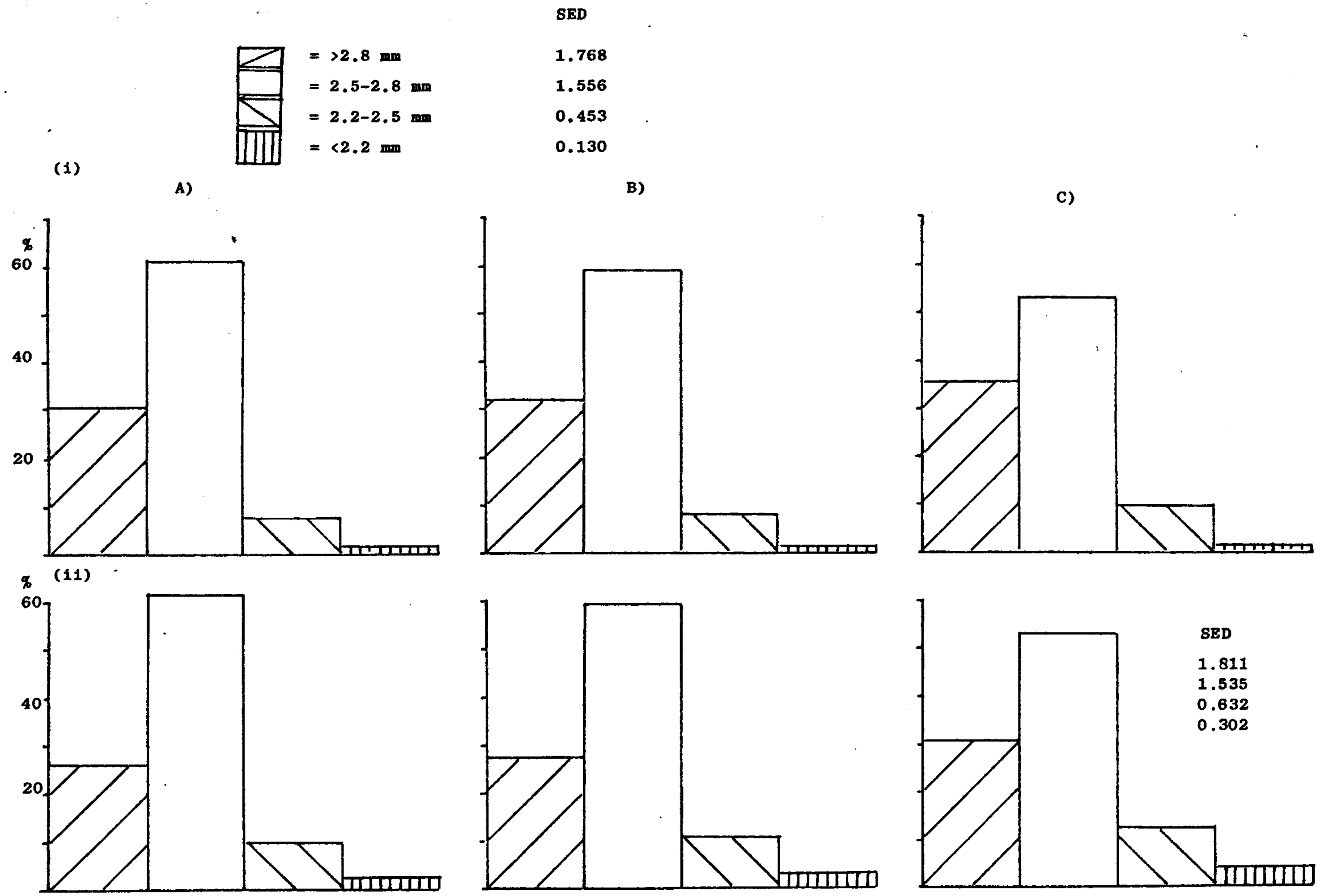
ii by number

<u>Key</u>:

A = N1

B = N2

C = N3


SED
= >2.8 mm
= 2.5-2.8 mm
= 2.2-2.5 mm
= <2.2 mm
1.768
1.556
0.453
0.130
(i)
A)
B)
C)
%
60
40
20
(ii)
SED
1.811
1.535
0.632
0.302

considering pooled varieties. However for a required seed size of 2.2 to 2.8 mm the N2 treatment gave the highest yield of useable grain when both varieties were considered together.

However due to the interactions between nitrogen and variety in the proportion of grains within any specific size category the optimum nitrogen treatment for the yield of grains within any specific category depended upon the variety.

There were no significant differences between the nitrogen treatments in the TGWs of the resultant seed when taken from either the combine harvested grain sample or from the hand harvested plots (Table 30, Fig. 57).

Nitrogen treatments did not significantly influence grain nitrogen content or hot water extract estimates of the grain (Table 30).

### 4.4.6 Yield and yield components

4.4.6.1 Yield There was a significant difference between nitrogen treatment N1 and the other nitrogen treatments in the yield of grain obtained with N1 yielding approximately 1.5 t $ha^{-1}$ less grain (Fig. 56).

There were significant interactions between variety, nitrogen and density in the grain yield at final harvest (Fig. 57). Within a low nitrogen regime (N1) there were differences between the varieties in their response to increasing density with the variety Tipper reaching its maximum grain yield at an initial sowing density of 300 seeds $m^{-2}$. At the highest sowing density the grain yield was reduced by over 1 t $ha^{-1}$. In Igri with the N1 nitrogen treatment there was an increase, albeit small, in the yield of grain with increasing plant density.

N2 and N3 nitrogen treatments of the variety Tipper resulted in grain yield differences between the imposed densities with the low density treatments being lower yielding under both nitrogen treatments. However the N3 nitrogen treatment was able to compensate for an inadequate plant density resulting in increased yields compared to those of the N2 treatment at a similar density.

In Igri the reduction in yield at D2 with nitrogen treatment N3 cannot be adequately explained.

**Table 29** The yield of grain of specific size classifications as influenced by variety and nitrogen

| Size (mm) | Igri | | | Tipper | | |
|---|---|---|---|---|---|---|
| | N1 | N2 | N3 | N1 | N2 | N3 |
| > 2.8 | 2.78 | 3.12 | 3.41 | 1.21 | 2.00 | 2.49 |
| 2.5 + | 6.10 | 7.43 | 7.34 | 5.87 | 7.11 | 7.37 |
| 2.2-2.8 | 3.75 | 4.93 | 4.69 | 5.23 | 5.76 | 5.65 |
| Screenings of < 2.2 | 0.07 | 0.08 | 0.12 | 0.07 | 0.12 | 0.16 |

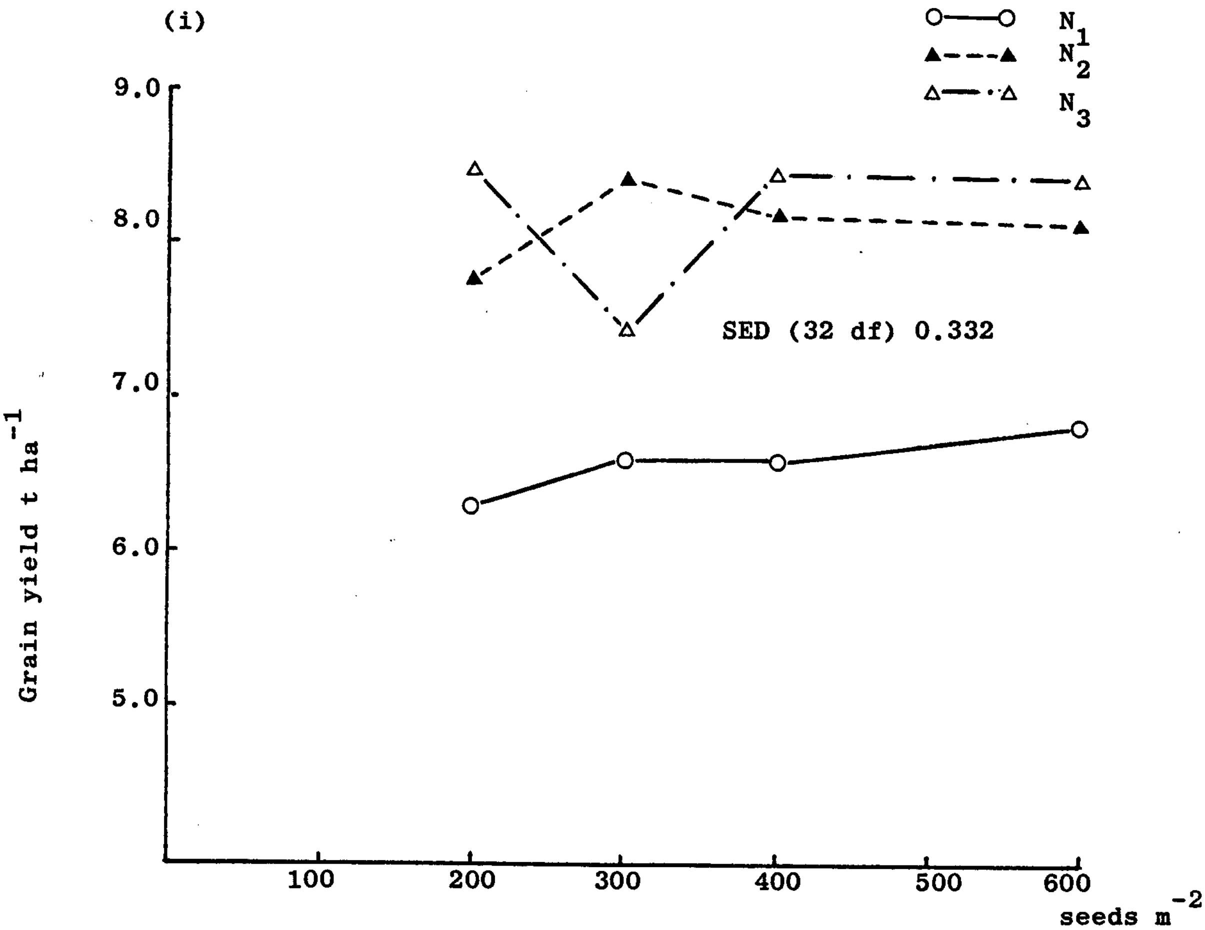
**Table 30** The effect of nitrogen treatment on grain characteristics

| | N1 | N2 | N3 | SED | Sig |
|---|---|---|---|---|---|
| TGW (g) | 41.97 | 41.19 | 42.45 | 0.541 | ns |
| N% | 1.846 | 1.919 | 1.899 | 0.038 | ns |
| HWE | 301.19 | 297.99 | 299.35 | 1.455 | ns |

**Fig. 56** The effect of variety, density and nitrogen interactions

i Igri

ii Tipper


(i)
N1
N2
N3
9.0
8.0
7.0
6.0
5.0
Grain yield t ha-1
SED (32 df) 0.332
100
200
300
400
500
600
seeds m-2

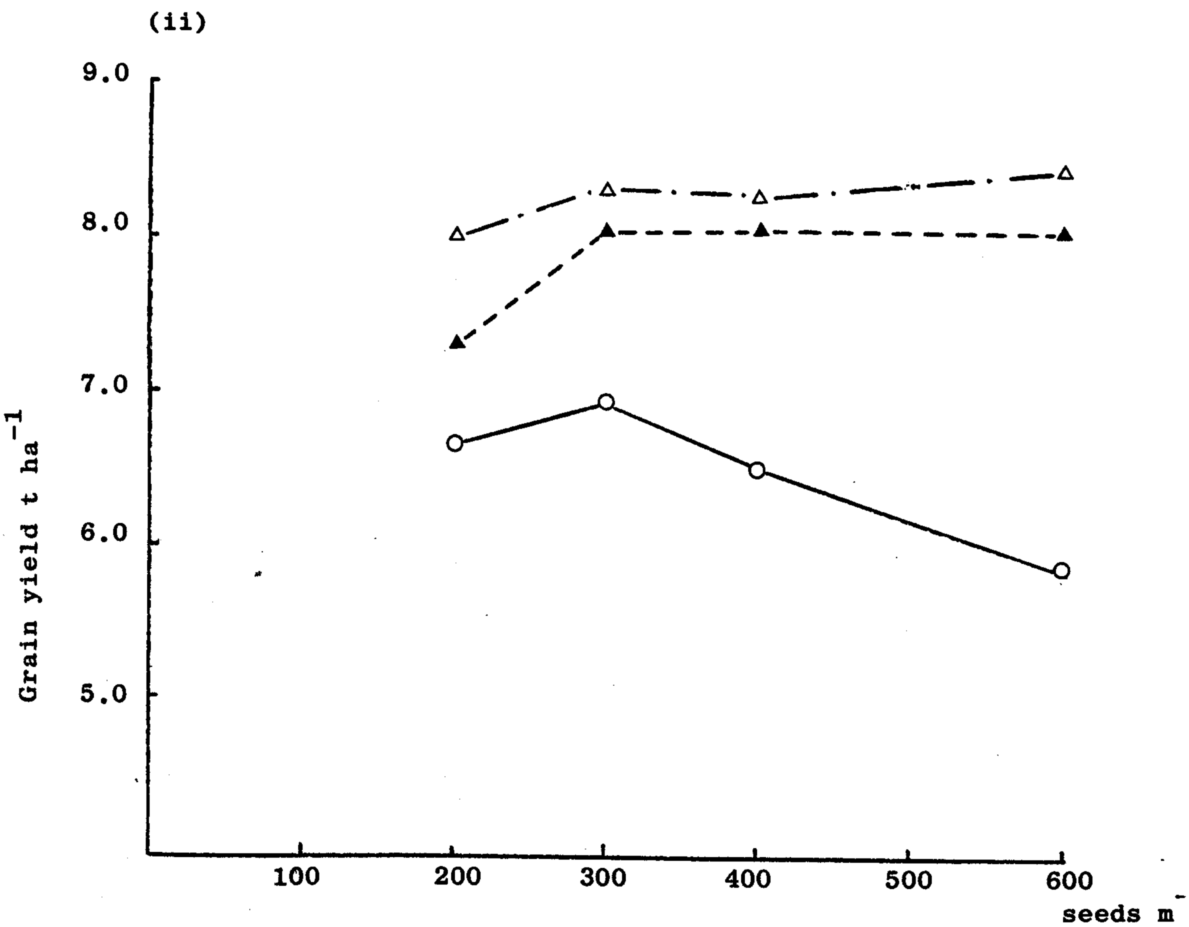

(ii)
9.0
8.0
7.0
6.0
5.0
Grain yield t ha-1
100
200
300
400
500
600
seeds m-

**Fig. 57** The effect of nitrogen on grain yield and yield components

i Grain number $ear^{-1}$

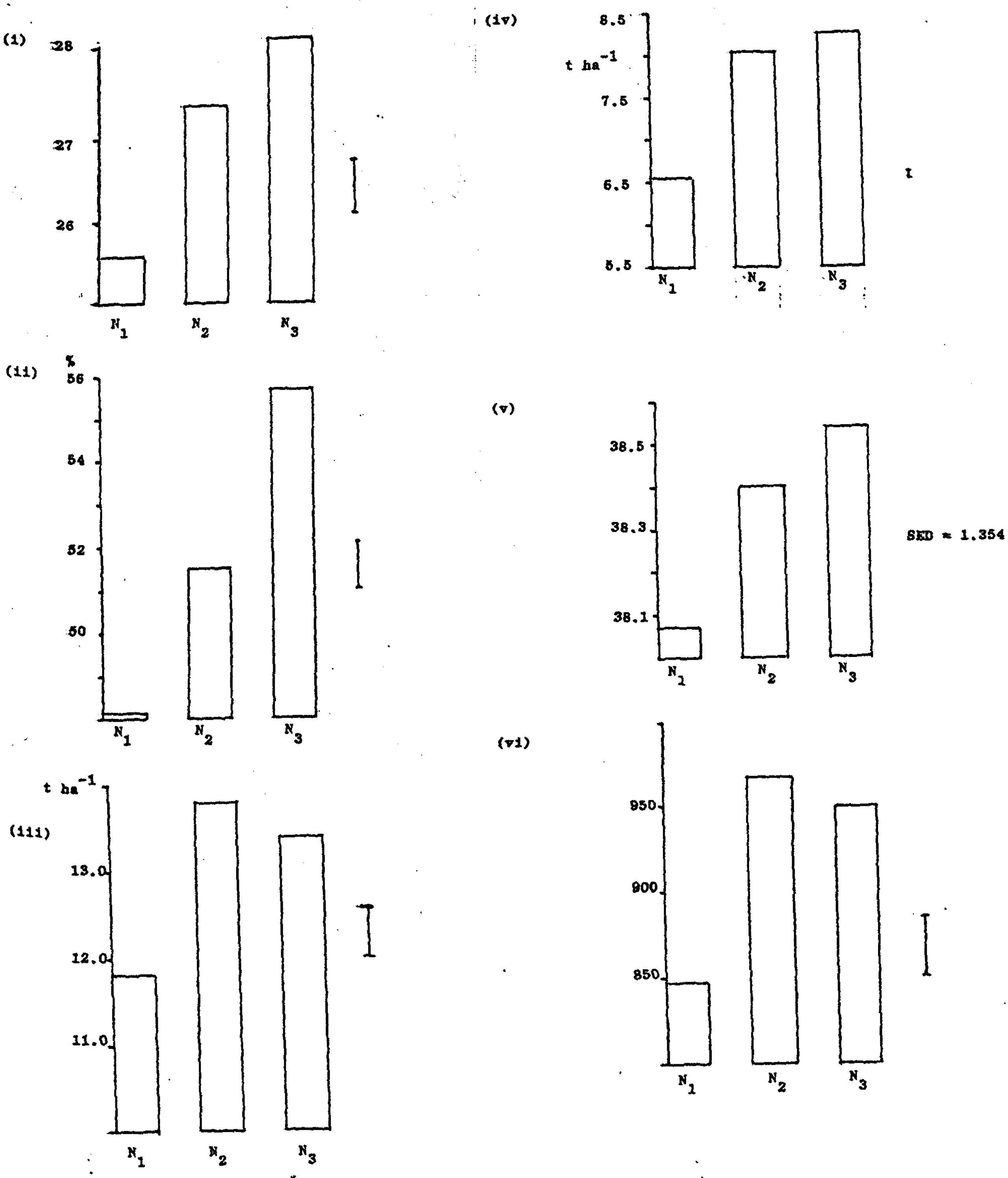
ii Fh

iii Above ground biomass

iv Grain yield t $ha^{-1}$

v TGW 0% MC

vi Tillers $m^{-2}$


(i)
28
27
26
N1
N2
N3
(ii)
%
56
54
52
50
N1
N2
N3
t ha-1
(iii)
13.0
12.0
11.0
N1
N2
N3
(iv)
8.5
t ha-1
7.5
6.5
5.5
N1
N2
N3
(v)
38.5
38.3
38.1
SED = 1.354
N1
N2
N3
(vi)
950
900
850
N1
N2
N3

4.4.6.2 Yield components N1 had significantly less grains per ear on the main ear than N2 and N3 nitrogen treatments which themselves differed by 0.75 grains per ear with N3 having the greater number (Fig. 56). There was a significant interaction between variety and nitrogen with Tipper having a greater response to the N3 nitrogen treatment (Table 31).

Both tiller and ear numbers were modified by nitrogen treatments with N1 having significantly fewer tillers and ears per unit area than the N2 and N3 nitrogen treatments (Fig. 56).

### 4.4.7 Final harvest biomass and harvest indices

Final harvest biomass significantly differed between nitrogen treatments with N1 having a lower biomass yield than N2 and N3 which were not significantly different. There were also significant differences between all three nitrogen treatments in the harvest indices obtained from hand harvested samples with the Fh of N3 being over 7% higher than that of N1 (Fig. 56).

## 4.5 Rothwell 1981-82

The 1981-82 Rothwell experiment was designed to complement experiment WB5 which was conducted at Sutton Bonington. Similar varieties and seed densities were used in each trial. Full details of nitrogen rates and timings are outlined in Table 32(ii) and full trial details are indicated in Table 32(i).

No sequential destructive growth analyses were undertaken but stem count areas were designated in each plot by the insertion of two canes 0.33 m apart on each of three adjacent central rows of each plot. Plant establishment was assessed on 5 Nov, 37 DAS.

At final harvest these specified areas were removed from the trial and analysed for their yield components in the laboratory. The remainder of each plot was combine harvested using a Hege small plot combine harvester. A 2 kg subsample of grain was removed from each combine harvested sample. This was used for grain moisture analysis and seed size distribution studies.

**Table 31** The interaction between variety and nitrogen in the number of grains per ear

i) Main

ii) Remainder ears

i)

| Variety | Nitrogen | | | SED (32Df) |
|---|---|---|---|---|
| | N1 | N2 | N3 | |
| Igri | 23.35 | 23.97 | 24.31 | 0.0927 |
| Tipper | 27.72 | 30.69 | 31.89 | |

ii)

| | N1 | N2 | N3 | SED (32Df) |
|---|---|---|---|---|
| Igri | 21.42 | 22.14 | 22.92 | 1.572 |
| Tipper | 25.23 | 29.30 | 28.29 | |

**Table 32**

i) Rothwell 1981/82 – Field trial details

| | |
|---|---|
| Site: | Cabourne 8 |
| Previous crop: | Winter oilseed rape |
| Soil type: | Well drained shallow chalky soil with areas of deeper loam or clay flinty soils |
| Drilling date: | 29/9/1981 |
| Fungicides: | Tilt MBC (Propiconazole + carbendazim) 19/4/1982 |
| | Tilt (Propiconazole) 21/5/1982 |
| Herbicide: | Cleaval (Cyanazine + mecoprop) 14/4/1982 |
| Varieties sown: | Igri, Tipper |
| Seed densities: | 200, 300, 400 and 600 seeds sown $m^{-2}$ |
| Nitrogen treatments: | See Table 32 ii |

ii) Rothwell 1981/82 – Nitrogen inputs - rate and timing (kg $ha^{-1}$)

| Treatment | Seedbed | 20 Nov | 15 Feb | 28 Mar | Total |
|---|---|---|---|---|---|
| N1 | 25 | 0 | 40 | 40 | 105 |
| N2 | 25 | 40 | 40 | 80 | 185 |
| N3 | 25 | 40 | 40 | 120 | 225 |

### 4.5.1 Nitrogen treatments

Due to errors at the time of the third nitrogen top dressing (28 March) the nitrogen treatments became unequally replicated with only 19 N1 treatments but 29 N3 treatments. This unbalanced design for nitrogen treatments was analysed separately from the individual comparisons between varieties and between densities and the variety-density interactions. SED values presented for the differences between nitrogen treatments are the SED values between N1 and N3, i.e. the minimum and maximum replicated treatments. Estimates of SED values between N1 and N2 and between N2 and N3 can be obtained from:

$$SED = \sqrt{\Delta^2 \left( \frac{1}{n_1} + \frac{1}{n_2} \right)}$$

## 4.6 Results

Table 33 illustrates the correlation matrix between grain yield and final harvest yield components.

Grain yield was strongly positively correlated with grain numbers per unit area (Fig. 58) but not with plant number $m^{-2}$, ear number per plant (Fig. 58), grain number per main culm ear or TGW.

The number of ears $m^{-2}$ was positively correlated with the above ground biomass (Fig. 58) and with the number of plants $m^{-2}$. The number of plants $m^{-2}$ positively influenced the total above ground biomass. As the number of plants $m^{-2}$ increased the number of viable grains per mainstem ear decreased. In this experiment there was also a significant negative linear relationship between final plant number and the proportion of the total plant dry weight harvested as grain, i.e. the harvest index (Fig. 58).

As in other experiments there was a strongly negative relationship between grain number per $m^2$ and TGW with a reduction of approximately 2 g for an increase of 1,000 grains $m^{-2}$ between 13,000 and 21,000 grains $m^{-2}$.

**Table 33** *Correlation matrix Rothwell 198/82*

| Component | No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Yield | 1 | 1.00 | | | | | | | | |
| Fh | 2 | 0.0347 ns | 1.00 | | | | | | | |
| Ears $m^{-2}$ | 3 | -0.2051 ns | -0.1692 ns | 1.00 | | | | | | |
| Ears $plant^{-1}$ | 4 | 0.0267 ns | 0.0307 ns | 0.5235 xxx | 1.00 | | | | | |
| Grain number $ear^{-1}$ (main) | 5 | 0.1122 ns | 0.1268 ns | -0.1253 ns | 0.1811 ns | 1.00 | | | | |
| Plants $m^{-2}$ | 6 | -0.2152 ●ns | -0.3424 ●x | 0.5074 xx | -0.4111 x | -0.3546 x | 1.00 | | | |
| Biomass | 7 | -0.0346 ns | -0.2234 ns | 0.6963 xxx | 0.2326 ns | 0.1203 ns | 0.5610 ●xxx | 1.00 | | |
| TGW | 8 | -0.616 ns | -0.0995 ns | 0.0939 ns | 0.0338 ns | 0.0363 ns | 0.0021 ns | 0.0462 ns | 1.00 | |
| Grain no. $m^{-2}$ | 9 | 0.5521 ● xxx | 0.1202 ns | -0.1741 ns | -0.0053 ns | -0.0063 ns | -0.1201 ns | -0.0650 ns | -0.8609 ● xxx | 1.00 |
| | No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

Df = 37

Asterisks signify significance levels e.g. x $P < 0.05$, xx $P < 0.01$, xxx $P < 0.001$, ns = not significant

● indicates illustrated relationships

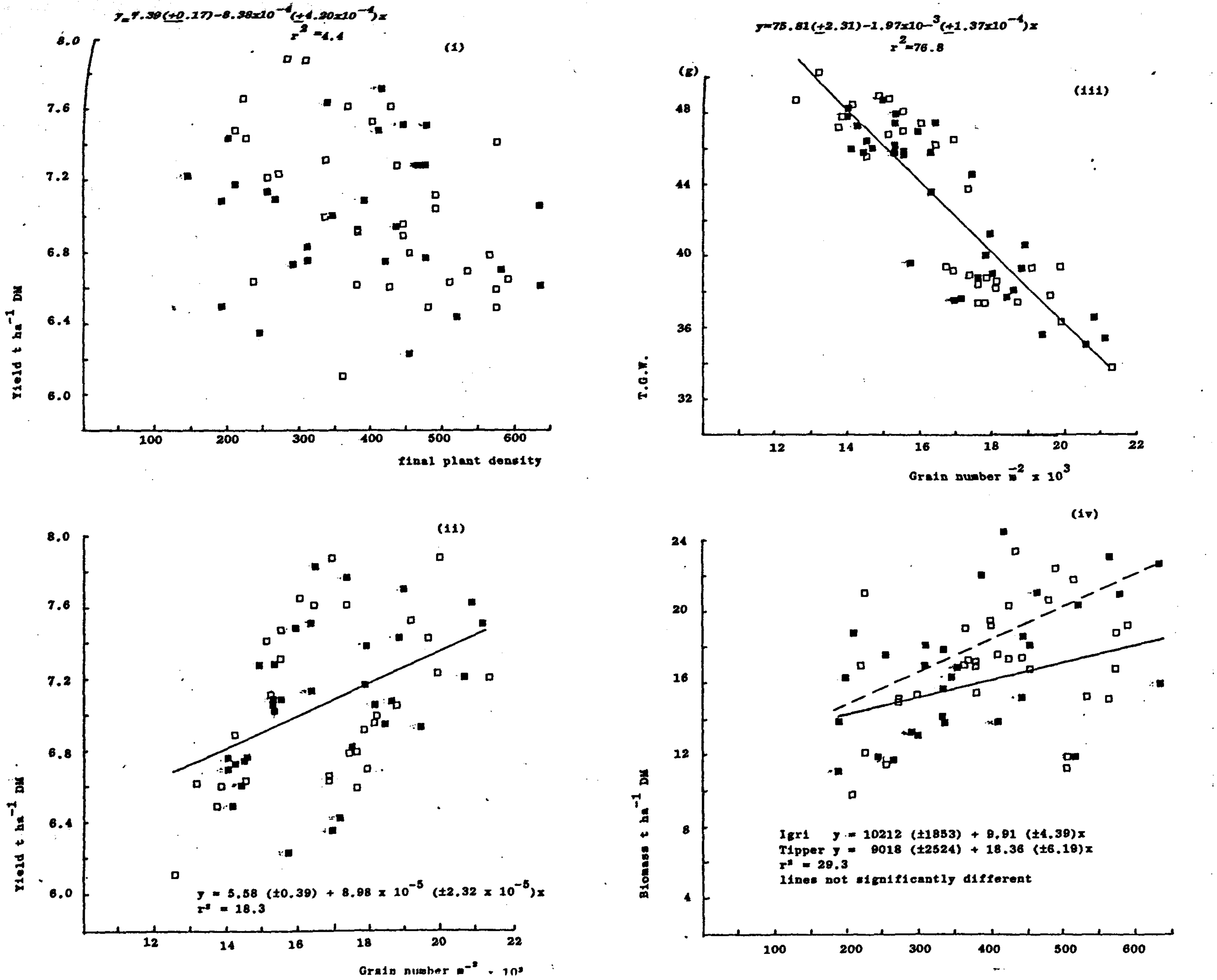
**Fig. 58**

i The effect of final plant density on harvested grain yield

ii The effects of grain number $m^{-2}$ on grain yield

iii The effect of grain number $m^{-2}$ on TGW

iv The influence of final plant number on above ground biomass yields


y=7.39(+0.17)-8.38x10^-4(+4.20x10^-4)x
r^2=4.4
(i)
Yield t ha^-1 DM
final plant density
y=75.81(+2.31)-1.97x10^-3(+1.37x10^-4)x
r^2=76.8
(g)
(iii)
T.G.W.
Grain number m^-2 x 10^3
(ii)
Yield t ha^-1 DM
y = 5.58 (±0.39) + 8.98 x 10^-5 (±2.32 x 10^-5)x
r^2 = 18.3
Grain number m^-2 x 10^3
(iv)
Biomass t ha^-1 DM
Igri y = 10212 (±1853) + 9.91 (±4.39)x
Tipper y = 9018 (±2524) + 18.36 (±6.19)x
r^2 = 29.3
lines not significantly different

### 4.6.1 Seed size distribution

4.6.1.1 Variety The proportion of seeds falling into each size classification did not differ significantly bewteen varieties with over 68% of the seeds being greater than 2.8 mm in size in both varieties (Table 34). Less than 10% of all harvested seeds were below 2.5 mm in size.

4.6.1.2 Density No significant differences occurred between the density treatments in the proportion of seed falling into each size classification (Table 34). Within each density between 66% and 72% of all grains were located in the largest size classification.

### 4.6.2 Grain yield

There were significant variety-density interactions in the harvested yield of grain (Fig. 59). Within the variety Igri grain yield increased with increasing plant sowing density with both the N1 and N2 nitrogen treatments. However a slight yield reduction was experienced at high plant densities with the N3 nitrogen treatment. This was possibly due to increased lodging resulting from both high stem numbers and excessive nitrogen fertilization.

Within Tipper grain yield was reduced with increasing plant density at the lowest nitrogen level N1. Increasing plant density above 400 seeds $m^{-2}$ did not cause a significant yield reduction in the N2 nitrogen treatment but at the highest nitrogen rate N3 a significant yield reduction was caused by the increasing plant number. Parmentier (1959) (cited by Darwinkel, 1980) had previously noted in winter wheat crops that as crop densities increased there was a concomitant increase in the risk of lodging, disease and pest infestations.

## 4.7 Density

The initial seed sowing density influenced most yield components and thus significantly influenced harvested grain yield (whether obtained ex-combine harvester or by estimation from yield components) (Fig. 60).

Increasing plant density decreased the number of ears per plant, the grain number per main ear, the weight of the main ear and the mean

**Table 34** Seed size distribution – Proportion by seed weight as influenced by i) Variety, and ii) Density

i)

| Size (mm) | Igri | Tipper | SED (46Df) |
|---|---|---|---|
| > 2.8 | 68.2 | 70.5 | 2.64 |
| 2.5-2.8 | 23.7 | 22.9 | 1.99 |
| 2.2-2.5 | 5.2 | 4.4 | 0.42 |
| < 2.2 | 2.8 | 2.1 | 0.36 |

ii)

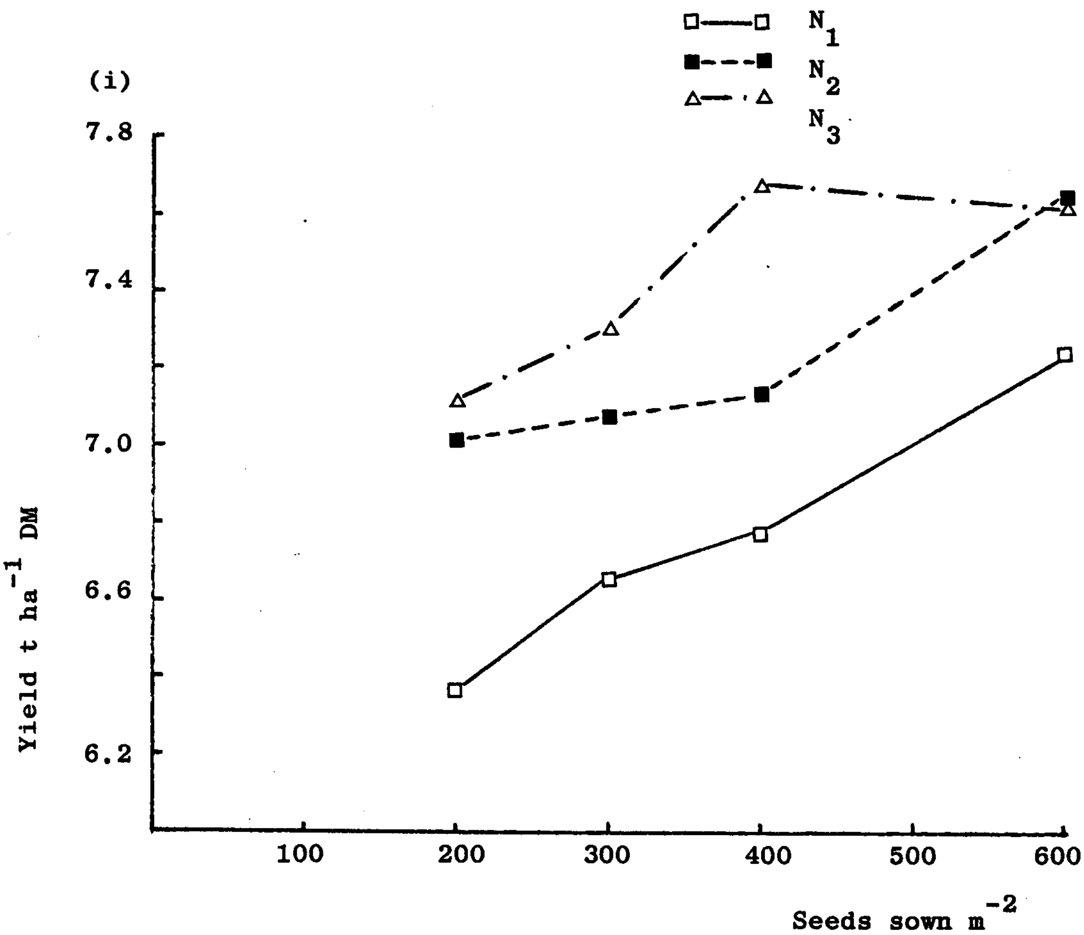
| Size (mm) | 200 | 300 | 400 | 600 | SED (46Df) |
|---|---|---|---|---|---|
| > 2.8 | 71.5 | 69.8 | 66.8 | 69.4 | 3.74 |
| 2.5-2.8 | 21.9 | 23.0 | 25.2 | 23.3 | 2.81 |
| 2.2-2.5 | 4.3 | 4.8 | 5.2 | 4.9 | 0.59 |
| < 2.2 | 2.3 | 2.4 | 2.8 | 2.4 | 0.52 |

**Fig. 59** The effect of nitrogen treatment and density on grain yield of

i Igri

ii Tipper

(i)


N1
N2
N3
7.8
7.4
7.0
6.6
6.2
Yield t ha-1 DM
100
200
300
400
500
600
Seeds sown m-2

(ii)

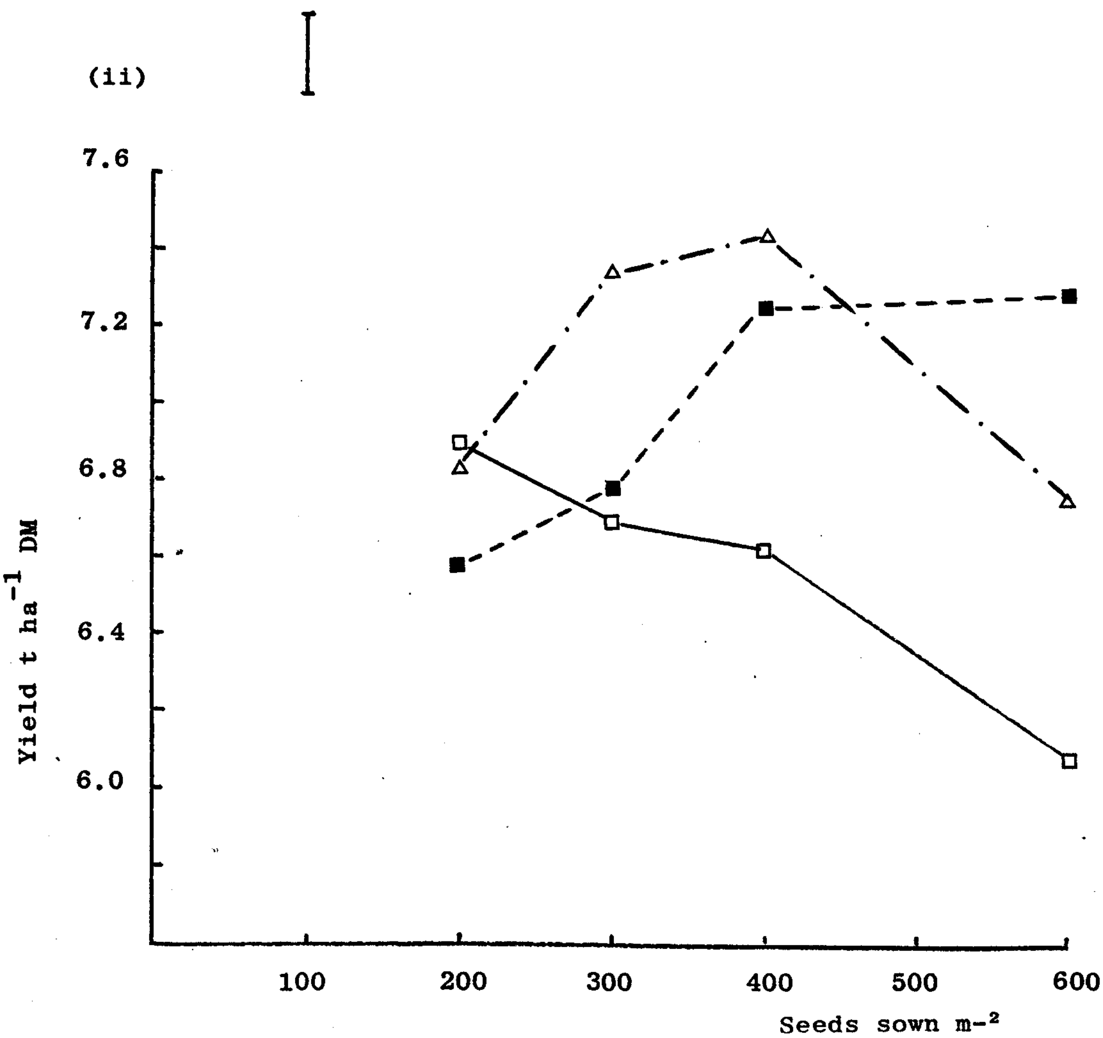
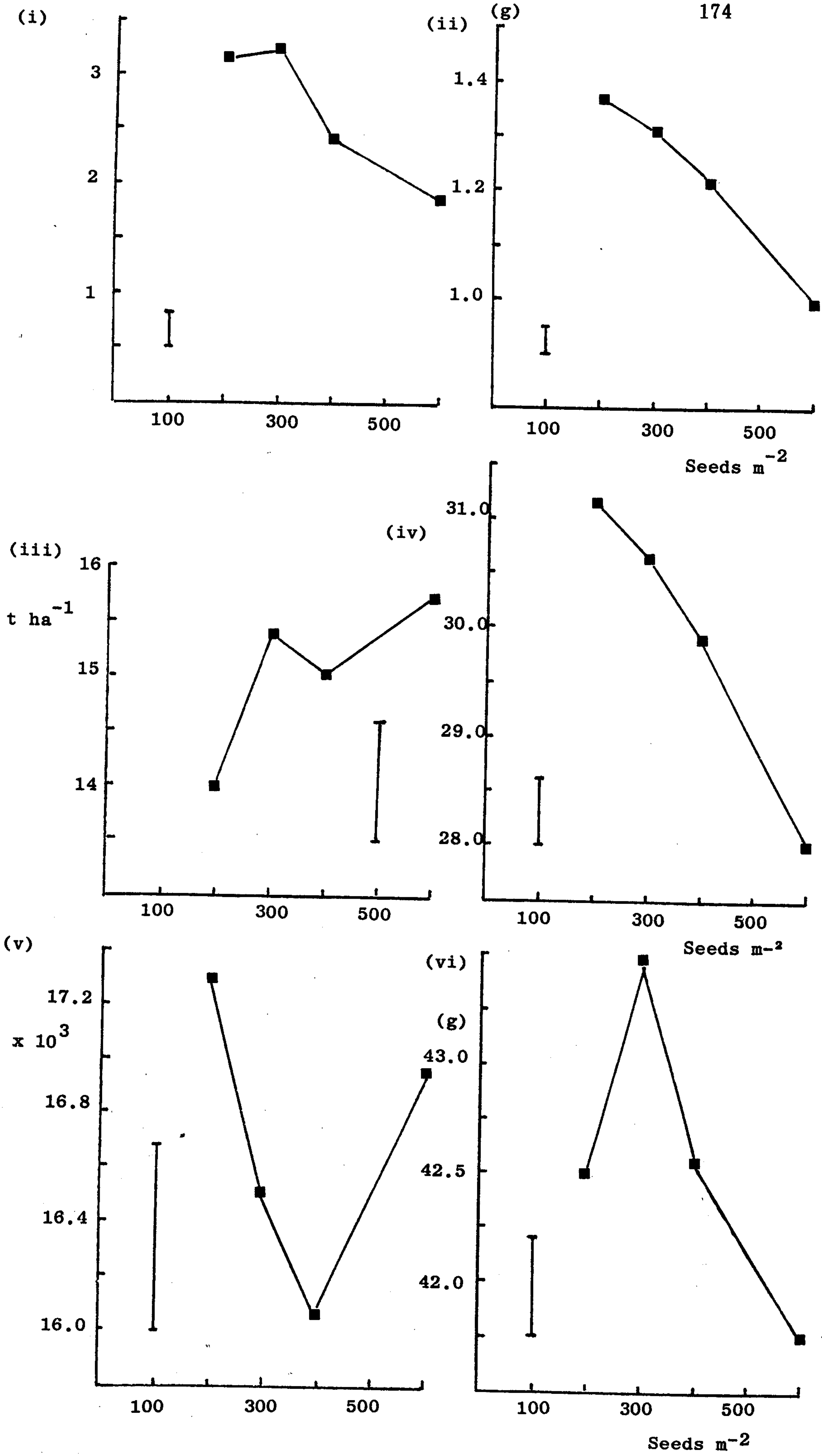

7.6
7.2
6.8
6.4
6.0
Yield t ha-1 DM
100
200
300
400
500
600
Seeds sown m-2

**Fig. 60** The influence of initial sowing density on

| | |
|---|---|
| i | Ear number per plant |
| ii | Weight per main ear |
| iii | Above ground biomass yield |
| iv | Grain number per main ear |
| v | Grain number $m^{-2}$ |
| vi | TGW 0% MC |


(i)
3
2
1
100
300
500
(ii)
(g)
1.4
1.2
1.0
100
300
500
Seeds m-2
(iii)
t ha-1
16
15
14
100
300
500
(iv)
31.0
30.0
29.0
28.0
100
300
500
Seeds m-2
(v)
x 10^3
17.2
16.8
16.4
16.0
100
300
500
(vi)
(g)
43.0
42.5
42.0
100
300
500
Seeds m-2

grain weight. However increasing plant density resulted in an increase in the number of ears $m^{-2}$ and an increase in the total above ground biomass (Fig. 60). Density did not consistently modify grain number per $m^{-2}$ and thus as grain yield was dependent on grain number it was found that grain yield was not modified consistently with increasing plant density. Although biomass increased with increasing plant density there was a concomitant decrease in harvest index.

## 4.8 Nitrogen

The effects of nitrogen supply on grain yield can be variable depending on quantities and times of application. Grain yield usually increases with increased nitrogen rates until a plateau region is reached. Grain yield increases have usually been attributed to increases in ear number $m^{-2}$ and grain number $ear^{-1}$ (and thus grain number $m^{-2}$) caused by additional nitrogen and not usually to increases in TGW (Pearman, Thomas & Thorne, 1978; Scott, Dougherty & Langer, 1977; Whingwiri & Stern, 1982; Darwinkel, 1983). For winter wheats the relationship between grain yield and grain number was shown to be linear by Evans (1978) and Spiertz (1978) but curvilinear by Darwinkel (1978) and Fisher, Aguilar & Laing (1977). However this relationship depends upon growing conditions, variety and yield level (Darwinkel, 1980).

Nitrogen treatments influenced final harvest yield components. Increasing total applied nitrogen significantly increased the total above ground biomass from less than 13.5 t $ha^{-1}$ at N1 to over 15.7 t $ha^{-1}$ at N2 and N3 with no significant differences occurring between N2 and N3 (Fig. 61). The highest nitrogen treatment resulted in a greater number of ears per plant (Fig. 61) with each main stem ear having more grains per ear than the N1 treatments (Fig. 61). High ear numbers per unit area with a high above ground biomass tends to result in a crop which is more prone to lodging. The results indicated a harvest index reduction by the N3 treatment from those achieved by the N1 and N2 treatments (Fig. 61). The reduction in main ear dry weight by the N3 treatment would indicate that the main ear although possessing more grains per ear than ears from the N1 treatment was not able to adequately fill those grains (Fig. 61). This may have been due to the increased lodging experienced by this treatment.

The N1 nitrogen treatment significantly increased the proportion of harvested seeds found in the largest size classification (Table 35).

