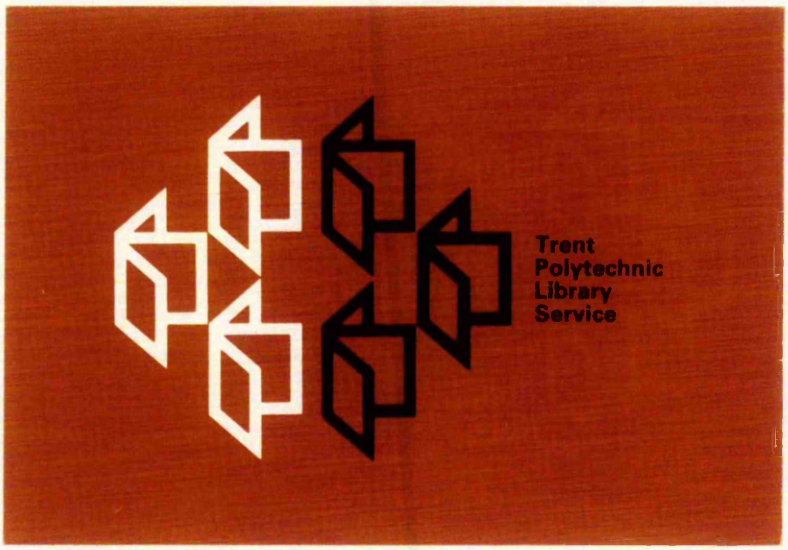
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PHYSIOLOGICAL FACTORS AFFECTING YIELD IN ALLIUM CEPA cv. KELSAE

BY

D.V. LOUIS. B.Sc. M.Sc.

A thesis submitted to the Council of National Academic Awards in partial fulfilment for the degree of Doctor of Philosophy.

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3. The author has attended conferences and programmes of study relevant to the present study.

4. Due acknowledgements have been made for the assistance given during the course of this work and in the presentation of the thesis on which it is based.

Signed ..D.V. Lowis.....
(Candidate)

Signed ..M.Daniel.....
Director of Studies

ABSTRACT

Physiological factors affecting yield in *Allium cepa* cv. Kelsae

by

D.V. LOUIS. B.Sc. M.Sc.

The interactive control engendered between light quality and daylength and light quality with different plant growth regulators applied exogenously was studied on a range of gross morphological and cellular characters affecting yield in *Allium cepa* cv. Kelsae. In regard to light quality, attention was focused on the possible roles performed by the low and high R:FR ratios emitted from Philips Colour 37 (C37) and Atlas White (AW) fluorescent light sources respectively. The influence of multifarious plant growth regulators on bulbing was also determined under greenhouse and field conditions.

Increasing the daylength from 11 to 20 h with C37 rather than AW light, not only enhanced leaf blade and leaf sheath length, but also initiated bulbing with a concurrent cessation in leaf development when the daylength exceeded 14 h. Furthermore a daylength extension from 17 to 20 h shortened the time to bulb inception by 2 weeks.

C37 light increased the leaf area, fresh and dry weight of the total plant, leaves and combined basal region & leaf sheaths when compared to AW light, whereas the contrary applied to the root fresh and dry weight. Furthermore the enhancement in leaf area by C37 light was largely attributed to an augmentation in epidermal and palisade mesophyll cell width and length expanding both leaf length and width. IAA, $GA_{4/7}$ and ethrel C inhibited plant growth and interacted with light quality on certain plant characters by reducing the expected increase under C37 light to the level achieved with AW light and the relevant plant growth regulator. In contrast phosphon D particularly augmented leaf expansion with the response being greater under C37 rather than AW light. Notable leaf area diminutions affected by IAA, $GA_{4/7}$ and ethrel C were chiefly ascribed to the former two reducing epidermal and palisade mesophyll cell width and hence leaf breadth, whilst the latter retarded epidermal and palisade mesophyll cell length and thereby leaf height. On the other hand greater cell division activity may be responsible for the enlarged leaf width exacted by phosphon D.

Under greenhouse and field conditions $GA_{4/7}$ and GA_3 produced torpedo shaped bulbs and tillers, whilst only the former character developed following treatment with IAA. In contrast round bulbs were predominantly evoked by phosphon D, whereas early development of small flat shaped bulbs characterised the response to ethrel C.

As in other species the regulation of growth and development in *Allium cepa* cv. Kelsae appears to be complex. Furthermore the responses evoked by light and plant growth regulators on this particular variety are discussed in relation to effects produced and possible mechanisms involved in other onion cultivars and different plant species.