**Fig. 61** The influence of nitrogen treatment on

| | |
|---|---|
| i | Ear number per plant |
| ii | Weight per main ear (g) |
| iii | Above ground biomass (t $ha^{-1}$ DM) |
| iv | Grain number per main ear |
| v | Grain number $m^{-2}$ (x $10^3$) |
| vi | Harvest indices (%) |

<u>Key:</u>

N1 (19 Rep)

N2 (24 Rep)

N3 (29 Rep)

= SED (max-min)

$$SED = \sqrt{s^2 \; \frac{1}{n^1} + \frac{1}{n^2}}$$

here taking $n^1 = 29$ $n^2 = 19$ $s^2$ = residual mean squared

e.g. for Ear number per plant

| | N1 - N3 | N1 - N2 | N2 - N3 |
|---|---|---|---|
| SED | 0.281 | 0.292 | 0.262 |

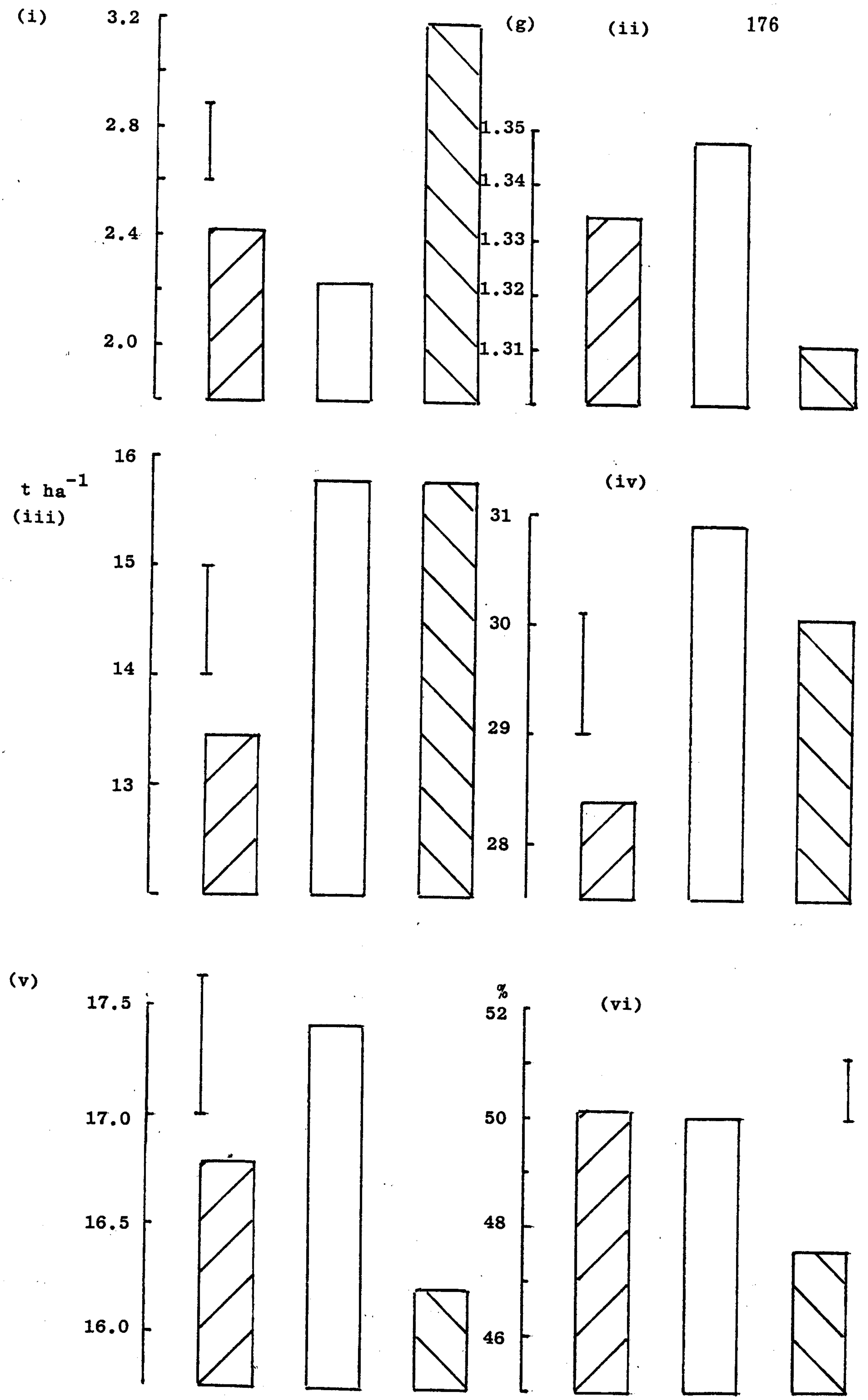

(i)
3.2
2.8
2.4
2.0
(g)
(ii)
1.35
1.34
1.33
1.32
1.31
t ha$^{-1}$
(iii)
16
15
14
13
(iv)
31
30
29
28
(v)
17.5
17.0
16.5
16.0
%
52
(vi)
50
48
46

**Table 35** The effect of nitrogen treatments on seed size distribution i) by weight, and ii) by number

i)

| Size (mm) | N1<br>19* | N2<br>24 | N3<br>29 | SED<br>max-min |
|---|---|---|---|---|
| > 2.8 | 75.4 | 67.7 | 66.9 | 2.90 |
| 2.5-2.8 | 18.7 | 24.9 | 25.0 | 2.16 |
| 2.2-2.5 | 4.1 | 4.8 | 5.3 | 0.51 |
| < 2.2 | 1.8 | 2.6 | 2.8 | 0.41 |

ii)

| Size (mm) | N1<br>19* | N2<br>24 | N3<br>29 | SED<br>max-min |
|---|---|---|---|---|
| > 2.8 | 66.3 | 57.0 | 56.5 | 3.30 |
| 2.5-2.8 | 21.6 | 27.2 | 26.5 | 1.87 |
| 2.2-2.5 | 6.7 | 7.9 | 8.4 | 0.83 |
| < 2.2 | 5.4 | 7.8 | 8.5 | 1.23 |

19* = Number of replicates

Lodging of the N3 treatment would have caused reduced grain filling resulting in lower numbers of grains achieving their potential size. The N1 treatment with lower numbers of ears per plant and lower numbers of grains per ear had thus a reduced sink size. Thus although the N1 treatment source size was also reduced (i.e. a lower above ground biomass was achieved) it was adequate to enhance grain filling resulting in a higher proportion of larger sized grains. Thousand grain weight was positively correlated with the proportion of seeds falling into the largest size classification and as TGW is negatively correlated with grain number $m^{-2}$ it follows that TGW (and thus a larger proportion of large seeds) will generally be achieved with lower numbers of seeds $m^{-2}$.

Owing to the nitrogen treatments imposed it was not possible to attribute yield component modification to differences in nitrogen application rates or to differences in the splitting of the nitrogen top dressings. Further work is need to investigate nitrogen responses of the winter barley crop at this site.

## 4.9 The Effects of Maternal Plant Influences on Grain Yield and Quality Characteristics of Seed

The seed is the heir to all the environmental influences acting upon it before sowing. In order to investigate the suitability of grain for use as seed harvested grain from WB1 was drilled in the autumn of 1981. All redrilled plots were sown at the same seed density and received the same treatments throughout. For analysis all plots were assumed to have received the treatment previously pertaining to the trial in year 1.

Results from year 2 final harvest analysis showed that, as expected, the varieties differed in their grain yield and yield components but year 1 sowing density did not significantly influence grain yield or yield components in year 2. Nitrogen treatments imposed in year 1 had no significant effects on grain yield, yield components or grain characteristics in year 2.

Thus from this preliminary investigation it can be reported that neither the initial sowing density nor the applied nitrogen treatment in year 1 significantly influenced the final grain yield, yield components or grain characteristics of those grains harvested in year 2. This raises the question "apart from germination capacity what characteristics determine a good seed sample?"

# Chapter 5

# A DISCUSSION ON THE MODIFICATION OF THE BARLEY SEED CROP BY HUSBANDRY INPUTS

## 5.1 Introduction

Experiments WB1, WB5 and Rothwell 1981-82 were conducted to examine the effects of winter barley variety, initial sowing density and fertilizer nitrogen application rates and timings on the suitability of the harvested grain for use as seed.

Experiments WB1 (Chapter 3) and WB5 (Chapter 4) were monitored throughout their growth and development whilst the trial conducted at Rothwell, Lincs. (Chapter 4) was assessed at final harvest only.

In all three experiments the same two varieties, Igri and Tipper, were drilled (section 3.2). The seed densities under investigation ranged from 200 to 650 seeds sown $m^{-2}$. Nitrogen treatments varied between trials. Summaries of nitrogen treatments in each trial are given in Tables 7, 20 and 32.

The influences of the three major factors within the experiments will be discussed separately with significant interactions noted where appropriate.

## 5.2 Variety

### 5.2.1 Tillering

The varietal differences that have been found to occur in the pattern (Figs 3 and 35) and extent (Figs 2 and 34) of tillering represent changes in plant habit that may require modification of husbandry inputs to the crop.

Tipper under all conditions examined produced fewer tillers. However the majority were produced earlier in the plant's growth (Figs 2 and 35). This pattern of production may require inputs of nitrogen to be made at differing timings to those employed for a high tillering variety such as Igri. The reduced production of tillers in Tipper may be disadvantageous in a year with adverse weather conditions which may reduce both tiller and plant number.

The wide range of ages and developmental stages of tiller usually produced by the winter barley crop can make timing of inputs difficult. Thus the early production of all tillers from Tipper, all of which have a high tillering efficiency (Table 13), would allow more accurate timing of inputs.

The increased tillering efficiency of the variety Tipper by definition means that fewer unproductive tillers are present during development. Thus fewer of the assimilated produced are produced by non-fertile tillers. Thus fewer photosynthates become unavailable for remobilization upon tiller death.

### 5.2.2 Leaf area

The differences between varieties in LAI and GAI were shown in Figs 4 and 36.

The LAI and GAI values obtained for both varieties in WB5 were lower than those of WB1. This may have been due to the atypical spring weather pattern in 1982.

The relative contributions to total LAI by individual tiller categories of both varieties were outlined in Figs 5 and 37. The contribution of the mainstem and main primary tillers to total leaf area depended both upon the variety and upon the tillering pattern. Lower numbers of tillers at any time during growth and development led to a higher contribution to total LAI by the mainstem and early primary tillers. Throughout growth the lower tillering variety Tipper had a greater proportion of its LAI contributed by the mainstem and main primary tillers (Fig. 37).

Few measurements were made of the decline in leaf area post anthesis, thus although peak LAIs varied between varieties it was not possible accurately to determine the differences between the varieties in their rate of decline in photosynthetic area.

### 5.2.3 Biomass

Experiments WB1 and WB5 differed in both peak and final above ground biomass yields (Figs 7 and 38). Within each trial the varieties differed in either their peak or final biomass yields; Igri having the higher peak value in WB5 and the higher peak and final biomass values in WB1.

In both varieties and in both years the decline in biomass from peak to final yield was approximately 2.5 t $ha^{-1}$. This decline may have been partially caused by large grain losses due to sparrows (WB1) or to large amounts of awn and grain loss prior to the final harvest. The loss of barley ears caused by brackling of the stem could have caused a reduction in harvested biomass although care was taken to retrieve all shed ears from the harvested area. (Table 8).

The contribution of the mainstem and varying tiller orders to total plant weight reflects the pattern of partitioning of leaf area index between the tillers. The mainstem in both experiments contributed the greater amount to the total plant weights with the actual amount depending upon the period of growth (Fig 8)

The variety Igri had a higher proportion of the total weight of the plants contributed from the lower order primary and secondary tillers than Tipper. At 151 DAS in WB1 13% of the total plant weight of Igri was contributed by the late primary and secondary tillers compared to less than 2% in the variety Tipper. The coleoptile tiller in both trials was found to contribute a higher proportion of the total plant weight in the variety Tipper than in Igri.

The constancy of weight contribution by the mainstem and primary tillers in Tipper reflects the tillering efficiency where little tiller death was experienced resulting in the maintenance of large, early produced tillers through to final harvest.

### 5.2.4 Grain yield components

5.2.4.1 Seed size distribution In both WB1 and WB5 the varieties differed in their seed size distribution (Figs 13 and 39). Igri had the majority of the seeds above 2.8 mm in size whereas the majority of the seeds of Tipper were between 2.5 and 2.8 mm in size. However in each size classification the mean grain weights of Igri seeds were greater than similarly sized seeds of the variety Tipper. The differences between varieties in mean grain weight declined as mean grain size was reduced. The differences between varieties in mean grain weights at specified seed sizes may have been due to differences in grain filling resulting in equivalent sized grains but with a varying degree of grain fill. These differences may also have been due to differences in grain densities.

In the experiment conducted at Rothwell in 1981-82 there were no significant differences between the varieties in the proportion of seeds in each size category. In both varieties over 68% of all seeds were greater than 2.8 mm in size with less than 10% of seeds being below 2.5 mm in size (Table 34).

5.2.4.2 Harvest index The fraction of total biomass that was present as grain was not significantly influenced by variety in WB5 with the harvest indices of the mainstem ranging from 50.8 to 52.8% only (Table 23). However in WB1 Tipper had lower harvest indices than Igri in all tiller categories examined although overall harvest indices indicated that Tipper had a greater tillering efficiency. In both varieties the ranking of tillers for harvest index in declining order was mainstem, T1, T2, T3, CT. There was no significant relationship between grain yield and the harvest index obtained.

5.2.4.3 Grain nitrogen and hot water extract Both grain nitrogen content and hot water extract values differed between varieties in WB1 with Tipper, as expected, having a lower grain nitrogen content and a concomitantly higher hot water extract value (Table 11). The values obtained for grain nitrogen content in year two (experiment WB5, Table 22) were above those achieved in experiment WB1. However there were no significant differences between the varieties in either grain nitrogen percentage or HWE values in WB5.

5.2.4.4 Germination Germination tests on seeds harvested from WB1 showed no significant differences between varieties in the germination percentages either immediately after harvest (September 1981) or after long term storage at normal room temperature and humidity (June 1983) (Fig 11).

### 5.2.5 Grain yield

Final grain yield differed between experiments and between varieties within trials (Tables 9 and 23, Fig. 59). The grain yield components were modified by the varieties. Two and three way interactions between variety, nitrogen treatment and density were recorded.

In experiment WB5 modifications of the grain yield components by the varieties did not result in any significant alteration of the grain yield. In WB1 however the grain yields differed by approximately 1 t $ha^{-1}$ with Igri being the higher yielding variety.

Igri had a higher number of ears $m^{-2}$ and a higher TGW than Tipper but lower numbers of grains per ear (both mainstem and tillers) (Table 23). The increased number of ears per unit area resulted from the high tillering capacity of the variety Igri (Fig. 3). However this high production of tillers with ears results in both low order primary and secondary tillers producing ears. In general the ears from these tillers possess fewer grains per ear thus reducing mean grain number per ear (Fig. 9). Decreasing tiller age reduced the harvest indices of the tiller (Fig. 24). Thus either grain number or grain weight, or both, have to be reduced in a lower order tiller compared to the mainstem. The timing of development of the ear of a lower order tiller and its position upon the plant for the interception of translocated assimilates both tend to reduce the number of grains that were initiated upon the ear and also reduce the rate of survival of the potential grain sites. These factors combine to give both a lower potential and a lower actual grain number per lower order tiller ear. Mean grain weight upon the ear depends partially upon post anthesis assimilate production and partly upon assimilates stored prior to anthesis in the upper parts of the stem. The degree of reliance on translocation of stored assimilates may differ between varieties. This, coupled with the modification of leaf area duration post anthesis, may have given rise to the higher mean grain weights of the variety Igri (Table 16).

In all three experiments there was a significant negative relationship between grain number per unit area and mean grain weight (Tables 10, 25 and 33). This relationship differed between varieties with Tipper having a more stable mean grain weight over a range of values for grain number per unit area.

In both WB5 and Rothwell 81-82 final grain yield per unit area was positively correlated with grain number per unit area (Tables 25 and 33). However in WB1 grain yield was strongly correlated with grain number per ear and with mean grain weight (Table 10). The correlated relationships varied with the variety.

There were no significant correlations between grain yield and the final number of plants per unit area (Fig. 11). However at high plant densities the variability in the obtained grain yield declined. Thus for increased consistency in grain yields a high plant population is desirable.

To achieve a high grain yield a high above ground biomass yield is required (Figs 11 and 41). Severe environmental stress may decrease the proportion of the biomass that is grain. Harvest index is not systematically related to yield. Thus a high biomass is essential for the maximization of yield. To achieve this a high plant population is required. This high population of plants enables high ear population to be achieved. There was a strong positive correlation between ear number per unit area and yield (Table 10).

In the experiment conducted at Rothwell the final grain yield was significantly influenced by an interaction between all three variables (Fig. 59). The variety Igri increased in yield with increased sowing densities with N1 and N2 nitrogen treatments (105 and 185 kg ha$^{-1}$ N rspectively). However with high initial sowing densities (above 400 seeds m$^{-2}$) the highest nitrogen rate (N3, 225 kg ha$^{-1}$ N) caused a significant yield reduction possibly due to the increased lodging of the crop. The yield reduction at the high density with supra optimal nitrogen rates may have also been associated with high numbers of grains per ear but low individual grain weights caused by poor grain filling (Figs 60 and 61). Tipper reacted to the low nitrogen treatment N1 (105 kg ha$^{-1}$ N) by decreasing grain yield at increasing plant densities. With 185 kg ha$^{-1}$ N grain yield reached a maximum at 400 sown seeds m$^{-2}$ with no significant alteration of yield at a higher density. High nitrogen application again caused a reduction of grain yield at the highest initial sowing density.

Significant interactions occurred between variety, nitrogen treatment and density in experiment WB5 (Fig. 57). At the lower total amount of nitrogen (N1) Igri and Tipper responded differently to increasing plant densities. Igri increased its harvested grain yield at all sowing densities with low nitrogen levels whereas Tipper reached its maximum yield at an initial density of 300 seeds m$^{-2}$ with a decrease in yield experienced at higher sowing densities. At the higher rate of nitrogen increased yield with increased density occurred for the low tillering variety Tipper. At low plant densities the addition of larger amounts of nitrogen

(N3) top dressing increased the grain yield compared to treatment N2 at similar densities.

The increased yield of N3 above N2 at low plant densities in the variety Tipper was primarily due to the increased number of grains per ear resulting from the late top dressing of nitrogen.

## 5.3 Density

A range of plant densities were assessed to determine the effects of density on those compounds of plant growth and development influencing the quality of the harvested seed. Plant densities investigated ranged from 200 to 600 sown seeds $m^{-2}$ although not all densities were assessed throughout each experiment.

### 5.3.1 Seed and plant survival

The proportion of sown seeds present as established plants one to two months after drilling did not differ significantly between densities. At final harvest the densities differed in the percentage of sown seeds present as plants with a lower proportion of the seeds sown in the higher densities being present as plants compared to the low density drillings. Row widths were similar for all sowing densities. Thus at high densities a greater degree of inter-plant competition would have been expected within the row. High densities resulted in the earlier onset of both inter- and intra-plant competition. Increased competition resulted in a reduction of both tiller number per plant and plant number per unit area. Initial establishment did not vary between densities as no competitive forces were experienced by the plant until after tillering had commenced. Initial plant density depended upon the germination capacity of the seed and its ability to germinate in non ideal situations, i.e. its vigour.

Figs 16 and 46 indicate that the production of the first primary tiller (T1) was not influenced by initial sowing density, thus inter-and intra-plant competition must have been experienced after this stage.

### 5.3.2 Tillering

High initial sowing density produced a higher number of stems per unit area but a lower number of stems per plant (Figs 15 and 45) than lower density crops. This modification of stem number by sowing density is maintained throughout growth resulting in differential numbers of ears, both per plant and per unit area, with differences in sowing density (Figs 21 and 51).

The attainment of peak stem number was found to be associated with initial sowing density. In WB1 (Fig. 15) peak stem number per plant at the highest initial sowing density was achieved at 68 DAS compared to the attainment of the peak stem number of the lowest density which occurred at 151 DAS. This differential timing of peak stem number per unit area may cause difficulties in the timing of chemical inputs to the winter barley crop that are aimed at maintaining tiller number or minimizing tiller loss from its peak.

The early cessation of tillering at high density was probably caused by a high degree of competition experienced within the tiller community.

The varieties investigated responded differently to the imposed plant densities. At all densities Igri produced a higher number of tillers per plant than Tipper (Fig. 17). Igri produced a large number of late primary and secondary tillers especially at the lowest plant density (Fig. 17(i) and (ii)). The production of large numbers of small, later produced tillers can be seen in Fig. 17 where at 151 DAS (peak tiller number of the low density treatment) 1.6 tillers per plant were categorized as late primary or secondary tillers in the low density treatment compared to only 0.35 tillers per plant in the same categories at the highest plant density.

The tillering efficiencies of the major tiller categories were recorded in each density in experiment WB1. The tillering efficiencies of all tillers, and of the total tiller population, decreased with increasing sowing density. Tillering efficiency also decreased from T1 to T4 because of a lower number of grains per ear and a lower mean grain weight on later produced ears. In general the tillering efficiency of Tipper (overall value) was greater than that of Igri. However in both the low and the high density treatments the tillering efficiencies for lower order primary and secondary tillers were lower in the variety Tipper than in Igri (Table 12). Thus the higher overall tillering efficiencies of Tipper at both low and high densities resulted from the high proportion of the stems that were high yielding mainstems with more stable grain weights than those of lower order tillers.

### 5.3.3 Leaf area

High initial sowing density generally resulted in crops of higher LAI and GAI values compared to low density crops although the differences between densities are not always significant (Figs 18 and 47).

In both WB1 and WB5 peak LAI values occurred between 225 and 230 DAS (Figs 18 and 47). However the peak LAI values of WB5 were approximately 50% of those of WB1.

Leaf area ratio (LAR), the ratio between leaf area and total plant dry weight, can be considered to be the product of two other ratios, those of specific leaf area (leaf area : leaf dry weight) and of leaf weight (leaf weight : total dry weight).

LAR characterizes the relative size of the organs of assimilation, basically the leaves. Seasonal changes in LAR usually reflect the interaction of ontogenetic factors, such as average leaf age and positioning of the leaf with respect to plant age, with environmental factors, such as increases in LAR with shading and high levels of nitrogen (Kvet, Ondok, Necas & Jarvis, 1971). There is generally a decrease in LAR with plant age (Thorne, 1960).

In WB1 the 'leafiness' of the plant (the LAR) increased rapidly throughout the early period of autumn growth (Fig. 6). The declining light intensity available at this time led to decreased leaf thickness whilst increasing leaf length and breadth thus resulting in larger but thinner leaves. During this time leaves were produced in quick succession without a concomitant increase in stem. The decline in LAR until peak tillering at 151 DAS reflected the lack of continued high rates of production of new leaves whilst increased production of dry matter occurred. This increase in dry matter resulted from the increased amount of structural tissues within the plant. The rise in LAR to approximately correspond with the peak LAI was caused by the production of large leaves upon the plant with, however, an increasing proportion of the dry material being present as stem. Peak SLA occurred at peak LAI where leaf production was optimized by both light and temperature conditions. The decrease in SLA was influenced by the increased production of structural tissues and the decline in total leaf area.

Both SLA and LAR were modified by density. Both reached their minimum value at peak stem numbers $m^{-2}$. The significant difference between densities at the minimum LAR value was influenced by the higher number of stems per unit area produced. These all had increased dry weights caused by increased modification to form their structural tissues.

A high LAI is essential to the production of sufficient assimilates for the achievement of the optimum yield. Assimilates produced before anthesis are required for the production of the yield potential whereas post anthesis assimilates are directed towards the maximization of those components of yield determined before anthesis.

### 5.3.4 Biomass

In both monitored experiments the initial sowing densities influenced the total above ground dry matter production with high density drillings having higher biomass values (Figs 19 and 48). However these differences in biomass were not always significant and were not always maintained until final harvest (Fig. 11).

The peak biomass values achieved in WB1 were greater than those of WB5. In both trials a loss of biomass from peak yield to final yield of the order 2-3 t $ha^{-1}$ was found. The extent of this fall in biomass was not significantly influenced by sowing density. Suggested reasons for this decline in biomass were outlined in section 3.2.3.

The contribution of the mainstem and primary tillers to the total plant weight depended upon the initial sowing densities (Fig. 20). In densities with a high number of tillers per plant (D1 in WB1 and D1 and D2 in WB5) the contribution to total plant weight of the mainstem was reduced. In WB1 the mainstem of the highest density treatments contributed approximately 45% of the total plant weight compared to less than 30% within the low plant density treatments.

The proportional weight contribution by the mainstem and main primary tillers declined as stem numbers per plant increased (Fig. 20). The contribution of the mainstem and the main primary tillers increased after peak tillering when the death of late primary and secondary tillers occurred.

5.3.4.1 The coleoptile tiller The contribution of the coleoptile tiller to total plant weight depended upon the initial sowing density with the highest density plots having a smaller percentage of plants with the coleoptile tiller. At the highest density in WB1 the coleoptile tiller contributed less than 5% of the total plant weight. In WB5 even at the lowest plant density the contribution to total plant weight by the CT was less than 10% (Fig. 49).

Thus the CT which emerges relatively early in the growth of the barley plant, although present in modest numbers during the early growth and development of the crop, contributes little to the total leaf area index or crop biomass. Its final contribution to grain yield is low with reduced numbers of grains per ear and mean grain weights compared to the main primary tillers. The tillering efficiency of the coleoptile tiller was low under all treatments being lower than or equivalent to the T3 tiller in value.

The reasons for the poor emergence and establishment of the coleoptile tiller has been discussed by Cannell (1969b). However it is suggested that the low tillering efficiency and the low yielding ability of the coleoptile tiller results from the positioning of this tiller on the plant (Fig. 1). The pattern of assimilate transfer from the mainstem and main primary tillers to the coleoptile tiller is not clear. If transfer of assimilates to the CT is poor the assimilates available to the tiller will only have been produced within that tiller. Prior to the expansion of the leaves of the coleoptile tiller the resources for growth are from the first leaf. This leaf is often the smallest leaf on the barley plant and thus contributes little to the emerging coleoptile tiller. The coleoptile tiller is also reliant upon the primary root system for the uptake of water and mineral nutrients as the adventitious root system is developed at the crown node and not at the coleoptile node adjacent to the seed.

Thus in all respects the coleoptile tiller is adversely situated with the movement of photosynthates and mineral ions having to take place from the main plant to the CT in a reverse flow. Uptake of nutrients solely by the CT is hampered by the small and shallow rooting primary root system.

### 5.3.5 Grain yield components

5.3.5.1 Seed size distribution High initial sowing density resulted in fewer of the harvested grains being above 2.8 mm in size compared to low density treatments (Figs 25 and 50). The majority of the harvested grains from high density drillings was found to be between 2.5 and 2.8 mm in size. In the trial conducted at Rothwell there were no significant differences between the density treatments in the proportion of grains in any size category. In all sowing densities over 66% of all harvested grains were above 2.8 mm in size (Table 34).

The proportion of grains found in any size category depends both upon sink and upon source size. A decrease in source size or efficiency would result in a decreased production of assimilates that could be translocated to the developing grains — the sink. A reduction in post anthesis source produced assimilates would require an increased mobilization of pre anthesis stored assimilates from the upper internodes of the cereal plant. A shortfall in either assimilates produced by the source or in retranslocated assimilates would cause a reduction in the resultant grain (≡ sink) size although potential size had been determined prior to anthesis. A strong correlation exists between thousand grain weight and the proportion of those grains harvested that are found to be above 2.8 mm in size. Thus any reduction in mean grain weight resulting from reductions in assimilate transfer to the grains would result in a lower proportion of harvested grains being in the largest size category.

A reduction in sink size resulting from a decreased number of grains per ear causes a concomitant decrease in source production. However the reduced sink is adequately supplied with assimilates the majority of which are produced post anthesis. The reduced sink with an adequate source is able to achieve mean grain weights close to the established potential. Decreasing the sink allows a greater number of grains to achieve a size and weight near to their potential thus resulting in an increased proportion of grains being above 2.8 mm in size.

5.3.5.2 Grain nitrogen content and HWE Differing initial sowing densities had no consistent significant effect on the grain nitrogen content or the hot water extract values obtained (Table 14 and 30). In WB1 increasing sowing densities resulted in slightly higher grain nitrogen percentage and lower hot water extract values although the differences between densities were not significant (Table 14).

5.3.5.3 Harvest index The harvest indices obtained for all tiller categories were highest for those treatments with low initial sowing densities (Fig. 24). The harvest indices declined from the mainstem to the T4 tiller in each density treatment. The decline in harvest indices at high densities resulted from the lower number of grains per ear and the lower thousand grain weights achieved by grains at high sowing densities.

The attainment of a high biomass yield by increasing plant density will be rendered useless unless a high percentage of this dry matter can be harvested as grain. The reduction of mean harvest index by increased plant density resulted in higher grain yields expected from a higher initial sowing rate not being achieved.

### 5.3.6 Grain yield

In none of the trials was final grain yield consistently significantly influenced by initial sowing density (Figs 48 and 60). However, as expected, the yield components were significantly altered by sowing density (Figs 21 and 60).

High initial sowing density resulted in a high number of plants per unit area being present at final harvest although the percentage survival of sown seeds to plants present at final harvest was reduced at high densities. An increased plant density at final harvest resulted in a lower number of ears per plant (Fig. 40) but a higher number of ears $m^{-2}$ compared to lower sowing densities. Although ear numbers were increased by increasing sowing density the proportion of ears with below 10 grain per ear increased.

Grain numbers per ear, both on mainstem ears and on tiller ears, were reduced at high plant densities (Fig. 51). A reduction in mean grain weight was also experienced with an increased plant population (Fig. 51). However when mainstem ears were subdivided into three regions, i.e. basal 6 grains, apical 6 grains and mid region of the ear (Section 2.2.2) no significant differences between densities were evident in the mean grain weights of grains taken from within one section. In all densities the mean grain weights from the mid section of the ear were greater than the grain weights from the basal or apical regions of the ear. Further investigations on the range of grain weights within an ear were conducted in later PGR experiments (Section 2.2.2).

It has been previously shown (McLaren, 1981) that grain yield was strongly related to grain number per $m^{-2}$. Modification of sowing densities which result in changes in ear number $m^{-2}$ and grain number per ear did not have consistent effects on the number of grains $m^{-2}$ (Tables 10 and 25, Figs 40, 41 and 42).

## 5.4 Nitrogen

### 5.4.1 Preamble

The effects of the applied nitrogen depended on the quantity and timing of the fertilizer treatments. In all three experiments the nitrogen treatments varied in total amounts applied. The timings planned for experiments WB5 and Rothwell 81-82 were to influence the crop at similar times. In these two experiments the actual timing varied by less than fourteen days between sites.

In year one (WB1) a seedbed nitrogen treatment was compared to two treatments with no addition of nitrogen in the seedbed. In all three nitrogen treatments a total of 150 kg $ha^{-1}$ N was applied (Table 7).

In WB5 the effects of regularly applied nitrogen were considered in N2. Treatment N3 was aimed to show the influences of later applied nitrogen on the grain yield components. The addition of only 80 kg $ha^{-1}$ N in N1 investigated the effects of poor maternal plant nutrition on the quality of the resultant seed (Table 20).

Nitrogen treatments at Rothwell investigated a range of applied nitrogen rates from sub- (150 kg $ha^{-1}$) to supra- (225 kg $ha^{-1}$) optimal. All three nitrogen treatments included the use of seedbed nitrogen at the rate of 25 kg $ha^{-1}$ N (Table 32).

### 5.4.2 Tillering

The addition of seedbed nitrogen increased the early production of tillers (Fig. 26). This addition of nitrogen early in the plants' growth advanced the timing of peak tillering with the maximum number of stems $m^{-2}$ occurring at 112 DAS for N1 compared to 151 DAS for N2 and N3.

The application of the first top dressing of nitrogen on 27 January (131 DAS) was applied too late to influence the peak tiller number of treatment N1. However the addition of a large quantity of nitrogen at this time (N2) increased the peak number of tillers obtained (Fig. 26). The second top dressing of nitrogen decreased the rate of decline of tillers post peak tillering with the higher amounts of nitrogen maintaining tiller numbers more successfully. The peak number of tillers per plant was greatest in the N1 nitrogen treatment with a maximum of 5.35 tillers per plant compared to 5.2 (N2) and 4.95 (N3).

In WB5 treatments N2 and N3 increased the number of tillers produced and also increased the duration of tillering so that peak tiller numbers in these treatments occurred approximately 50 days later than peak tiller number in treatment N1 (170 DAS compared to 122 DAS) (Fig. 52). The lower rate of autumn nitrogen resulted in a peak tiller number in N1 of 6.2 tillers plant$^{-1}$ compared to 7.35 tillers plant$^{-1}$ in treatment N2. Treatment N3 was not monitored throughout the growth of the crop although full analysis of grain yield components was undertaken at final harvest. The total nitrogen applied in N1 was only 50% of that in N2 but at the final harvest the number of tillers per plant only varied from 3.7 per plant (N1) to 4.4 per plant (N2). A further nitrogen treatment with nil applied nitrogen would have allowed the determination of the yielding ability of the site relying on the residual nitrogen levels within the soil.

### 5.4.3 Leaf area

In experiment WB1 the addition of seedbed nitrogen increased the leaf area index obtained above those of treatments which were without this nitrogen application. The benefits in terms of increased LAI were only evident until 180 DAS. Peak LAI for treatment N1 was significantly lower (Fig. 27) than the peak value of N2 or N3. The addition of the larger amount of nitrogen top dressing on 6 April increased the peak LAI significantly.

There were no significant differences between the nitrogen treatments in WB5 until 170 DAS (Fig. 53). At the start of stem extension the additional nitrogen in N2 gave significantly higher LAI values at 171 and 206 DAS. The additional nitrogen in N2 resulted in a higher peak LAI than that achieved with the N1 treatment although the difference was not significant.

In both WB1 and WB5 GAI followed a similar pattern to LAI.

LAR was significantly influenced by nitrogen treatments. From 180 DAS the LAR of N1 treated plants was lower than that of the N2 treatment. Less leaf expansion occurred in those plants with lower nitrogen applications. The plants were however still increasing in dry weight due to the expansion of the stems and to the increase in non grain ear components, i.e. an increase in the structural rather than the photosynthesizing materials.

It is possible that under stress grain fill can in part be satisfied from preanthesis stored assimilates that are remobilized if conditions ameliorate (Aspinall, 1984). In non stressed conditions grain filling is usually completed with assimilates from active sources post anthesis. Thus any reduction in the primary source size as shown by the reduced LAR will cause either more assimilates to be remobilized from the region of storage or the grain weights to be reduced.

The contribution by the mainstem and monitored tillers to the leaf area depended upon the period of growth of the crop and upon the nitrogen treatment. A higher proportion of the total leaf or green area was contributed by the mainstem and main primary tillers in those treatments which reduced the number of late primary and secondary tillers, e.g. the N1 treatment in both WB1 and WB5. In all nitrogen treatments the contribution of the mainstem fell as peak stem number was approached but increased when tiller number declined.

### 5.4.4 Biomass

Autumn seedbed nitrogen increased crop dry matter yields until 180 DAS albeit not always significantly (Fig. 29). However in WB5 differential applications of autumn nitrogen did not influence crop biomass during the early growing season (Fig. 54).

In WB1 all three nitrogen treatments had similar total nitrogen applications. No differential effects on spring growth were recorded for the three timings of nitrogen. Differential rates of nitrogen in WB5 significantly influenced spring biomass yields with both peak and final dry matter yields being higher with the N2 nitrogen treatment (Fig. 54).

Thus high biomass yields both in the autumn and throughout spring growth were influenced by nitrogen treatments with high nitrogen levels increasing the above ground dry matter yield.

### 5.4.5 Grain yields and yield components

Both the quantity and timing of applied nitrogen influenced the grain yield and yield components recorded in each trial (Table 15, Figs 51 and 61).

In WB1 with all three nitrogen treatments receiving similar total nitrogen applications few differences were evident in yield components between treatments. Yield ex-combine harvester was reduced by the lower rate of nitrogen top dressing although from hand harvested samples nitrogen treatments did not significantly affect TGW or grain number $m^{-2}$. Higher grain yields in treatment N2 were due to non-significant differences in both TGW and grain number $m^{-2}$.

Low nitrogen top dressings increased the proportion of ears present that had less than 10 grains per ear whereas treatment N2 increased the proportion of ears with more than 21 grains (Fig. 31). However differences in the ear populations did not modify the seed size distribution in any nitrogen treatment. In all cases over 35% of harvested seed was between 2.5 and 2.8 mm in size. Over 15% (by number) of the seeds were below 2.2 mm in size (Fig. 33).

The application of 100 kg $ha^{-1}$ N on 6 April (N3) increased the harvest indices of the majority of tiller categories although not always significantly. This increase in Fh was usually due to a small and non-significant influence on TGW.

In WB5 nitrogen treatments differed in both total nitrogen applied and timing of the applied nitrogen.

Low levels of applied nitrogen (N1) reduced the total grain yield by approximately 1.5 t $ha^{-1}$. This lower yield was due to a reduction in many of the yield components (Fig. 56). Low rates of nitrogen decreased the number of grains upon the mainstem ear, TGW, ear number $m^{-2}$, biomass yield and Fh although not all of these reductions reached the level of significance (Fig. 56).

5.4.5.1 Seed size distribution Differential nitrogen rates influenced the proportion of seeds found in each of four size categories. Higher rates of later nitrogen top dressing increased the proportion of grains above 2.8 mm in size and reduced the proportion between 2.5 and 2.8 mm. In all nitrogen treatments below 4% (by number) of grains were below 2.2 mm in size (Fig. 55).

In the experiment conducted at Rothwell both nitrogen rates and timings differed between treatments. High total nitrogen resulted in a high total yield of dry matter (Fig. 61). However the N3 treatment had a reduced harvest index from those obtained at lower nitrogen rates (Fig. 61). Increasing the nitrogen applied to 225 kg $ha^{-1}$ N increased the number of ears per plant present (Fig. 61) and improved the number of grains per ear (Fig. 61) although this high rate of nitrogen decreased the overall ear weight due to poor grain filling of those sinks present (Fig. 61).

Adequate grain filling of limited sinks was achieved in the N1 treatment with an increased proportion of seeds being greater than 2.8 mm in size (Table 35). The proportion of grains that were greater than 2.8 mm in size was positively correlated with the recorded TGW. Thus the TGW of grains from N1 was higher than those of treatments with higher rates of applied nitrogen.

5.4.5.2 Grain nitrogen content Grain nitrogen content in WB1 was significantly influenced by timing of applied nitrogen (Table 14). The highest rate of nitrogen applied on 6 April significantly increased grain nitrogen above those achieved by similar rates of total applied nitrogen but at differing timings. In WB5 with modifications in both total amount and timing of nitrogen no significant differences between nitrogen treatments were recorded in grain nitrogen content or hot water extract values obtained (Table 22).

5.4.5.3 Germination Germination tests on grains harvested from WB1 were conducted in September 1981 and June 1983. There were no significant differences between nitrogen treatments in the germination percentages obtained in the first assessment (Table 22). Here there was also no significant difference between seeds above 2.8 mm and below 2.2 mm in size in the germination values obtained. In June 1983 grains from nitrogen treatment N3 had a significantly lower germination percentage than those from N1 or N2 treatments. However in no case was germination reduced below 95% (Table 22). This reduction in germination ability may have been associated with the relative immaturity of the embryo in larger seeds associated with the N3 treatment. The grains were possibly not fully developed when harvested.

## 5.4.6 Soil residual nitrogen

Thus it is possible by modification of the total amount of nitrogen applied and the timing of applications of nitrogen, to manipulate the growth and development processes of the winter barley crop so leading to alterations in the ultimate grain yield components and final grain yield.

The growing cereal plant has access not only to applied fertilizers during the growing season but also to the nitrogen supplied by the soil and by any residual manures or organic materials present. Optimum fertilizer requirements for both grain yield and the production of quality seeds will be related to the amount of nitrogen that will be supplied by the soil and to the proportion of the applied nitrogen that will be incorporated into the plant. Weather, soil type, previous crop and husbandry treatments will all modify the nitrogen availability and uptake. Thus advanced information on all such aspects of nitrogen modification would increase the accuracy of the optimum amount of fertilizer to be applied. However until these facets of the crops' environment can be fully identified and their effects predetermined or at least regulated the application and timing of nitrogen must be based on generalized information but taking full account of previous cropping and the expected residual nitrogen levels, the soil type, the application of organic manures, the expected weather pattern and the individual crop's needs.

# Chapter 6

# THE INFLUENCES OF PLANT GROWTH REGULATORS ON THE WINTER BARLEY SEED CROP

## 6.1 Introduction to PGR1

### 6.1.1 Tillering

In experiments on various monocotyledonous crops the application of gibberellic acid ($GA_3$) has been found to reduce tiller numbers. Effects have been reported in barley (Kirby & Faris, 1970; 1972), in wheat (Jewiss, 1972; Batch et al., 1980; Hutley-Bull & Schwabe, 1980; 1982) and in grasses (Jewiss, 1972; Hampton, 1983). However work at Aberdeen by Mirghani (1978) and Koranteng and Matthews (1982) showed increased production of tillers after $GA_3$ was applied to barley.

Workers at Wye College (Hutley-Bull & Schwabe, 1980; 1982) found that the sequential application of small doses of gibberellic acid prior to the initiation of floral primordia inhibited the growth and subsequent emergence of tiller buds with only those tiller buds that carried differentiated leaf and spikelet primordia suffering minimum inhibition from $GA_3$ treatment. Hutley-Bull and Schwabe (1980) found that repeated applications of $GA_3$ accelerated the development of the primary shoot and increased the growth rate of those tillers that had emerged prior to treatment. The result of acceleration of primary shoot development and tiller bud inhibition was to limit the number of tillers present to those which existed at the time of treatment. Field trials by Batch et al. (1980) showed that $GA_3$ applications decreased tiller production but increased tiller survival. This often resulted in increased ear production but the effects on grain yields were variable. This increase in ear number after $GA_3$ application in both field and pot experiments (Koranteng & Matthews, 1982) was shown to result from an increase in the proportion of early primary tillers forming ears although ear production from the major secondary tillers was suppressed.

Batch et al. (1980) suggested that applications of $GA_3$ needed to be timed around spikelet initiation to elicit any GA response, although in further work they failed to find any relationship between rate, frequency and volume of $GA_3$ application, and ear number and yield. However Hutley-Bull and Schwabe (1982) and Koranteng and Matthews (1982) both found that $GA_3$ application prior to spikelet initiation produced responses in wheat and barley respectively.

Growth retardants such as (2-Chloroethyl) trimethyl ammonium chloride (CCC) have been used for many years to reduce the length of the internodes of wheat crops thus giving greater resistance to lodging. However applications of this chemical at the usual time, between stem extension and ear emergence, are too late to influence the important features of the cereal crop, such as maximum tiller number, leaf and spikelet numbers.

Hutley-Bull and Schwabe (1982) noted that whilst $GA_3$ treatment tended to hasten development and thus to shorten the intervals between specific morphogenic events and to reduce the number of organs laid down in successive phases of development the application of growth retardants such as CCC had the opposite effect.

Tillering of graminaceous crops increases their capacity to compensate for fluctuations in plant density and thus leads to consistency of yield. Tillering studies have been summarized by Kirby (1968, 1969) and Thorne (1974). Hutley-Bull and Schwabe (1982) found that CCC and other retardants such as PP333 (paclobutrazol) affected tillering in a similar manner to that caused by a fluctuation in daylength. That is, initially retardant treated plants had fewer emergent tillers than control plants but subsequently tiller numbers on the treated plants exceeded those on control plants. Hutley-Bull and Schwabe (1982) noted that with plants growing in short days at relatively low temperatures primary tiller production was not significantly affected. However the response to growth retardant application was evident in the number of secondary and tertiary tillers produced. Thus the application of growth retardants influences the contribution by various tiller categories to total tiller number present at any time.

Applications of CCC at ZGS 13 (Koranteng & Matthews, 1982) to spring barley under a high nitrogen regime decreased the peak number of tillers but increased the number of ears per unit area, the number of grains per ear and the grain yield. Humphries (1968a) suggested that the increased number of ear bearing tillers post application of CCC to wheat in the field was a result of increased tillering efficiencies and not due to an increase in total tiller numbers. By tiller ringing Koranteng and Matthews (1982) showed that the use of CCC increased the proportion of 'late' tillers that acted as uniform sinks for assimilates, producing ears and thus contributing to final grain yield. The hypothesis formulated by Koranteng and Matthews (1982) to explain growth modification by CCC was that by early retardation of established main stems and primary tillers the growth of late primary and early secondary tillers was enhanced. With continued suppression of the earlier formed shoots the later produced tillers were able to 'catch up' and thus were able to compete for available resources.

6.1.2 Seed sizes

Thousand grain weights are dependent upon the number and weight of grains of different sizes. Thus the consideration solely of TGW from any experiment may give an inaccurate picture of the sizes of grains present on the cereal ear.

Aufhammer and Bangerth (1982) noted that in Kolibri wheat grain weight increased from the base of the ear to the centre and then decreased again to the uppermost regions. This variation in grain weights was explained by the difference in times of initiation of the grain sites within the ear and also by the associated variations in time of anthesis up and down the ear.

The extent, source and significance of seed size variation in some major field crops has been reviewed by Wood, Longden and Scott (1977). Within a cereal crop the major sources of seed size variation will be partly caused by genetic differences, nutritional effects, disease and the position of the seed on the inflorescence (Hampton, 1981a). Grain position reflects differences in flowering time or nutrition of developing seeds which may be acting as differential sinks for limited supplies of mineral nutrients or carbohydrates (Wood et al., 1977). Tillering cereal plants present further complications as interconnected tillers on one plant have different initiation and flowering dates. Dennis-Jones (cited by Wood et al., 1977) showed that 35% of the variation in seed weight was due to between plant differences, 13% due to differences between ears and 52% to different locations within the ear.

The significance of seed size influences in graminaceous crops has been noted by many workers although there is disagreement about its importance (Kaufmann & McFadden, 1963; Section 1.3.1). In general large seeds produce large seedlings (Hampton, 1981a), however Brenchley (1923) noted that in very large barley grains the endospermic reserves may be in excess of the requirements of the embryo thus selection for the very largest grains may be of little benefit. Wood et al. (1977) suggested that large young plants with greater leaf areas in their early stages intercept more radiation so that greater quantities of assimilates are available for growth. The advantages in using large seed rather than small seed is only important when seeds are sown on an equal number basis. Hampton (1981a) indicated that the importance to the farmer of seed size will be in the influence that seed size has on establishing the desired population for cereal production. Trials by Wood et al. (1977) have shown that high vigour is not necessarily related to large seed size and Hampton (1981b) noted that seed weight which reflects seed size was not significantly related to field emergence in trials on New Zealand seed wheat lines.

Thus bulk seed at harvest contains a wide range of seed sizes resulting from differences in genetic composition, nutrition, pest and disease effects and seed position within the spike. However these seeds may not all be of equal value for resowing.

Hence one major desired action of the applied PGRs was to manipulate grain size within the barley ear to thus increase within-ear uniformity with probable benefit in improved quality of seed samples. The modification of tillering patterns by the applications of PGRs may enhance the between-ear uniformity of grain sizes.

## 6.2 General Materials and Methods

Experiment PGR1 was conducted adjacent to WB5 (Chapter 4). Nitrogen treatments were the same as those in treatment N2 of WB5 (Table 20). All plots were drilled to a density of 325 seeds $m^{-2}$ sown.

Two varieties of winter barley were investigated, Igri (Section 3.2) and Fulmar.

$GA_3$ as 90% gibberellin $A_3$ was applied to the winter barley plots prior to double ridge production at a concentration of 30 ppm in 1000 l $H_2O$ $ha^{-1}$ (30 g ai $ha^{-1}$) for each application in three sequential doses on 5, 8, 14 November 1981.

CCC when used as an anti-lodging agent had a recommended rate of application of 1.8 l (0.83 kg ai) in 200-450 l $H_2O$ $ha^{-1}$. In PGR1, however, with the aim of modifying crop growth the concentration used for CCC was 1000 µg $ml^{-1}$ which was equivalent to 0.23 kg ai $ha^{-1}$ CCC. This was applied in 225 l $H_2O$ $ha^{-1}$ on 5 November 1981.

### 6.2.1 Experimental procedure / growth analysis techniques

6.2.1.1 Individual grain weights Individual grain weights along main-stem ears were assessed using the method outlined in Section 2.2.2.

6.2.1.2 Rooting studies Bruinsma (1982) reported that the application of growth retardants impeded the growth of root systems less than that of the shoot system thus lowering the shoot : root ratio. In previous studies with CCC (e.g. Humphries, Welbank & Williams, 1967) it has been noted that in a dry season a larger root system was produced than that from untreated plants. This led to yield increases attributed to the retention of extra tillers that were maintained through until harvest due to the increased uptake of water and nutrients by the increased root system.

Other workers (e.g. Bragg, Rubino, Henderson, Fielding & Cannell, 1984; Hanus, 1967) have shown that the application of CCC to winter cereals can affect their rooting patterns.

Bragg et al. (1984) showed that in winter barley the application of 0.46 kg ai ha$^{-1}$ at 3-4 leaf stage at the beginning of December increased the maximum depth of rooting of sample taken in May. But in July no differences were noted in the rooting patterns between CCC treated and control plants. This may have been due to the difficulty of the investigators to distinguish between live and dead roots caused by the maturation of the crop.

Hanus (1967) working on spring wheat showed a decrease in root growth shortly after an application of CCC but a heavier root system present at final harvest. Early work by Humphries (1968b) showed an increase in the size of the root system of wheat between May and August after spring treatment with CCC. Flint (1984) showed that following CCC treatment root activity in the "upper and middle zones" (20-40 cm depths) was increased but with little effect on the penetration of the main seminal roots to depths greater than 1 m.

Root samples down to 1 m were taken with a jarrot auger two weeks post anthesis. Roots were separated from the soil by a mixture of flotation and sedimentation. Cleaned roots were oven dried to a constant weight (Section 2.7.1).

## 6.3 Results

### 6.3.1 Plant survival

Plant survival was not significantly affected by PGR treatment. In all cases over 94% of those plants established by mid October were present at final harvest with the variety Fulmar having a higher survival percentage (data not presented).

### 6.3.2 Tillering

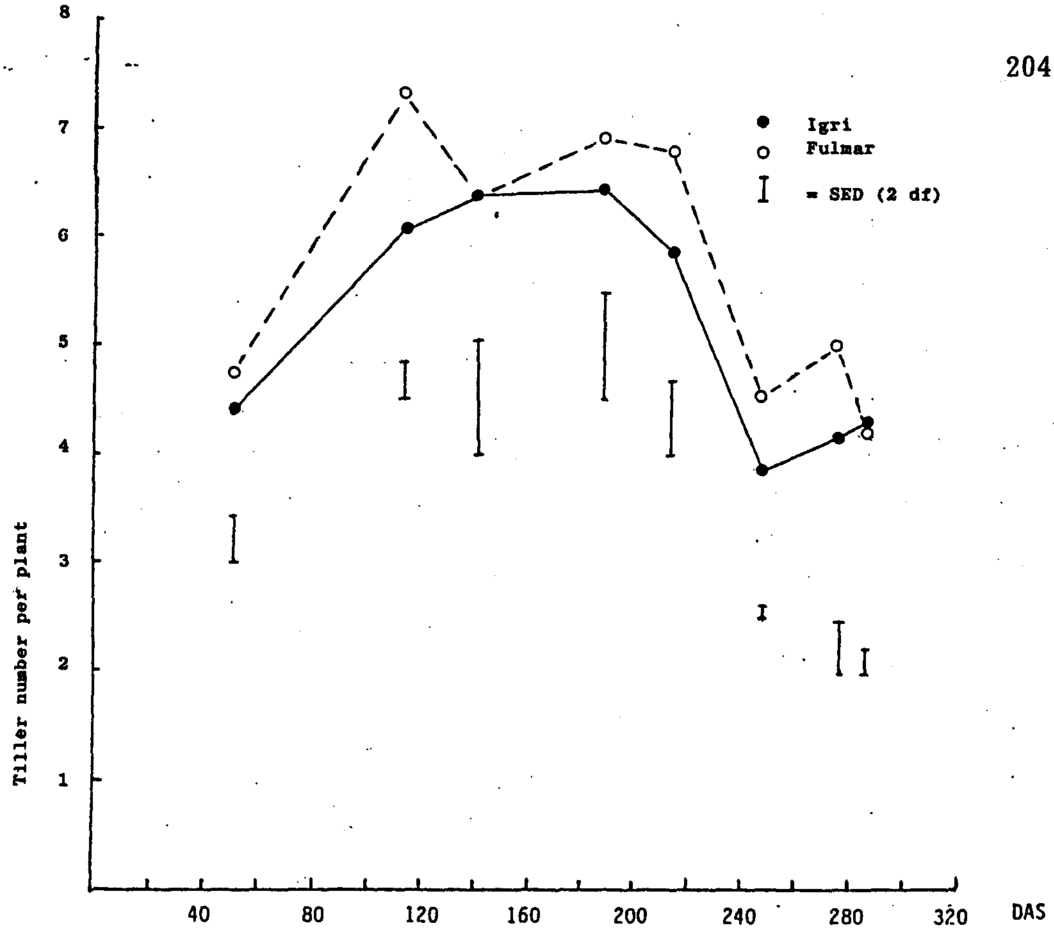
At all but the final harvest the number of tillers per plant of Fulmar was higher than that of Igri (Fig. 62). In both varieties decline in tiller numbers occurred from approximately 190 DAS (5 April) to reach a final tiller number of 4.25 tillers per plant.

The PGR treatments significantly altered the number of tillers per plant (Fig. 62). In both cases the number of tillers of the $GA_3$ treated plants was significantly less than the CCC or control plants for the majority of crop growth. Differences between the control plants and those treated with CCC were not significant. Peak tiller number per plant was reached at 116 DAS on the $GA_3$ treated plants and at 191 DAS on the control plants. Although peak tiller number varied from 5.4 tillers per plant with the $GA_3$ treated plants to 8.6 on the control plants the final tiller numbers were not significantly different. Tillering efficiencies were 53.5% for the control plots, 52.8% for the CCC treatments and 75.9% for the $GA_3$ treatments when estimated on a tiller number per plant basis.

The PGR treatments differed in the patterns of tillering resulting from treatments. These differences are outlined in Fig. 63. Individual tiller categories were monitored until 217 DAS. In the $GA_3$ treatment the only secondary tiller produced in any appreciable quantity was the T11 tiller. However secondary tiller production occurred to a greater extent in both the CCC and control treatments. At peak tiller number for each treatment the following number of secondary and late primary tillers were present per plant; 2.2 (control), 0.5 ($GA_3$) and 1.3 (CCC). At the final date of tiller assessment tillers were categorized as T1, T2, CT, T3 and "others". In this final category there were 3.8 tillers per plant in the control treatments, only 1.1 tillers when treated with $GA_3$ and 3.3 tillers per plant when treated with CCC. In all treatments the number of T1 and T2 tillers per plant were not significantly different.

**Fig. 62** The effect of i Variety and ii PGR treatment on the number of tillers produced per plant

(i)


Igri
Fulmar
= SED (2 df)
Tiller number per plant
DAS
40
80
120
160
200
240
280
320
1
2
3
4
5
6
7
8

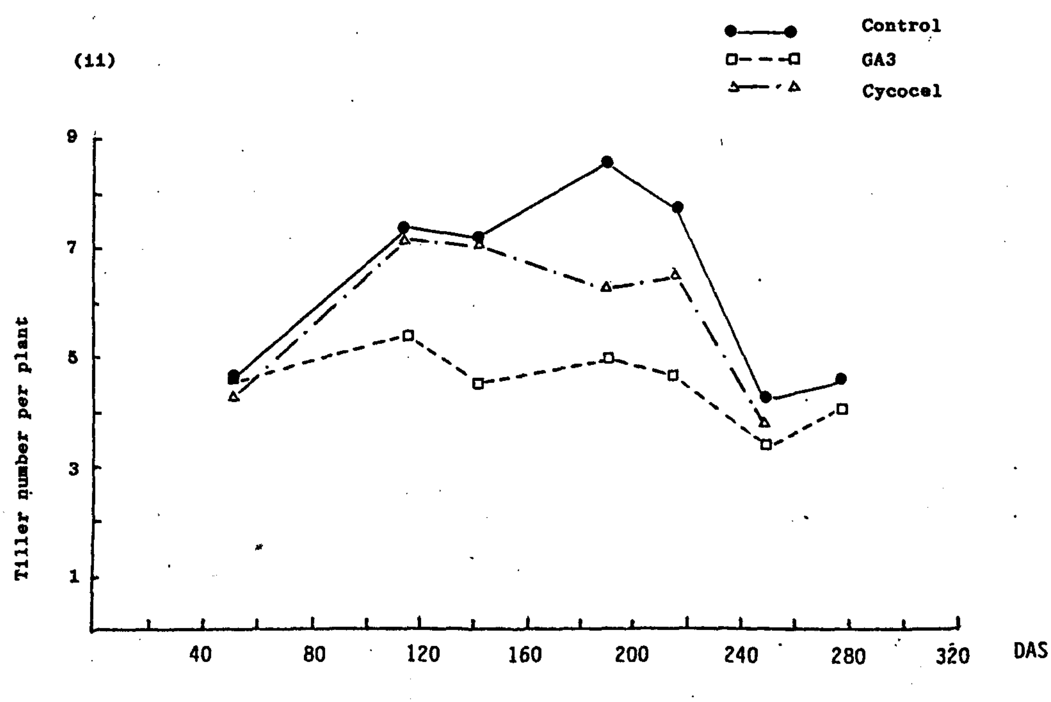

Control
GA3
Cycocel
(ii)
Tiller number per plant
DAS
40
80
120
160
200
240
280
320
1
3
5
7
9

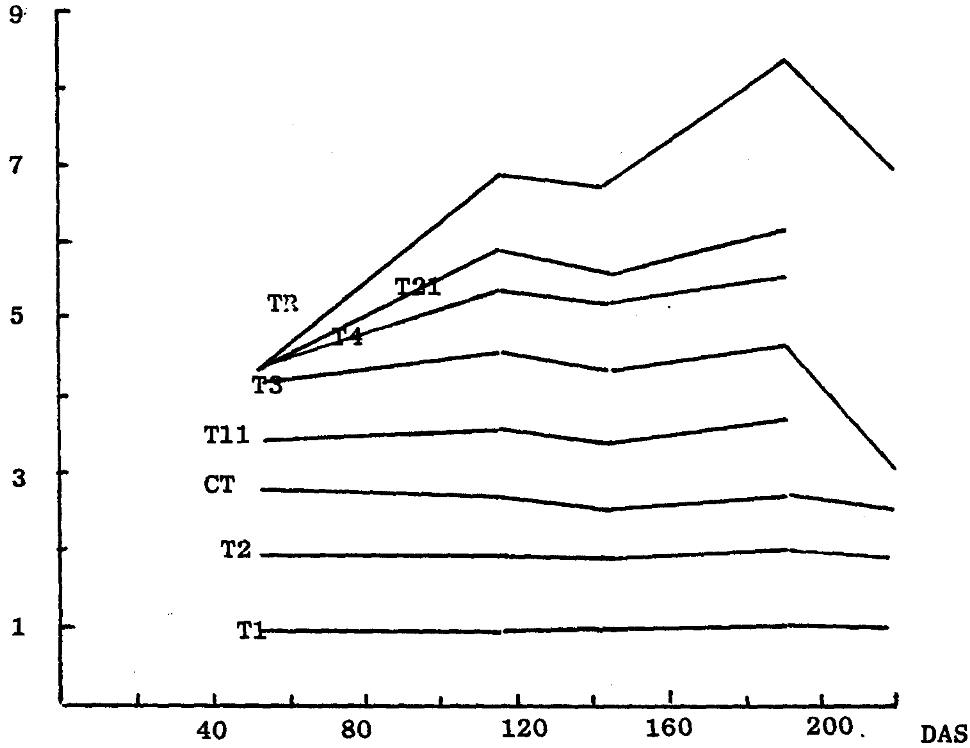
**Fig. 63** The effect of PGR teatments on the tillering patterns of experiment PGR1 (pooled varieties)

i Control

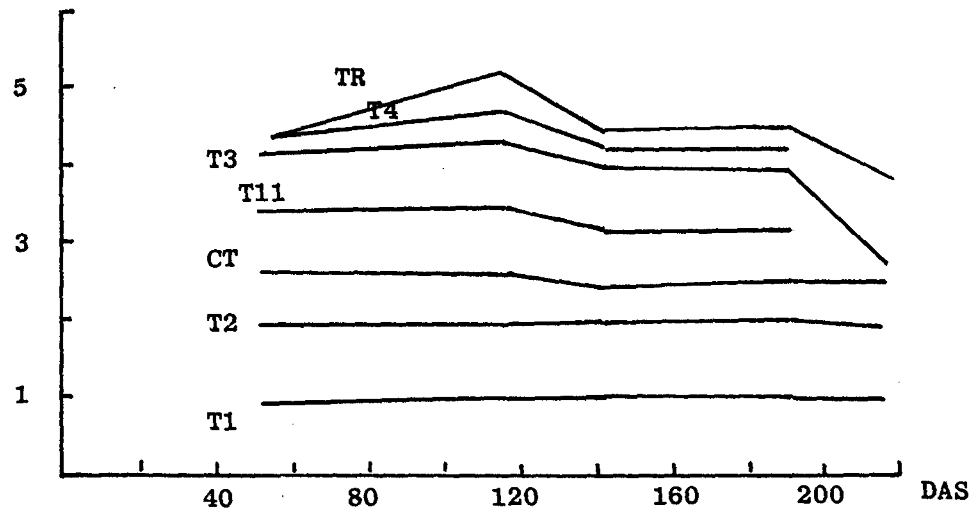
ii $GA_3$

iii Cycocel

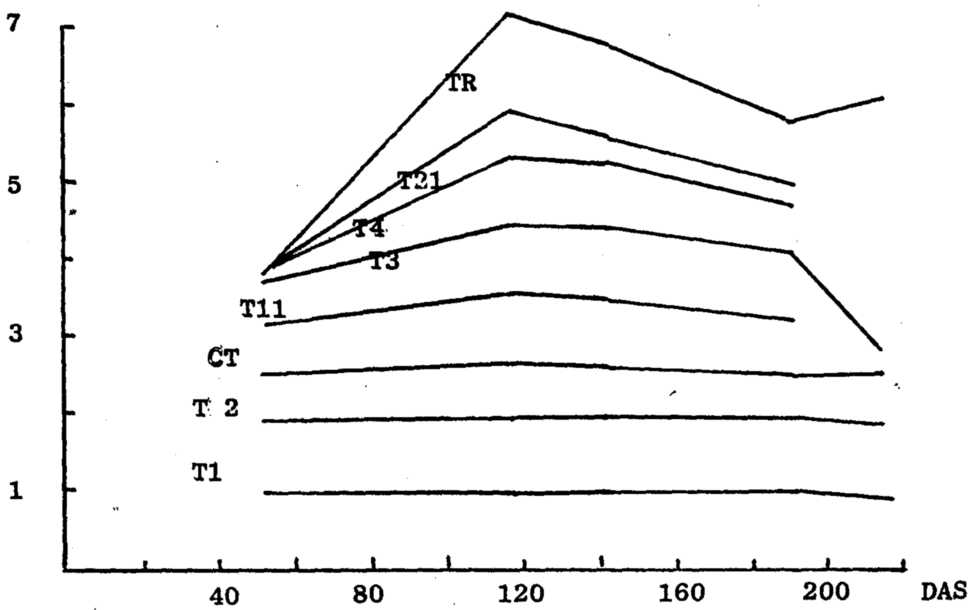
(i)


9
7
5
3
1
TR
T21
T4
T3
T11
CT
T2
T1
40
80
120
160
200
DAS

(ii)


5
3
1
TR
T4
T3
T11
CT
T2
T1
40
80
120
160
200
DAS

(iii)


7
5
3
1
TR
T21
T4
T3
T11
CT
T 2
T1
40
80
120
160
200
DAS

### 6.3.3 Leaf area

Varieties did not differ significantly in their leaf area indices (Fig. 64). Peak LAI for both varieties was reached at approximately 217 DAS. Peak LAI value for Igri was similar to that obtained in experiment WB5 for the same variety.

PGR treatment did not generally influence LAI (Fig. 64). Final LAI values obtained at 250 DAS differed between PGR treatments with the LAI of $GA_3$ treated plants being reduced from that of the control plants.

### 6.3.4 Biomass

Varieties did not differ significantly in their biomass yields except at 250 DAS where Fulmar outyielded Igri by 3.2 t $ha^{-1}$ DM (Fig. 65). However peak biomass and final biomass values were not significantly different between the varieties.

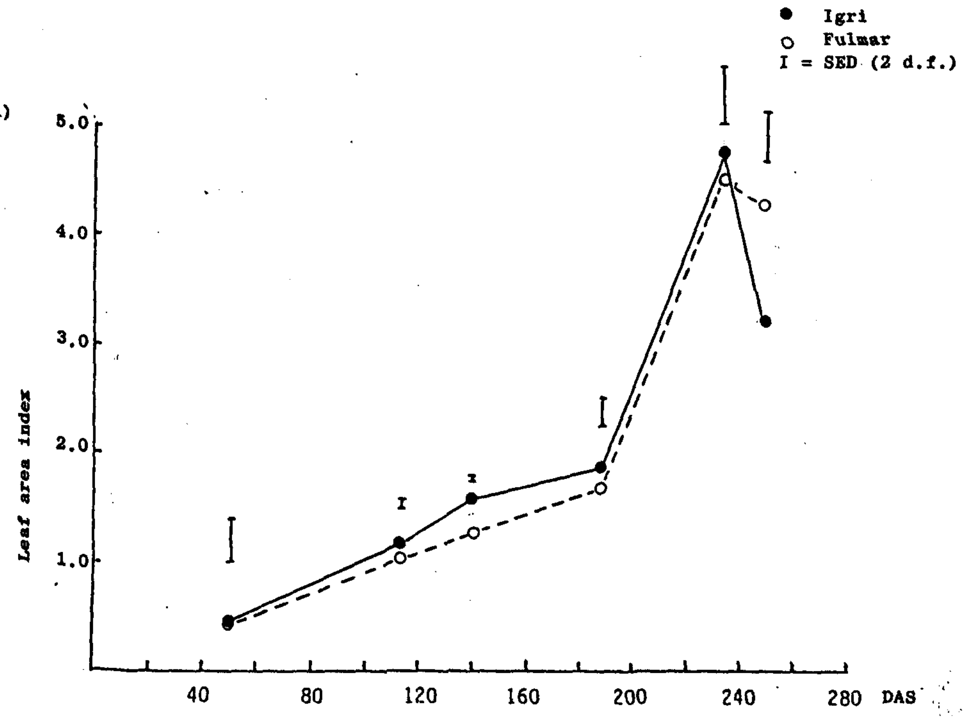
Prior to 217 DAS PGR treatment did not significantly influence the total above ground biomass figures obtained. After this date $GA_3$ treated plants had significantly lower biomass values than those of the control. The difference between the control and $GA_3$ treatments being approximately 2 t $ha^{-1}$ DM at peak biomass on 278 DAS and nearly 4 t $ha^{-1}$ DM at 289 DAS. PGR treatments differed in their yield reduction from peak to final biomass yields with the control treatment only being reduced by 0.5 t $ha^{-1}$ DM. However the reduction in biomass of the CCC treatment was 3.2 t $ha^{-1}$ and of the $GA_3$ plants 2.4 t $ha^{-1}$ (Fig. 65).

Varieties differed significantly in their response to the addition of various PGRs in their biomass yields at the final growth analysis dates (Fig. 65). In all treatments there was a reduction in biomass yield from peak biomass to final biomass yield with the proportional decline depending upon the variety and PGR treatment.

As noted above (Section 6.3.2) Fulmar has a higher number of tillers per plant than Igri during most of its growth thus, as would be expected, the proportional contribution by the mainstem and primary tillers to total weight was lower (Fig. 66). The proportional contribution to total weight of the mainstem decreased until peak tiller number was reached after which time its weight contribution increased with the mainstem of Igri contributing 38% of the total plant weight compared to

**Fig. 64** The influence of i Winter barley variety and ii PGR treatment on the LAI until 260 DAS

(i)


Igri
Fulmar
I = SED (2 d.f.)
5.0
4.0
3.0
2.0
1.0
Leaf area index
40
80
120
160
200
240
280
DAS

(ii)

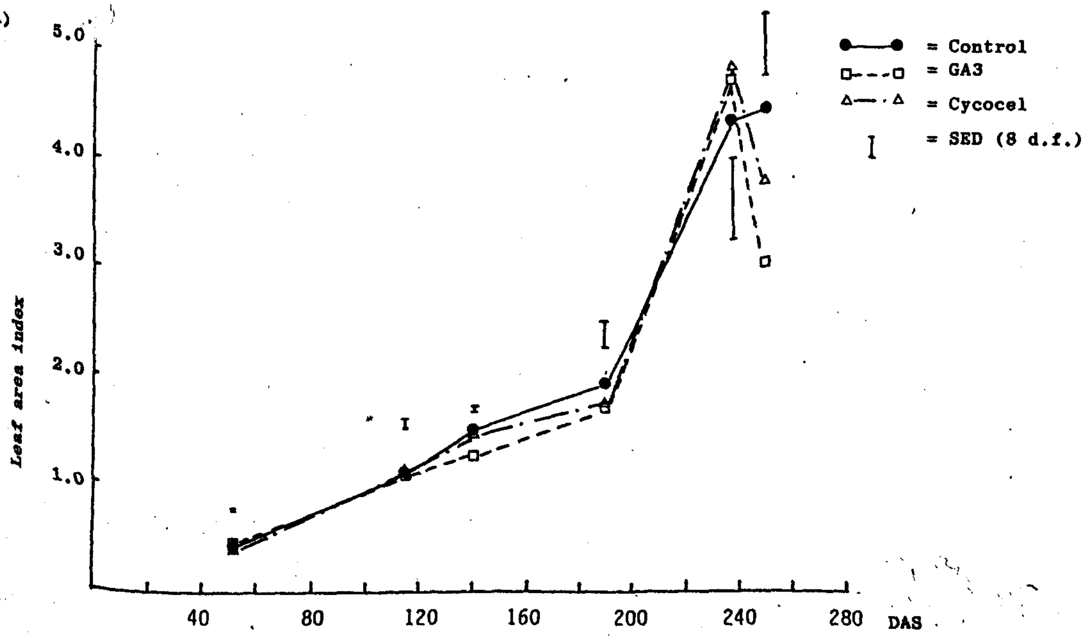

= Control
= GA3
= Cycocel
= SED (8 d.f.)
5.0
4.0
3.0
2.0
1.0
Leaf area index
40
80
120
160
200
240
280
DAS

**Fig. 65** The effects of variety and PGR treatments on the above ground biomass yield in PGR1

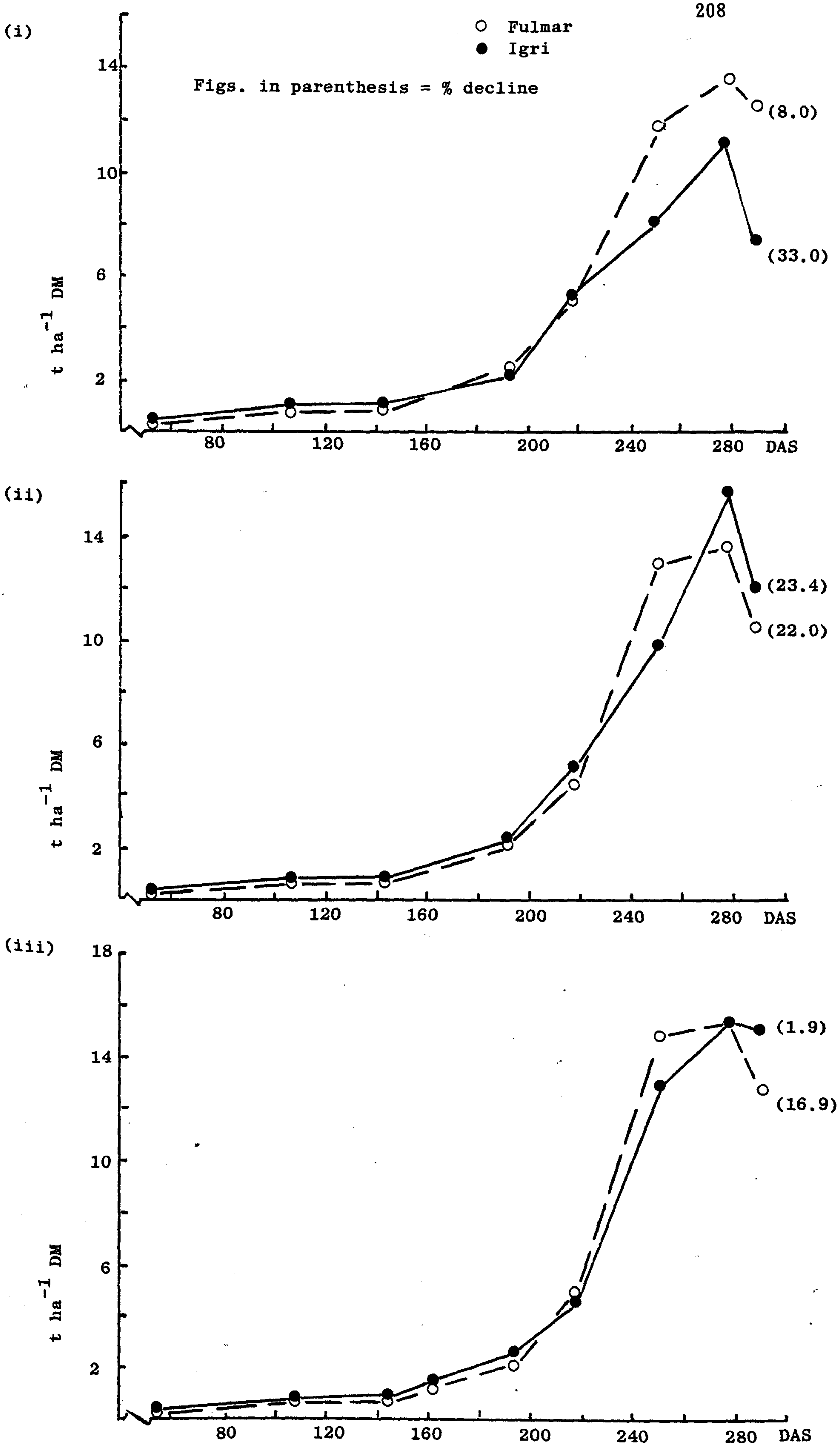
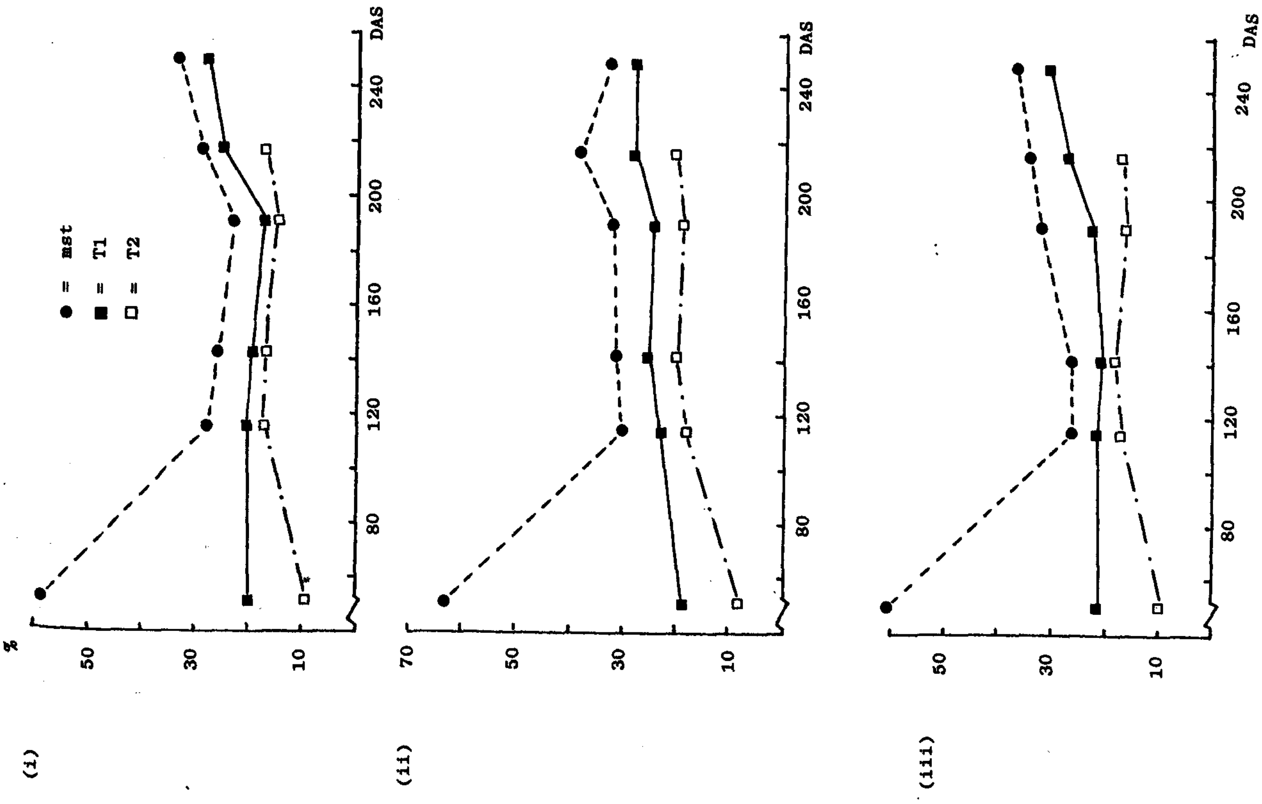

(i)
○ Fulmar
● Igri
Figs. in parenthesis = % decline
(8.0)
(33.0)
t ha$^{-1}$ DM
14
10
6
2
80
120
160
200
240
280
DAS
(ii)
(23.4)
(22.0)
(iii)
18
(1.9)
(16.9)

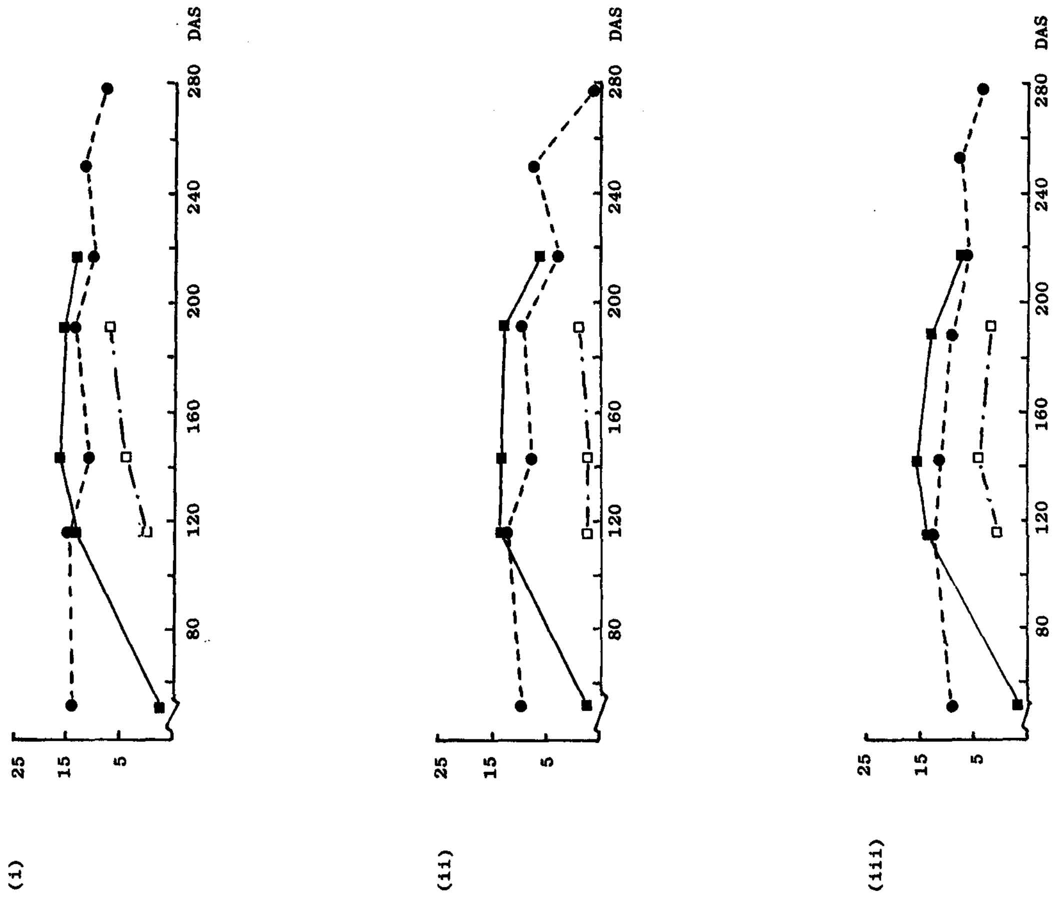
**Fig. 66** The proportion of total plant weight contributed by each tiller category as influenced by PGR treatments

i Control

ii $GA_3$

iii Cycocel


● = mst
■ = T1
□ = T2
%
(i)
(ii)
(iii)
DAS



T3
T4
CT
(i)
(ii)
(iii)
DAS

31.5% in Fulmar. The varieties differed in the contribution to total plant weight of both the CT and T3 tillers.

The contribution to total plant weight of individual tiller categories was modified by PGR treatments (Fig. 66). Until 220 DAS the contribution by the individual tiller categories of mst, T1 and T2 were greater in the $GA_3$ treated plants being over 30% at all times.

In no treatment did the proportional contribution to total plant weight of the T2 tiller exceed 20%. The contribution of the CT and later emerged primary tillers (e.g. T3 and T4) differed between PGR treatments. In all treatments the contribution to total weight by the CT tiller was below 10% with the values steadily declining from 120 DAS until the final monitoring at 278 DAS.

### 6.3.5 The mainstem – weight

The weight of the mainstem culm after the onset of stem extension differed between PGR treatments with the weight of $GA_3$ treated mainstem being greater than that treated with CCC at 217 DAS (Table 36). However at the three subsequent harvest dates the mainstem culm weight was lower in the $GA_3$ treated plants than the CCC or control plants, the differences being significant between the $GA_3$ and control. The stem weight reduction and percentage reduction are shown in Table 36.

### 6.3.6 Grain characteristics

Neither variety nor PGR treatment significantly influenced the grain nitrogen content, however in both varieties the grain nitrogen content of the $GA_3$ treated plants was above that of the control or CCC treatments (Table 37).

Hot water extract values differed significantly between varieties with Fulmar having a higher malting potential under all treatments. There were no significant differences between PGR treatments in the hot water extract estimates (Table 37).

As previously shown in the manipulation of biomass by PGR applications Fulmar was less modified by PGR applications than the variety Igri. This is shown again when considering the interaction between PGR applications and variety on seed size distribution (Fig. 67).

**Table 36** Weight of main stem – peak and final stem weights

| | Control | $GA_3$ | Cycocel | (PGR) SED (8Df) |
|---|---|---|---|---|
| Peak stem weight (g) | 0.864 | 0.717 | 0.748 | 0.0589 |
| Final stem weight (g) | 0.498 | 0.352 | 0.517 | 0.036 xx |
| Reduction (g) | 0.366 | 0.365 | 0.231 | - |
| % Reduction | 42.4 | 50.9 | 30.9 | - |

**Table 37** The effects of variety and PGR treatments on

i) Grain nitrogen content, and

ii) HWE

i)

| | Control | $GA_3$ | Cycocel | SED (2Df) (variety) |
|---|---|---|---|---|
| Igri | 2.307 | 2.463 | 2.413 | 0.0266 ns |
| Fulmar | 2.378 | 2.444 | 2.381 | |
| SED (PGR) (8Df) | 0.0460 | ns | | |

ii)

| | Control | $GA_3$ | Cycocel | SED (2Df) (variety) |
|---|---|---|---|---|
| Igri | 281.79 | 274.22 | 278.59 | 1.221 xx |
| Fulmar | 286.10 | 282.25 | 285.17 | |
| SED (PGR) (8Df) | 1.723 | ns | | |

**Fig. 67** Seed size distribution. The effects of PGR treatment on seed size distribution by weight of

i Igri

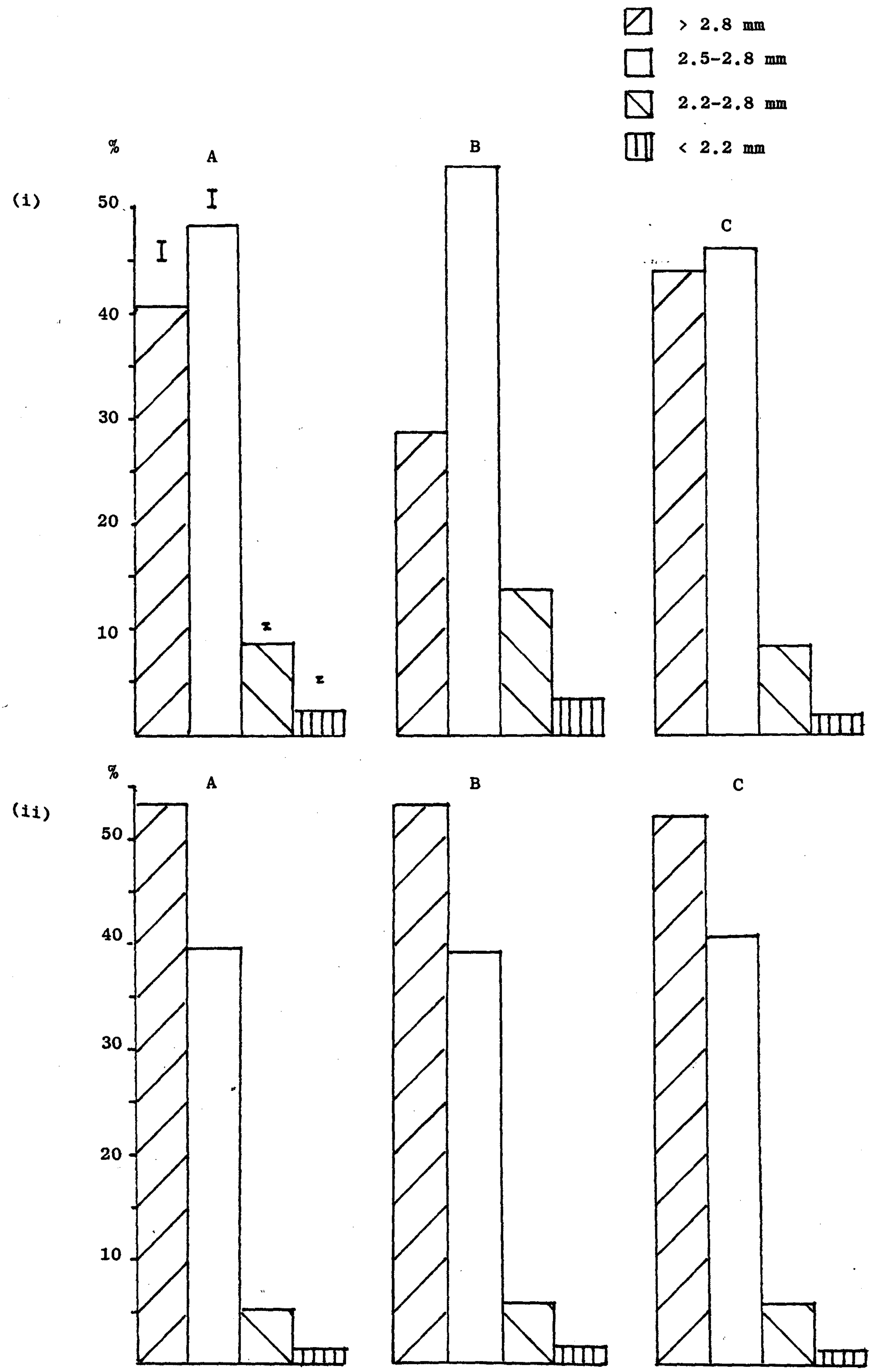
ii Fulmar

Key:

A = Control

B = $GA_3$

C = Cycocel



> 2.8 mm
2.5-2.8 mm
2.2-2.8 mm
< 2.2 mm
(i)
(ii)
%
A
B
C
50
40
30
20
10

Within the variety Igri the majority of the harvested seeds were between 2.5 and 2.8 mm in size in all PGR treatments. However with Fulmar the greatest proportion of seeds were found to be above 2.8 mm in size. Igri when treated with $GA_3$ had a reduced percentage of seeds above 2.8 mm in size but treatment with CCC increased the proportion of seeds in this size category. These results were similar when the proportions falling into each category were assessed by number or by weight.

### 6.3.7 Yield

Grain yield was significantly influenced by PGR treatment with the grain yield of $GA_3$ treated plants being only 67% of that of the untreated control in Igri and 88% of the control value in Fulmar (Table 38). The application of CCC only reduced grain yield in the variety Igri where yield was reduced to 84% of the control.

The yields of the varieties did not differ significantly although over PGR treatments Fulmar yielded 0.14 t $ha^{-1}$ more than Igri.

The yields of grain within specific size categories are important for the seed industry. Within the variety Igri the greatest yields of seeds within all stated seed size categories were obtained from the untreated control (Table 38). However in Fulmar greatest yields of seeds between 2.2 and 2.5 mm in size and greater than 2.5 mm in size were obtained from the CCC treated plots.

### 6.3.8 Germination tests and resultant seedlings

Germination tests (ISTA, 1976) on seed harvested from PGR1 showed that variety significantly influenced the percentage germination of seeds below 2.8 mm in size with Fulmar having significantly lower germination percentages in each of the three size classifications (Table 39). Germination percentage declined with a reduction in average seed size and seed weight with only 65% of Fulmar seeds below 2.2 mm in size germinating.

PGR applications had no significant effect on the germination of harvested seeds (Table 39).

At the termination of each germination test seedlings were removed from the growing medium, washed to remove adhering sand particles and then oven dried to a constant weight. Seedling weight was

**Table 38** The effects of PGR treatment on two varieties of winter barley

i) Yield

| | Control | $GA_3$ | Cycocel | (PGR) SED (8Df) |
|---|---|---|---|---|
| Igri | 8.68 (100) | 5.80 (67) | 7.26 (84) | 0.547 x |
| Fulmar | 7.67 (100) | 6.77 (88) | 7.70 (100) | |
| (variety) SED (2Df) | | 0.817 | | |

(Figs in parenthesis are the percentage of the control yields of each variety)

ii) The yield of grain within specific size classifications (t $ha^{-1}$)
The effects of variety and PGR treatment

| | Igri | | | Fulmar | | |
|---|---|---|---|---|---|---|
| Size (mm) | Control | $GA_3$ | Cycocel | Control | $GA_3$ | Cycocel |
| > 2.8 | 3.55 | 1.65 | 3.19 | 4.09 | 3.09 | 4.02 |
| 2.5 + | 7.74 | 4.79 | 6.54 | 7.14 | 6.26 | 7.15 |
| 2.2-2.5 | 4.94 | 3.94 | 3.93 | 3.45 | 3.05 | 3.57 |
| < 2.2 | 0.18 | 0.20 | 0.14 | 0.12 | 0.12 | 0.11 |

**Table 39**

i) The effects of variety on percentage germination (non-transformed data)

| Size (mm) | Igri | Fulmar | SED (8Df) | Sig |
|---|---|---|---|---|
| > 2.8 | 90.43 | 89.50 | 1.364 | ns |
| 2.5-2.8 | 92.29 | 86.78 | 0.736 | x |
| 2.2-2.5 | 90.30 | 79.60 | 0.870 | xx |
| < 2.2 | 81.96 | 64.99 | 2.507 | xx |

ii) The effects of PGRs on percentage germination (non-transformed data)

| Size (mm) | Control | $GA_3$ | Cycocel | SED (8Df) | Sig |
|---|---|---|---|---|---|
| > 2.8 | 91.05 | 89.50 | 89.34 | 1.918 | ns |
| 2.5-2.8 | 88.25 | 88.92 | 91.43 | 1.531 | ns |
| 2.2-2.5 | 81.30 | 83.70 | 89.80 | 3.25 | ns |
| < 2.2 | 74.50 | 73.94 | 71.98 | 2.245 | ns |

expressed as weight per 100 seedlings. There were no significant differences between the varieties in the weight of seedlings recovered from any specific size category (Table 40). There was a reduction in weight of resultant seedlings as grain size decreased. The application of PGRs did not significantly affect the weight of seedlings produced from any grain size classification (Table 40).

Significant differences occurred between the two varieties in the TGW obtained from the harvested sample with Fulmar having a lower TGW in all treatments (Table 41).

PGR treatments differed significantly in the TGWs obtained. $GA_3$ treated plants produce grains with significantly lower TGW values than those obtained from the control or CCC treated plots.

### 6.3.9 Root weight and distribution

Applied CCC significantly reduced the total dry weights of the cereal roots obtained down to a depth of 1 m. Reductions in dry weight from the control were evident in each of the 20 cm depth increments harvested except for the 60-80 cm depth. There were no significant differences between the CCC and the control treatments in the proportion of total root weights that were present in each 20 cm layer (Fig. 68).

The application of $GA_3$ significantly reduced the total root dry weight. A higher proportion of the total weight of the roots obtained was located in the upper 20 cm of the soil profile compared to the control plants.

Differences occurred between PGR treatments in the shoot : root ratios obtained when using above ground biomass figures from the growth analysis harvest at 250 DAS. Cycocel did not influence the root : shoot ratio from that obtained with the untreated control but $GA_3$ treatments decreased the shoot : root ratio and thus similarly increased the root : shoot ratio.

### 6.3.10 Individual grain weights; the effect of variety and PGR treatment

The number of grains per mainstem ear was not constant (Fig. 69). The mode value for the control treatment of the variety Igri being 22 grains per ear whilst that of Fulmar was 20 grains per ear.

**Table 40**

i) Seedling weight – per 100 germinated seeds (g)
– by variety

| Size (mm) | Igri | Fulmar | SED (2Df) | Sig |
|---|---|---|---|---|
| > 2.8 | 4.67 | 4.81 | 0.318 | ns |
| 2.5-2.8 | 3.70 | 3.87 | 0.268 | ns |
| 2.2-2.5 | 2.88 | 2.83 | 0.164 | ns |
| < 2.2 | 2.15 | 2.09 | 0.148 | ns |

ii) The effects of PGR treatment on the weight (g) of seedlings from 100 germinated seeds

| Size (mm) | Control | $GA_3$ | Cycocel | SED (8Df) | Sig |
|---|---|---|---|---|---|
| > 2.8 | 4.78 | 4.48 | 4.97 | 0.580 | ns |
| 2.5-2.8 | 3.83 | 3.58 | 3.94 | 0.292 | ns |
| 2.2-2.5 | 2.78 | 2.90 | 2.87 | 0.336 | ns |
| < 2.2 | 2.10 | 2.08 | 2.18 | 0.186 | ns |

**Table 41** TGW %MC

| | Control | $GA_3$ | Cycocel | Mean | (variety) SED (2Df) |
|---|---|---|---|---|---|
| Igri | 41.08 | 38.66<br>(94) | 41.32<br>(100.6) | 40.36 | 0.132<br>x |
| Fulmar | 39.49 | 38.61<br>(98) | 39.66<br>(100.4) | 39.24 | |
| Mean | 40.29 | 38.64<br>(96) | 40.48<br>(100.5) | - | |
| (PGR) SED (8Df) | | 0.132 xxx | | | |

Figs in parenthesis = % of control TGW

**Fig. 68** The effect of PGRs on root distribution down to 1 m two weeks post anthesis

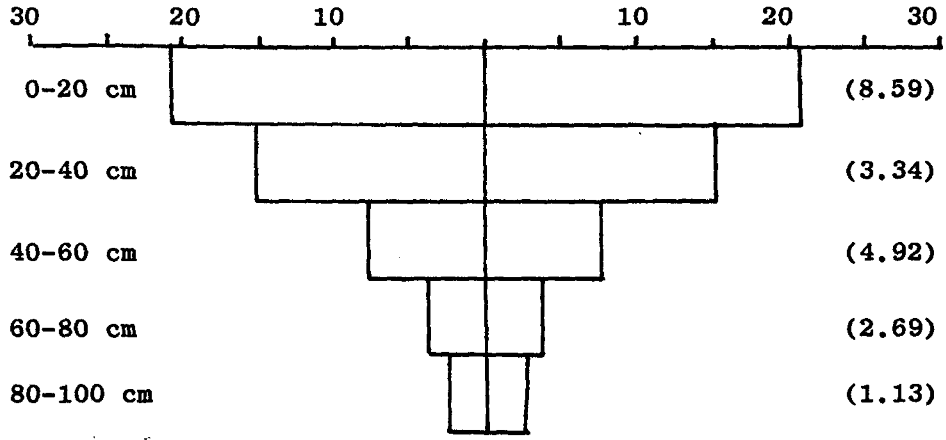
i Control

ii $GA_3$

iii Cycocel

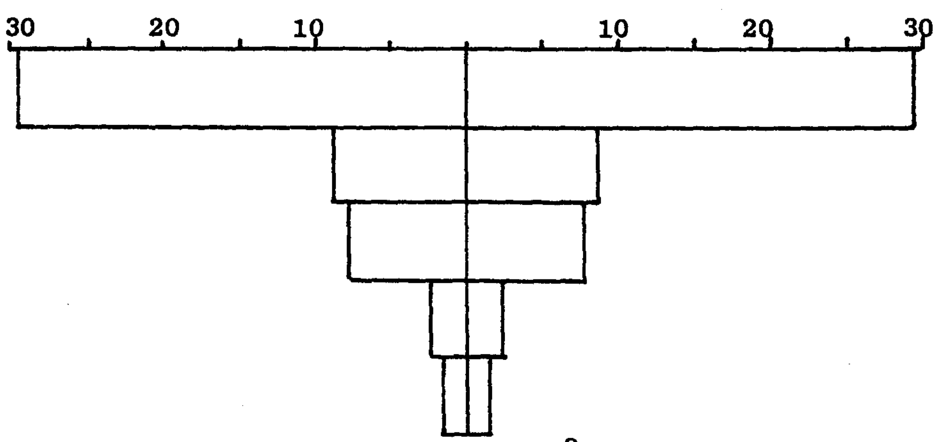
SED (8 Df) values in parenthesis

(i)



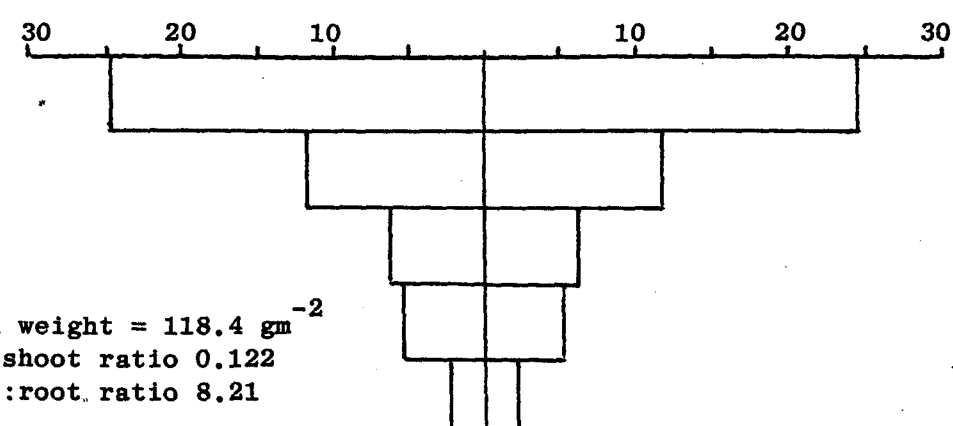

Total weight = 156.1 $gm^{-2}$
root:shoot ratio 0.121
shoot:root ratio 8.24

(ii)




Total weight = 121.1 $gm^{-2}$
root:shoot ratio 0.151
shoot:root ratio 6.60

(iii)



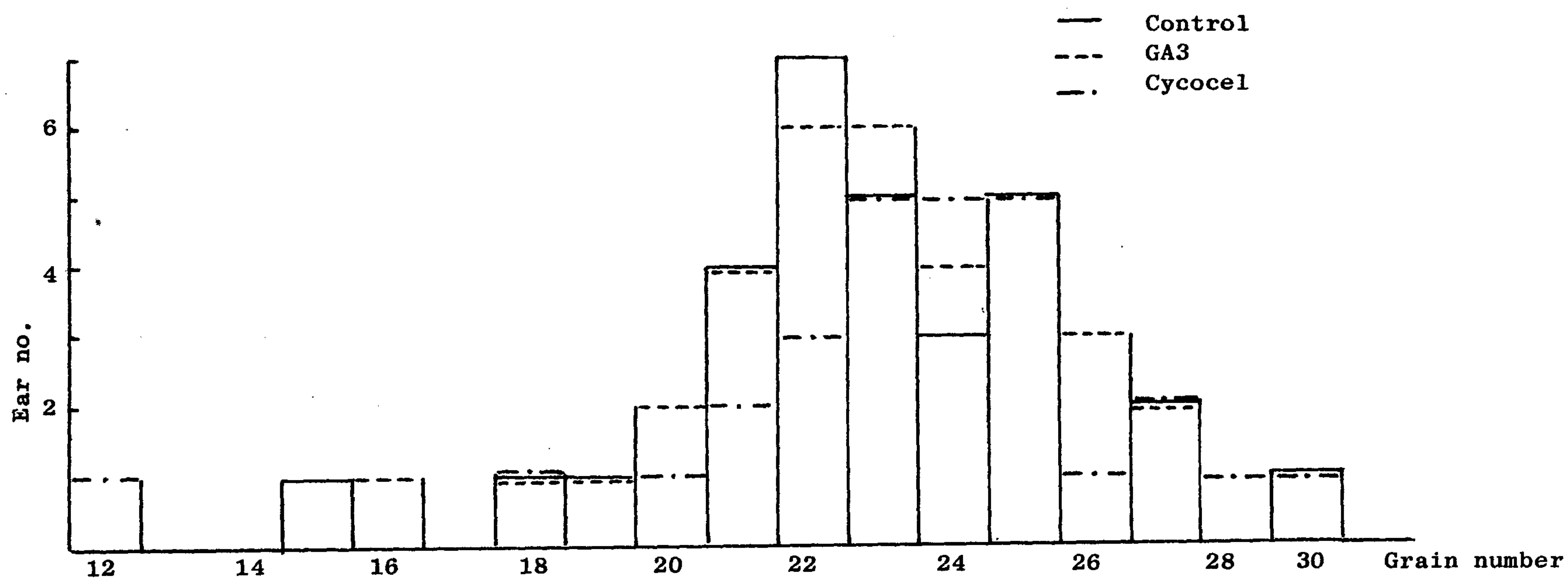

Total weight = 118.4 $gm^{-2}$
root:shoot ratio 0.122
shoot:root ratio 8.21

**Fig. 69** The distribution of ear sizes as measured by grain number per ear — the influence of variety and PGR

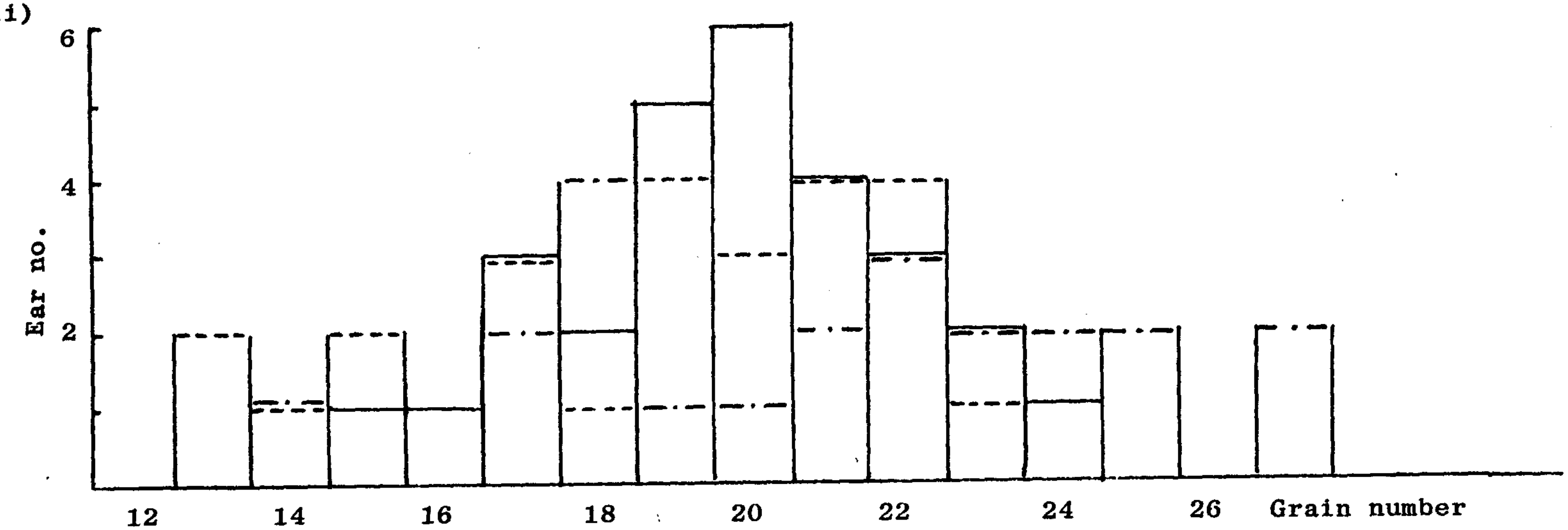
i Igri

ii Fulmar

(i)


Control
GA3
Cycocel
Ear no.
6
4
2
12
14
16
18
20
22
24
26
28
30
Grain number

(ii)


Ear no.
6
4
2
12
14
16
18
20
22
24
26
Grain number

Within each treatment weights of grains for specified sites were meaned over many ears. However as grain number per ear was not constant fewer grains were used to give the mean grain weight for uppermost sites upon the ear. The determination of mean grain weight at any specific site within the ear took no account of the numerical position of the grain. Thus topmost grains from a small ear were possibly equated to middle grains from a large ear.

The patterns of individual grain weight differences along an ear are shown in Fig. 70. There were no differences between the treatments in the rate of decline of grain weights within the ear from grain number 9 to grain 21 (grains numbered from basal regions) (Fig. 71). Varieties did not differ in their decline in grain weights between these two grain positions.

To assess the effects of PGR treatments on specific sized ears, and thereby eliminate the effects of ear size differences, ears with either 25 or 24 grain sites per ear were chosen. The mean grain weight values were assessed for each grain site within each size category ear. No differences between treatments in the pattern of distribution of the grain weights was evident (Fig. 71). However on the variety Fulmar it was noted that when the plants had previously been treated with $GA_3$ the grain weights of each position on the ear were lower than on the control treatments.

In each variety and within each treatment the maximum grain weight occurred at position 7 or 9 on the ear. Within all ears the apical grains had lower mean grain weights than the basal grains.

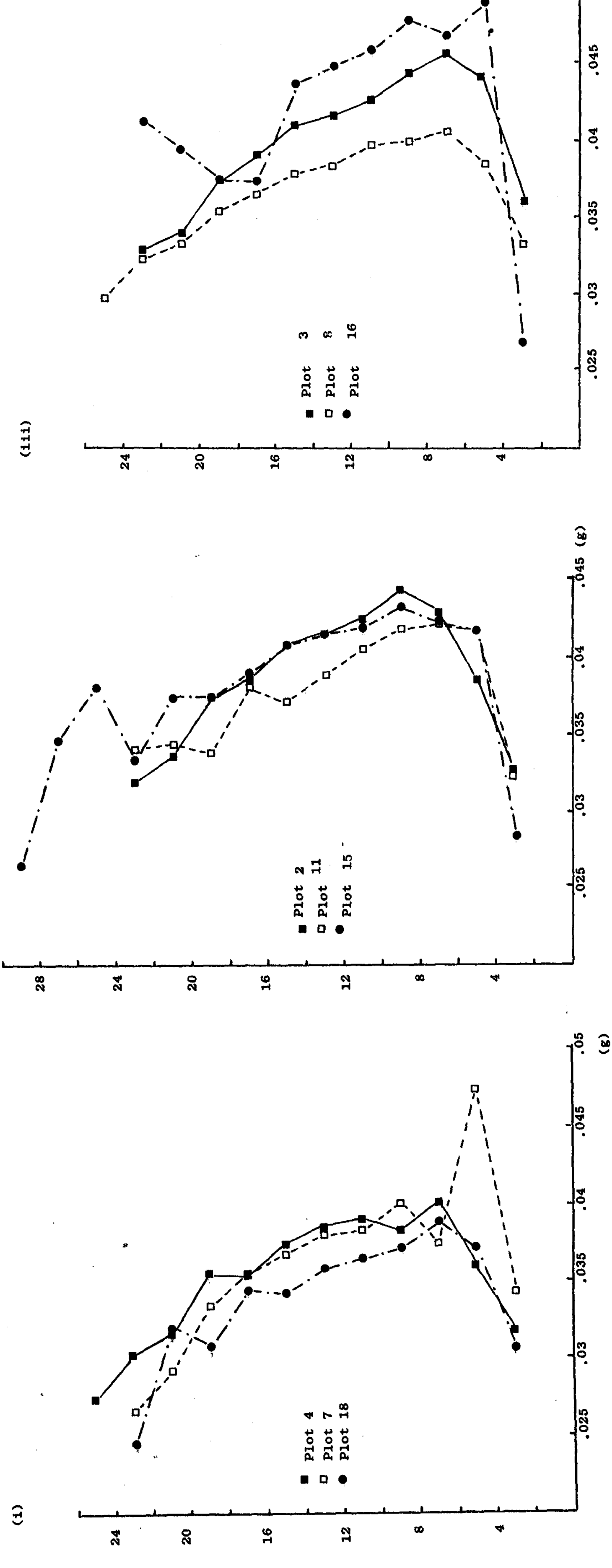
## 6.4 Introduction to WB6

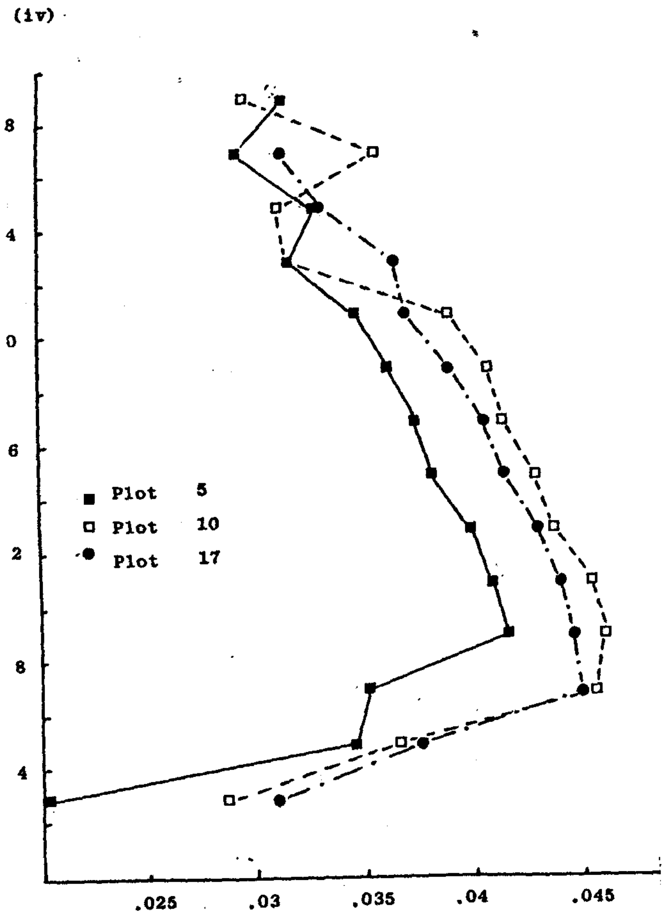
Chemicals such as herbicides, fungicides, insecticides and growth regulators are now commonly applied to crops for specific purposes relating to management and yield. Usually, however, the effects of these chemical inputs have not been considered with respect to their effects on the resultant grain produced or their subsequent effects on the resown crop.

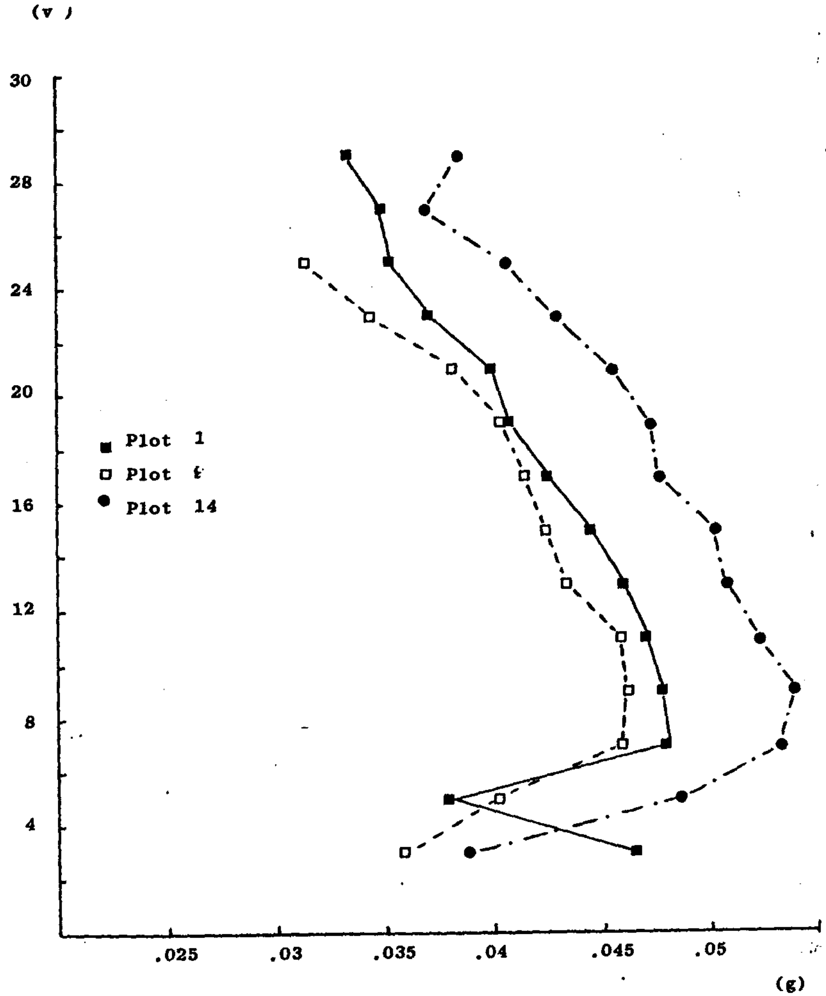
It thus was decided to investigate the effects of a range of commercially available plant growth regulatory chemicals applied at various dates to the winter barley variety Tipper and to assess their influences on the grain yield and yield components.

**Fig. 70** The influence of variety on seed weight distribution within the barley ear

- i Fulmar $GA_3$
- ii Fulmar CCC
- iii Fulmar Control
- iv Igri $GA_3$
- v Igri CCC
- vi Igri Control


(i)
Plot 4
Plot 7
Plot 18
24
20
16
12
8
4
.025
.03
.035
.04
.045
.05
(g)
(ii)
Plot 2
Plot 11
Plot 15
28
24
20
16
12
8
4
.025
.03
.035
.04
.045 (g)
(iii)
Plot 3
Plot 8
Plot 16
24
20
16
12
8
4
.025
.03
.035
.04
.045


(iv)
Plot 5
Plot 10
Plot 17
.025
.03
.035
.04
.045


(v)
Plot 1
Plot
Plot 14
30
28
24
20
16
12
8
4
.025
.03
.035
.04
.045
.05
(g)

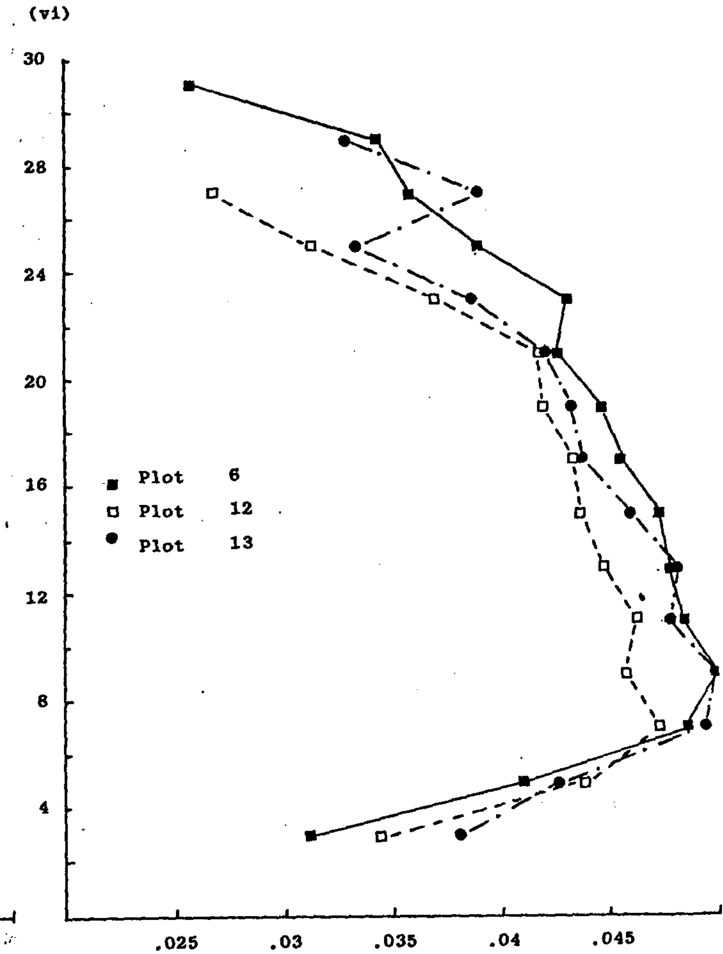
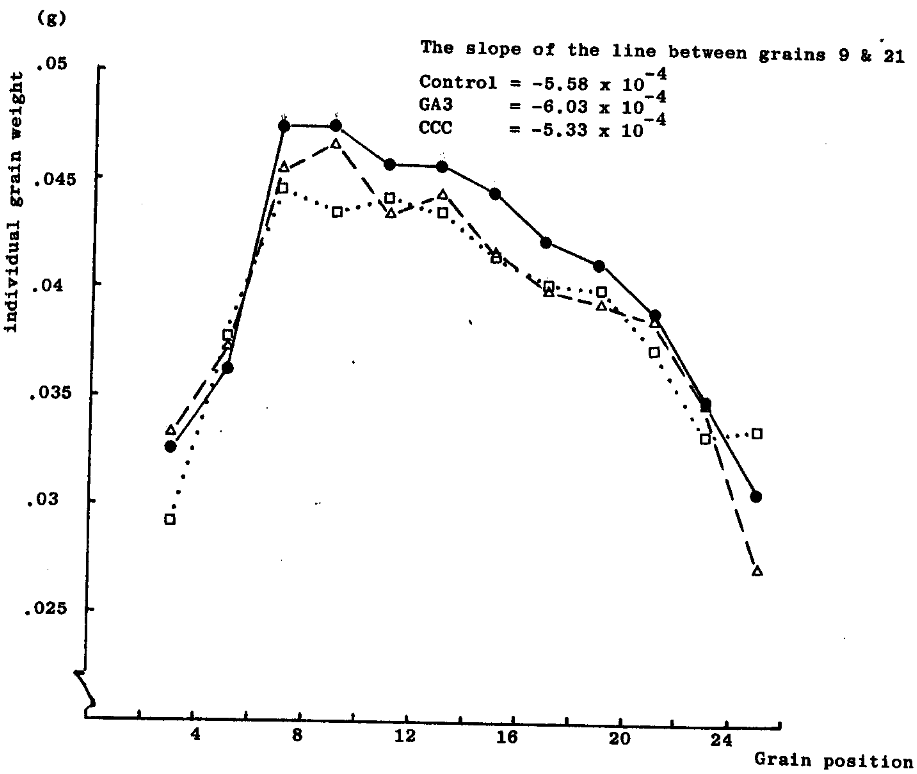

(vi)
Plot 6
Plot 12
Plot 13
30
28
24
20
16
12
8
4
.025
.03
.035
.04
.045

**Fig. 71** The effect of variety and PGR treatment on grain weight distribution within the ear (similar sized ears used)

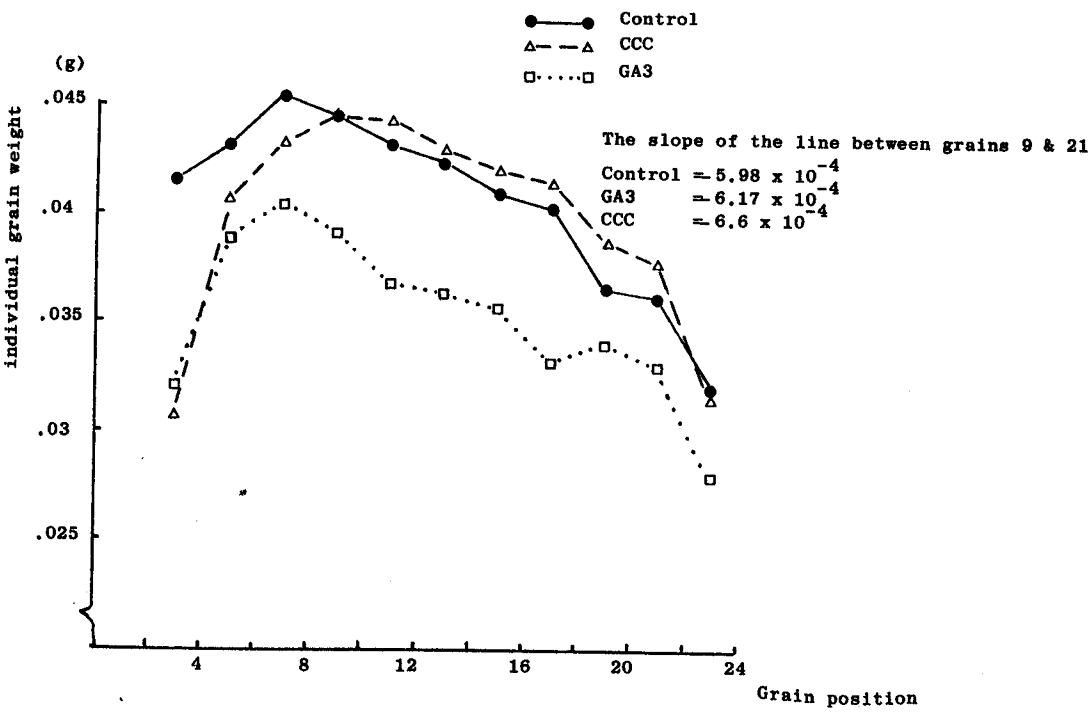
i Igri

ii Fulmar

(i)


(g)
individual grain weight
.05
.045
.04
.035
.03
.025
The slope of the line between grains 9 & 21
Control = -5.58 x 10^-4
GA3 = -6.03 x 10^-4
CCC = -5.33 x 10^-4
4
8
12
16
20
24
Grain position

(ii)


Control
CCC
GA3
(g)
individual grain weight
.045
.04
.035
.03
.025
The slope of the line between grains 9 & 21
Control = 5.98 x 10^-4
GA3 = 6.17 x 10^-4
CCC = 6.6 x 10^-4
4
8
12
16
20
24
Grain position

## 6.5 Materials and Methods

### 6.5.1 Site and general materials

Experiment WB6 was conducted in field 25 of the University of Nottingham farm at Sutton Bonington. Full site details are as in Gregory, McGowan and Biscoe (1978). Full experimental details are in Table 5. The previous crop being second early potatoes no seedbed nitrogen was applied. In total 60 kg $ha^{-1}$ nitrogen was applied as a top dressing. All plots were drilled to a density of 450 seeds $m^{-2}$. Only one variety of winter barley, Tipper (Section 3.2), was investigated.

### 6.5.2 Chemical applications

Five chemical treatments and one control were employed in a three replicate randomized block design.

$GA_3$ as 90% Gibberellin $A_3$ was applied to Tipper prior to the double ridge stage at a concentration of 30 ppm in 1000 l $H_2O$ $ha^{-1}$ (30 g ai $ha^{-1}$) for each application in three sequential doses on 27, 30 October and 2 November 1982.

Treatments 5C¼ and 5C½ consisted of different amounts of 5C Cycocel applied to the crop during the last week in October 1982. 5C½ was equivalent to that concentration used in experiment PGR1 (Section 6.2) with 5C¼ being equivalent to 0.12 kg ai $ha^{-1}$. Both rates of chlormequat were applied in 225 l $H_2O$ $ha^{-1}$.

Both the Cerone and 5C Sp treatments were spring applied. The chemicals 5C Cycocel and Cerone (Table 3) were applied at the recommended rates for use as anti-lodging agents. However the timing of applications differed from that recommended with both chemicals being applied during the first week of March 1983.

### 6.5.3 Rooting studies

Root distribution and extent were assessed on two occasions during growth. The first date of root sampling was at approximately 5 weeks after the application of the autumn applied PGRs. The second analysis of root distribution occurred in mid June, two weeks after peak anthesis.

During analysis one root cores were taken with a jarrot auger down to a depth of 50 cm and the resultant soil core samples divided into five depth increments. At the second harvest soil cores down to 1 m were obtained by augering. These were subsequently divided into 6 depth increments.

Once separated the roots were assessed using the methods of McGowan et al. (1983) and outlined in Section 2.4.2.

Only three treatments of 5C¼, $GA_3$ and the control were investigated for root length determination at both dates.

6.5.4 Soil water analysis

In order to assess soil water status, crop water use and rooting depth under the different treatments the following measurements were made using the Neutron probe (Bell, 1969; 1973):

i) Soil moisture deficit.
ii) Cumulative crop evaporation.
iii) Effective root extraction depth.
iv) Water use efficiency.

Access tubes were installed in March to a depth of 1.25 m with minimal disturbance to the crop or soil (McGowan & Williams, 1980). Three replicates of each treatment were monitored to a depth of 1 m in 0.1 m increments.

From discontinuities in the water content-time curve at varying depths in the soil it was possible to determine the advancement of the "drying front" down the soil profile and hence to estimate effective rooting depth (McGowan, 1974). A measurement for dynamic field capacity was taken to be the percentage soil water content at which rapid water extraction started. From this soil water deficits and cumulative crop evapotranspiration were calculated.

6.5.5 Grain growth

In order to determine the effects of the selected PGR treatments on rate and duration of grain filling with the variety Tipper five randomly selected plants were removed from each plot at 2-3 day intervals from awn emergence until final harvest.

Ears from these plants were analysed as previously outlined in Section 2.2.

6.5.6 Sequential growth analysis

Growth analysis harvests were taken frequently during 1982/83 with tiller numbers, tiller category contributions to total weight and area, LAI and biomass values being recorded.

6.5.7 Final growth analysis

Final growth analysis areas consisted of 3 x $\frac{1}{3}$ m adjacent lengths of row from row numbers 3, 4 and 5 from the southern edge. Final yield components were determined on a subsample of 25 plants from this hand harvested area.

6.5.8 Yield determination

Combine harvested yield values were obtained from a minimum of 15 x 1.5 m of plot using a Walter and Wintersteiger small plot combine. All yield values were corrected for moisture content which was determined on a minimum of 300 g of grain which was oven dried immediately after harvesting.

6.5.9 Seed characteristics

The seed size distribution of 2 x 100 g of grain removed from the bulked sample was analysed. TGW estimates were obtained from both the hand harvested grain sample and those grains from the combine harvested sample.

Replicated grain samples were also analysed for nitrogen content and hot water extract potential.

Seeds were subject to a standard germination test in sand (Section 2.10) after a four day period of chilling to 4°C to break dormancy. At the termination of the germination test the growing seedlings were removed, washed to remove adhering particles of sand and oven dried. Seedling dry weight was expressed as weight per 100 germinated seedlings.

## 6.6 Weather Conditions

### 6.6.1 Characteristics of the 1983/83 growing season

Exceptionally high rainfall in August 1982 resulted in poor conditions for cereal harvesting but ideal conditions for the sowing and germination of the subsequent crops. The ensuing autumn and winter conditions were similar to the long term average with the exception of temperatures in January and March which were twice the long term average. There then followed two months (April and May) of heavy rainfall accompanied by below average temperatures. June and July were very dry with only 37 mm of rain occurring during these two months. Thus from the end of May, at the commencement of soil water monitoring, soil moisture deficits built up rapidly throughout the soil profile (Fig. 72).

## 6.7 Results

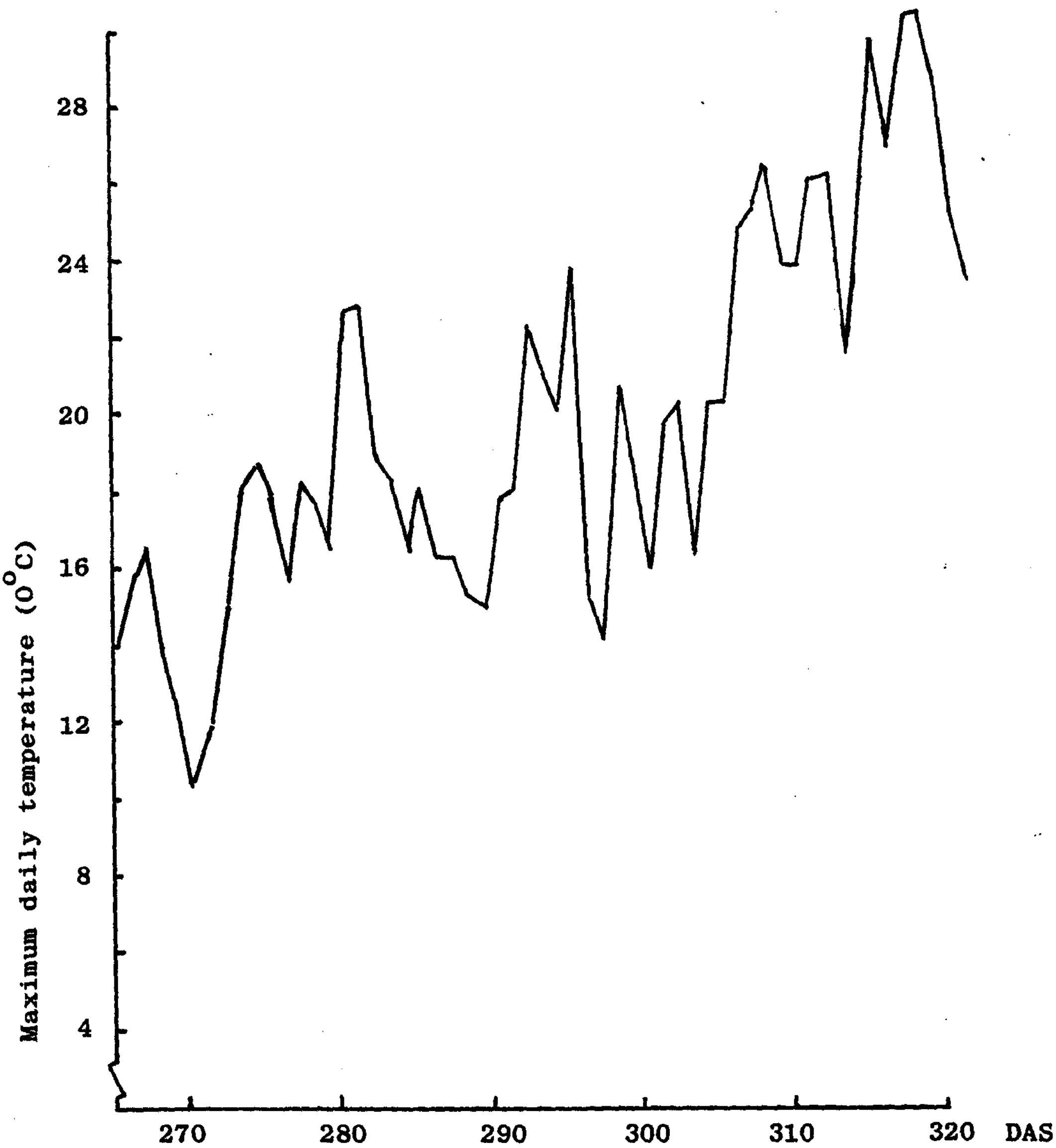
### 6.7.1 Rooting studies

The assessment of root lengths using the method of McGowan et al. (1983) showed great variability between the replicated samples in individual horizons and total root lengths with coefficients of variation of the total root length being 27.4% in the first root harvest. The proportional distribution of roots down to 50 cm differed with the PGR treatment with 5C Cycocel treated plots having over 35% of their total root lengths in the top 10 cm of the profile (Fig. 73).

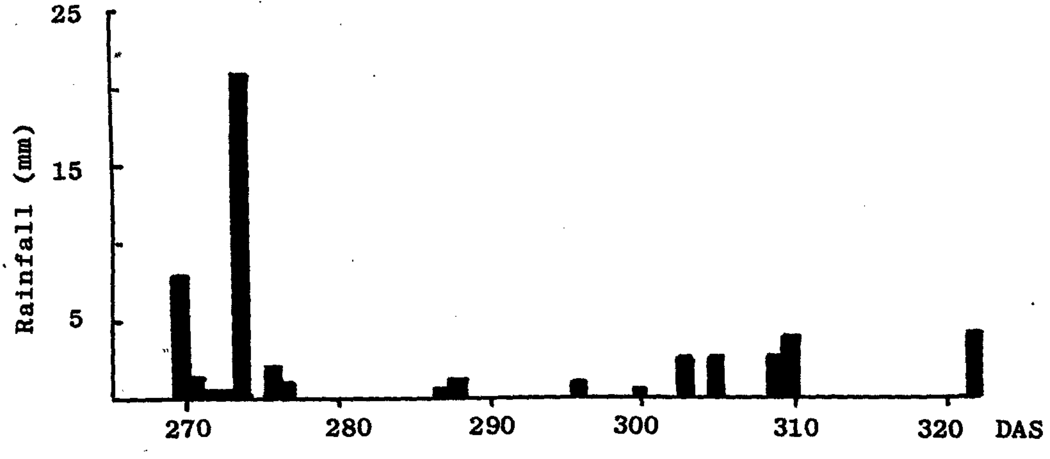
Under 10% of the total root length was found at the lowest depth sampled in December 1982, however root sampling to a greater depth may have indicated differences in depth of rooting with the PGR treatments. Root lengths present per $cm^3$ of soil decreased down the soil profile. This agrees with the work of Gregory et al. (1978), Kirby and Rackham (1971) and Welbank et al. (1974) all of whom showed that, in general, the lengths of cereal roots in each successive layer decreased with depth.

The second root harvest of experiment WB6 was designed to coincide with anthesis, the time of maximum recorded root lengths on the winter wheat crop (Welbank et al., 1974). However root samples were taken post anthesis, a time when many workers, e.g. Welbank and Willams (1968); Mengel and Barber (1974); Biscoe et al. (1975) have found large

**Fig. 72** Maximum daily temperature (i) and daily rainfall (ii) for the period 273 to 322 DAS



Maximum daily temperature ($^{O}$C)
28
24
20
16
12
8
4
270
280
290
300
310
320
DAS

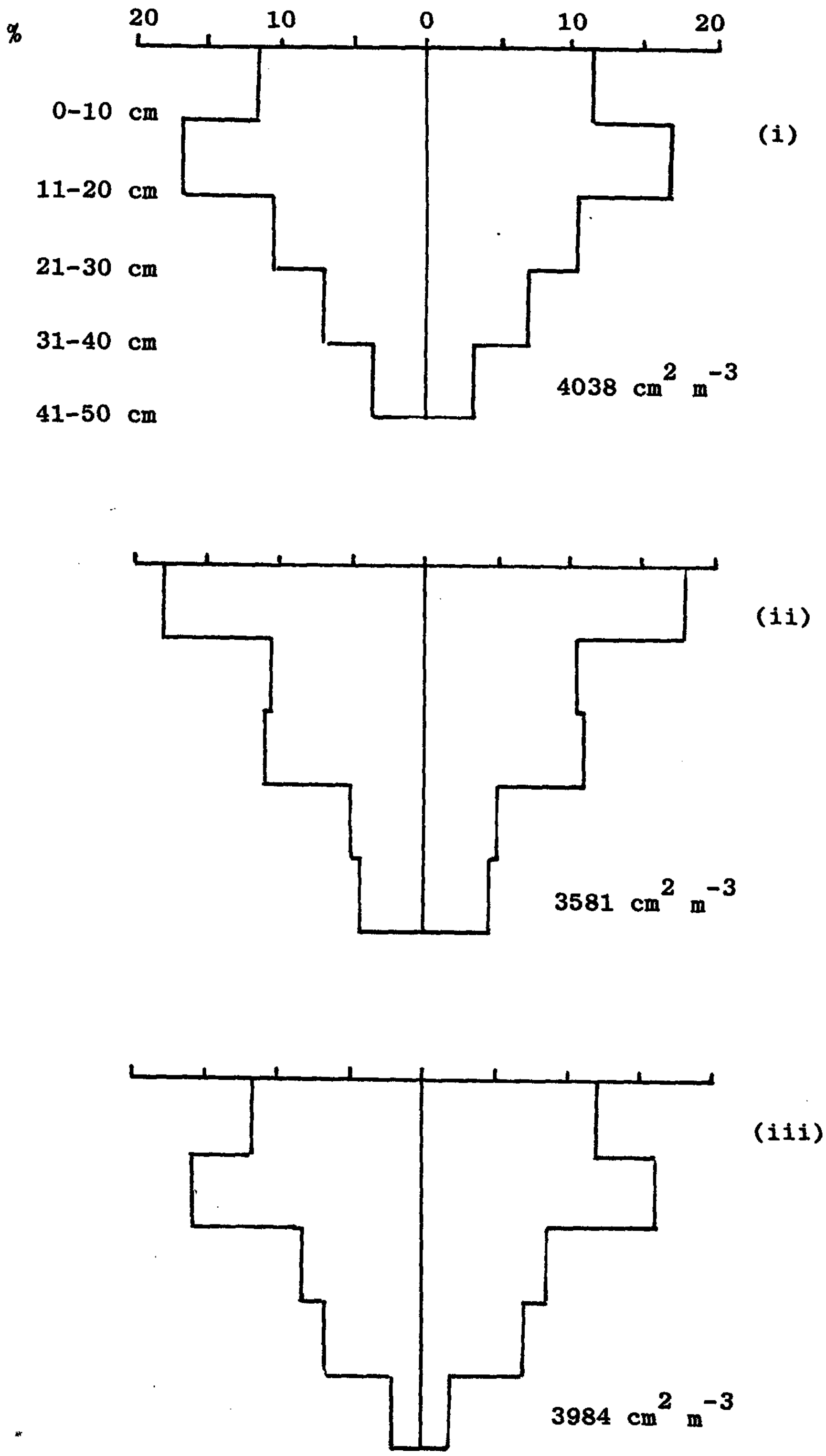
Rainfall (mm)
25
15
5
270
280
290
300
310
320
DAS

**Fig. 73** The influence of PGR treatments on root lengths down to 50 cm – December 1982

i Control

ii 5C¼

iii $GA_3$


%
20
10
0
10
20
0-10 cm
11-20 cm
21-30 cm
31-40 cm
41-50 cm
(i)
4038 cm$^2$ m$^{-3}$
(ii)
3581 cm$^2$ m$^{-3}$
(iii)
3984 cm$^2$ m$^{-3}$

decreases in root dry weight. However Gregory et al. (1978) found that with the winter wheat variety Huntsman total root dry weight remained relatively constant from anthesis until final harvest although the distribution of roots within the profile was altered. Thus root sampling at this time may give an underestimate of the maximum root lengths of the cereal plant. The values obtained of root lengths (cm $cm^{-3}$ soil) agree with the general pattern of root weight distribution outlined by Gregory et al. (1978) with the exception being the root lengths present in the top 10 cm of the profile (Fig. 74).

Approximately 10% of the total root length was present between 80-100 cm depth (Fig. 75). Thus the extraction of soil cores to a greater depth may have helped to determine the effects of the applied PGRs on the maximum rooting depth.

Between treatment effects on the proportional distribution of root length or the root lengths per unit volume were rarely significant. The general trend being for PGR treatments to increase the number and proportion of roots present in the uppermost layers of the profile and to conversely decrease the number and proportion in the mid region of the soil profile. However these general differences were not statistically significant.

### 6.7.2 Depth of water extraction by roots

Roots increasingly extracted water from greater depths in the soil as the soil water deficit increased in successive horizons. Changes in the maximum depth of water extraction (the effective rooting depth) are shown in Fig. 76 for the three treatments studied. However the maximum depth of extraction does not necessarily indicate actual rooting depth. Gregory et al. (1978) showed that although cereal roots were found down to 2 m maximum water extraction throughout growth was at shallower depth.

The above average rainfall during April and May caused the movement of the drying front (the maximum depth at which roots extracted water) to move little until the beginning of June (Agnew, 1984).

Potential evaporation was calculated using a modification of the method originally described by Penman (MAFF, 1967), using standard meteorological measurements made at a field station less than 1 km from the field site. Potential evaporation and rainfall were used to calculate a

**Fig. 74** The distribution of root lengths at varying depths down the soil profile at 2 weeks post anthesis

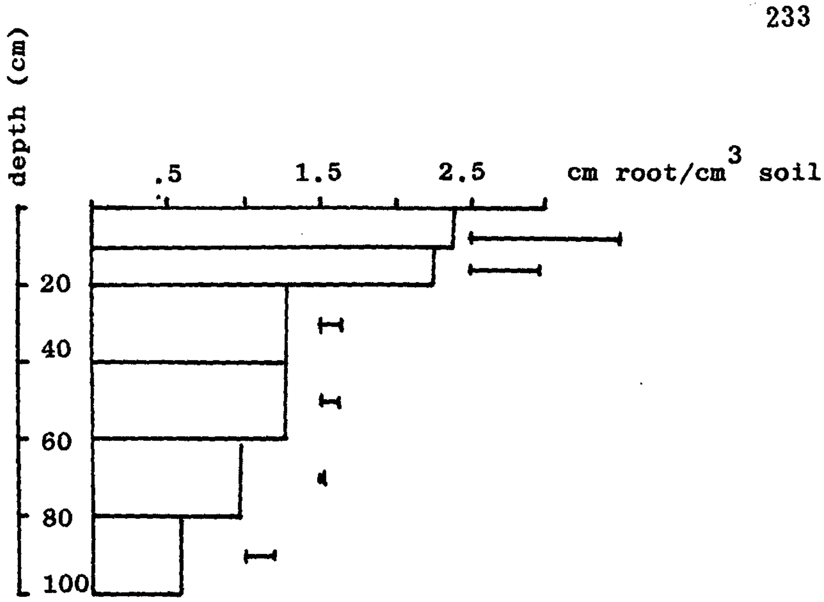
i Control

ii 5C¼

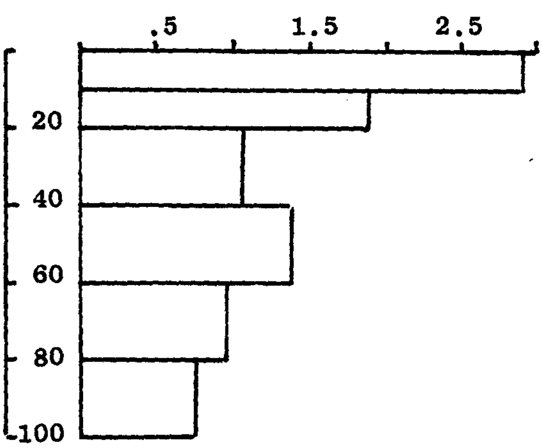
iii $GA_3$

⊢—⊣ = SED (4 Df)

(i)


depth (cm)
.5
1.5
2.5
cm root/cm3 soil
20
40
60
80
100

(ii)


.5
1.5
2.5
20
40
60
80
100

(iii)

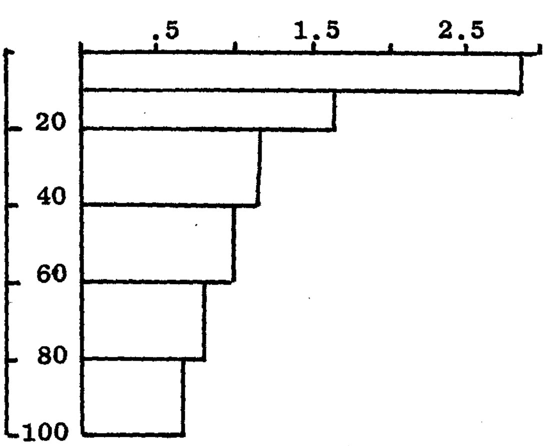

.5
1.5
2.5
20
40
60
80
100

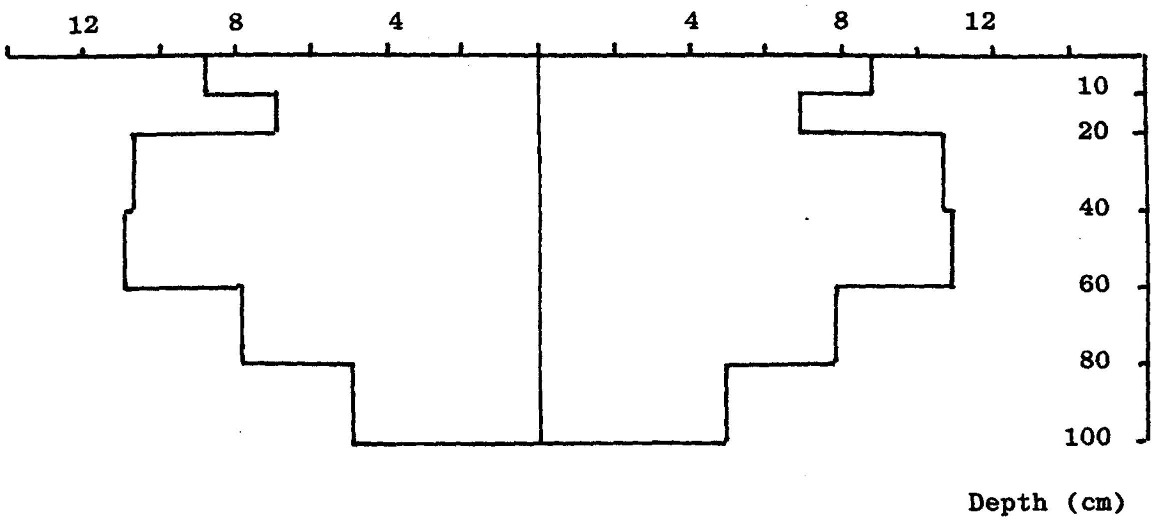
**Fig. 75** The proportion of total root lengths found in various depths down the profile. Roots harvested in June 1983

i Control

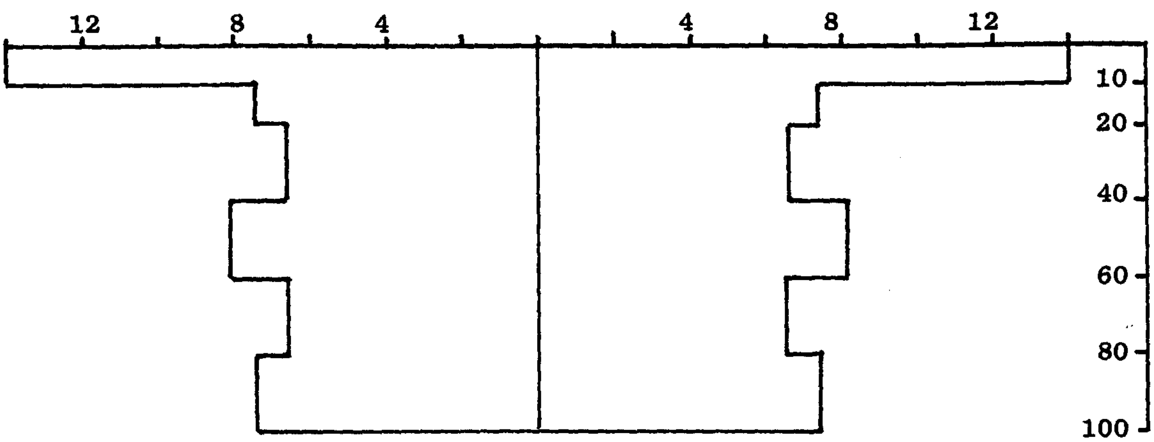
ii 5C¼

iii $GA_3$

(i)


12
8
4
4
8
12
10
20
40
60
80
100
Depth (cm)

(ii)


12
8
4
4
8
12
10
20
40
60
80
100

(iii)

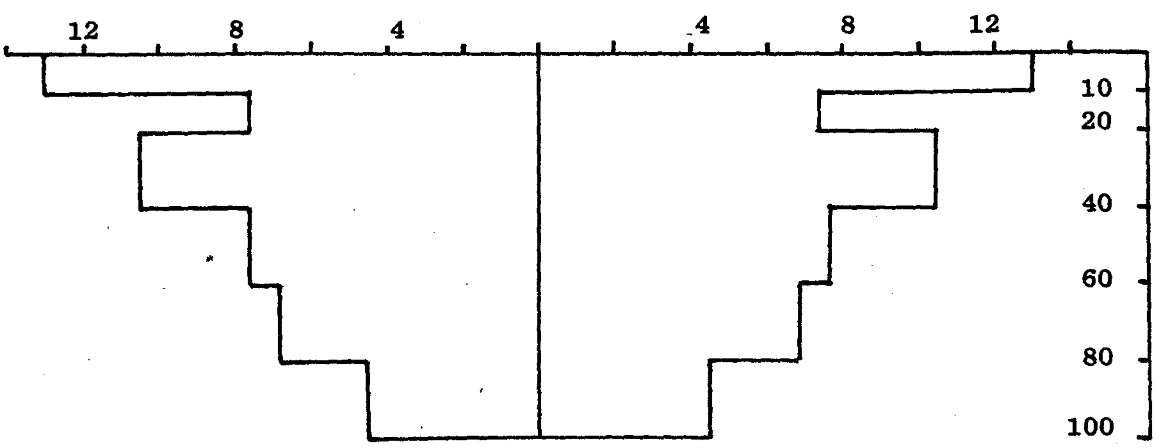
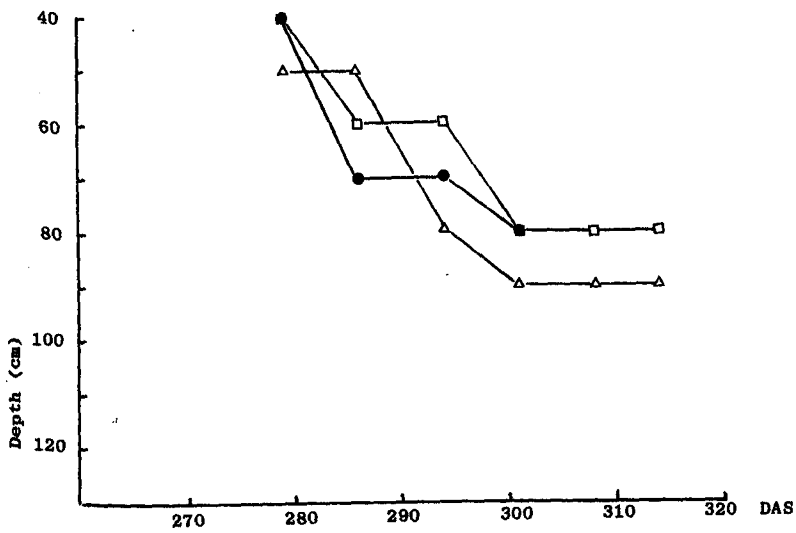

12
8
4
4
8
12
10
20
40
60
80
100

**Fig. 76**

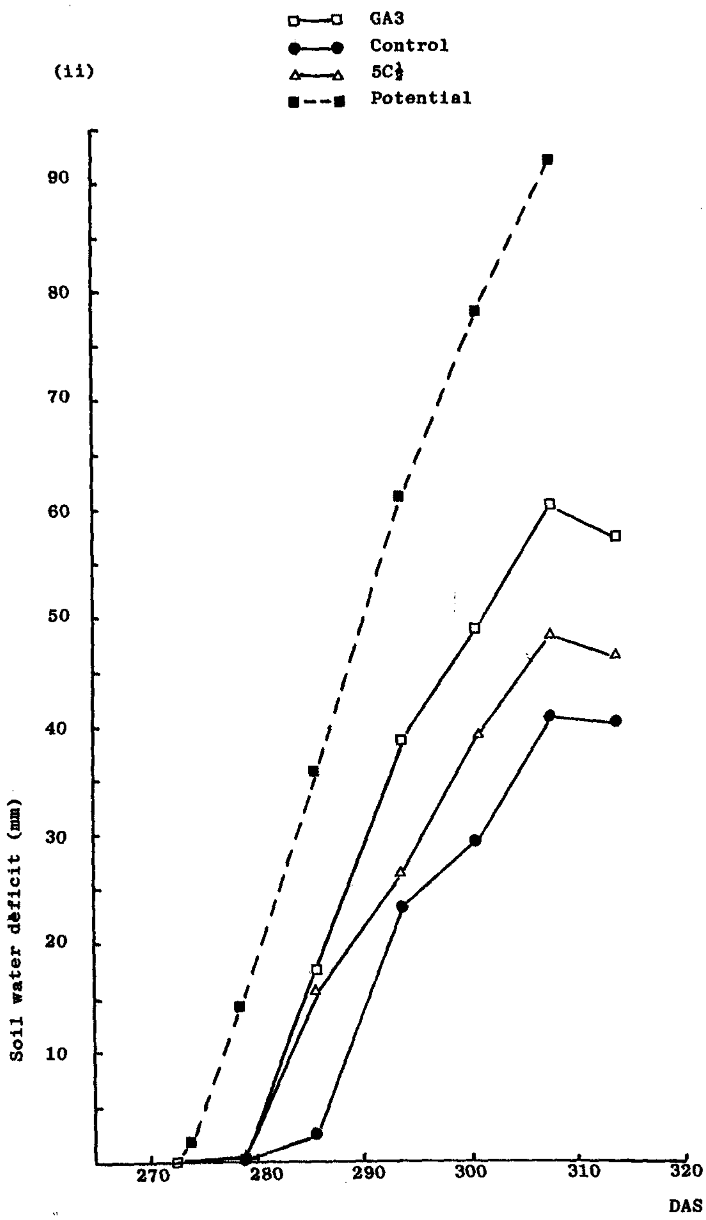
i The effects of PGR treatment on the maximum depth of water extraction

ii The potential and actual soil water deficits from 270 to 315 DAS

(i)


40
60
80
100
120
Depth (cm)
270
280
290
300
310
320
DAS

(ii)


GA3
Control
5C½
Potential
90
80
70
60
50
40
30
20
10
Soil water deficit (mm)
270
280
290
300
310
320
DAS

potential soil water deficit with respect to the beginning of the use of the neutron probe where the soil was assumed to be at field capacity. This potential was compared to the actual deficits measured by the neutron probe.

From the beginning of June soil water deficits started to increase at a rapid and near constant rate at least until the final neutron probe measurement at 314 DAS (Fig. 76).

Throughout the period of observation the potential deficit was greater than the deficit estimated from neutron probe analysis due to the onset of senescence of the cereal crop post-anthesis. As maturity advanced the discrepancy between the potential and actual deficits increased.

### 6.7.3 Soil water deficits in individual soil horizons

A procedure adopted by Gregory et al. (1978) was used to facilitate further analysis of the soil water data collected. The soil was arbitrarily divided up into three broad bands, 0-40, 40-80 and 80-120 cm.

Soil water deficits in individual horizons are shown in Fig. 77 for the three treatments examined. Soil drying proceeded down to the profile from one horizon to the next so that soil water deficits started to accumulate in a lower horizon well before horizons above had attained maximum deficits.

Exploitation of the horizon 0-40 cm began before 280 DAS whilst water removal from the intermediate depth started about 295 DAS. The small amount of deficit that was attained at the lowest depth (80-120 cm) was only initiated from approximately 300 DAS.

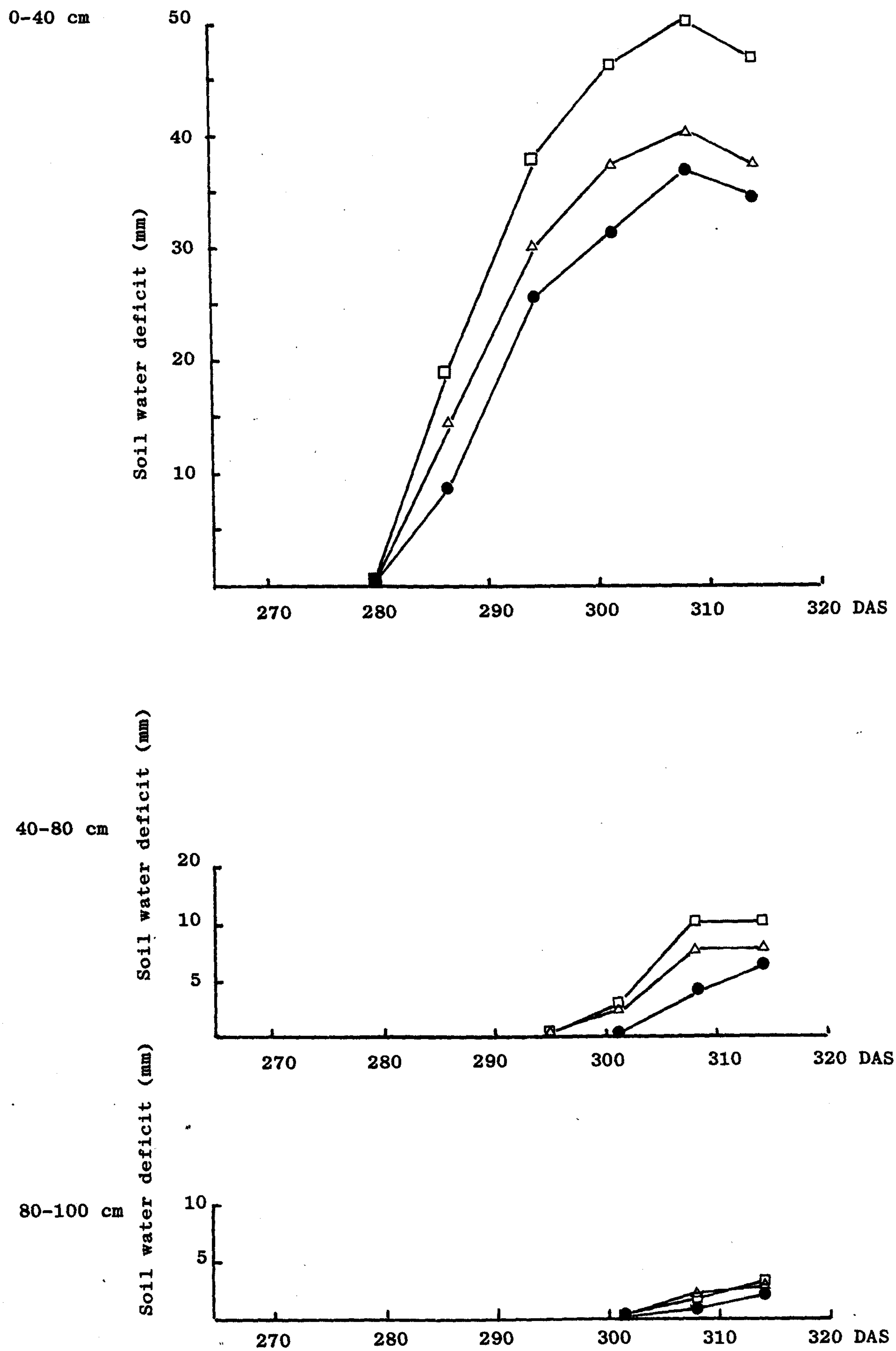
In each division of the horizon the measured soil water deficit (SWD) obtained from the $GA_3$ treated plots was greater than either the 5C Cycocel treatment or the control plots. Thus the increased total soil water deficit found with the $GA_3$ treatments resulted from increased soil water deficits in each of the three horizons.

From 179 DAS differences were evident between treatments in terms of the overall soil water deficits attained. The differences between $GA_3$ and control plants reaching a maximum of 19.5 mm by 308 DAS.

### 6.7.4 Soil water content

Measurements of the soil water content on 31 May (273 DAS) and 11 July (314 DAS) showed no great differences between the treatments

**Fig. 77** The actual soil water deficits in three horizons within the soil profile


0-40 cm
Soil water deficit (mm)
50
40
30
20
10
270
280
290
300
310
320 DAS
40-80 cm
Soil water deficit (mm)
20
10
5
270
280
290
300
310
320 DAS
80-100 cm
Soil water deficit (mm)
10
5
270
280
290
300
310
320 DAS

(Fig. 78). However at the earlier date soil water content was lower in the top 40 cm of the profile in those plots that had had their plants treated with either 5C Cycocel or $GA_3$ than in the control plots. At the later date the $GA_3$ treated plots again had lower soil water contents at depths down to 30 cm. However below 40 cm at both dates no differences were evident in the soil water content throughout the profile. The soil water content in all treatments and at all depths was less at 314 DAS than at 278 DAS.

Fig. 79 shows the changes in soil water content with time for selected depths. For ease of interpretation the curves are vertically displaced on the volumetric water content scale with the initial water content (taken at 273 DAS) of each layer shown at the beginning of each line.

From early June rainfall was below average and soil water content decreased progressively in all soil layers. The quantity of water lost from each layer decreased with depth. McGowan (1974) has shown that when considering soil water contents at any one depth there is an initial gradual loss of water from field capacity. This is followed by an accelerated rate of water loss which has been attributed to extraction of water by plant roots. At all other depths soil water content remains relatively constant for a period before undergoing rapid water loss. At depth in the soil profile there tends to be little change in the water content-time curves indicating that the water content remains constant or in some cases the water content declines gradually during the season. The discontinuity in the water content curves represents the arrival of a drying front associated with root water extraction (McGowan, 1974).

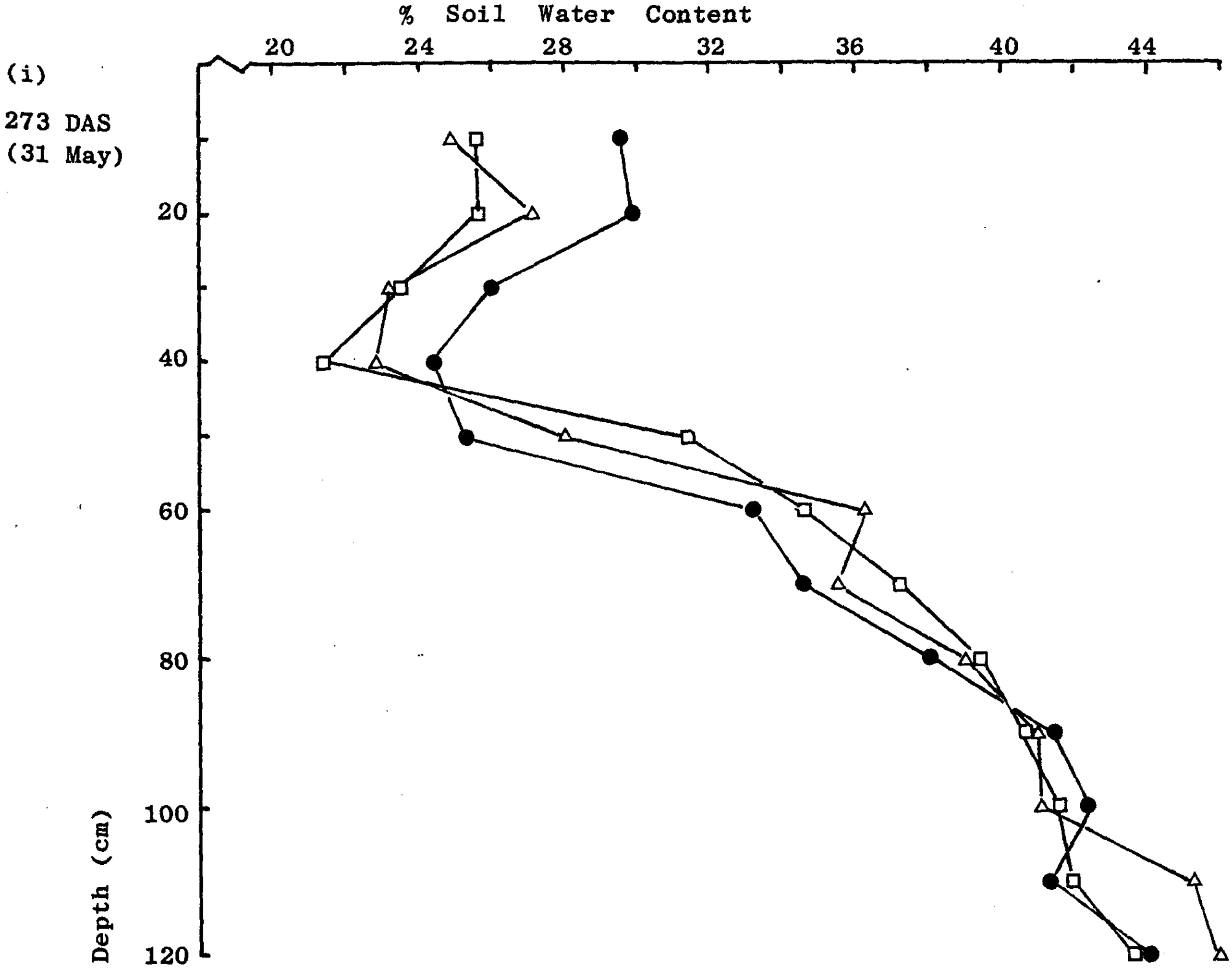
### 6.7.5 Water use efficiency

Plant growth is closely related to transpiration and often the productivity of a crop is expressed in terms of its water use efficiency (WUE). The water use efficiency is defined as the quotient of dry or marketable weight of a crop produced per unit area over the depth of water required in evapotranspiration to produce the crop. The ratio can be expressed in a number of ways. Here the ratio is defined as the amount of water used by evapotranspiration (the largest part of which is lost by transpiration) in producing a unit of crop biomass. The crop produced is to a large extent under the control of man but the evapotranspiration or

**Fig. 78** The percentage soil water content down the soil profile

i 31 May (273 DAS)

ii 11 July (314 DAS)


% Soil Water Content
20
24
28
32
36
40
44
(i)
273 DAS
(31 May)
20
40
60
80
100
120
Depth (cm)

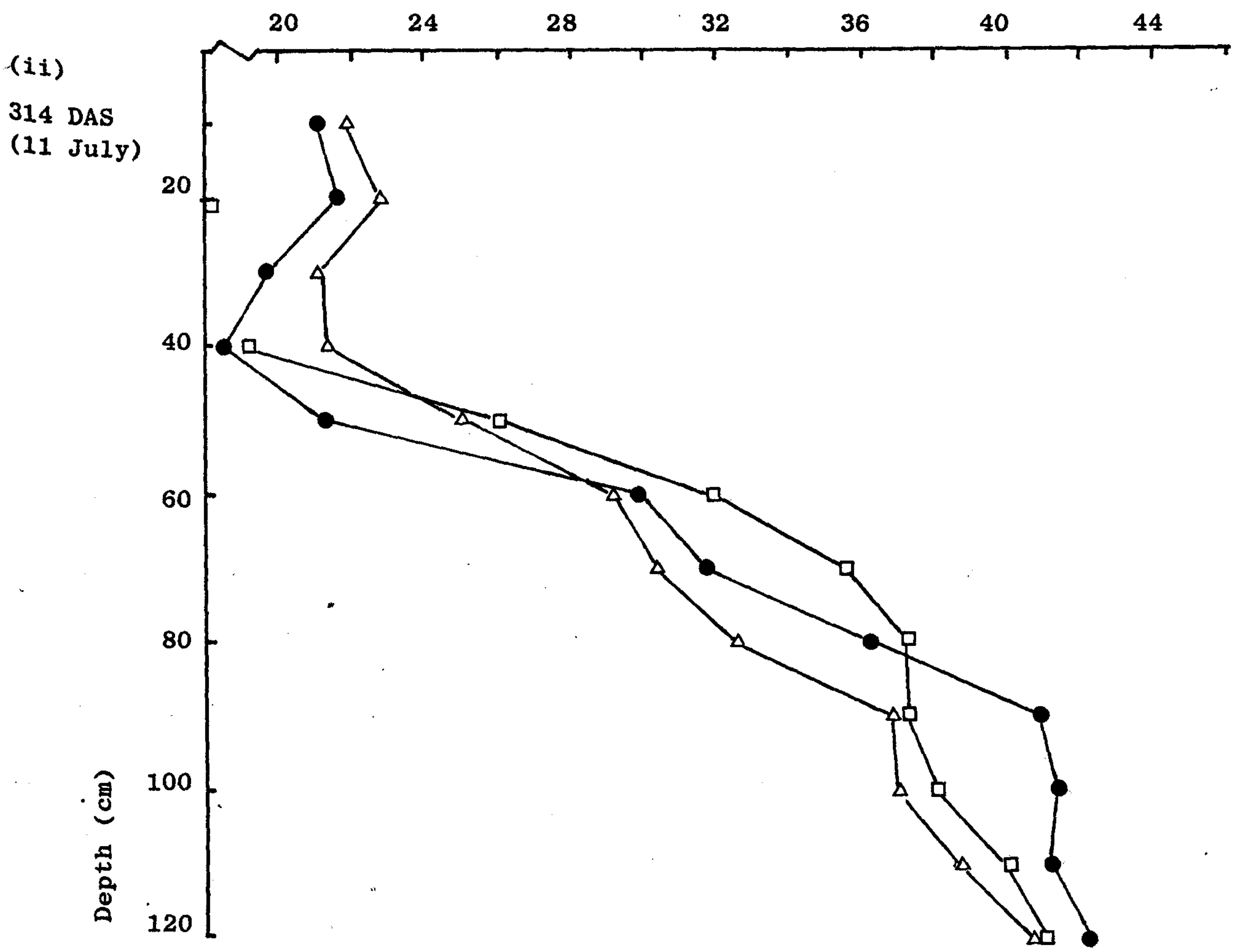
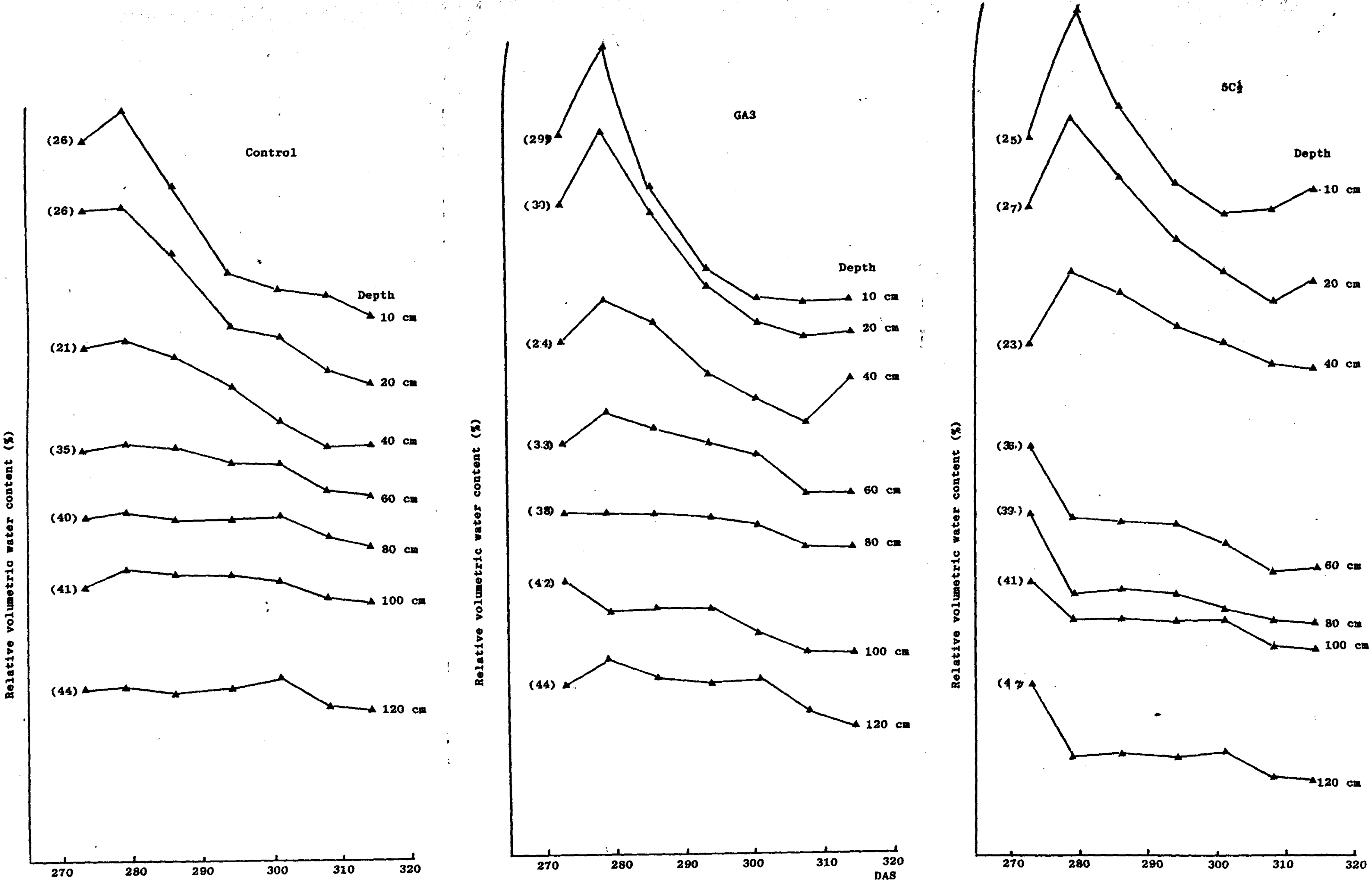

20
24
28
32
36
40
44
(ii)
314 DAS
(11 July)
20
40
60
80
100
120
Depth (cm)

**Fig. 79** The change in soil water content at selected depths measured throughout the growing season. The initial water content of each layer is shown at the start of each line

i $GA_3$

ii Control

iii 5C½


Control
GA3
5C½
Depth
10 cm
20 cm
40 cm
60 cm
80 cm
100 cm
120 cm
(26)
(26)
(21)
(35)
(40)
(41)
(44)
(29)
(30)
(24)
(33)
(38)
(42)
(44)
(25)
(27)
(23)
(35)
(39)
(41)
Relative volumetric water content (%)
270
280
290
300
310
320
DAS

denominator of the equation is dependent on the environmental conditions and on the availability of water.

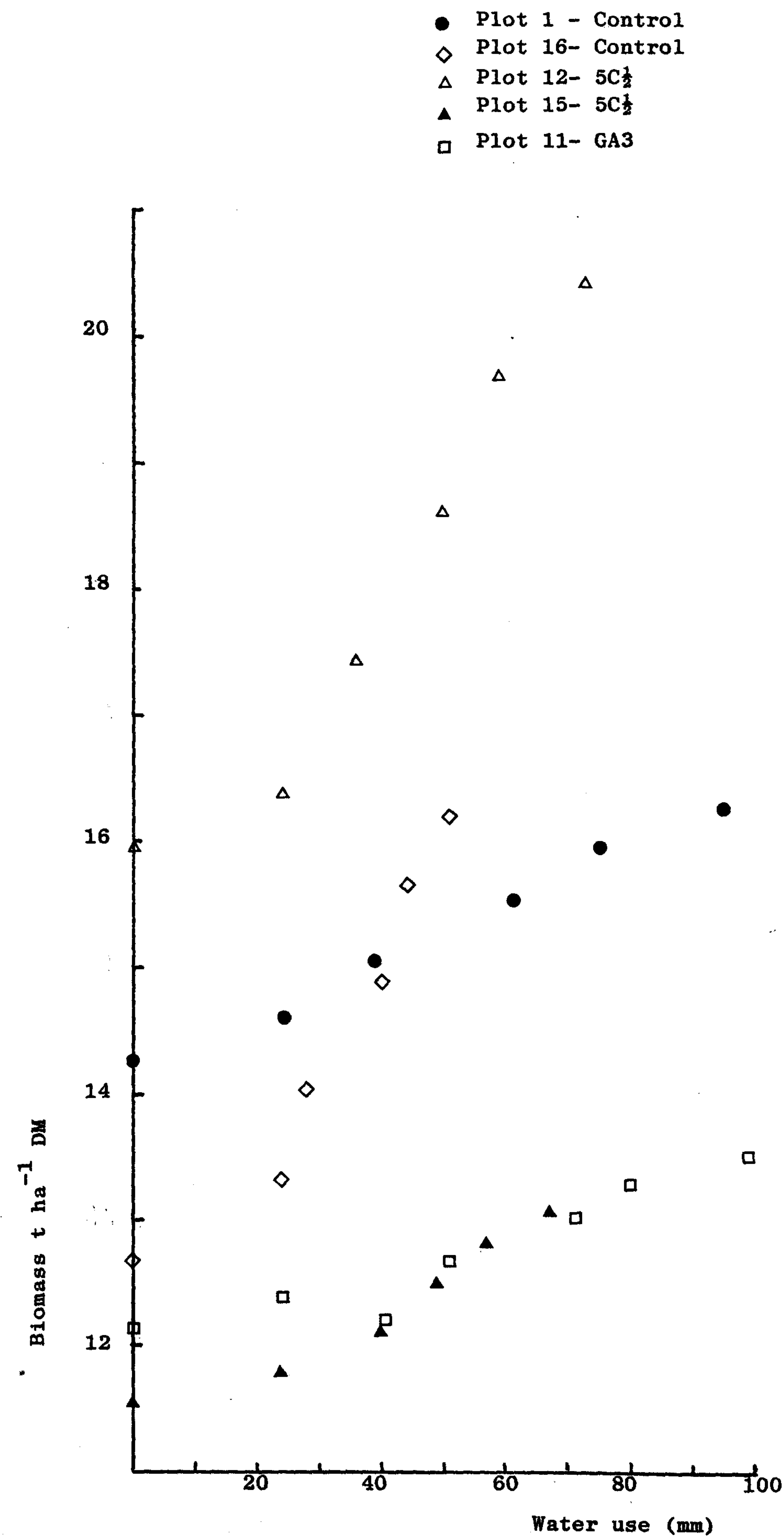
Figs 80 and 81 indicate the water use efficiency from 273 until 308 DAS. Total dry matter production was estimated assuming a linear increase in dry weight between harvest 5 (239 DAS) and final growth analysis harvest at 308 DAS. This takes no account of the loss of material through senescence and the subsequent fall of leaves and non-fertile tillers, thus the biomass values obtained are underestimates of the true values which would thus result in a reduction of the WUE.

Fig. 80 data was derived from the cumulative water deficits and cumulative rainfall figures with the associated dry matter production from each plot. In all plots there was a linear relationship between water useage and the production of dry matter. However inter-plot differences masked any treatment differences. Fig. 81 represents the mean cumulative water deficit and rainfall and the mean biomass accumulation for each treatment averaged over three replicates. Here there was no significant difference in estimated WUE (determined by the slope of the regression line) between the two PGR treatments of 5C½ and $GA_3$. However the mean WUE of the PGR treatments was significantly lower than that of the control plants (2.36 compared to 4.82 for the PGR and control treatments respectively).

Many workers (e.g. Viets, 1962; 1965; Hanks & Rasmussen, 1982; Tanner & Sinclair, 1983; Wilson, Jamieson, Jermyn & Hanson, 1985) have investigated the relationships between crop growth and water use. Most have shown that crop dry matter production was related linearly to water use efficiency or transpiration efficiency where evapotranspiration was divided into its two components. Thus Wilson et al. (1985) argued that crop dry matter production could not be increased without using more water in transpiration as the conditions required for the achievement of maximum yield are the same as for maximum water use. Hence improved WUE can be achieved by lowering the proportion of total evapotranspiration caused by water evaporation from the soil and removing the water loss caused by the transpiration of non-productive plants.

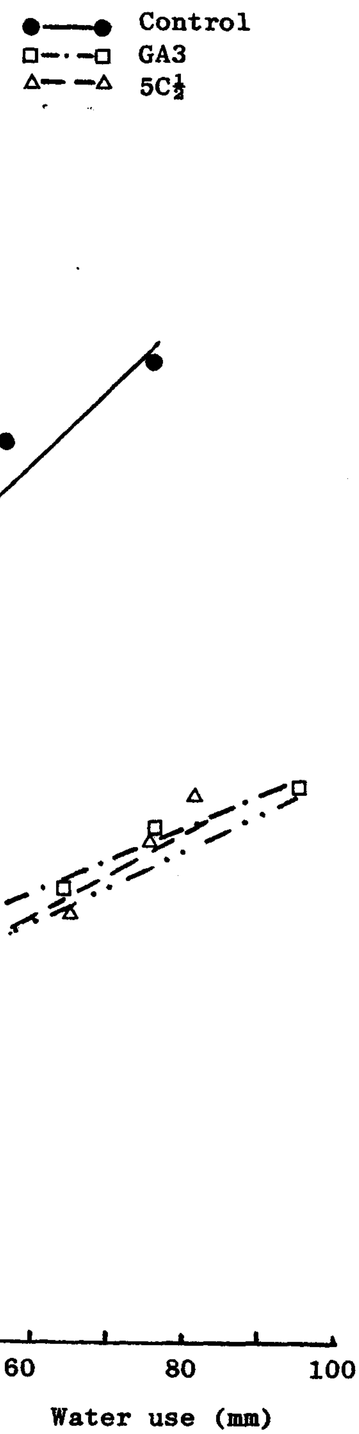
Conflicting reports of the effects of CCC on the rooting of cereal plants have been published (e.g. De, Giri, Saran, Singh & Chaturvedi, 1982). Cooke, Hoad & Childs (1983) have shown that the effects of CCC were dependent upon both the environment and the variety. However little

**Fig. 80** Water use efficiency : comparison between different plots



Plot 1 - Control
Plot 16- Control
Plot 12- 5C½
Plot 15- 5C½
Plot 11- GA3
20
18
16
14
12
Biomass t ha$^{-1}$ DM
20
40
60
80
100
Water use (mm)

**Fig. 81** Pooled water use and pooled dry matter production for each treatment




Control $y = 1384\ (\pm 21) + 4.818\ (\pm 0.469)\ x$

GA3 $y = 1263\ (\pm 6.5) + 2.112\ (\pm 0.141)x$

5C½ $y = 1209\ (\pm 27.5) + 2.711\ (\pm 0.471)x$

(GA3 and 5C½ combined:) $y = 1228\ (\pm 15.4) + 2.362\ (\pm 0.232)x$

information is available upon the effects of CCC (or indeed other regulatory chemicals) on the WUE of cereals.

In a recent study on the effects of autumn applied 5C Cycocel on Igri Green and Dawkins (1985) have reported that chlormequat significantly reduced LAI due to smaller individual leaves whilst not influencing leaf number. However green canopy persistence was improved by chlormequat application which also increased leaf laxity. It was suggested that an increase in leaf area duration by CCC treatment caused a concomitant increase in the transpiration losses of the crop which at this time constitute a major component of crop evapotranspiration. However Wilson et al. (1985) stated that the conditions required for the attainment of maximum yield are the same as for maximum water use. Thus the increased water use associated with CCC should have been related to an increase in yield. However no data for water use when related to grain yield was presented. Grain yield of cereal crops are closely related to the amount of total dry matter produced as the harvest index is not systematically related to yield (Biscoe, 1979; McLaren, 1981; Gallagher & Biscoe, 1978).

A linear relationship exists between the rate of biomass production in barley and the amount of solar radiation absorbed by the foliage (Gallagher & Biscoe, 1978; Monteith & Elston, 1983). However incident radiation per unit area does not vary significantly between neighbouring sites and season (Monteith, 1978) thus biomass yield is dependent upon:

i) Canopy size,
ii) distribution and orientation of the canopy, and
iii) efficiency of conversion of irradiance into crop dry matter.

(Green & Dawkins, 1985)

Thus CCC application has been shown to influence the growth and development of Igri winter barley (Chapters 3 and 4) and canopy orientation of this cultivar (Green & Dawkins, 1985). However there is limited information on the conversion efficiency of absorbed irradiance into biomass. Thus although the constancy of mean seasonal efficiency of conversion has been noted by Monteith and Elston (1983) the application of

CCC may cause modifications in this efficiency which could subsequently lead to a reduction in biomass production which, when coupled with the manipulation of growth and development and leaf orientation by CCC application, may be sufficient to significantly alter the efficiency of water use in the production of dry matter.

### 6.7.6 Root distribution — the effects on water uptake

Root growth patterns of field grown crops usually reflect soil conditions more than crop genetics (Portas, 1973; Russell, 1977) and variation in moisture suuply is frequently the major cause of differences in root growth (Reicosky, Millington, Klute & Peters, 1972). Root distribution determines to a large extent soil water availability and also the pattern of water extraction (Allmaras, Nelson & Voorhees, 1975). Relatively small differences in root density in the deeper layers of the soil can cause large differences in water extraction (Chaudhary & Bhatnagar, 1980) as the younger roots in the deeper soil layers are stated to have higher water uptake efficiencies (Taylor & Klepper, 1973; Stone, Nickell & Mayaki, 1976).

In WB6 from the beginning of June the upper soil layers were dry thus a major portion of the transpired water must have been supplied from the region of higher water content in the lower portion of the root zone. The extent to which this would meet the transpirational demands would depend upon the number and area of the roots present and the environmental conditions influencing transpiration (Chaudhary & Bhatnagar, 1980). Thus as the soil dried out down the profile water was extracted by the roots from lower depths. Thus any modification of rooting, either total or distribution, by PGR application may alter the water uptake by the roots and thus may modify soil water availability to the plants.

In Figs 73 and 74 it was noted that autumn applications of PGRs modified the proportional root distribution within the soil profile with both monitored PGR treatments increasing the percentage of roots within the upper layers of the soil and reducing the percentage of roots present within the 20-80 cm layers. Thus reduction of rooting at depth may influence the water extraction from low levels within the soil profile.

### 6.7.7 Plant growth characteristics

6.7.7.1 Plant number Neither plant number at establishment nor final plant number was significantly affected by the PGR treatments employed. Final plant number was equivalent to approximately 67% of those seeds sown per unit area (data not presented for plant numbers).

6.7.7.2 Tillering Throughout growth the total number of tillers per plant did not differ significantly between PGR treatments (Fig. 82). The control plots of Tipper again showed a flattened tiller production curve with maximum tiller number per plant not exceeding four.

6.7.7.3 Biomass production Due to the environmental conditions prevailing in the autumn and winter plant dry weight increased rapidly and reached approximately 2 t $ha^{-1}$ DM by the beginning of 1983. Throughout the growing season there were no significant differences between the three treatments presented in the dry matter accumulation (Fig. 82).

6.7.7.4 Harvest indices The distribution of biomass between the grain and the straw and chaff differed between PGR treatments with the subsequent harvest indices being influenced (Fig. 83). The Fh of $GA_3$ treated plots being significantly greater than that achieved by the control plots. Spring application of 5C Cycocel was the only PGR treatment to cause a reduction in Fh.

Harvest indices were very low in experiment WB6 with the maximum mean Fh being less than 34% ($GA_3$) and the minimum mean Fh being less than 20% (5C Cycocel spring application).

### 6.7.8 Grain yield and yield components

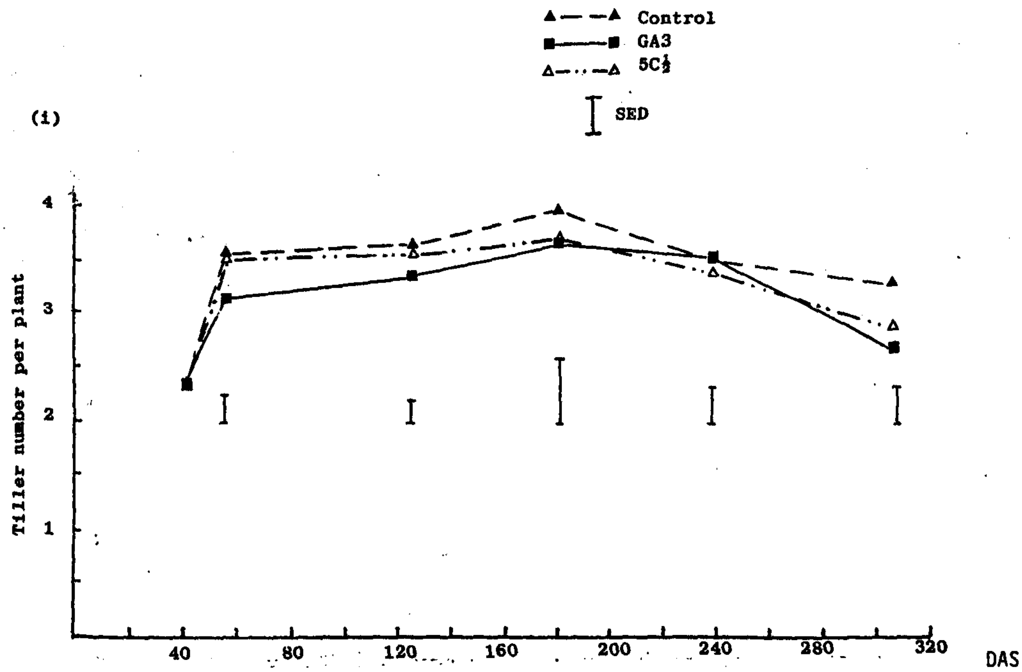
Table 42 illustrates the grain yield and yield components of the PGR treated crops. A significant reduction occurred in the grain yield of $GA_3$ treated crops compared to the untreated control. This yield reduction was caused by a reduction in all the principal yield components compared to the control. The other PGR treatments did not significantly differ from the control in their yield components. Grain yield, excluding that of the $GA_3$ treated plots, was between 6.19 and 6.75 t $ha^{-1}$ DM.

**Fig. 82**

i The effect of PGR treatment on the number of tillers per plant

ii The effect of PGR treatment on above ground biomass yields

(i)


Control
GA3
5C½
SED
Tiller number per plant
4
3
2
1
40
80
120
160
200
240
280
320
DAS

(ii)

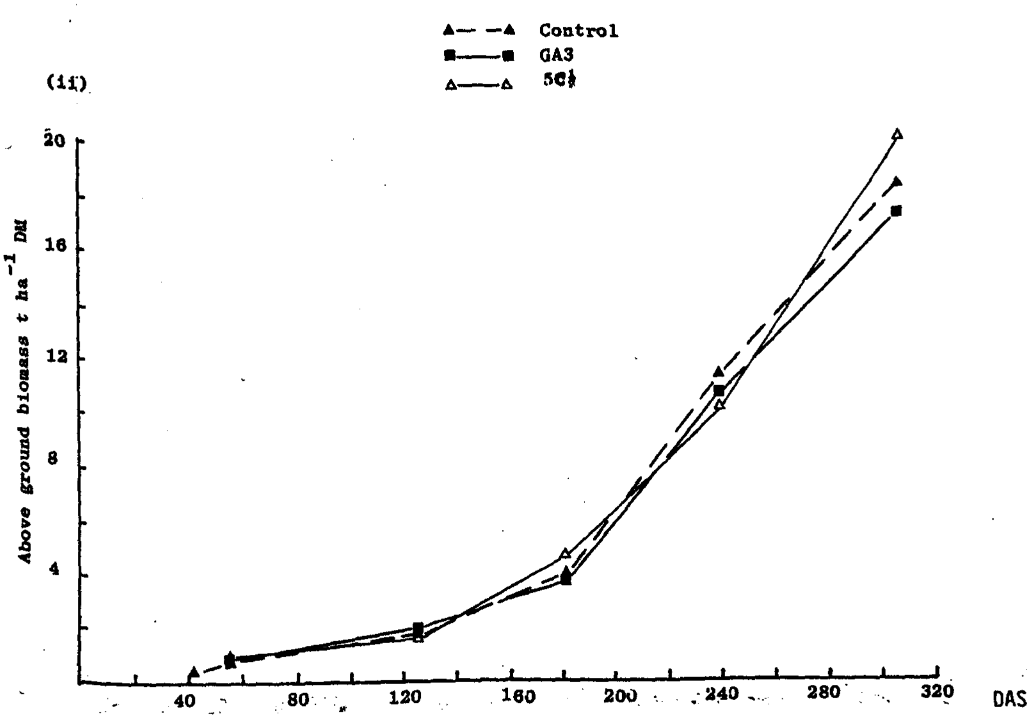

Control
GA3
5C½
Above ground biomass t ha$^{-1}$ DM
20
16
12
8
4
40
80
120
160
200
240
280
320
DAS

**Fig. 83** The influence of PGR treatments on

- i Mean Fh
- ii Remainder Fh and main stem Fh
- iii Grain yield
- iv Straw yield

<u>Key:</u>

1 Control

2 5C¼

3 Cerone

4 5C½

5 5C Sp

6 $GA_3$

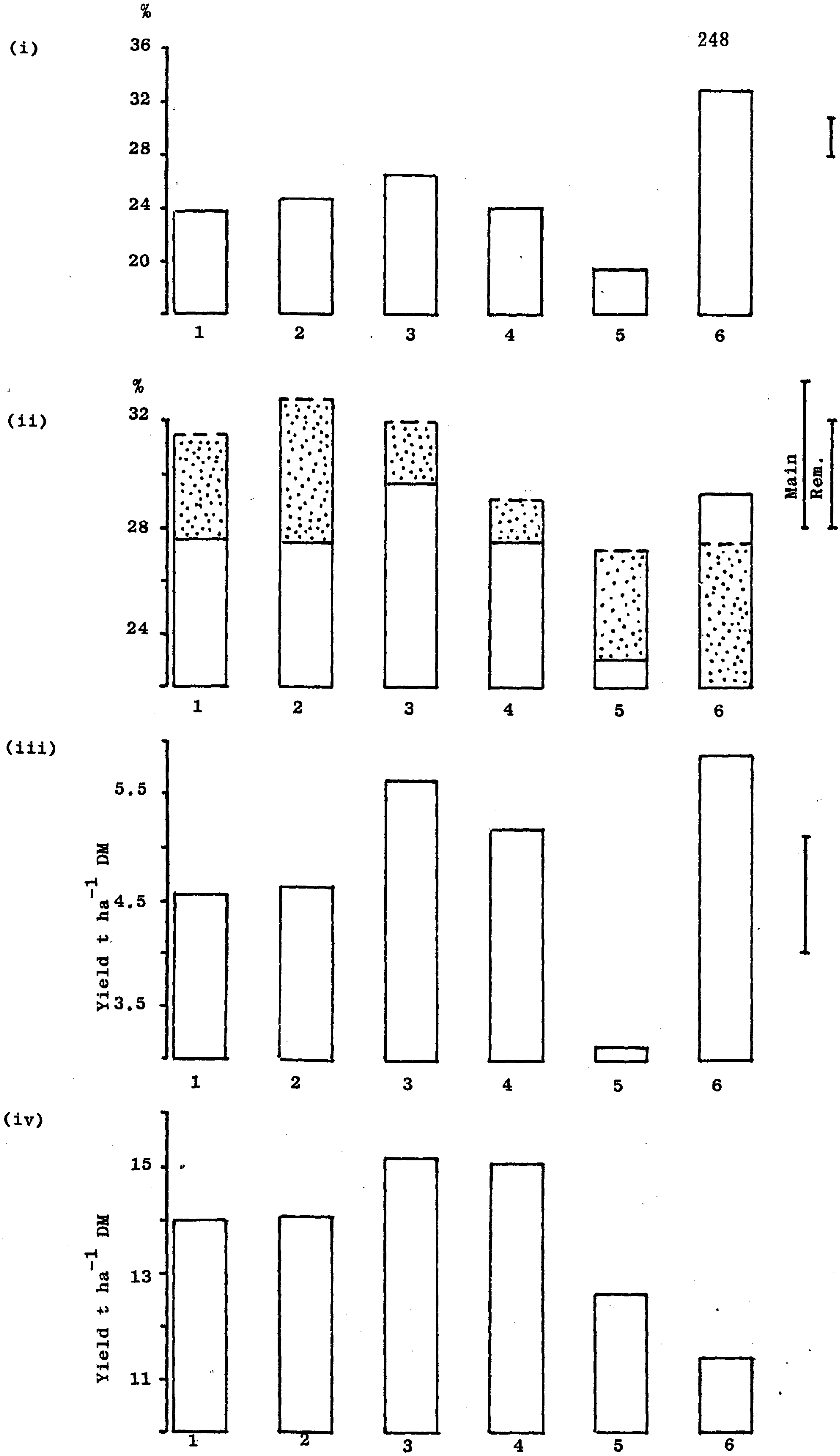

(i)
%
36
32
28
24
20
1
2
3
4
5
6
(ii)
%
32
28
24
Main
Rem.
(iii)
Yield t ha$^{-1}$ DM
5.5
4.5
3.5
(iv)
15
13
11

***Table 42*** *The influence of PGR treatments on grain yield and yield components of the variety Tipper*

| | Control | 5C¼ | Cerone | 5C½ | 5C Sp | $GA_3$ | SED (10Df) |
|---|---|---|---|---|---|---|---|
| Yield estimated from combine harvested sample | 6.51 | 6.38 | 6.75 | 6.19 | 6.71 | 5.46 | 0.22 |
| Ears $m^{-2}$ | 928 | 980 | 1080 | 795 | 940 | 822 | 108.1 |
| Grains $ear^{-1}$ main | 36.9 | 33.0 | 32.4 | 32.8 | 33.8 | 31.4 | 1.54 |
| Grains $ear^{-1}$ T1 | 33.5 | 29.0 | 31.5 | 28.4 | 31.9 | 31.6 | 1.6 |
| Grains $ear^{-1}$ T2 | 32.0 | 28.0 | 30.7 | 29.0 | 29.6 | 28.2 | 2.22 |
| TGW (g) main | 22.9 | 24.9 | 23.3 | 27.2 | 16.9 | 18.9 | 5.93 |
| TGW (g) T1 | 24.4 | 24.8 | 23.8 | 28.0 | 19.8 | 22.1 | 5.86 |
| TGW (g) T2 | 24.9 | 25.4 | 22.3 | 28.3 | 21.5 | 20.3 | 8.14 |
| TGW (g) T3 | 23.7 | 25.6 | 21.3 | 21.5 | 21.5 | 17.8 | 9.00 |
| Fh % main | 31.5 | 32.8 | 32.0 | 29.1 | 27.2 | 27.4 | 5.56 |
| Ave MC % | 15.3 | 17.1 | 15.5 | 15.3 | 15.0 | 15.9 | 0.55 |

6.7.8.1 Grain number per ear In general grain number per ear declined from the mainstem ear to T1 and again to T2 (Table 42). In all stem categories the grain number per control ear was greater than that of the ears from PGR treated plots. The ranking of treatments in their number of grains per ear was not consistent in the three tiller categories monitored.

6.7.8.2 Thousand grain weight TGW for all treatments and for all tiller categories was low with the maximum TGW being 27.2 g (Table 42). No consistent decline in grain weight was noted from the main ear to the T3 ear. No significant differences between treatments were evident in any of the monitored tiller categories.

6.7.8.3 The relationships between grain yield and yield components As in Section 4.2.9 grain yield components were examined in terms of their effects on final grain yield. As only three replicates of each treatment were present no clear indication of the differences between PGR treatments were considered possible in the correlations between individual yield components or yield components and yield. The number of degrees of freedom (Df) used is defined to be the number of pairs of values used to calculate the coefficient minus 2. Here Df was further reduced by the presence of missing values in the data.

The correlation matrix for experiment WB6 is illustrated in Table 43. The following figures represent the relationships between yield components and also between specified yield components and grain yield.

Unlike WB5 grain yield was more closely related to ear number per plant (Fig. 84) than to grain number per unit area (Fig. 84) where no significant correlation occurred. The final plant density significantly influenced the number of ears $m^{-2}$ with an extra 100 ears $m^{-2}$ being produced for an increase in plant numbers of 50 $m^{-2}$ at least within the range 200-375 plants $m^{-2}$ (Fig. 84).

There was again no significant relationship between final plant number and grain yield per unit area (Fig. 84). The number of paired values available (18) does not allow the conclusion to be drawn that high plant numbers would be required to reduce the variability of grain yield. However, unlike WB5 (Section 4.2.9), final plant numbers were only in the range 220 to 380 plants $m^{-2}$.

**Table 43** *Correlation matrix WB6 1982/83*

| Factor | No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Plant no. $m^{-2}$ | 1 | 1.00 | | | | | | | | |
| Ears $m^{-2}$ | 2 | 0.55 ● x | 1.00 | | | | | | | |
| Ears $Plant^{-1}$ | 3 | -0.42 ns | 0.52 ns | 1.00 | | | | | | |
| Yield t $ha^{-1}$ | 4 | 0.03 ● ns | 0.57 x | 0.62 ● x | 1.00 | | | | | |
| Yield g $m^{-2}$ | 5 | 0.03 ns | 0.57 x | 0.62 x | 1.00 | 1.00 | | | | |
| Grain no. $m^{-2}$ | 6 | 0.17 ns | 0.13 ns | -0.03 ns | -0.11 ns | -0.11 ns | 1.00 | | | |
| Average grain no. (main) | 7 | 0.15 ns | -0.02 ns | 0.24 ns | -0.47 ns | -0.47 ns | 0.19 ns | 1.00 | | |
| TGW | 8 | -0.17 ns | 0.14 ns | 0.25 ns | 0.38 ns | 0.38 ns | -0.91 ● xxx | -0.46 ns | 1.00 | |
| Biomass | 9 | 0.20 ns | 0.29 ns | 0.11 ns | 0.39 ● ns | 0.39 ns | -0.66 ● xx | 0.13 ns | 0.66 ● xx | 1.00 |
| | No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

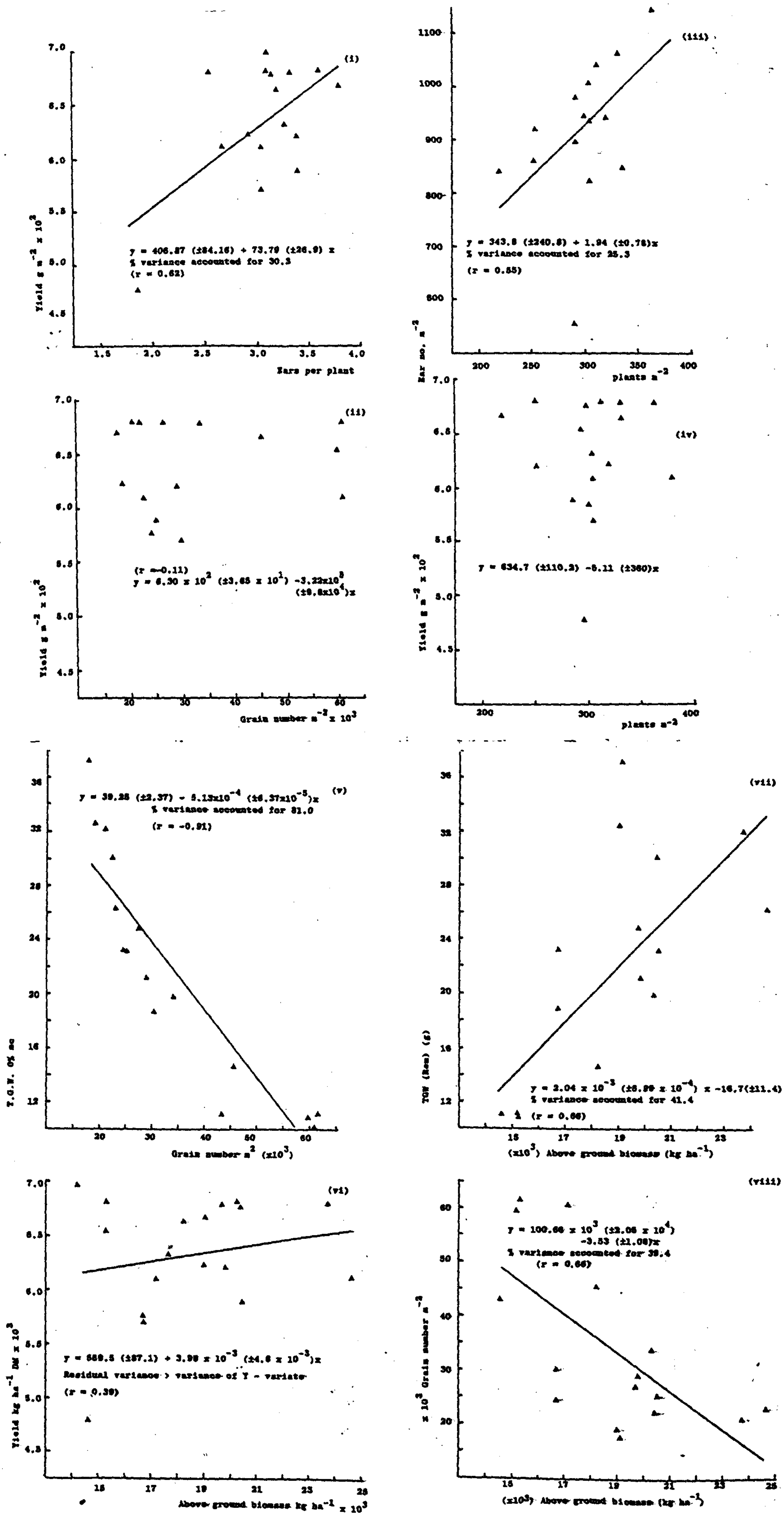
Df = 12

Asterisks signify significance levels
e.g. x= $P< 0.05$, xx= $P< 0.01$,
xxx= $P< 0.001$, ns = not significant

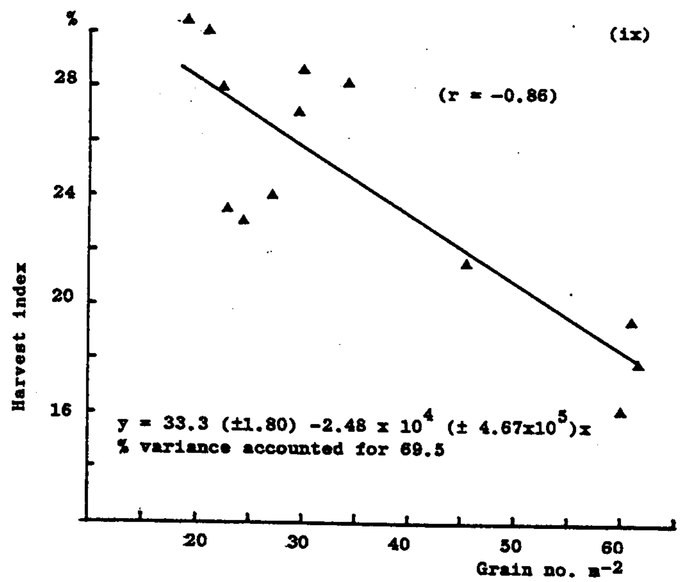
● indicates illustrated relationships

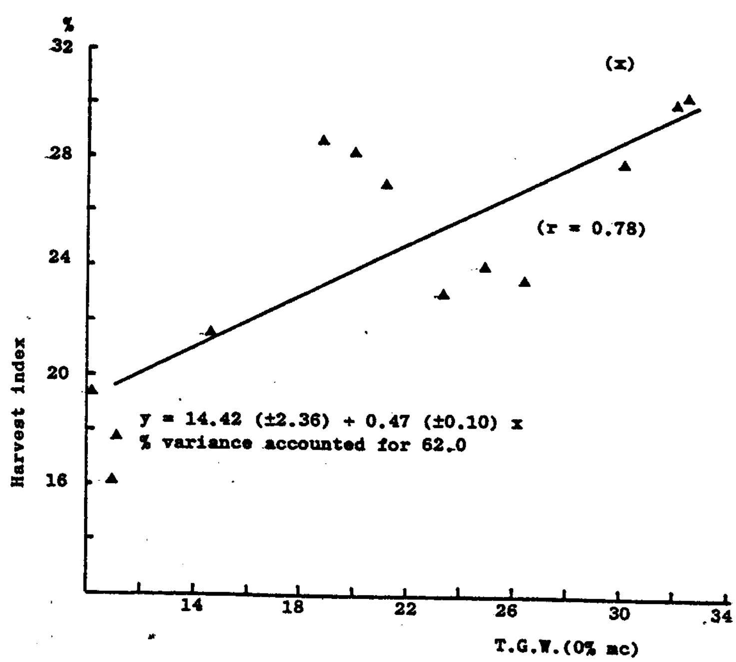
**Fig. 84** The influence of:

| | |
|---|---|
| i | Ear number per plant on grain yield |
| ii | Grain number per ear on grain yield |
| iii | Plant number $m^{-2}$ on ear number $m^{-2}$ |
| iv | Plant number $m^{-2}$ on grain yield $m^{-2}$ |
| v | Grain number $m^{-2}$ on TGW |
| vi | Biomass yield on grain yield |
| vii | Biomass yield on TGW |
| viii | Biomass yield on grain number $m^{-2}$ |
| ix | Grain number $m^{-2}$ on Fh |
| x | TGW on Fh |



(i)
y = 406.87 (±84.16) + 73.79 (±26.9) x
% variance accounted for 30.3
(r = 0.62)
Yield g m-2 x 10^2
Ears per plant
(iii)
y = 343.8 (±240.8) + 1.94 (±0.78)x
% variance accounted for 25.3
(r = 0.55)
Ear no. m-2
plants m-2
(ii)
(r = -0.11)
y = 6.30 x 10^2 (±3.65 x 10^1) -3.22x10^3 (±9.8x10^4)x
Yield g m-2 x 10^2
Grain number m-2 x 10^3
(iv)
y = 634.7 (±110.3) -6.11 (±360)x
Yield g m-2 x 10^2
plants m-2
(v)
y = 39.28 (±2.37) - 5.13x10^-4 (±6.37x10^-5)x
% variance accounted for 81.0
(r = -0.91)
T.G.W. 0% mc
Grain number m2 (x10^3)
(vii)
y = 2.04 x 10^-3 (±6.99 x 10^-4) x -16.7(±11.4)
% variance accounted for 41.4
(r = 0.66)
TGW (Res) (g)
(x10^3) Above ground biomass (kg ha-1)
(vi)
y = 569.5 (±87.1) + 3.99 x 10^-3 (±4.6 x 10^-3)x
Residual variance > variance of Y - variate
(r = 0.39)
Yield kg ha-1 DM x 10^3
Above ground biomass kg ha-1 x 10^3
(viii)
y = 100.66 x 10^3 (±2.06 x 10^4)
-3.53 (±1.08)x
% variance accounted for 39.4
(r = 0.66)
x 10^3 Grain number m-2
(x10^3) Above ground biomass (kg ha-1)


(ix)
(r = -0.86)
y = 33.3 (±1.80) -2.48 x 10^4 (± 4.67x10^5)x
% variance accounted for 69.5
Harvest index
%
28
24
20
16
20
30
40
50
60
Grain no. m-2


(x)
(r = 0.78)
y = 14.42 (±2.36) + 0.47 (±0.10) x
% variance accounted for 62.0
Harvest index
%
32
28
24
20
16
14
18
22
26
30
34
T.G.W.(0% mc)

Thousand grain weight of the seed sample was linearly related to grain number $m^{-2}$. A reduction of approximately 2.6 TGW occurring for an increase in 5000 grains $m^{-2}$ (Fig. 84).

In experiment WB5 it was argued that for increases in grain yield a high above ground biomass was required due to the relative stability of the total biomass that is partitioned into grain. However in WB6 there was no significant linear relationship between above ground biomass and yield (Fig. 84).

Biomass did not significantly influence the number of ears per unit area produced (data not presented) but an increase in crop biomass did result in a reduction in grain number per unit area and a concomitant increase in TGW (Fig. 84). The effects of these two factors which are strongly negatively correlated are that yield is not modified by an increase in total crop biomass.

Harvest index was not significantly related to plant number or to grain yield but mean harvest index was significantly related to TGW (Fig. 84) ($r = 0.78$) and to grain number per unit area (Fig. 84) ($r = 0.86$). Mean harvest index ranged from 16 to 31% in this trial, a wider range than previously reported (Section 4.2.9) and below that usually expected for a winter barley crop.

The non-significant relationships between above ground biomass and grain yield and between grain yield and grain numbers per unit area may have been due to the lodging of the crop at the time of anthesis. This may have caused the high potential (i.e. the high grain number) to have been incompletely realised. Brackling and lodging of the crop prior to and immediately after anthesis may have caused poor translocation of pre-anthesis stored assimilates from the stem to the ear. Lodging of the crop caused the ears to be removed from their optimum position for interception of radiation and caused mutual shading of ears. Thus the lodged crop resulted in the yield components partially determined after anthesis (i.e. TGW) being reduced in mean weight due to source limitation. Potential sink size (i.e. number of grains per unit area) was determined prior to anthesis with absolute sink size being determined at anthesis. Thus a small proportion of those structures classified as grains at final harvest may have been non-pollinated grains. This would result in a high number of grains per unit area being recorded but a lower estimated TGW of those grains present. Self fertilization is usual in barley but not inevitable (Briggs, 1978). The horizontal orientation of the ears at anthesis may have hindered self fertilization and would severely reduce any exchange of pollen in that small proportion of ears or grains that were cross pollinated (pers. comm. T.C.K. Dawkins, 1984).

Lodging of cereal crops disrupts the water uptake by the plants. Water stress can be caused by severe bending of the stems and hence reduced water and mineral uptake. This would result in accelerated senescence of the crop. As grain fill depends partially on photosynthesis of the ear structures, peduncle and flag leaf post anthesis any reduction in green area duration would limit the production of assimilates necessary for grain filling to occur to its optimum level thus satisfying sink capacity.

6.7.8.4 Seed size distribution In all PGR treatments the majority of all sampled seeds were between 2.5 and 2.8 mm in size (Fig. 85). No significant differences occurred between PGR treatments in the percentage of seeds in any of the four size categories. In all cases there were proportionally more seeds (when assessed by number) in the lowest size category ($<$2.2 mm) than in the largest category ($>$2.8 mm).

6.7.8.5 Grain nitrogen content and HWE PGR treatments did not cause the grains to differ in their percentage nitrogen contents or in their estimated hot water extract values (Table 44).

6.7.8.6 Thousand grain weight In all cases TGW values were low with the maximum values being obtained from5C Cycocel autumn treatments and the lowest value from the spring application of the same chemical (Table 44).

6.7.8.7 Germination test and seedling weight No significant differences occurred between the PGR treatments in the percentage germination of seeds tested six weeks after harvest. In all cases the percentage germination was above 95% (Table 44).

PGR treatments did not significantly influence the weight of seedlings removed from the germination test medium at the termination of the test.

**Fig. 85** The effect of PGR treatment on seed size distribution by weight (---) and by number (—)

| | |
|---|---|
| i | Control |
| ii | 5C¼ |
| iii | Cerone |
| iv | 5C½ |
| v | 5C Sp |
| vi | $GA_3$ |

Key:

a = $>$ 2.8 mm

b = 2.5 - 2.8 mm

c = 2.2 - 2.5 mm

d = $<$ 2.2 mm

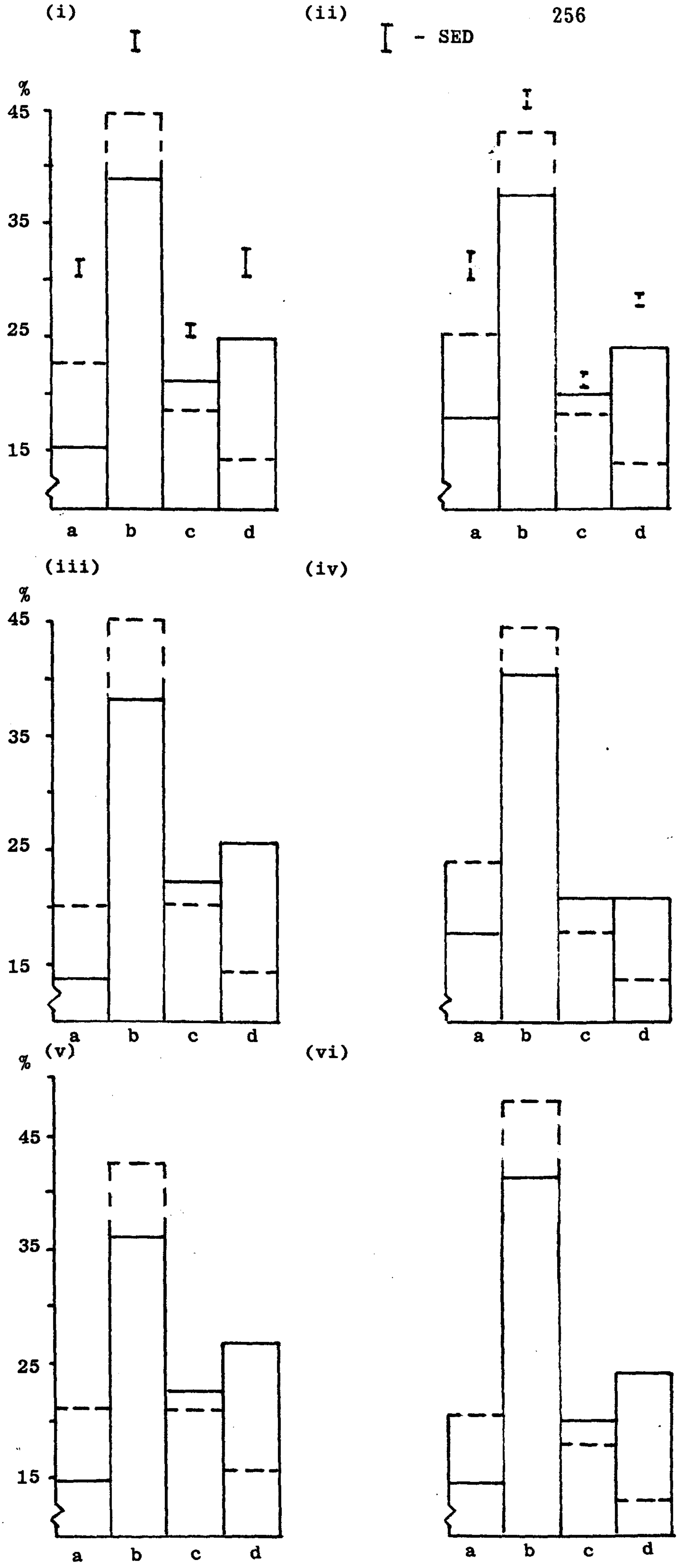

(i)
(ii)
I - SED
%
45
35
25
15
a
b
c
d
(iii)
(iv)
(v)
(vi)

**Table 44** The effects of applied plant growth regulators on grain characteristics, germination percentages and resultant seedling weights

| | Control | 5C¼ | Cerone | 5C½ | 5C Sp | $GA_3$ | SED (10Df) |
|---|---|---|---|---|---|---|---|
| Grain nitrogen % | 2.5 | 2.4 | 2.5 | 2.5 | 2.4 | 2.5 | 0.14 |
| HWE | 273.8 | 274.6 | 274.2 | 273.2 | 275.1 | 272.7 | 1.73 |
| TGW (main) 0% MC | 22.9 | 24.9 | 23.3 | 27.2 | 16.9 | 18.9 | 5.93 |
| Germination % | 96.5 | 95.3 | 97.3 | 97.0 | 95.2 | 95.7 | 1.57 |
| Arc-sine transformed germination data | 79.34 | 78.05 | 80.78 | 80.05 | 77.51 | 78.28 | 1.56 |
| Weight per 100 seedlings (g) | 2.25 | 2.66 | 2.54 | 2.37 | 2.35 | 2.51 | 0.18 |

### 6.7.9 Grain growth

Milthorpe and Moorby (1974) described the growth of cereal grains after fertilization as sigmoidal. Sofield, Evans and Wardlaw (1974) later introduced a linear approximation of grain weight increases. This proposed model has been subsequently used by Gallagher et al. (1975) and Green, Dawkins and McDonald (1984).

Thus final individual grain weight is equal to initial grain weight at anthesis plus the product of mean duration of grain filling and mean rate of grain filling.

Thus variations in final grain weight could arise from any of the three components of grain growth listed above.

Unlike work by Gallagher and Biscoe (1978) and Green et al. (1984) no phase of reduced grain growth was evident for 10-12 days after anthesis prior to the commencement of rapid grain filling (Evans et al., 1975). Thus one linear relationship was fitted from anthesis until the peak grain weight was reached (Fig. 86). This fitted line usually accounted for over 90% of the variance. Initial weight was taken as that occurring at anthesis. This accounted for between 10 and 22% of the final grain weight agreeing with the 15% estimated by Gallagher and Biscoe (1978) for both Huntsman winter wheat and Proctor spring barley.

Results show that the increase in ear dry weights per day did not differ between PGR treatments (Table 45). However this difference in dry weight increase per ear was confounded by the variable number of grains present upon each ear.

As grain number per ear was not measured at each ear growth harvest date it was assumed that grain number was constant after anthesis. Grain number present at final harvest was thus taken to be constant throughout grain filling.

Maximum ear dry weight differed between PGR treatments. This again may have been grain number dependent.

Ear filling duration was estimated as the time from anthesis to the attainment of a constant ear weight thus giving the final phase of grain growth a horizontal plateau of zero slope but of an intercept equivalent to final grain weight (Gallagher & Biscoe, 1978). Ear filling duration was estimated to be 30-32 days depending upon PGR treatments.

**Fig. 86** Main ear growth patterns for barley treated with various PGRs in comparison with an untreated control

| | |
|---|---|
| i | Control |
| ii | 5C¼ |
| iii | Cerone |
| iv | 5C½ |
| v | 5C Sp |
| vi | $GA_3$ |

Key:

A = initial grain weight at anthesis

B = maximum grain weight

C = final grain weight

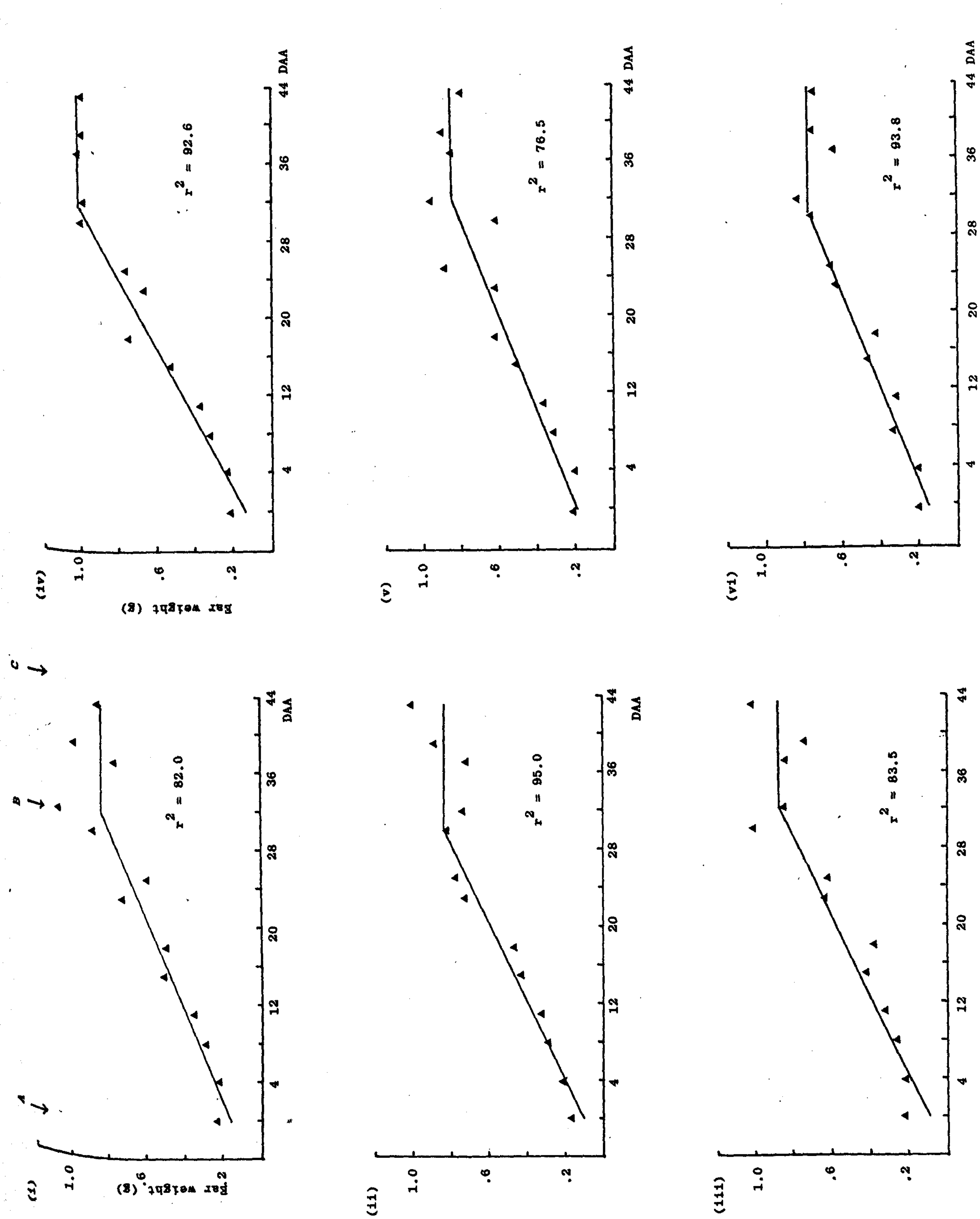

(i)
(ii)
(iii)
(iv)
(v)
(vi)
Ear weight (g)
1.0
.6
.2
4
12
20
28
36
44
DAA
A
B
C
$r^2$ = 82.0
$r^2$ = 95.0
$r^2$ = 83.5
$r^2$ = 92.6
$r^2$ = 76.5
$r^2$ = 93.8

**Table 45** *Main ear grain growth — WB6*

*The influence of PGR treatments on grain growth (mg/day), duration and TGW*

| | Ear weight anthesis (g) | Ear weight increase $day^{-1}$ (slope) | Ear weight maximum (g) | Grain fill duration (d) | Correlation coefficient r (linear mid section) | Ear growth (g/day) | Grain no. ear (main) | Estimated grain growth (mg/day) | Estimated TGW (g) | TGW from hand harvested samples |
|---|---|---|---|---|---|---|---|---|---|---|
| Control | 0.1647 $\pm$ 0.0437 | 0.0214 $\pm 2.48 \times 10^{-3}$ | 0.84 | 32 | 0.96 | 0.0214 | 36.9 | 0.58 | 23.02 | 22.9 |
| 5C¼ | 0.1133 $\pm$ 0.0343 | 0.0241 $\pm 1.95 \times 10^{-3}$ | 0.84 | 30 | 0.98 | 0.0241 | 33.0 | 0.73 | 25.33 | 24.9 |
| Cerone | 0.0945 $\pm$ 0.0698 | 0.0243 $\pm 3.56 \times 10^{-3}$ | 0.88 | 32 | 0.92 | 0.0243 | 32.4 | 0.75 | 26.92 | 23.3 |
| 5C½ | 0.1409 $\pm$ 0.0272 | 0.0272 $\pm 2.56 \times 10^{-3}$ | 1.00 | 32 | 0.97 | 0.0272 | 32.8 | 0.83 | 30.85 | 27.2 |
| 5C Sp | 0.1875 $\pm$ 0.0684 | 0.0201 $\pm 3.87 \times 10^{-3}$ | 0.84 | 32 | 0.89 | 0.0201 | 33.8 | 0.59 | 24.43 | 16.9 |
| $GA_3$ | 0.1580 $\pm$ 0.0196 | 0.0196 $\pm 1.77 \times 10^{-3}$ | 0.76 | 30 | 0.97 | 0.0196 | 31.4 | 0.60 | 23.03 | 18.9 |

Estimated grain growth per day was calculated from ear weight increases per day and grain number per ear. Thus individual grain growth was estimated to range from 0.58 mg $d^{-1}$ (control) to 0.83 mg $d^{-1}$ (5C½) (Table 45).

Green et al. (1984) worked with similar rates of autumn applied 5C Cycocel on the variety Igri. They found that the rate of grain growth during the mid phase of growth (equivalent to the linear phase reported here) was reduced by autumn chlormequat applications but the duration of grain filling was extended by 10 days. However this increase in time of grain filling was not sufficient to completely compensate for the reduction in growth rate induced by chlormequat application and thus resulted in a lower final grain weight (Green et al., 1984).

However no evidence of increased duration of grain filling was evident in experiment WB6. Differences between treatments for rates of ear growth were small, however when grain numbers per ear were considered all PGR treatments enhanced the rate of grain filling above that of the control with the 5C½ treatment improving the grain growth to a greater extent. Consistency in grain filling duration with an increase in rate of grain filling resulted in an increased mean grain weight from the 5C½ treatment.

## 6.8 Introduction to PGR2

A previous experiment (Section 6.1) showed that varieties differed in their responses to PGR applications. This may have been related to the tillering capacities of the different varieties. Thus suppression of tillers, for example by modifying the sowing density, may alter the effects of an applied PGR.

Interactions between applied nitrogen fertilizer and the PGRs Cycocel and Terpal (an aqueous solution containing 305 g $l^{-1}$ Mepiquat Chloride + 155 g $l^{-1}$ Ethephon) have been noted (Herbert, 1983). These interactions occurred under severe lodging conditions or when nitrogen levels or some other factor had given rise to stress conditions in the crop.

High plant density may, under certain circumstances, be considered to exert stress upon the plant stand. High plant density may reduce stem diameter and weight, grain number per ear and individual grain weight. High density crops have also been shown to be more prone to lodging than those of lower densities (Kirby & Faris, 1972).

Thus the objective of this trial was to investigate the effects of sowing density, PGR treatment and their possible interactions in the growth, development and final yield of the winter barley variety Fenella.

## 6.9 Materials and Methods

Experiment PGR2 was conducted in field 2 of the University of Nottingham farm at Sutton Bonington on soils of the Arrow series consisting of coarse, loamy fluvial drift overlying Keuper marl at about 1 metre depth (Hebblethwaite & McGowan, 1977). The variety used in this experiment was Fenella from Nickerson RPB Ltd. Drilling took place on 1 November 1981. All field husbandry treatments are outlined in Table 5.

Density treatments imposed were of 200, 400 and 600 seeds sown $m^{-2}$. This density range was equivalent to that employed in experiment WB5 (Chapter 4). Two chemical PGRs were investigated. These were Cerone (containing 480 g $l^{-1}$ 2-Chloroethyl phosphonic acid (Squires et al., 1980)), applied at the rate of 1 l $ha^{-1}$ product in 225 l $H_2O$, and New 5C Cycocel, an aqueous solution containing 644 g $l^{-1}$ chlormequat chloride with added choline chloride, applied at 0.23 kg ai $ha^{-1}$. This was applied in 225 l $H_2O$. The rate of application for Cycocel was similar to that applied in experiment PGR1 (Section 6.1). Plots were sprayed on 17 February 1982 when less than 3 tillers per plant had been produced.

## 6.10 Results

### 6.10.1 Preamble

No significant interactions between plant density and PGR applications were shown in any parameter measured in this trial.

The two PGRs applied produced few significant modifications in crop growth and development and no significant differences in the grain yield obtained at final harvest.

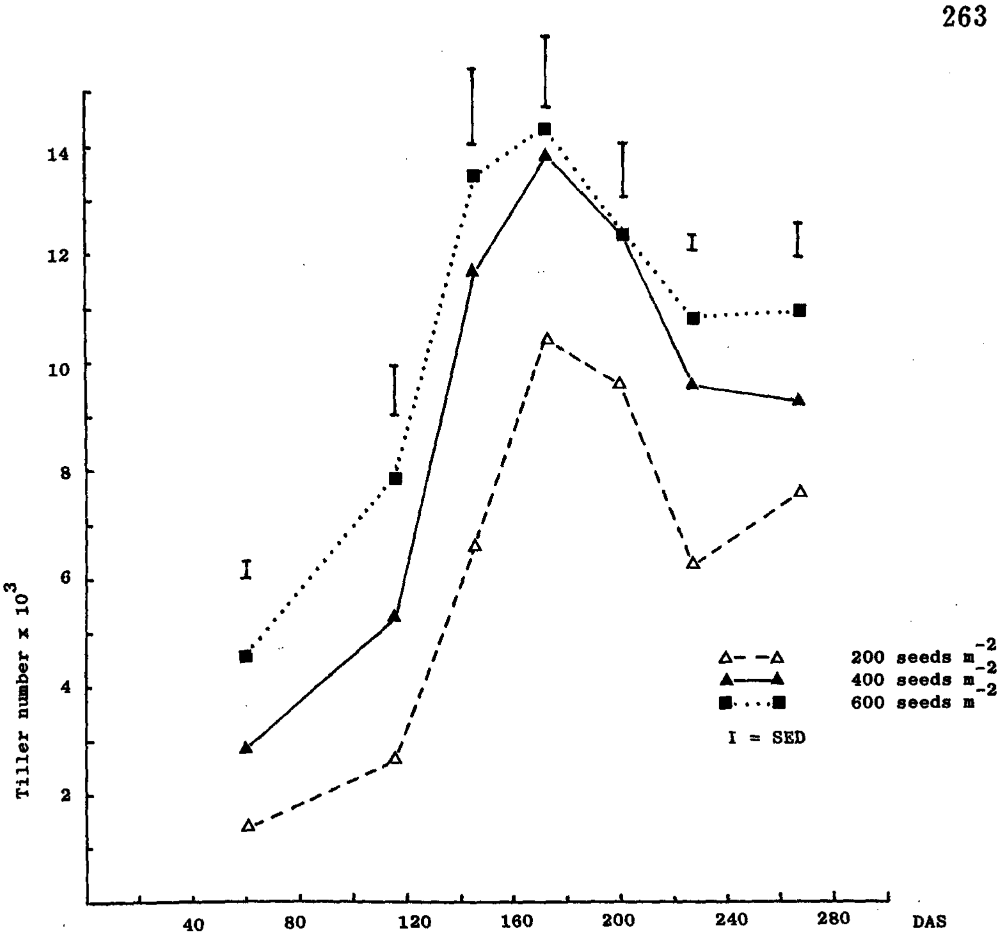
### 6.10.2 Tiller number

Significant differences occurred between initial sowing densities in the number of tillers produced per unit area (Fig. 87). At all times throughout growth the ranking of initial densities for their production of

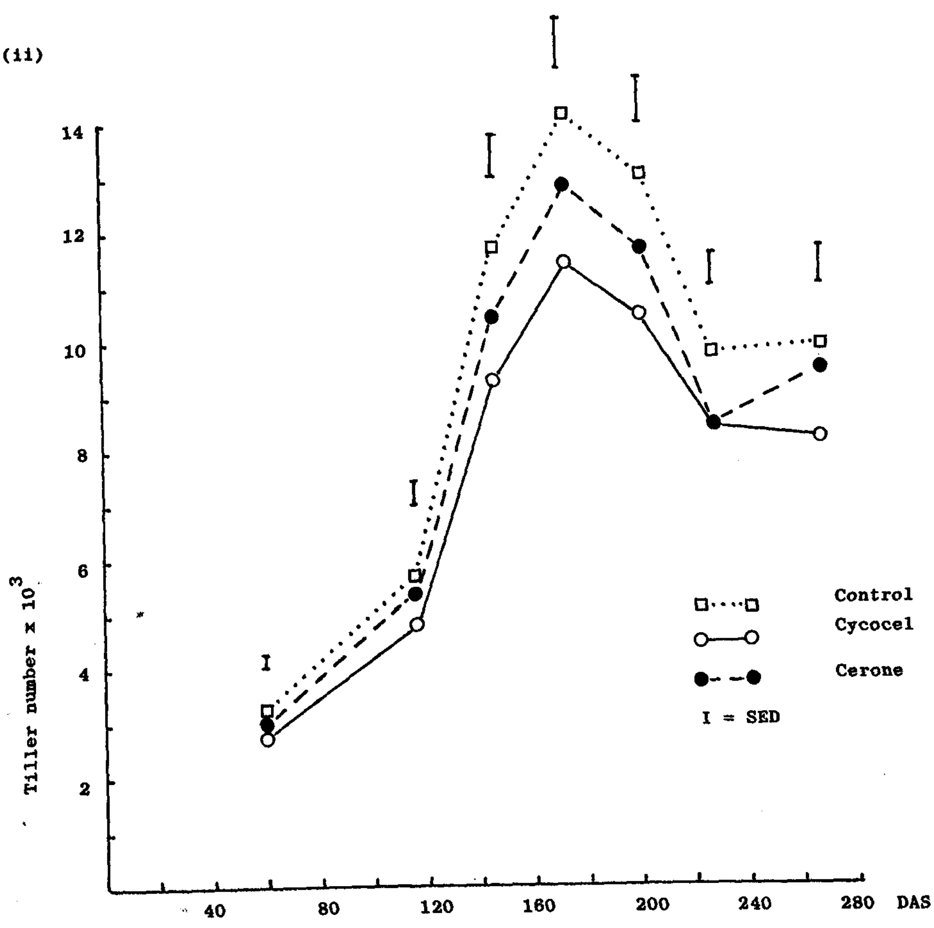
**Fig. 87** The effect of i Plant density and
ii PGR treatment

on the number of tillers $m^{-2}$ throughout growth

(i)


Tiller number x $10^3$
14
12
10
8
6
4
2
40
80
120
160
200
240
280
DAS
200 seeds $m^{-2}$
400 seeds $m^{-2}$
600 seeds $m^{-2}$
I = SED

(ii)


Tiller number x $10^3$
14
12
10
8
6
4
2
40
80
120
160
200
240
280
DAS
Control
Cycocel
Cerone
I = SED

tillers $m^{-2}$ remained constant with the highest density producing the highest number of tillers $m^{-2}$. When considered on a tiller number per plant basis low initial seed densities produced a greater number of tillers per plant. All densities reached their peak tiller number at a similar time of approximately 173 DAS after which time tiller number declined.

No significant differences were noted between the PGR treatments and the control in the number of tillers produced per unit area (Fig. 87), although in general Cycocel produced a lower maximum tiller number.

### 6.10.3 Area

Green area indices throughout growth were not significantly influenced by PGR treatments (data not presented).

High sowing density enhanced early leaf cover compared to that achieved by the low density treatments (Fig. 88). Prior to peak GAI there were significant differences between the 200 and 600 seeds $m^{-2}$ sowing densities. These differences were maintained post peak GAI although the differences were statistically non-significant.

### 6.10.4 Biomass

No significant differences occurred between PGR treatments in the biomass accumulation throughout growth and development.

Significant differences occurred between initial sowing densities in the biomass at specified times during growth (Fig. 88). Prior to stem extension high sowing density treatments had significantly higher biomass values than low density treatments.

No decline in biomass was noted prior to the termination of this experiment (Fig. 88). This may have been due to the long period (40 days) between the penultimate and the final harvest in which no estimates of above ground biomass were taken.

The earlier attainment of peak biomass with the high density treatment may have been attributable to the earlier onset of lodging and brackling experienced at this density.

### 6.10.5 Seed characteristics

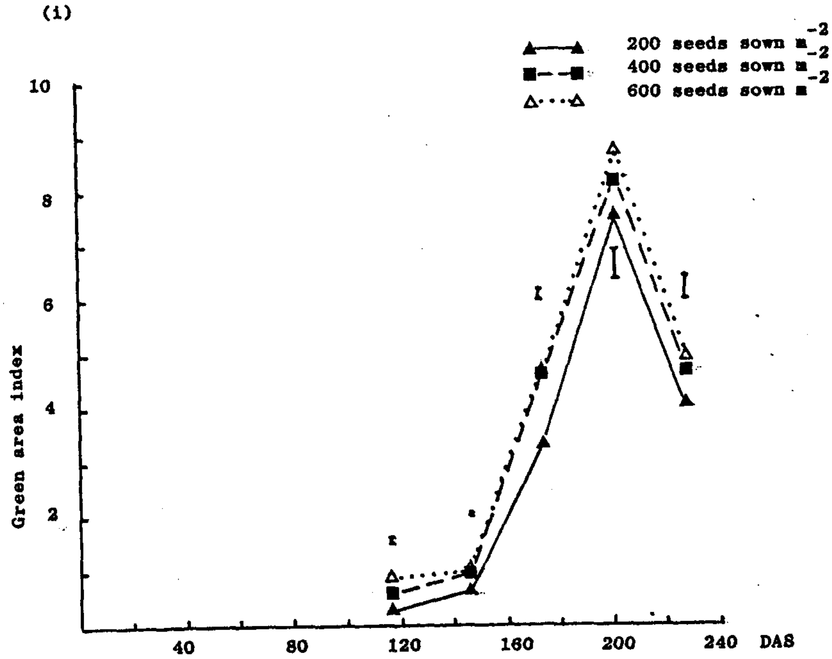
6.10.5.1 Seed size distribution Increased density resulted in an alteration of the seed size distribution within the variety Fenella (Fig. 89). As

**Fig. 88** The effect of plant density on

i GAI

ii Above ground biomass

(i)


200 seeds sown m-2
400 seeds sown m-2
600 seeds sown m-2
Green area index
10
8
6
4
2
40
80
120
160
200
240
DAS

(ii)

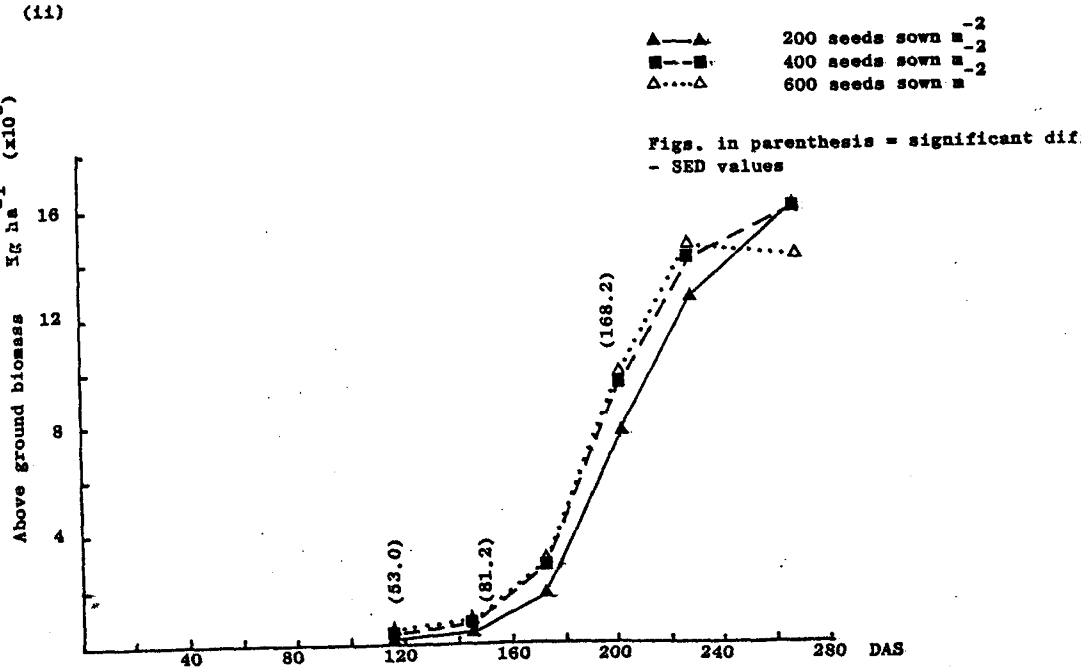

200 seeds sown m-2
400 seeds sown m-2
600 seeds sown m-2
Figs. in parenthesis = significant diff
- SED values
Above ground biomass Kg ha-1 (x10 3)
16
12
8
4
(53.0)
(81.2)
(168.2)
40
80
120
160
200
240
280
DAS

**Fig. 89** The influence of initial sowing density on seed size distribution

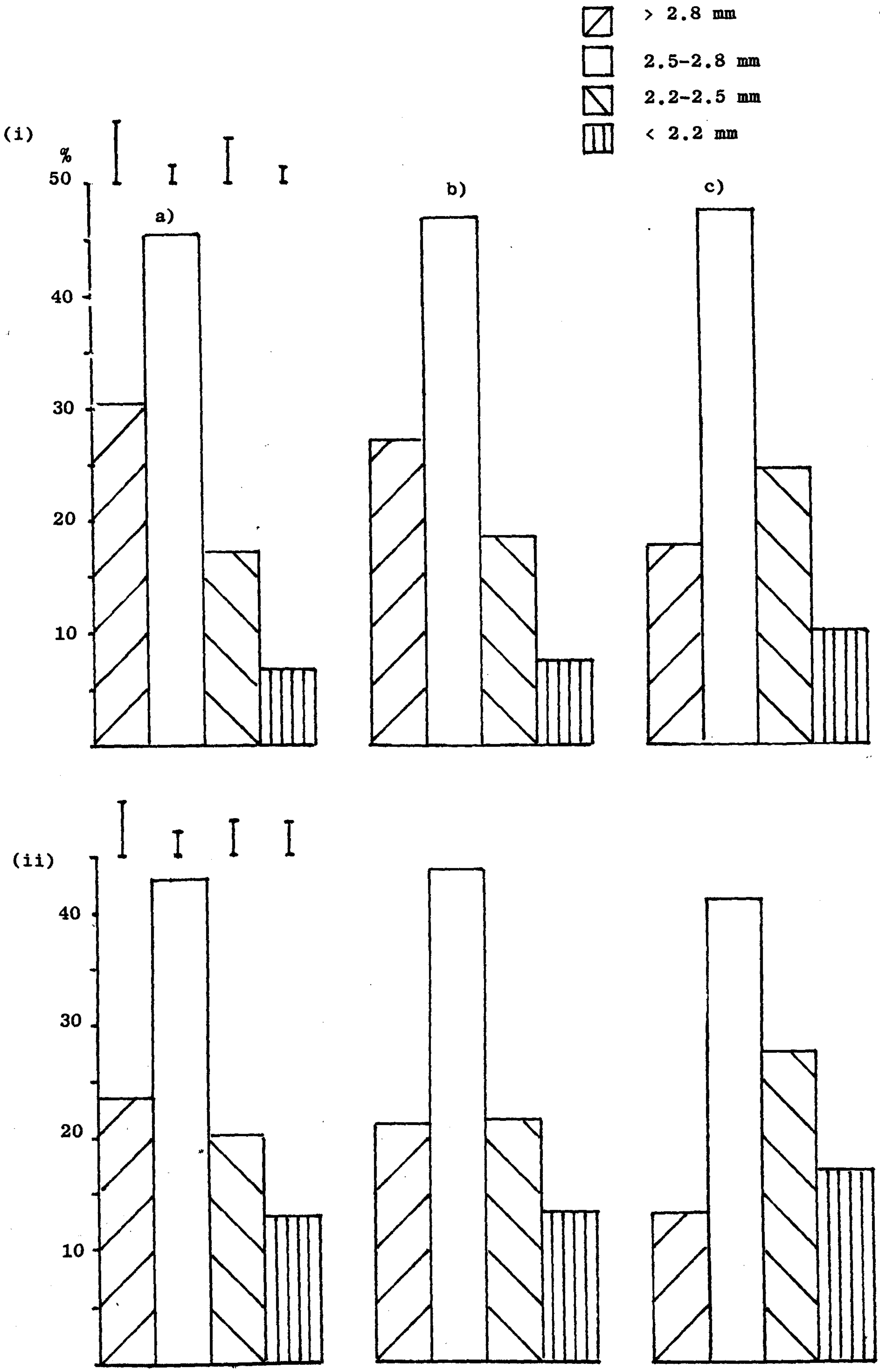
i by weight

ii by number

a) 200 seeds $m^{-2}$

b) 400 seeds $m^{-2}$

c) 600 seeds $m^{-2}$


> 2.8 mm
2.5-2.8 mm
2.2-2.5 mm
< 2.2 mm
(i)
%
50
40
30
20
10
a)
b)
c)
(ii)
40
30
20
10

density increased the proportion of seeds in the greatest size category (>2.8 mm) decreased but the proportion of seeds below 2.5 mm increased.

There were no significant differences between the PGR treatments in the size distribution of grains. In all cases the majority of grains were between 2.5 and 2.8 mm in size.

In all treatments over 12% of the grains were below 2.2 mm in size. These small grains may have been the result of early lodging of the crop which limited the flow of assimilates to the grain and reduced the photosynthetic ability of the ears and awns.

6.10.5.2 Grain nitrogen and HWE Neither grain nitrogen content nor HWE values were significantly influenced by applied PGRs (Table 46).

Initial sowing density in this experiment did not significantly influence grain nitrogen content or hot water extract values although increased density tended to result in lower seed nitrogen contents and higher HWE values (Table 46).

6.10.5.3 Seed yield The optimum initial seed density for the production of seeds within specific size categories is dependent upon the seed size required. For the maximum production of grain greater than 2.8 mm in size the lowest initial seed density was the optimum density (Table 47). However as the required seed size diminished the maximum yield of grain within that size grouping was produced by increased initial sowing density.

Neither PGR treatment enhanced significantly the production of grain from any specified size category.

### 6.10.6 Grain yield and yield components

Grain yield, both from combine harvested samples and from hand harvested samples, reached its peak value at intermediate densities (Fig. 90). The discrepancy between methods of yield estimation was approximately 0.5 t $ha^{-1}$ DM with the combine harvested values being the lower.

Total crop biomass significantly differed between sowing densities with the highest density resulting in a reduced above ground biomass (Fig. 90).

Neither density nor PGR treatments significantly influenced the harvest indices of the main stems obtained, although the Fh values

**Table 46** The influence of (i) PGR treatment and (ii) Density on grain nitrogen content and HWE

i)

| | PGR | | | |
|---|---|---|---|---|
| | Control | Cycocel | Cerone | SED |
| Nitrogen % | 1.957 | 1.976 | 1.975 | 0.0228 |
| HWE | 291.99 | 291.23 | 291.13 | 0.978 |

ii)

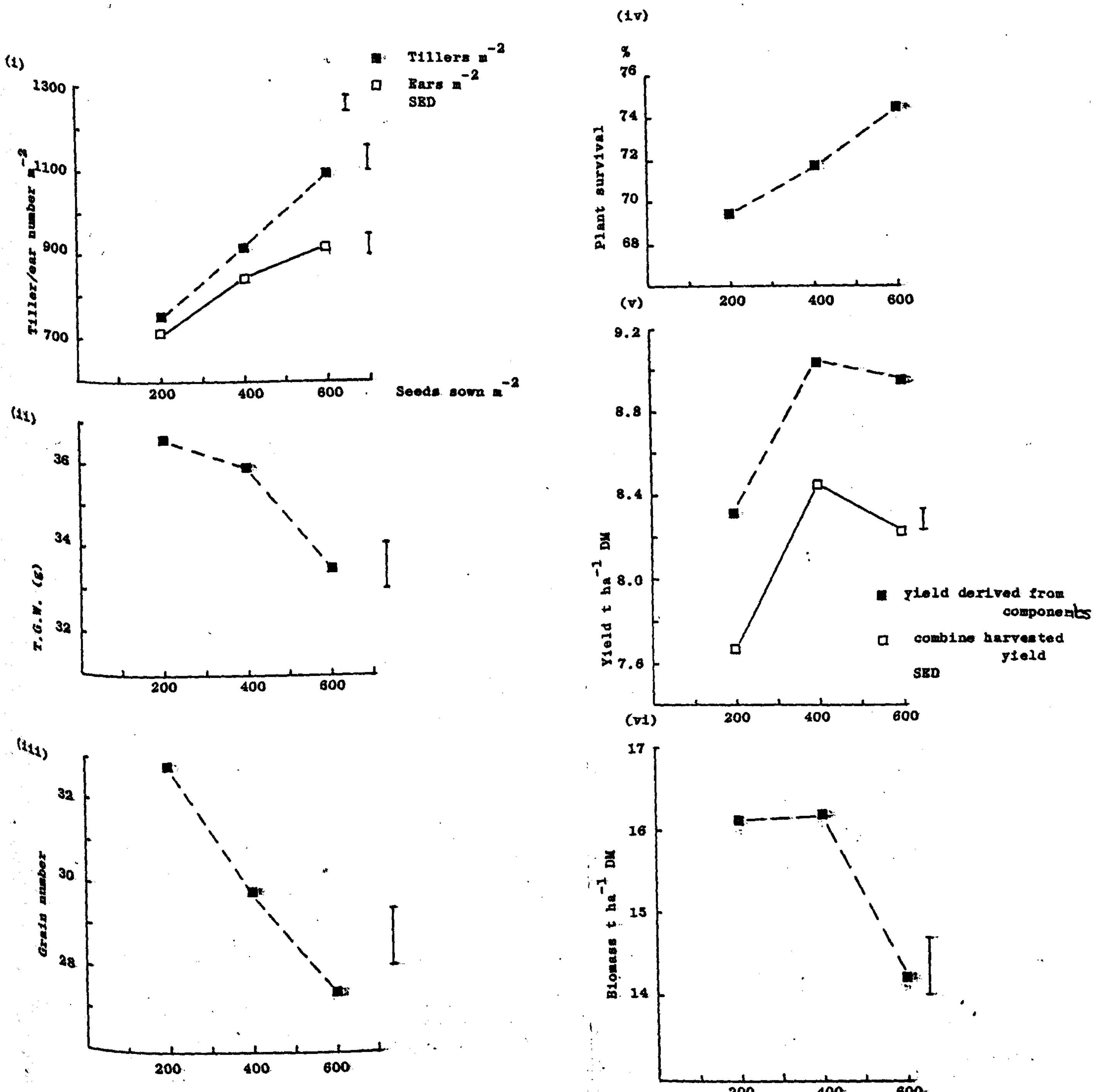
| | Density (seeds sown $m^{-2}$) | | | |
|---|---|---|---|---|
| | 200 | 400 | 600 | SED |
| Nitrogen % | 2.002 | 1.966 | 1.940 | 0.033 |
| HWE | 290.36 | 291.79 | 292.20 | 1.231 |

**Table 47** The effect of density on the grain yield (t $ha^{-1}$ 0% MC) of specified seed size categories

| | Density (seeds sown $m^{-2}$) | | |
|---|---|---|---|
| Size (mm) | 200 | 400 | 600 |
| $>$ 2.8 | 2.54 | 2.47 | 1.58 |
| 2.5 + | 6.32 | 6.69 | 5.84 |
| 2.2-2.8 | 5.20 | 5.90 | 6.46 |
| $<$ 2.2 | 0.57 | 0.68 | 0.91 |

**Fig. 90** The effect of initial sowing density on:

- i Tillers $m^{-2}$ ( ■ ) and ears $m^{-2}$ ( □ )
- ii TGW
- iii Grain number per main ear
- iv Percentage plant survival
- v Grain yield t $ha^{-1}$
- vi Biomass t $ha^{-1}$


(i)
Tillers m-2
Ears m-2
SED
1300
1100
900
700
Tiller/ear number m-2
200
400
600
Seeds sown m-2
(ii)
36
34
32
T.G.W. (g)
200
400
600
(iii)
32
30
28
Grain number
200
400
600
(iv)
%
76
74
72
70
68
Plant survival
200
400
600
(v)
9.2
8.8
8.4
8.0
7.6
Yield t ha-1 DM
yield derived from components
combine harvested yield
SED
200
400
600
(vi)
17
16
15
14
Biomass t ha-1 DM
200
400
600

obtained for those plants treated with Cycocel were greater in all density treatments (data not presented).

As initial sowing density increased the number of tillers and ears per unit area increased. However increased ear number was accompanied by a reduced number of grains per ear and a lower thousand grain weight (Fig. 90).

The proportion of total tillers present at harvest that produced ears declined with increasing plant density (from approximately 95% at the low density to 84% at the highest density).

No significant differences occurred between PGR treatments in the final grain yield either estimated from yield components or derived from the combine harvested yield.

No yield components were significantly influenced by the applied regulatory treatments.

## 6.11 Objective of the Growth Room Experiment 1982/1983 – the Effect of PGRs

This experiment was conducted to investigate the effects of a range of plant growth regulators on the tillering and rooting patterns of the winter barley variety Igri (Section 3.2) and to determine whether specified exogenous hormones could modify the early growth of the cereal plant to thus enhance its suitability for the production of seeds.

## 6.12 Materials and Methods

This trial was undertaken in a controlled environment room at the School of Agriculture, Sutton Bonington. The growth room was maintained at a 16 hour photoperiod, light being provided by high pressure mercury vapour lamps arranged to give an irradiance of 330 W $m^{-2}$ at plant height. Temperatures of 18°C (day) and 7°C (night) were regulated by refrigeration and heating under the control of two aspirated thermostats. Throughout the experiment room temperature was monitored using a thermograph and a shielded thermometer.

Ten uniformly sized seeds of the variety Igri were sown in each of 15 pots at a depth of 2 cm, this depth being chosen to minimize the production of coleoptile tillers. The seedling number was reduced to 5 per pot one week after crop emergence.

The growing medium used was a 50 : 50 b.v. mixture of loam and grit. Each pot had an application prior to sowing of 30 g J.I. Base fertilizer and 5 g chalk.

Each pot consisted of four 20 cm depth hollow pipes of internal diameter 17 cm arranged vertically. Because of the design of the pots and the growing medium utilized the pots were free draining. Watering was undertaken when deemed necessary (usually 2-3 times per week) with a similar quantity of water per pot being applied.

Seeds were sown on 11 November 1982 and emergence was first recorded on 16 November. Plants were monitored daily and emerging tillers were identified and ringed according to their position of emergence using small, coloured wire rings.

All plants were sprayed on 9 December when they had reached leaf appearance stage (LAS) 5 + 2 (ZGS 23-24). The plants of each pot were sprayed with 10 $cm^3$ of solution which was a sufficient volume to allow for minimal run-off. A 0.05% solution of Tween 20 (Polyoxyethylene sorbitan monolaurate) (Sigma Chemical Company) was added to each solution prior to spraying to act as a wetting agent. All treatments were applied by means of a hand held sprayer with an adjustable nozzle. Application rates are shown in Table 48.

The above ground portions of the plants were harvested on 5 January 1983, 27 days after spraying. The plants were carefully loosened from the soil and the bases trimmed so that all the roots remained in situ. Aerial sections of the plants were removed to the laboratory and there subdivided into their component tiller categories. Tiller number per category and total leaf number in each category were recorded prior to individual components being oven dried to a constant weight.

Root harvests were taken on 6 January 1983. Each 80 cm high column of pots was subdivided into 4 sections corresponding to one tube division of approximately 20 cm. The roots were severed at the junction between two 20 cm layers by the insertion of a thin metal plate which also allowed the uppermost section to be removed without difficulty. Each independent layer was then individually labelled and stored in a 5°C cold room for a maximum of one week. The roots were separated from the loam mixture by a technique of flotation and sedimentation. A known fresh weight sample of the cleaned roots was then stained using the method

**Table 48** Growth room trial – Application of PGR chemicals

| Treatment | g ai $ha^{-1}$ | Amount applied (ml) | 0.05% Tween 20 solution (ml) |
|---|---|---|---|
| $GA_3$ | 4.95 | 1.56 | 8.4 |
| $2GA_3$ | 9.90 | 3.20 | 6.8 |
| 5C Cycocel | 4.61 | 7.8 | 2.2 |
| Tween 20 | - | - | 10.0 |
| Control | - | 10.0 | - |

of McGowan et al. (1983) and subsequently analysed for root length. The remainder of the root sample was then oven dried to a constant weight.

## 6.13 **Results**

### 6.13.1 Tiller emergence and productivity

Table 49 indicates the first date upon which tillers of specified categories emerged. At the termination of the experiment at 52 DAS the first four primary tillers all had associated secondary tillers although no tertiary tillers or coleoptile tillers were present. Table 50 indicates the average number of stems per plant and the leaf number of associated tillers. The application of $GA_3$ reduced the number of stems per plant but did not reduce the average number of leaves per tiller. The application of CCC did not modify tiller number or leaf number per tiller from that obtained by the water control.

The PGR treatments had significant effects on the proportion of tillers present in each category. In Fig. 91 100 per cent is equivalent to each of the 15 plants within one treatment possessing a stated tiller. Both $GA_3$ treatments reduced the proportion of plants with late primary tillers and also decreased the number of tillers present in secondary tiller categories. In the control treatments no specified tiller category had less than a 60% representation whereas $GA_3$ treatments had 20% or less tillers present in some secondary tiller classifications.

The proportional weight contribution by each tiller complex showed no significant differences between the treatments (Figs 92 and 93). In all PGR treatments the weight distribution highlights the reduction in weight of the T1 complex caused by the non production of the first primary tiller. Both $GA_3$ treatments produced a greater proportion of the total plant weights in the mst and T2 complexes, 52% in the $2GA_3$ treatment, compared to 45% in the control although the differences were non-significant.

### 6.13.2 Leaf number

Within the majority of the primary tiller categories the application of $GA_3$ reduced the number of leaves per tiller albeit not significantly (Fig. 94). Applications of $GA_3$ increased the number of leaves per mainstem above that of the control.

**Table 49** PGR growth room trial 1982/83 –Time of emergence of tiller categories

| Tiller category | Time of emergence/(DAS) | |
|---|---|---|
| mst | 16/11 (6) | |
| T1 | 30/11 (19) | |
| T2 | 3/12 (22) | ← Date of spraying |
| T11 | 9/12 (28) | |
| T3 | 9/12 (28) | |
| T21 | 10/12 (31) | |
| T4 | 15/12 (33) | |
| T12 | 16/12 (34) | |
| T31 | 17/12 (35) | |
| T5 | 21/12 (39) | |
| T22 | 25/12 (43) | |
| T13 | 26/12 (44) | |
| T32 | 26/12 (44) | |
| T23 | 29/12 (47) | |
| T6 | 3/1 (52) | |
| T41 | 3/1 (52) | ← Final harvest |

**Fig. 91** The proportion of the potential number of tillers present in each tiller category

| | |
|---|---|
| i | Control |
| ii | $GA_3$ |
| iii | $2GA_3$ |
| iv | CCC |

Key:

| | | | |
|---|---|---|---|
| 1 | Mst | 9 | T23 |
| 2 | T1 | 10 | T3 |
| 3 | T11 | 11 | T31 |
| 4 | T12 | 12 | T32 |
| 5 | T13 | 13 | T4 |
| 6 | T2 | 14 | T4+ |
| 7 | T21 | 15 | T5 |
| 8 | T22 | 16 | T6 |

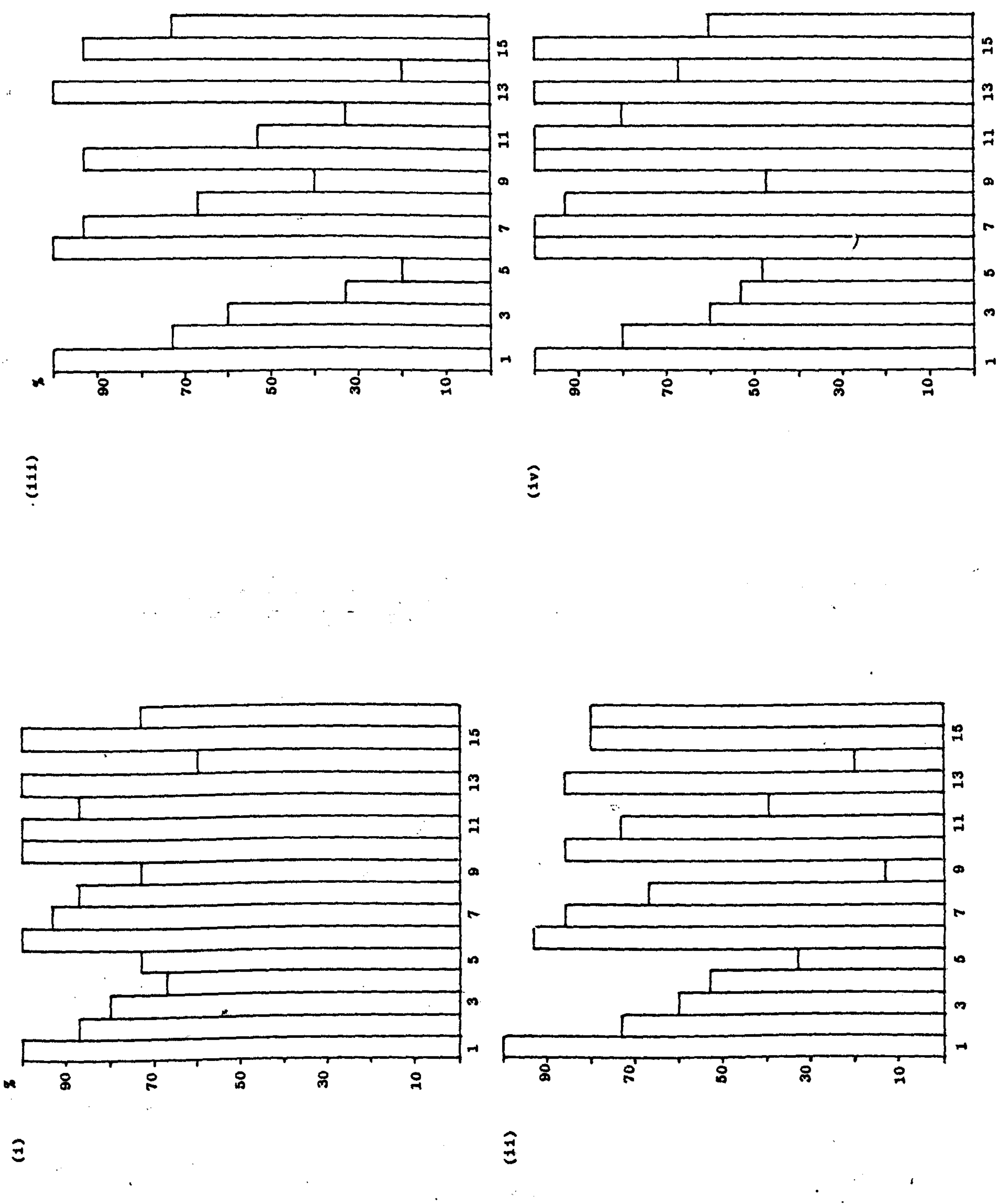

(i)
(ii)
(iii)
(iv)
%
90
70
50
30
10
1
3
5
7
9
11
13
15

**Fig. 92** The proportional contribution by mainstem, primary and secondary tillers to total plant weight

| | |
|---|---|
| i | Control |
| ii | $GA_3$ |
| iii | $2GA_3$ |
| iv | CCC |

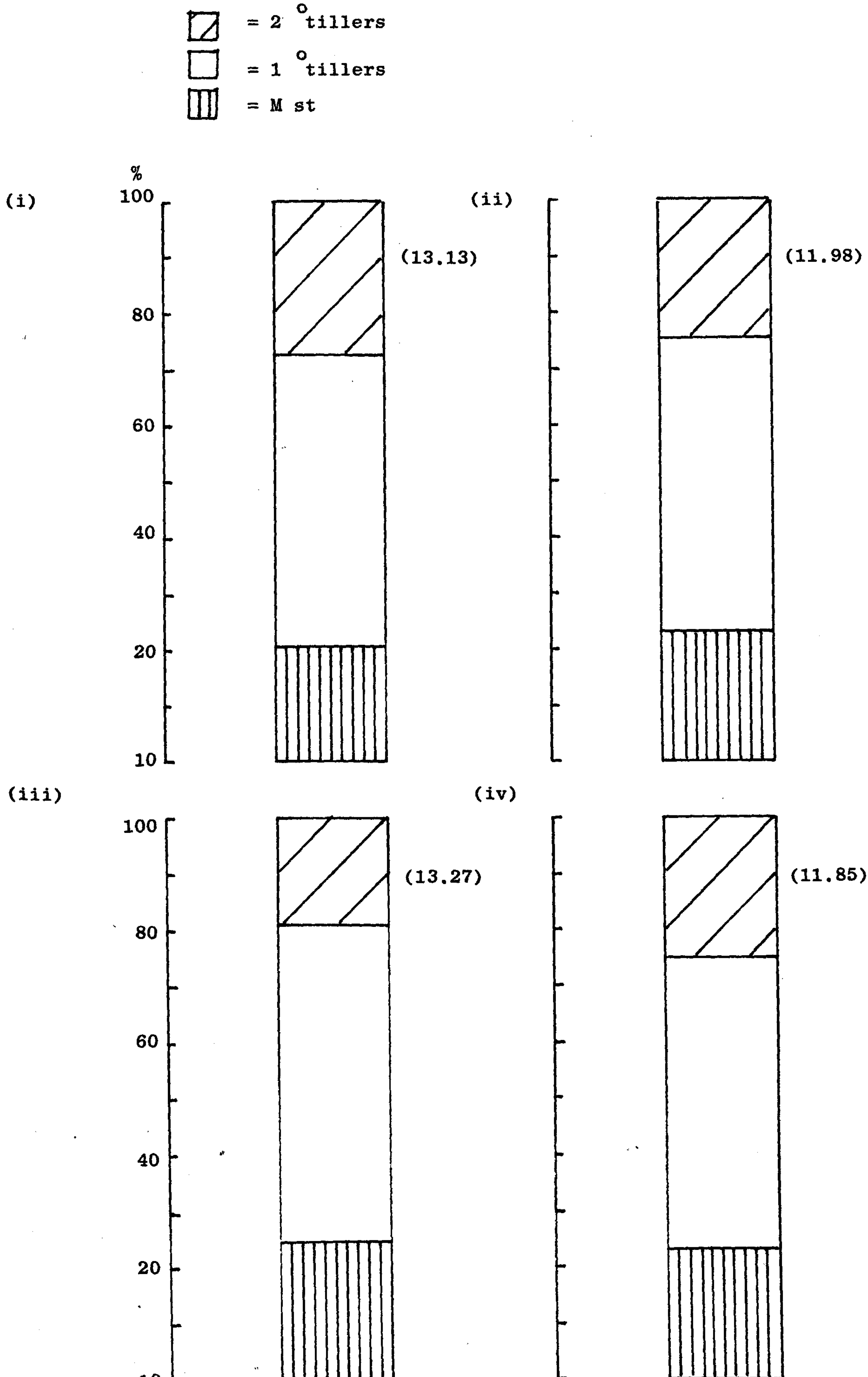

= 2 °tillers
= 1 °tillers
= M st
%
(i)
100
80
60
40
20
10
(13.13)
(ii)
(11.98)
(iii)
100
80
60
40
20
10
(13.27)
(iv)
(11.85)

**Fig. 93** The proportion of total dry weight in each tiller complex as influenced by PGR treatments 27 days after spraying

i Control

ii $GA_3$

iii $2GA_3$

iv CCC

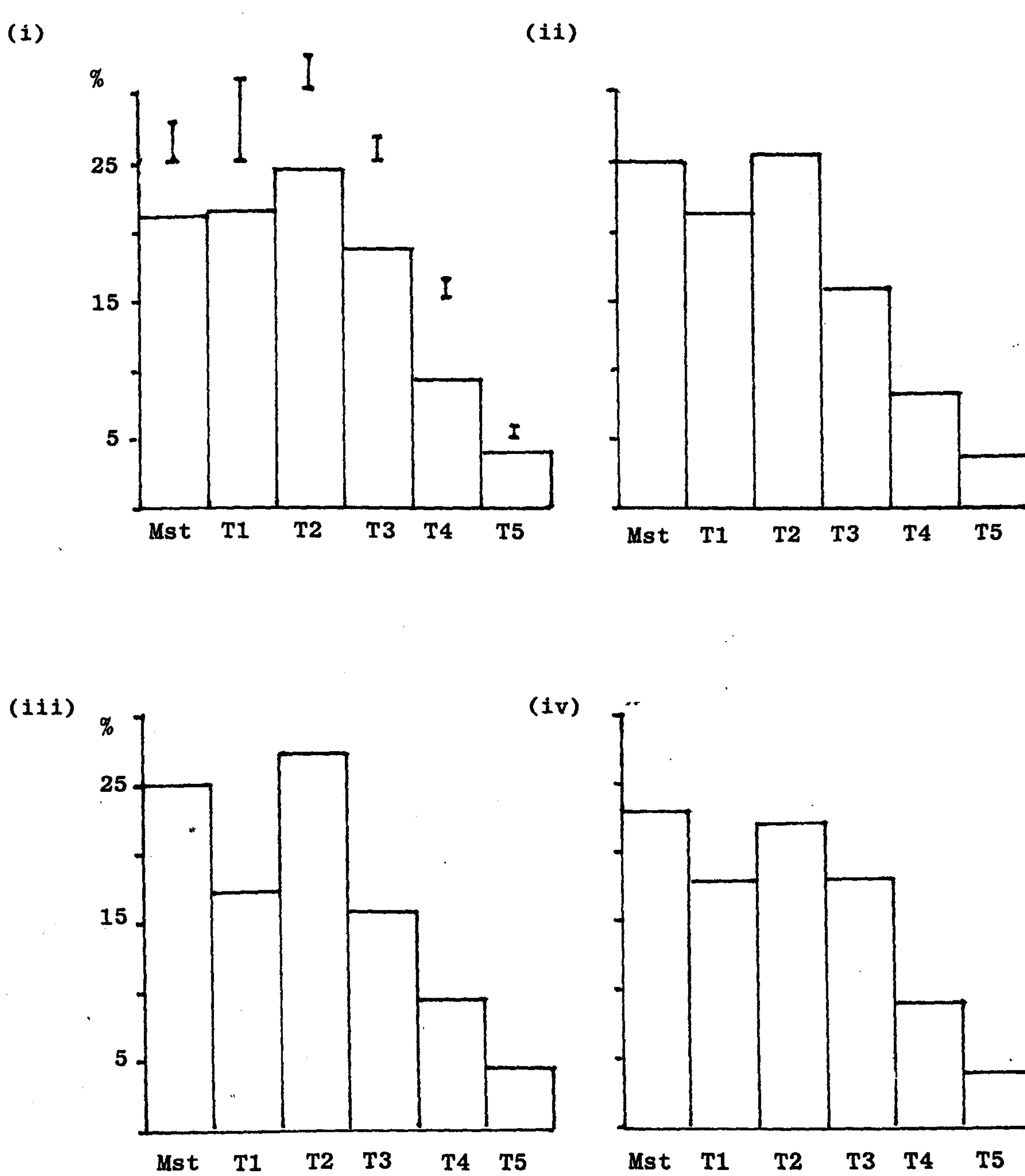
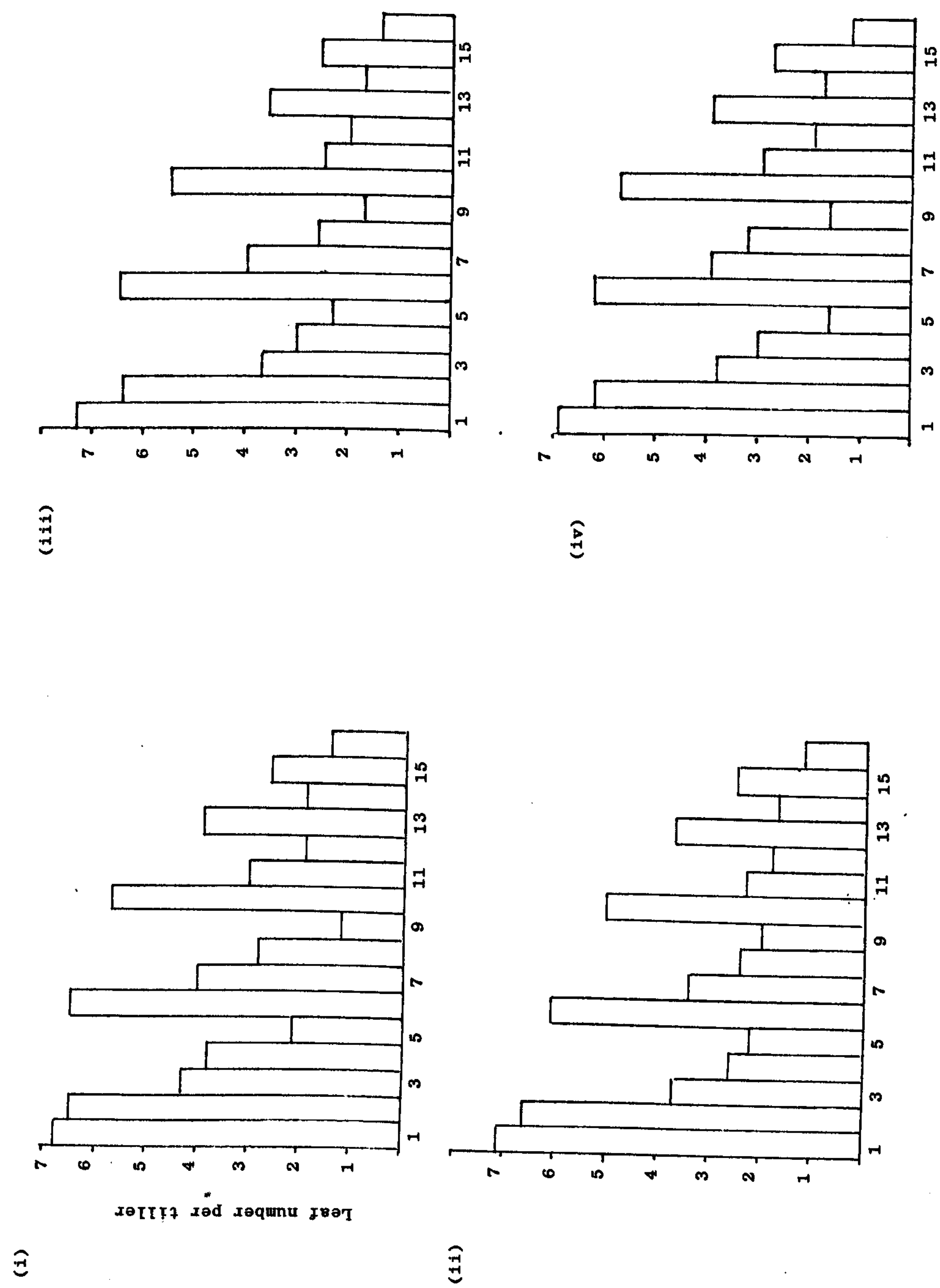

(i)
%
25
15
5
Mst T1 T2 T3 T4 T5
(ii)
Mst T1 T2 T3 T4 T5
(iii)
%
25
15
5
Mst T1 T2 T3 T4 T5
(iv)
Mst T1 T2 T3 T4 T5

**Fig. 94** The effects of applied PGRs on the number of leaves per tiller

| | |
|---|---|
| i | Control |
| ii | $GA_3$ |
| iii | $2GA_3$ |
| iv | CCC |

Key as in Fig. 91


(i)
(ii)
(iii)
(iv)
Leaf number per tiller
1 2 3 4 5 6 7
1 3 5 7 9 11 13 15

### 6.13.3 Rooting studies

Root analysis showed no significant differences between treatments in the root dry weights obtained per pot (Table 50). No significant differences were obtained in the estimated root lengths calculated using the technique of McGowan et al. (1983). However in both methods of estimation those values obtained for the CCC treatments were lower than those of the control. Calculated root : shoot ratios showed that the application of CCC increased the proportion of the total plant weight that was shoot.

No consistent or significant differences occurred between the PGR treatments in the proportional distribution of root weights within the growing column (Fig. 95). It was noted during root harvesting that the roots had rapidly reached the base of the column after which time they grew horizontally and proceeded to proliferate around the perimeter of the basal pot. Thus for an accurate assessment of the rooting of the winter barley plants during this experiment a taller column should have been used and/or the experiment terminated a few days earlier.

No significant differences occurred between the treatments in the proportion of total root length in each depth increment (Fig. 95). In each treatment a greater proportion of the total root length was found in the top 20 cm of the column. The PGR treatments increased the proportion of the total root lengths found in the top 20 cm albeit not significantly.

**Table 50** PGR growth room trial – Final harvest (54 DAS) components

i) Above ground components

| | Control | $GA_3$ | $2GA_3$ | Cycocel |
|---|---|---|---|---|
| Ave stem no. plant$^{-1}$ | 13.8 | 10.47 | 10.53 | 12.9 |
| Ave leaf no. plant$^{-1}$ | 52.7 | 40.2 | 42.7 | 48.9 |
| Ave leaf no. tiller$^{-1}$ | 3.82 | 3.84 | 4.05 | 3.80 |

ii) Roots

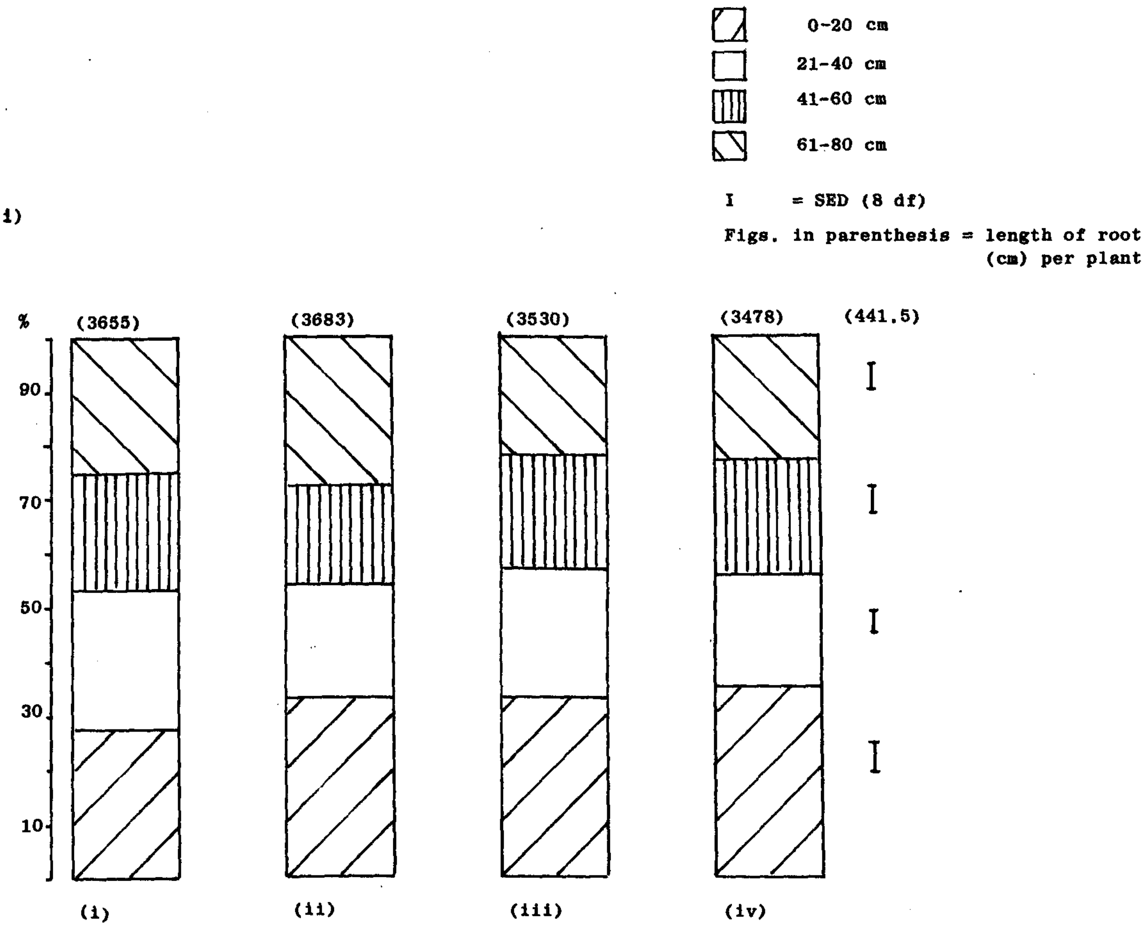
| | Control | $GA_3$ | $2GA_3$ | Cycocel | SED (8Df) |
|---|---|---|---|---|---|
| Root dry weight (pot) g | 6.78 | 6.76 | 7.42 | 4.39 | 1.95 |
| Root length plant$^{-1}$ (cm) | 3655 | 3683 | 3530 | 3478 | 441.5 |
| Root dry weight $m^{-2}$ (g) | 3.19 | 3.18 | 3.49 | 2.06 | 0.915 |
| Root : shoot ratio | 1 : 1.94 | 1 : 1.77 | 1 : 1.79 | 1 : 2.70 | - |

**Fig. 95**

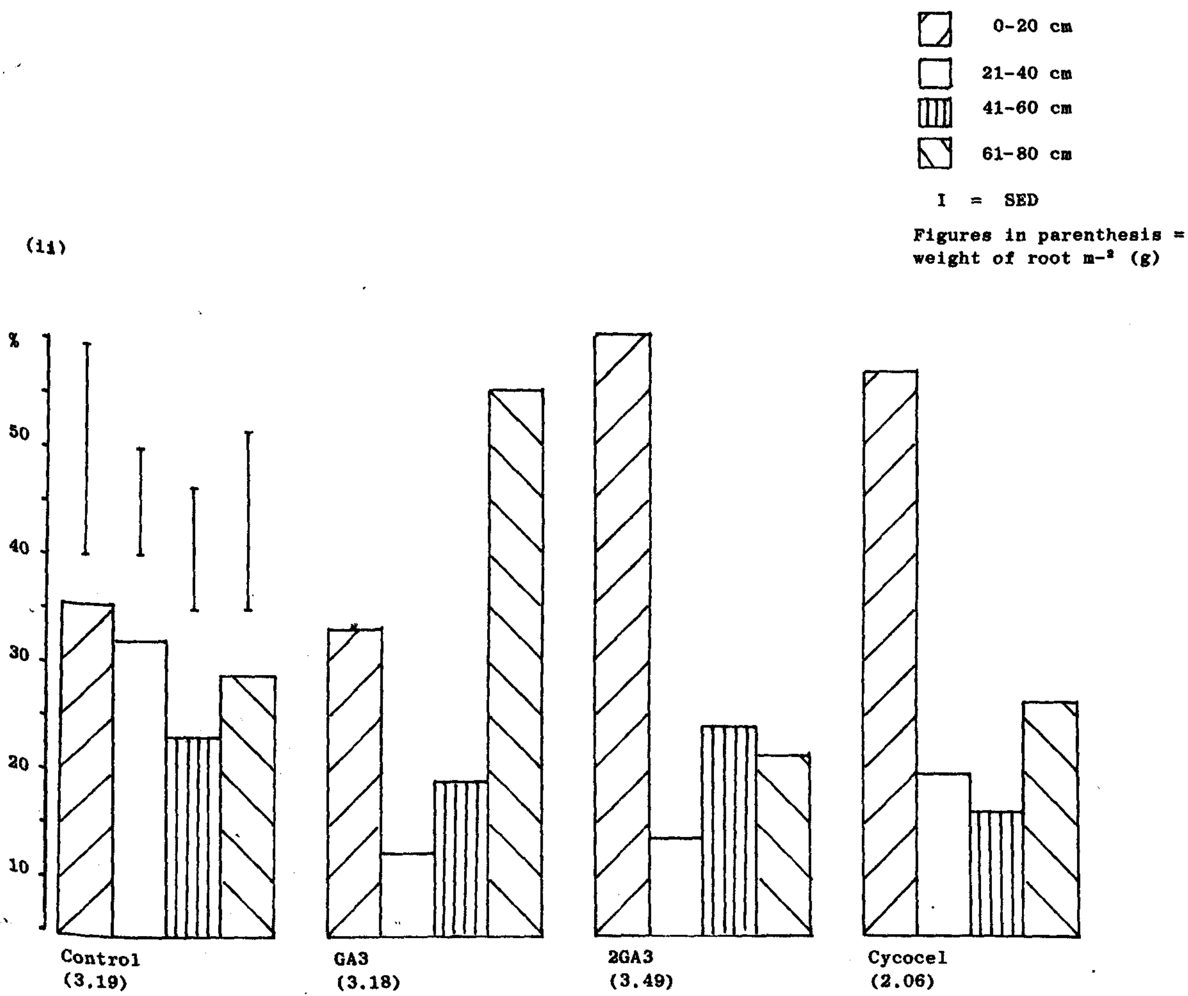
i The proportion of total root length in each 20 cm depth

ii The percentage of total estimated weight of roots contributed by each depth

(i)


0-20 cm
21-40 cm
41-60 cm
61-80 cm
I = SED (8 df)
Figs. in parenthesis = length of root (cm) per plant
%
90
70
50
30
10
(3655)
(3683)
(3530)
(3478)
(441.5)
(i)
(ii)
(iii)
(iv)

(ii)


0-20 cm
21-40 cm
41-60 cm
61-80 cm
I = SED
Figures in parenthesis = weight of root m-2 (g)
%
50
40
30
20
10
Control
(3.19)
GA3
(3.18)
2GA3
(3.49)
Cycocel
(2.06)

# Chapter 7

# MODIFICATION OF THE BARLEY SEED CROP BY PLANT GROWTH REGULATORS

## 7.1 Introduction

Lang and Thorpe (1983) recently stated that "it is axiomatic that a clear understanding of the physiological basis of crop productivity will be crucial to the realization of the full agricultural potential of plants".

The experiments discussed herewithin attempt to pinpoint those facets of barley growth and development which are suitable for manipulation with the aim of producing a uniformly sized seed sample with a suitable level of vigour. Prior to the commencement of chemical modification of the winter barley plant's growth it is desirable to understand how the plant reacts to its "normal" environment and how the responses may be enhanced.

Modification should be considered on a homogeneous plant stand and not on individual plants as it is the improvement of the crop rather than the plant that is of paramount importance.

All PGR work has been hindered by the lack of quantitative work with insufficient consideration being given to the effects of species, stage of development and environmental conditions on the effectiveness of any chemical treatment (Morgan, 1968; 1978).

Thomas (1976), Wareing (1976) and Luckwill (1976) have all indicated that the problem of synthetic PGRs is that they have many effects. Thus it would be unusual if the modifier did not affect more than one of the yield determining processes in any crop. These effects may be beneficial or adverse, thus the PGRs often fail to increase the yield as desired. Only a precise knowledge of the effects of the PGR on the specific crop will enable the full potential of the chemical to be exploited.

The interactions between PGRs and husbandry inputs have previously been noted (Daniels, Scarisbrick, Chapman & Noor Rawi, 1982). It may thus be possible in some cases to manipulate the husbandry of the crop to eliminate or minimize adverse responses to PGRs and enhance the yield improvement caused by the more promising regulators.

## 7.2 The Experiments

In experiment PGR2 the interactions between sowing densities and two differing regulators were investigated.

PGR1 was designed to investigate the manipulation of two dissimilar winter barley varieties under field conditions with the most widely available PGRs, i.e. 5C Chlormequat and $GA_3$, applied in the form of Berelex (ICI).

The controlled environment experiment used one variety of winter barley but similar regulators to those used in the previous summer's field study. The main purpose of the trial was to investigate the effects of the regulators in a known environment on root and tiller production.

The final PGR experiment, WB6, attempted to investigate in more detail the effects of growth regulators applied at various growth stages on the post anthesis period of grain filling and the ultimate grain production. A study of root production was conducted. This, in conjunction with the use of soil water analysis was undertaken to investigate the claims that various PGRs could modify root distribution, mineral and water uptake and drought tolerance.

Thus a thorough understanding of the physiology of the cereal plant and of the regulatory chemicals under investigation are of importance if the ultimate aims of the seed producer are to be achieved. The aim of any seed grower or seed merchant is to maximize the proportion of seeds within specific size categories whilst aiming for the highest practicable seed and seedling vigour for those seeds within the bulked sample.

However with any one batch of seeds there are many individual seeds all of which differ slightly in their size, weight, density and/or vigour. Each of these seeds has previously experienced different developmental and environmental conditions. The position of the plant, the ear category, the position on the ear of the individual grain may all cause differences within the seed.

The aim of any PGR treatment would be to minimize the differences between seeds so that the individuals within a bulk sample respond to a given environment or stress condition as one. It would be desirable if these responses could be predicted. Thus any seed sample could be categorized in terms of seed weight distribution, germination ability, predicted seedling vigour to a range of environmental stresses and potential final yield.

## 7.3 Vigour

Qualls and Cooper (1969) explained seedling vigour as "the weight of a seedling after the period of growth in a given environment". Thus seedling growth and development depends upon the amount of reserves that are present, the rapidity with which they are realized and the efficiency of their metabolism. Vigour results from a combination of adequate maturity at harvest and an absence of physiological ageing caused by either physiological deterioration or the presence of necroses.

In vegetable seed production it is possible to improve seed quality by modifying plant morphology, for example by altering plant spacing. Gray (1983) suggested that for carrots the evidence suggests that not only would variability in performance be decreased by growing crops at high densities but the optimum time for harvest could be more accurately judged. Modifying plant morphology by using PGRs can also improve seed quality (Lowe and Ries, 1972).

The hormonal status of harvested seeds effects dormancy and germination thus the treatment of parent plants with PGRs either before or during seed development could have major effects on the quality and vigour of the harvested seed.

### 7.3.1 Germination tests

Germination tests and subsequent seedling growth assessments were undertaken in experiments PGR1 and WB6 (Tables 39 and 44).

In PGR1 the varieties differed significantly in their percentage germination at all size grades below 2.8 mm with Fulmar having lower germination in all three categories. However the application of plant growth regulators did not significantly affect percentage germinations in any size category, neither did the PGRs influence the percentage of abnormal seedlings (Abrol, 1978) produced.

At the termination of the germination tests seedling dry weight was measured (Table 40). The weight of 100 harvested seedlings decreased as the seed size category declined. There were no significant differences between varieties or between PGRs in the harvested seedling weights.

In the final PGR experiment (WB6) the regulators did not influence percentage germination or 100 seedling weight when tested six weeks post harvest. With all treatments the germination percentage obtained was greater than 95%. There was no evidence that the larger seeds were subject to more damage in the harvesting process and thus more prone to attack by microorganisms.

Seed deterioration during storage is a function of time, temperature and moisture content (Roberts and Abdalla, 1968; Harrison and Perry, 1976). Seeds also deteriorate on the mother plant if harvesting is delayed by wet weather and during hot air drying if air flow is hindered. The end result of deterioration is loss of viability.

### 7.3.2 Grain nitrogen content

In years of high rainfall or in irrigated cereal crops the protein nitrogen content and 'quality' of the grain is lower than in drier conditions (Greaves & Carter, 1923; Shutt, 1935).

An assessment was made of the grain nitrogen contents of a subsample of seeds from each harvested plot in both years. In 1981-82 in both experiments PGR1 and PGR2 no significant differences were noted between regulators in the resultant grain nitrogen content (Tables 37 and 44). The lower grain nitrogen content in PGR2 may have been caused by differences in site, sowing date, nitrogen rates or nitrogen timings.

The applications of PGRs in WB6 caused no significant difference in grain nitrogen contents or in hot water extract values.

There is an inverse correlation between hot water extract and grain nitrogen content because extract is derived mainly from the carbohydrates of malt which decline as the proportion of nitrogenous materials increases. The hot water extract estimates in PGR1 were dependent upon variety with Fulmar having higher estimated extract values as would have been expected from a potential malting barley variety. The applied growth regulators did not influence HWE significantly.

Density had slight but non-significant effects on grain nitrogen content and estimated hot water extract values in experiment PGR2. As density increased the grain nitrogen content declined and the hot water extract values increased.

## 7.4 Grain Uniformity

The uniformity of a bulked seed sample is a desirable characteristic. It may prove attractive in the eyes of a purchaser and so help sales. The drilling of a uniformly sized seed lot with uniform vigour can result in an even plant stand thus giving individuals the same ability to become established and compete for light and nutrients.

In all the monitored experiments there was a negative linear relationship between mean thousand grain weight and grain number per unit area (Fig. 85). In the final PGR experiment there was a decline of approximately 2.6 g per thousand seeds for every increase in 5000 grains per square metre. There is a positive correlation between the percentage of seeds in a sample greater than 2.8 mm and the thousand grain weight. Within similar seed size categories the TGW of the seeds of the variety Igri were greater than those of Fulmar as the varieties differed in their grain densities. Bayles (1977) found that in winter wheat and in spring barley the thousand grain weight of a grain sample was influenced by grain density. Millet and Pinthus (1984) noted that in wheat crops grain density was independent of grain volume or grain weight. The variability between samples was minimal with grain densities only ranging between 1.397 and 1.492 g $cm^{-3}$ for 59 varieties.

An attempt was made to determine grain densities of the two varieties of winter barley in each size fraction. However the method employed was not sensitive enough for accurate measurements to be obtained.

These differences in densities between samples would have contributed to the inaccuracy of a specific weight estimate. The measurement of specific weight is only of limited value as a measure of grain filling, distinguishing only between the extremes of poorly or well filled samples for a particular variety. However specific weight estimates give little information on samples of intermediate quality.

The use of the measurement of thousand grain weight fails to distinguish between small plump grains and large shrivelled grains whilst sieving may not note the differences between shrivelled and plump grains of the same diameter.

Severe lodging occurred in two out of the three field experiments on plant growth regulators. In both WB6 and PGR2 TGW was low with a high proportion of the sieved grain being below 2.2 mm in size.

## 7.5 Final Grain Weight

Recent work by Cottrell and Dale (1984) suggests that differences in final grain weight may be established by the double ridge stage. A good correlation occurs between the spikelet width at the double ridge stage and the final individual grain weight, thus supporting the hypothesis that potential grain size is dertermined very early in the plant's growth and long before anthesis.

However actual grain size may be less than the potential maximum if the supply of assimilates or other metabolites is limited (Cottrell & Dale, 1984). Scott et al. (1983) noted that cereal grains have a potential maximum size beyond which they cannot grow regardless of assimilate supply.

If there is a causal relationship between final or potential grain weights and spikelet width at double ridge then the factors which affect this will be important. Within an ear a gradient of relative sizes, established very early in the plant's development is reflected in the relative size of the grains at maturity. Thus the final grain size along the ear of barley varies and grain in the lower part of the ear can be twice as heavy as those grains at the tip. Cottrell and Dale (1984) working with Maris Mink found that no grains were set in the first position above the collar. Grain weight on the ear gradually increased from positions 2 to 7 and then decreased with ascending position along the ear until the final position at grain position 24.

In PGR1 the grain weights along the harvested mainstem ears were recorded (Figs 70 and 71). The mode values for the grain numbers per mainstem ear on the control plots were 22 and 20 for Igri and Fulmar respectively (Fig. 69).

An assessment was made of the mean grain weight values along the ear. No significant differences between PGR treatments were found in the pattern of distribution. However the application of $GA_3$ to the variety Fulmar reduced the mean grain weight at each position along the barley ear (Fig. 70). No specific reasons can be given for this overall decline in grain weights.

In both Fulmar and Igri the basal two grains per ear were not filled. The maximum grain weights occurred at position 7 or 9 on the ear irrespective of the ear size. In all ears the distal segment of the ear had lower mean grain weights than those grains harvested from the basal region.

Single grains from the same ear were shown to have a dry weight range from 27 mg to 46 mg (Igri — Cycocel treated). This range of values upon a single ear has been found by Aufhammer and Bangerth (1982) on spring wheats where there can be a twofold variation in grain weights.

The rate of decline of mean grain weight from position 7 or 9 on the ear to the top grains within the ear was not modified by regulatory treatments (Fig. 71).

### 7.5.1 Grain size

The relationship between seed size and vigour and between size and potential yield benefits have been discussed in Section 6.1.2. The National Institute for Agricultural Botany (NIAB) guidelines (NIAB, 1982) for quality seed states, amongst other requirements, that the seed should be of good germination capacity and be graded to a uniform size. However no indication is given of the desired seed size. Carver (1977b) noted that large seeds can significantly outyield small seeds of the same cultivar when drilled at a constant seed number per unit area. However when grain was drilled by seed weight the larger seeds would result in a much reduced population which may cause a reduction in harvested grain yield. For each variety the optimum seed size to seed population relationship must be determined taking into account the morphology and physiology of the individual variety.

The modification of the relative balance between seed size and seed population must be considered for each variety at each time of sowing. By the drilling of small grains of a highly tillering cereal variety early in the growing season it is perfectly feasible to produce a high yielding crop. The key to success of any sown crop is to match the seed size, quality and sowing rate to the conditions prevailing and the required end product. The use of large grains in all conditions may be unnecessary. As early as 1733 Jethro Tull (1733) noted that small, thin seeds were capable of producing "as large ears full of bodied corn as the full bodied seed selected with great care".

In his review of the production of quality cereal seed Carver (1980) discussed the implications for all those involved in cereal seed production in the change from drilling by weight to drilling by seed number. He suggested that the actual yield of the seed crop may become less important and that the main factor in seed production will be the number of uniform seeds produced per unit area. Table 51 (taken from Carver, 1980) illustrates the differences between two seed crops:

**Table 51** The influence of 1000 grain weight on the subsequent use of a contract seed crop (from Carver, 1980)

| | A | B |
|---|---|---|
| Yield t $ha^{-1}$ | 7 | 7 |
| Yield t after 10% cleaning losses | 6.3 | 6.3 |
| No. of 50 kg units produced | 126 | 126 |
| Hectares drilled (at 160 kg $ha^{-1}$) | 39.4 | 39.4 |
| TGW | 60 | 35 |
| Seed no. produced (m) | 105 | 180 |
| Hectares drilled (at 4 m seeds $ha^{-1}$) | 26.25 | 45 |

It can be seen that the crop producing seeds of a lower mean grain weight produces more seeds although the grain yields of the two crops are identical. If the desired seed size of the resultant crop was known prior to the drilling of the seed crop the husbandry inputs could be manipulated to achieve the desired goal.

The modification of the cereal yields within specific size categories was attempted by the use of PGRs. It was hoped that the addition of the PGRs would modify both between ear differences and within ear differences. Dennis-Jones (cited by Wood et al., 1977) found that with Proctor spring barley 35% of the variation in seed weight was due to between plant differences, 13% due to differences between ears and 52% due to the location of grains within the ears. In the experiments reported here no specific attempts were made to minimize the between plant differences in the resultant grain weights. It may have been possible to achieve this by the use of similarly sized seeds, uniformity of planting depths and accurate between plant spacings (achievable by hand planting 'on the square' with non-germinating seeds being replaced by extra plants).

In PGR1 the varieties responded differently to the applied PGRs in the distribution of seeds (Fig. 67). Both CCC and $GA_3$ decreased the yield of seeds within the two largest size categories (i.e. those seeds of 2.5 mm and above and those seeds greater than 2.8 mm) for the variety Igri. However in Fulmar only $GA_3$ reduced the seed yield in the upper size category. In PGR2, conducted during 1981-82, no applied PGRs enhanced the production of grain within any size category.

## 7.6 Biomass

It has previously been indicated that within the cereal crop a high final biomass yield is important for the production of a high grain yield. Biscoe (1979), McLaren (1981) and Green and Ivins (1984) have all reported a strong correlation between total biomass production and grain yield. Thus variations in yield are principally modified by changes in total crop dry matter production. Gallagher and Biscoe (1978) noted that harvest index changes are not directly related to changes in grain yield.

In this set of PGR experiments few differences were evident between growth regulators in their effects on biomass accumulation or final biomass yield. In PGR1 the application of $GA_3$ in the autumn decreased the biomass production from approximately 217 DAS. However the varieties Fulmar and Igri differed in their response to the regulator with Igri having its peak biomass yield and final biomass yield reduced more than similar parameters in the variety Fulmar (Fig. 65). The application of CCC to Igri increased the peak biomass and final yield compared to the modification of biomass within Fulmar.

This difference between varieties in their response to the applied regulators cannot be fully explained. The applications of PGRs were applied to both varieties at the same calendar date. No attempt was made to identify the differences in apical developmental stages that may have been present between the varieties at the time of application.

Thus the varieties may have differed in their endogenous hormone status and/or their sensitivity to the applied chemicals at the time of application.

More specificity is needed in the timing of inputs. The targeting of specific chemicals to modify and manipulate specific stages within the development of the plant requires detailed knowledge of the biochemistry and physiology of the site chosen for manipulation and of the whole plant.

WB6 and PGR1 differed in their peak biomass values achieved (Figs 65 and 82). However the lower mean peak biomass yields obtained in PGR1 produced, in general, higher grain yields than in WB6. This was due to the extremely low proportion of total biomass harvested as grain in WB6. This was possibly caused by the onset of lodging post anthesis which reduced the grain filling ability of the developing seeds.

Experiments WB6 and PGR1 differed in their biomass production over the autumn and winter. In winter wheat (variety Avalon) T.C.K. Dawkins (Personal communication) has shown a close relationship between dry matter produced in March and sowing date. The two trials cited above differed by 11 days with experiment WB6 being drilled earlier.

Bonari and Macchia (1980) showed that earlier sowings of winter barley often emerged at a faster rate thus enhancing the increase in duration of growth over and above that of earlier sowings per se.

Green, Furmston and Ivins (1985) reported that differences between the entire duration of growth for winter barley crops sown at different times manifest themselves during the early stages of crop development. They also concluded that yield components that are determined by conditions early in growth are more likely to be influenced by time of sowing than those principally regulated by events later in the season. The advantages of early drilling in the production of crop biomass in WB6 were maintained throughout the growing season although the high biomass did not result in the expected high grain yield.

Dissimilar varieties were used in these two experiments thus it is not possible to directly compare the final yield components of the varieties examined.

## 7.7 Roots

The root system may be viewed as a mirror image of the shoot system. Thus any modification of the plant by husbandry means or by the addition of PGRs may be expressed both by the aerial plant components and by those plant organs normally neglected by the experimenter, the plant roots.

The ideal form of a root system is unknown. In some conditions a small root system may be advantageous as it may ensure that water reserves are present in the soil in late summer drought conditions which may allow an adequate grain yield to be secured.

A better understanding of roots should help to identify the kinds of systems that most favour agricultural yields in given climates and soil types. Plant breeders have generally ignored root system characteristics in selecting desirable phenotypes (Jackson & Stead, 1983). Thus large differences in structure and size of root systems that exist between species of crop plant and their cultivars or genotypes are products of evolutionary selection relating more to survival than to heavy agricultural yields (Jackson & Stead, 1983). The practical difficulties of screening potentially beneficial root systems are immense. One method of modification of root systems in the short term may be the use of chemical regulators.

Very little information is available on the chemical manipulation of root systems under field conditions (e.g. Atkinson & Crisp, 1982; Bragg et al., 1984; Hanus, 1967).

One practical consideration in influencing root systems with PGRs is the difficulty of applying chemicals to roots in the soil. One approach may be the use of seed dressings to influence seedling roots. Indirect manipulation by addition of chemicals to the aerial shoot and subsequent transport within the plant is also possible. The incorporation of plant growth regulators into the growing medium is probably unlikely to be totally successful.

However the improvement that may accrue from controlling root growth must be held in abeyance until agronomic and physiological data is available to show the changes in root characteristics that may enhance yield or root efficiency (either for water use or mineral uptake).

In a recent review of regulation of root growth Jackson (1983) stated that "there can be no doubt that manipulating root systems by whatever means (cultivation practice, drainage, fertilization, choice of cultivars, growth regulators) is central to the achievement of high productivity in arable farming". This echoed the work of Gregory et al. (1978) who stated that root and shoot growth should not be studied independently if a clear understanding of plant growth was to be obtained.

In general the tested plant growth regulators had no consistent measurable effects on rooting (either total dry weight or the proportion of roots within individual horizons in the profile (Fig. 68, 73, 74, 75, Table 50).

Within the growth room experiment where plants were grown in stacked bottomless tubes the root growth of the plant was unlikely to be representative of the root growth experienced in the field due to differences in soil structure, packing, temperature and moisture distribution compared to undisturbed soils.

In all experiments reported herewithin the distribution of roots within the profile was similar to that reported for the winter wheat crop by Gregory et al. (1978). That is, the proportion of roots either by number or by weight decreased down the soil profile (Fig. 74).

The variability of the growth of roots in time and their spatial distribution is a major source of error. In all PGR experiments at least three replicates were taken at each sampling date. Great variability between replicates was common with coefficients of variation (CV) for total root lengths being greater than 27% for the first root harvest in PGR1. The CV values increased with increasing depth down the profile due to the combination of soil heterogenicity and the problem of sampling few roots. Gregory et al. (1978) obtained CVs of greater than 80% at depths of 100-110 cms using four replicated winter wheat samples although achieved CVs in the order of 20% for total root weight down to 1.5 m.

Thus as the variability between root samples is very high under 'normal' conditions the effects of the applied PGR would have to be great to be detectable in the field.

## 7.8 Water Use

In many cereal growing areas of the world drought is a major constraint on yield. In the UK there is no regular pattern of drought — either in timing, intensity or duration. However losses due to drought have been estimated as being between 10 and 20% of the present average yield (Austin, 1983). Although the effects of water stress depend not only on the severity and length of the stress but also when it occurs. Any factors which can improve the abstraction of water from depth or the efficiency of use of abstracted water may enable the cereal plant to overcome drought stress and hence to minimize grain yield reductions.

It has been previously shown that the applied PGRs had no consistent influence either on total root production or on root distribution down the soil profile (Fig. 68). However in WB6 it has been shown that applications of either $GA_3$ or CCC reduced the water use efficiency of the cereal crop (Figs 81 and 82). With plants treated with CCC or $GA_3$ every unit of water used by the cereal plant produces a lower biomass yield than untreated control plants. This is contrary to the results of other workers, e.g. Malhotra and Cheema (1976), El-Damaty, Kuhn and Linser (1965) and Larter et al. (1965). El-Damaty et al. (1965) reported that Cycocel treated wheat plants under drought conditions used water more economically than untreated plants especially for grain production. Larter et al. (1965) found that barley plants treated with Cycocel under water deficit conditions used less water than untreated plants for producing unit weight of dry matter although the yield was unaffected.

However Plaut and Halevy (1966) found that CCC had little or no effect on dry matter products, grain yield or water requirements of plants given water regularly or exposed to short periods of drought.

Many workers have shown that crop biomass production was related linearly to water use efficiency (Sections 6.5.4. and 6.7.5). Thus as has been previously described, a high grain yield can only be achieved by the production of a high biomass. This in turn will only be accomplished by the use of a large amount of water.

## 7.9 Plant Growth and its Relationship to Yield and Grain Quality

To produce maximum yield the cereal crop must be grown so that it intercepts light efficiently (Gallagher & Biscoe, 1978). Light interception depends primarily upon the leaf area index and on the leaf arrangement within the crop. Leaf expansion early in the growing season is enhanced by warm temperatures, nitrogen and sufficient soil moisture. Large increases in biomass during early crop growth can be achieved by increases in leaf area, e.g. by earlier sowing.

Only a small number of tillers are needed to give both optimum yield and sufficient adaptability to a range of environments (Bingham, 1971; Jones and Kirby, 1977). This view of reduced tillering was also employed by Donald (Donald, 1979) in his formulation of a barley plant ideotype. He has shown that if semi-dwarf uniculm barleys are sown at double the standard seed rate the yield advantages of the uniculm above the locally grown variety are between 15 and 20 per cent.

In neither PGR1 nor WB6 was LAI and/or GAI influenced by the application of regulatory chemicals although the frequency of sampling may have resulted in any differences that may have been caused by the regulators being undetected (Figs 64 and 88).

The regulators, by modifying the tillering patterns of the winter barley varieties, also modified the percentage contribution of the mainstem and primary tillers to the LAI. In PGR1 using varieties that responded markedly to the application of PGRs the tillering pattern was reduced by the application of $GA_3$. This resulted in a lower contribution to total green area by the later primary and secondary tillers compared to the control or CCC treated plants. The modification by $GA_3$ of the tillering pattern resulted in a higher tillering efficiency. Thus the reduction in peak tiller number and the lower amount of tiller death results in the continued presence of larger, early established stems that are maintained through until final harvest (Figs 63, 82 and 87).

The death of small, non-productive tillers results in the binding of assimilates into organic materials. These assimilates are not readily available to the rapidly developing plant. Within plants that do not lose a high proportion of their tillers at the time of primordia death and rapid stem expansion the assimilates produced are still present and can be utilized by the developing plant.

The independence and/or interdependence of tillers within a plant have received limited attention. In many grasses reciprocal transfer of assimilates between tillers and the mainstem occurs (Clifford et al., 1973; Clemence, 1982).

Tillering patterns were monitored fully in PGR1 and in the growth room experiment. With a $GA_3$ application to the plant very few secondary tillers were produced except for the T11 tiller which was generally present (Figs 63, 92 and 93). The continued presence of the T11 tiller even when treated with $GA_3$ may have been because of its tiller bud commencement of growth prior to $GA_3$ application. Thus only the secondary tillers which had not received the correct endogenous hormonal signal for growth and development were suppressed.

The growth room experiment showed no reduction in the average number of leaves per tiller although a reduction in leaf number per plant was evident due to the lower number of stems per plant (e.g. when treated with Cycocel compared to 13.8 in the control) (Fig. 94).

In spring wheat (Power & Alessi, 1978), winter wheat (Darwinkel, 1978; 1979) and spring barley (Thorne, 1962) main shoots have been found to exceed ear bearing tillers in grain yield. However it has proved possible to decrease the difference between mainstem and tiller yields by the applications of high nitrogen dressings (Power & Alessi, 1978) indicating that the yielding capacity of tillers can be improved by the modification of husbandry inputs. Darwinkel (1980) working on winter wheat showed that grain yield per ear was considerably reduced in younger shoots because the number of grains per ear and the thousand grain weight both decreased. It has been reported that the effect of shoot age on ear development and the subsequent ear yield was more pronounced at higher plant densities (Darwinkel, 1980).

The reduction in grain yield of tillers compared to main shoots is not fully understood. In PGR1 tillers were monitored throughout their growth and final grain yield components were assessed from each tiller category. In general the number of grains per ear decreased as tiller age decreased. The T11 tiller was approximately equal to the T2 tiller within the variety Igri and of a lower order primary tiller category within Fulmar.

The number of grains per ear in each category depended upon the PGR treatment with, in general, Cycocel increasing the number of grains per ear above the control whereas $GA_3$ treated plants had lower numbers of grains per ear (Table 42).

In PGR1 the contribution to total ear number by the mainstem was greater than the contribution by any other tiller category. The percentage contribution to total ear number declined as the tiller age declined. Here the coleoptile tiller did not fit in with the expected pattern. The proportional contribution to final ear number depended both on variety and on PGR treatment with both PGR treatments reducing the percentage contribution to total ear number by the coleoptile tiller. Cannell (1969b) investigated the effects of temperature, light intensity and daylength on the frequency of occurrence of the coleoptile node and secondary tillers in barley. The development of the coleoptile was suppressed much more than that of the T1 tiller by high temperature, by reduced photoperiod or by low light intensity.

In PGR1 both peak and final mainstem weights were recorded. The reduction in weight between peak and final weight was approximately 0.36 g (control and $GA_3$ treatments) and 0.23 g (Cycocel). This corresponded to a weight reduction of between 31% (Cycocel) and 51% ($GA_3$) (Table 36).

If it is assumed that 73% of the loss of stem weight can be translocated to the developing ear (Austin, Morgan, Ford and Blackwell, 1980) this stem weight reduction would contribute approximately 0.267 g per developing ear (11 mg per developing grain). The mean grain weight of the harvested grain was 40 mg, thus the translocated assimilates from the mainstem could have contributed 27% of the final grain weight.

Both Gallagher et al. (1975) and Daniels et al. (1982) have shown that reserve mobilization is associated with low yielding crops whilst high yielding crops are associated with large positive increases in stem weight after anthesis. However both groups of workers have concentrated on the spring barley crop. More work is needed on the assessment of stem reserve contributions to the winter barley crop's yield.

# Chapter 8

# CONCLUSION

Any modification of the treatment of the growing crop that would lead to a seed more acceptable to the seed industry and ultimately to the grower should be welcomed. To understand where modifications may be possible in the winter barley crop it is essential to understand the growth, development and final yield components of the crop.

No attempt has been made herewithin to determine the optimum seed size for drilling of the winter barley crop. However it has been shown that seed size can be modified by manipulation of inputs.

Most buyers of seed still require a bold sample, that is, a uniformly large, well filled grain sample. However the use of large seeds may not necessarily always be the best option.

An increased area of cereals is now being drilled taking into account the number of seeds required per unit area and not the weight of seeds. Hence the drilling of similar numbers of seeds from both large and small seeded samples would require a higher weight of seeds being needed when grains were large. Thus by utilizing large seeds the cost of seed for the crop may be increased to a slight extent.

Size uniformity may be of more importance. The drilling of a uniformly sized seed sample with adequate germination capacity and vigour should result in more uniform germination and early seedling growth. The uniform spacing of equal sized grains may result in a delay of the onset of inter- and intra-plant competition allowing each grain to produce a similar number of tillers which can then be manipulated by the application of nitrogen or plant growth regulating chemicals to be maintained through until harvest. This population of similarly aged tillers should reduce the variability in time to maturity and enhance the production of similarly sized grains.

Modification of the basic imputs to any seed crop were used to assess the likely benefits of alteration of husbandry treatment in the production of grain to be used for seed.

A limited but increasing number of winter barley varieties are available to the farmer. These varieties differ in gross external morphology and in ultimate useage. It was thus decided to examine contrasting varieties of winter barley under a range of husbandry treatments.

The two main tested varieties, Igri and Tipper, differed in their growth and development and in their responses to alterations in seed density, nitrogen rates and applied PGRs. They differed in their production of tillers both in timing and the peak number of stems produced. These differences between varieties may alter the timing of inputs to individual varieties.

The varieties differed in their efficiency of tillering. Tipper with a lower number of tillers produced had a higher tillering efficiency. In varieties with a low tillering efficiency there is the potential for a large amount of assimilates to become bound within non-productive tillers.

Igri produces a large number of secondary and late primary tillers which in low plant density situations can contribute to grain yield. However the ears produced from these tillers had lower numbers of grains per ear each of which had lower mean grain weights.

The grain yield differed between varieties with Igri generally having a higher grain yield. This higher yield was associated with a larger number of ears per unit area (linked to its higher tillering capacity), a higher mean grain weights but a lower number of grains per ear (resulting from the contribution to yield of the later produced tillers).

The attainment of a low plant population with a concomitant lowering of yield or a greater variability in yield can in part be rectified by the addition of extra applied nitrogen. The use of correctly timed nitrogen top dressings can increase tiller production and tiller survival. Additional nitrogen can also increase the number of grains produced per ear. A positive correlation exists between grain number $m^{-2}$ and grain yield. Thus any increase in grain number caused by both an increase in ear number or by an increase in grain number per ear will generally result in an increase in grain yield.

Unfortunately at very high plant densities (above 400 seeds sown $m^{-2}$) the application of supra optimal levels of nitrogen can cause a reduction in grain yield. This is a result of a lowering of grain weights and a reduction in Fh. However the total above ground biomass yield was usually increased.

In all monitored experiments there was a significant negative linear relationship between grain number $m^{-2}$ and TGW. The relationship however differed between varieties with Tipper having more stable TGWs over a wide range of seed numbers.

The use of PGRs can modify the number of grains found within specific size categories. Within Igri the application of both Cycocel and Gibberellic acid decreased the proportion of seeds within the two largest size categories. Tipper responded to $GA_3$ only by reducing the yield of the seeds in the category greater than 2.8 mm. However the effects of applied PGRs were not consistent as the application of 5C Cycocel and Cerone in PGR2 had no significant effects on the proportion of seeds found within any size category. This difference may have been caused by differences in variety, the alteration of timing of application or by differences in environmental conditions prevailing at the time of application.

When considering the variable costs of cereal production the proportional contribution to total costs by the purchase of seeds is small.

If very small individual seeds are drilled a higher number of seeds per unit area may be needed to produce the desired seed population, for smaller seeds of certain varieties have a lower germination capacity and lower seedling weights.

If the farming industry moves to sowing a known number of seeds $m^{-2}$ rather than a known weight of seeds it may be advantageous if the seed producer achieves a higher number of grains within a similar grain yield; that is, seed number as well as overall seed yield will be important. However the prejudice amongst buyers of seeds against smaller sized seeds must be overcome.

Within a high density crop attention must be paid to plant spacing. With the current husbandry techniques a large number of seeds tend to be drilled within a narrow band. This leads to the early establishment of inter-plant competition. Thus each plant with limited area and resources for expansion does not fulfil its potential. It may be more realistic to develop husbandry techniques of distributing seeds so that each has a similar space around it to minimize inter-and intra-plant competition.

Unfortunately increasing initial sowing density can result in a decrease in grain yield due to increased lodging. This lodging is increased by supra optimal use of nitrogen. Lodging in cereals can result in non-certification of the seed crop due to the inability of the inspector to assess the crop.

Increase in sowing density results in a higher proportion of the developing stems being mainstems. It has been shown that the yield and grain size uniformity on mainstem ears is superior to that of tiller ears.

It has been postulated that increases in the proportion of stems that are mainstems would enhance seed size uniformity. However no treatments imposed here have been shown to modify the grain weight distribution within the cereal ear although differences in mean grain number per ear and mean ear weight have resulted from husbandry modifications.

Modification of initial sowing density results in a change in the grain yield components. Increasing density results in an increase in total ear number but a reduction in mean number of grains per ear. These two factors thus do not necessarily give rise to an increased number of grains $m^{-2}$. Thus as grain yield is correlated with grain number per unit area no consistent grain yield increases are related to this inconsistent modification of grain number.

Seed size uniformity can be modified by the use of altered sowing densities. High initial sowing density results in a decrease in the proportion of harvested grains above 2.8 mm with a concurrent increase in the proportion of grains between 2.5 and 2.8 mm. High initial sowing density generally results in a higher potential sink size, however this potential may not necessarily be fulfilled.

Density trials at Rothwell showed that modification of initial sowing densities did not significantly contribute to an alteration in the seed size distribution. This may have been due to the limited sink size which was readily satisfied by an adequate source.

Thus it may be necessary to compromise between grain number (sink potential) and grain fill (actual grain weight) depending upon both sink and source size. High sink potential results from a high plant number and optimum growing conditions. However grainfill may be suboptimal if source activity is limited post anthesis and retranslocation of pre-anthesis stored assimilates is not satisfactory to fulfil sink demands.

In experiment PGR2 no interactions occurred between sowing density and early spring applied PGRs. However alterations of PGR timing may have resulted in modifications of the effects of density on crop growth and development. Use of correctly timed anti-lodging PGRs may enhance grain production with higher plant numbers and with higher rates of applied nitrogen. The anti-lodging agents may decrease the grain fill reduction caused by early lodging resulting from both high nitrogen and high sowing densities.

In general the effects of applied nitrogen depends upon both the quantity and timing of the nitrogen applications. However, as in all nitrogen trials, the effects of nitrogen have been confounded by the unknown quantity of residual nitrogen present within the soil. Although all nitrogen trials were conducted on field in which the previous crop was wheat the residual nitrogen may have been different between fields and between seasons.

In this set of trials it has been possible to manipulate the growth, development and final yield of the winter barley crop by alterations in the timing of nitrogen applications. Nitrogen applied in the seedbed or as an autumn top dressing increased the early growth of the crop with a higher biomass yield and an increase in the rate of tiller production. Later additions of nitrogen top dressings increased the peak tiller number achieved. Addition of nitrogen after this time may enhance tiller survival thus giving rise to an increased ear population.

Thus by judicious use of correctly timed nitrogen top dressings differential stages of crop growth can be modified.

Nitrogen timing can also be used to increase the number of grains present at final harvest. This increase in grain number may have resulted from an increase in the total number of floret primordia initiated or from a reduction in the degradation of the distal grain sites.

Grain size uniformity depends upon the uniformity between plants, the uniformity between tillers upon the same plant and upon uniformity within the ear in one stem. Improvements in these components may be caused by the correct use of nitrogen.

It has been previously noted that adequate crop nutrition and/or adequate soil mineral reserves can partially compensate for the use of low vigour seed stocks. Thus the addition of seedbed nitrogen or early applied nitrogen top dressings should ensure adequate plant establishment and survival. This thus results in a more uniform plant stand.

High rates and correct timing of nitrogen may increase the number of tillers produced per plant, this thus leads to an increase in the variability in the tiller ages present. However timing of nitrogen to coincide with peak tiller production increases the survival of earlier formed tillers with a greater yielding potential. A wide range of tiller ages would result in a reduction in the mean number of grains present per ear and a lowering of the mean grain weight.

The achievement of adequate grain fill depends upon the balance between sink and source size. Low rates of nitrogen can cause a lowering of sink size. If however the reduction in source size is not as severe grain fill will be optimized giving rise to a smaller number of large grains. Even if source activity is reduced by the limited sink size the movement of stored assimilates from the upper internodes of the stem may compensate for the reduced activity and may still give rise to large grains.

The application of late spring nitrogen top dressings can enhance peak LAI and improve leaf area duration leading to a maximization of source potential. Late nitrogen also increases grain nitrogen content. There is some evidence that high nitrogen content seeds tend to be more able to germinate and produce viable seedlings under adverse conditions. Thus the application of late nitrogen to a maternal seed crop may enhance the suitability of the resultant grain as seed for the following crop.

It has been previously noted that winter barley varieties vary in their gross external morphology. However the morphological limitations of individual varieties can be circumvented by the circumspect use of plant growth regulatory chemicals.

Although a limited number of chemosynthetic growth regulatory substances were investigated and reported within this thesis it has been shown that addition of PGRs can modify the growth, development and yield of winter barley varieties. This limited range of applied PGRs was only used at few application rates and timings. However a number of beneficial modifications to the crop have been reported.

Early applications of gibberellic acid has been shown to reduce secondary and late primary tiller production thus resulting in a more uniform population of tillers. The use of $GA_3$ also improved the tillering efficiency of treated plants resulting in a decrease in tiller death upon stem elongation.

The response of the winter barley crop to the use of early applied $GA_3$ depended upon the variety under examination. The reasons for the differential responses may have been the individual varieties' biochemical status at the time of application of the PGRs, the timing of PGR applications in relation to internal developmental processes or the modification of the rate of breakdown of the applied regulators by different varieties.

Early applications of CCC were shown to have less effect within the crop than treatment by $GA_3$. CCC unlike previously reported experiments was not found to modify tillering patterns significantly. Neither was root distribution within the soil profile modified. Results reported here show a reduction in WUE with CCC resulting partially from inadequate water extraction at depth.

CCC was not found to modify the rate of grain fill or the duration of grain fill. Grain weight distribution within the main ear was similarly not influenced by CCC application.

The use of the growth regulator Cerone in experiments PGR2 and WB6 failed to bring about any modification of grain yield or grain yield components. This may have been due to the late timing of applications in both instances.

None of the applied PGRs significantly or consistently influenced the suitablility of the grain produced for seed.

Thus although the potential uses for the application of PGRs are vast more investigations need to be conducted to determine suitable chemicals, their rates and timings.

A number of pointers towards the optimization of seed production in winter barley can be given:

a) Varieties differ greatly in the relative importance of each of the yield components and so in order to manipulate the crop to full benefit each new variety must be examined in detail for such characteristics as tiller number and survival, grain number per ear and grain size distribution.

b) Excessive tillering should be avoided in seed crops to reduce the spread of tiller ages, but yield may be reduced if fertile tillers are lost for any reason especially if no others are available to replace them.

c) Smaller seeds may be acceptable to the commercial grower when high plant populations are being aimed for.

d) In theory better plant distribution might be used to give more uniform numbers of fertile tillers per plant. Higher densities might ensure that most of the ears produced were from mainstems or main primary tillers so aiding grain size uniformity.

e) The search for useful PGRs must continue as a means of gaining better control of tiller and ear uniformity.

There is some debate on how far a seed grower should aim to manipulate his crop beyond the needs of statutory seed certification. The industry is not clear on the desirability or necessity for size-graded seed and a lot depends on the supply and demand position in any year. If more carefully planned seed crops are to become common then it is believed that this work will have helped to draw up the plans. With hybrid cereals on the horizon (i.e. in national list trials) much more attention to the finer details in both production and use of this costly seed will be required.

Appendix I

## ROW BY ROW ANALYSIS 1983

### A1.1 Introduction

In most field scale cereal trial situations it has been found necessary to leave uncropped pathways between plots to aid crop monitoring and mechanical harvesting and to decrease the possible effects of one treatment on an adjacent plot of another and also to avoid intermingling of ears of varying treatments that may occur upon lodging of the crop. This practice has been described by Austin and Blackwell (1980), Fischer (1979) and Hadjichristodoulou (1983).

It has frequently been noted that estimates of yields from plots were higher when whole plots were harvested compared to when rows adjacent to the uncropped gangway were removed prior to harvesting (Bhalli, Day, Tucker, Thompson & Massey, 1964; Fischer, 1979, 1981). Austin and Blackwell (1980) have shown that south facing rows yield more than north facing edge rows. This has been attributed (Hadjichristodoulou, 1983) to the effects of the prevailing wind. Lower yields occur at the edge facing the prevailing wind or the uncropped field.

Fischer (1979) has shown that in small plot trials the relative yields of varieties contrasting in height were distorted in favour of taller varieties when grown in adjacent plots.

In WB6 (1982-83) visible edge effects could be seen throughout the crop's growth. This was most noticeable after the commencement of lodging. The outermost rows remained upright until harvest whilst the inner rows were uniformly lodged by maturity.

The present investigation was undertaken to determine the reasons for the differences between the rows and to elucidate the yield and yield components of each row.

### A1.2 Materials and Methods

Three discard plots from trial WB6 were used. The full experimental details are outlined in Table 5. Discard plots received the same husbandry treatments as the control plots within the trial. All plots were orientated in an east-west direction. Thus rows could be designated as Row 1 (south) to Row 10 (North). The distance between neighbouring rows was 15 cm and between adjacent plots 50 cm.

At final harvest ten adjacent 0.5 m rows across each discard plot were removed and grain yield, straw yield, tiller number, thousand grain weight and number of grains per ear recorded on a single row basis.

## A1.3 Results

Fig. A1 summarizes the influence of row position on yield, yield components and other measured traits. Row 1, the southernmost row was the highest yielding row. Rows 1 and 10 generally had more tillers per plant, more grains per main ear, a higher thousand grain weight and an increased harvest index compared to the innermost rows of each plot.

Table A1 shows the proportional increase of yield components from Rows 1 and 10 compared to Rows 5 and 6. The yield of Row 1 was 202 per cent greater than that of the averaged middle rows. The increase in yield of Row 10, at the northern edge of the plot, was 87% more than the inner rows. In only one characteristic, that of harvest index, was Row 10 inferior to the inner rows. Row 1 was superior in all the attributes.

Table A2 shows yields and yield components of plants at varying distances from the edge of each plot. The value of the inner row (taken as Row 5) component was assumed to be 100. The edge effect of each plot extended beyond the outermost row. This was most evident on the southern edge of each plot where the yield of Row 2 was 102 per cent greater than that of Row 5. The effect of uncropped areas between plots did not extend beyond the outer rows when considering the yield component of grain number per ear. For thousand grain weight the pathway effect extended at least to Rows 3 and 8. Numbers of tiller per plant were significantly reduced from the perimeter to the centre of the plots.

Table A3 indicates that grain number per unit area was the most important factor determining grain yield across all of the harvested plots. Grain number per square metre is the product of plant number per square metre x ear number per plant x grain number per ear.

Irrespective of row number higher grain yields were associated with larger ear populations and large numbers of grains per ear. Gallagher et al. (1975) recorded that the variation in grain number per unit area in

**Fig. A1** The effect of row position on grain yield and grain yield components

i Grain yield (t $ha^{-1}$)

ii Grain number per main ear

iii Tiller number per plant

iv Above ground biomass yield

v TGW (% MC) main ear

vi Harvest index

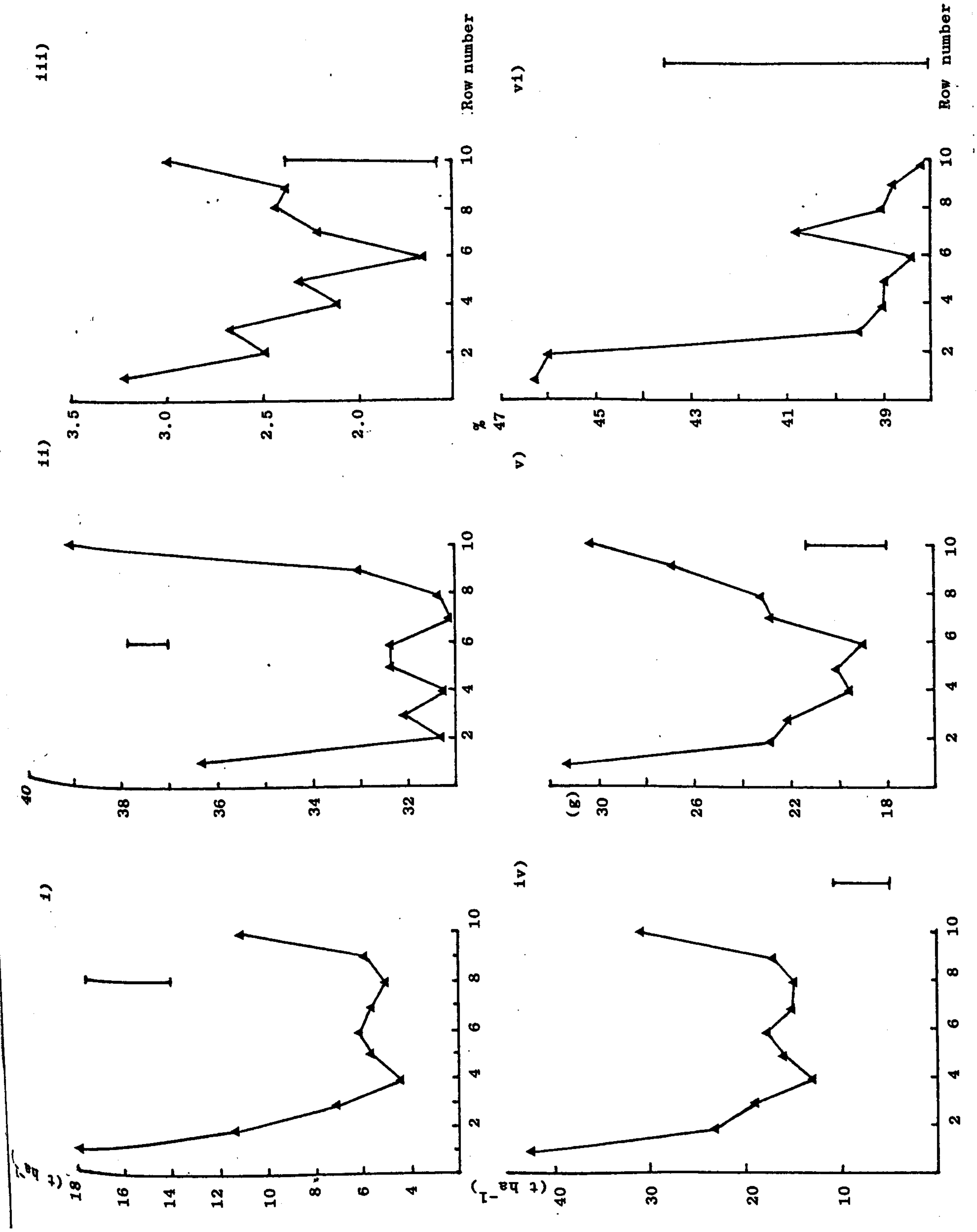

i)
ii)
iii)
iv)
v)
vi)
Row number
Row number
(t ha-1)
(g)
%

**Table A1** The percentage increase of rows 1 and 10 above that of rows 5 and 6 for yield components and final yield

| | Row 1 | Row 10 |
|---|---|---|
| Thousand Grain Weight (g) | 60.30 | 55.69 |
| Tillers per Plant | 61.71 | 50.63 |
| Harvest Index | 19.79 | -1.70 |
| Weight per Plant | 243.50 | 81.41 |
| Grain Number per Main Ear | 12.19 | 19.99 |
| Yield | 202.04 | 87.61 |

**Table A2** *The influence of row position on grain yield and yield components (value for row 5 100)*

| Row | South 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | North 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Relative Yield | 317 | 202 | 125 | 81 | 100 | 110 | 101 | 91 | 105 | 197 |
| Relative Grain Number (main) | 112 | 97 | 99 | 91 | 100 | 100 | 96 | 97 | 101 | 120 |
| Relative Tillers plant$^{-1}$ | 138 | 106 | 116 | 90 | 100 | 70 | 95 | 104 | 102 | 128 |
| Relative TGW (g) | 156 | 113 | 109 | 98 | 100 | 95 | 113 | 115 | 132 | 151 |
| Relative Biomass | 270 | 146 | 122 | 81 | 100 | 114 | 97 | 94 | 107 | 197 |
| Relative Weight per plant | 337 | 163 | 119 | 92 | 100 | 96 | 102 | 126 | 143 | 178 |
| Relative Harvest Index | 118 | 118 | 101 | 100 | 100 | 98 | 105 | 100 | 99 | 97 |
| Relative Plants m$^{-2}$ | 102 | 85 | 97 | 88 | 100 | 116 | 95 | 77 | 90 | 105 |
| Mean* Yield | | | | | | | 91 | 108 | 153 | 257 |
| Mean* Grain Number | | | | | | | 93 | 98 | 99 | 116 |
| Mean* Tillers pl$^{-1}$ | | | | | | | 92 | 110 | 104 | 133 |
| Mean* TGW | | | | | | | 105 | 112 | 122 | 153 |
| Mean* Biomass | | | | | | | 89 | 108 | 126 | 233 |
| Mean* Fh | | | | | | | 102 | 100 | 108 | 107 |

* Mean for rows 1 and 10, 2 and 9, 3 and 8, 4 and 7 presented

**Table A3** Statistical significance of linear fit from the regression of grain yield (t $ha^{-1}$ DM) with components of grain yield; Row by Row analysis 1983

| X | Intercept | Slope | % Variance accounted for | Sig (slope) |
|---|---|---|---|---|
| Harvest Index | -19.967 | 0.687 | 63.2 | xxx |
| TGW (Main) | - 5.957 | 0.597 | 28.5 | xx |
| Grain Number (main ear) | -35.438 | 1.332 | 49.2 | xxx |
| Ears $plant^{-1}$ | - 5.960 | 4.667 | 43.0 | xxx |
| Grain Number (Tillers) | -31.518 | 1.302 | 42.8 | xxx |
| Total Crop dry weight (g) | - 2.217 | 0.065 | 92.4 | xxx |
| Weight per plant (g) | - 1.320 | 1.574 | 68.1 | xxx |
| Grain Number per $m^{-2}$ | - 5.263 | $5.202 \times 10^{-4}$ | 58.4 | xxx |

Y axis = Yield

barley was generally attributable to differences in crop ear number. Here both ear number per unit area and grain number per main ear were responsible for determining the final estimated yield.

## A1.4 Discussion

From the results presented it can be noted that the effects of edge rows on yield and yield components were significant. The increase in yield was due to an increase in the number of tillers per plant, an increase in the grain number per ear and an increase in the thousand grain weight.

Hadjichristodoulou (1983) found that thousand grain weight was the least affected yield component in a similar trial on edge effects. The difference in this result may have been due to the lodging of the inner rows of the plots immediately post-anthesis. Lodging in a barley crop can be detrimental to both the yield and the quality of the harvested grain. Most incidences of lodging decrease the grain yield and reduce the thousand grain weight. The reduction in yield results from a decrease in translocation from the leaves to the ear and/or a decrease in photosynthetic efficiency of the leaves. This may be caused by an alteration of leaf inclination and thus suboptimal interception of the incident radiation.

In winter wheat experiments Austin and Blackwell (1980) calculated that plot yields would be 25 per cent greater than the true yield if the yield was calculated from the outer rows.

The estimated control plot yield of WB6 was 6.51 tonnes per hectare of dry matter. Hence the estimated yield from using solely edge rows would be 117 per cent greater than the true estimate obtained from a combine harvested sample. Plant number per unit area was not affected by row position, thus the straw and grain weight per plant was estimated to be 237 per cent greater in Row 1 and 78 per cent greater in Row 10 than the weight per plant from Row 5. This agrees with the findings of Austin and Blackwell (1980) who showed that the average yield per plant from the outer four rows was 178 per cent of that of the innermost rows.

Fischer and Kertesz (1976) have shown that grain yield of spaced plants was related to the ability of the individual plants to occupy more space and thus intercept more of the incident radiation. In the normal crop situation full light interception is reached rapidly and grain yield thus becomes a function of photosynthesis per unit of light intercepted and the distribution of the products of photosynthesis.

Thus edge rows in the spaced trial situation have an additional advantage over inner rows within a plot. The distance between rows in WB6 was 15 cm but between adjacent plots was 50 cm. Thus each edge row was potentially able to occupy an area more than twice the size of that occupied by inner rows. Therefore plants in the outer rows had the potential to utilize the additional nutrients and water that may have been available in the uncropped zone.

In other crops, e.g. peas, ways are now being investigated to eliminate the increase in estimated yield by the removal of outer rows from the trial plot (Heath, M., 1983 - personal communication). The removal of rows adjacent to uncropped pathways may be possible in crops which remain upright through until harvest but in barley trials lodging often occurs. Hence the elimination of edge rows would present great practical difficulties and result in large ear losses.

Within cereal variety trials the advantages of uncropped areas between plots are stated by Jensen and Federer (1964), Rich (1973) and Austin and Blackwell (1980). These are the removal of the effects of unequal heights of cereal varieties and of differing dates of maturity.

The disadvantages caused by edge effects can be reduced if, during crop monitoring and sampling, all measurements are taken from within the central six rows of the Øyjord plot.

There is at present no mechanism for removal of outer plot rows, thus the yield estimate from small plot trials will be greater than the yield from field scale or large plot trials (Widdowson, 1973). However Hadjichristodoulou (1983) has shown that although effects on grain yield were significant all varieties tested responded in a similar manner. Thus in cereal variety trials where only the relative yield differences are important the whole plots can be harvested without recourse to the necessity of removal of the edge rows.

However in seed rate trials sown with gaps between plots reliance on grain yields estimated from harvesting whole plots will lead to over estimation of the optimum economic seed rate (Saville, 1984). In seed rate trials grain yield harvested or calculated from yield components from the centre rows of trial plots are more likely to provide unbiased estimates of treatment effects than whole plot yields (Saville, 1984).

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