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CONTENTS

GLOSSARY OF ABBREVIATIONS AND PLANT GROWTH REGULATOR NOMENCLATURE

A.T.	-	Appendix Table.
AMO-1618	-	2' - isopropyl -4' -(trimethylammonium chloride)-5' -methylphenylpiperidine -1-carboxylate.
Ancymidol	-	α -cyclopropyl-2'-(p-methoxyphenyl)-5-pyrimidine methyl alcohol.
AW light	-	light quality emitted from Atlas White fluorescent tubes.
BA	-	benzylaminopurine.
BAP	-	blue light absorbing photoreceptor.
C37 light	-	light quality emitted from Philips C37 fluorescent tubes.
CEPA	-	2-chloroethylphosphonic acid.
Chl	-	total chlorophyll.
CONT	-	control.
2,4-D	-	2,4-dichlorophenoxyacetic acid.
DEHEG	-	N,N - diethyl -N- (2-hydroxyethyl) glycine.
DEOMC	-	N,N - diethyl -2- oxomorpholinium chloride.
DMMC	-	N,N - dimethylmorpholinium chloride.
DMOMC	-	N,N - dimethyl-2-oxomorpholinium chloride.
DWR	-	dry weight ratio.
Ethrel C	-	2-chloroethylphosphonic acid.
FAA	-	Plant tissue fixative containing aqueous ethyl alcohol, formalin and glacial acetic acid.
FR	-	far-red light.
GA	-	gibberellin.
h	-	hour.
IAA	-	Indole-3yl-acetic acid.
IPA	-	α -(Indol-3yl)- propionic acid.
Kinetin	-	6-furfurylaminopurine.
LAR	-	leaf area ratio.
Mepiquat chloride	-	1,1-dimethylpiperidinium chloride.
MH	-	Maleic hydrazide.
Morphactin	-	9-fluorenolcarboxylic acid.
NAA	-	Naphth-1yl- acetic acid.

NOA	-	β Naphth-2yloxy - acetic acid.
P.A.R.	-	photosynthetic active radiation between 400 and 700nm wavelengths (McCree, 1972).
P.I.B.	-	point of incipient bulbing.
Paclobutrazol	-	(2RS, 3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1H-1,2,4-triazol-1-yl) pentan-3-ol.
Pfr	-	phytochrome in far-red light absorbing configuration.
Phosphon D	-	tributyl-2,4-dichlorobenzylphosphonium chloride.
Pr	-	phytochrome in red light absorbing configuration.
P_{tot}	-	total phytochrome.
R	-	red light.
RGR	-	relative growth rate.
S.D.	-	standard deviation.
S.E.	-	standard error.
SLA	-	specific leaf area.
SPD	-	spectral photon distribution.
STS	-	silver thiosulphate.
SWC	-	specific water content.
TIBA	-	2,3,5- triiodobenzoic acid.
ULR	-	unit leaf rate.

1. GENERAL INTRODUCTION

1.1. Origin , characteristics and cultivation of the onion variety Kelsae

The inception of the exhibition onion (Allium cepa L.) variety Kelsae was from a simple cross made between "Crosslings Selected" x Dixon and Robinson's Premier (M.A.F.F., 1974)

General characteristics of the foliage for this variety are tall leaves of medium green to dark green colour with a glaucescent sheen attributable to a heavy wax coating. A broad elliptic shape with a high shoulder describes the bulb shape normally produced by the variety Kelsae. Furthermore, the outer skin colour can be expected to attain a yellow to brown hue, whereas the scale flesh develops a white to red colouration. In contrast, epidermal scale layers normally have a green pigmentation. Since two of the most important characters of anexhibition onion bulb are size and fresh weight, the Kelsae variety generally excells in these respects and under careful growing practices can achieve circumferences and fresh weights exceeding 600mm and 2.72 kg respectively.

Recommendations concerning the growing practice for the Kelsae variety, suggest sowing in late December to early January in either John Innes Seed or John Innes No.1 compost (Sinclair McGill (Horticultural) Ltd.). If trays are used, the seeds ought to be sown sparingly and to a depth of approximately 5mm. A greenhouse temperature range of between 13 and 15.5^{o}C is advocated from germination to prior emergence of the second leaf, while thereafter the temperature may be reduced to between 10 and 13^{o}C and the greenhouse ventilated depending on the weather conditions. Once the second leaf has developed, the seedlings ought to be thinned or potted on in John Innes No.1. compost and a further temperature reduction to between 7 and 10^{o}C considered once the transplants have established. In late March and early April the plants can be transferred to cold frames prior to planting out in late April to early May.

The onion bed should be prepared with plenty of farmyard manure, dug in during the winter and prior to planting, a dressing with 68g.m^{2} of general fertilizer and an addition of lime is also

advisable. The latter ingredient need only be applied if the pH of the soil falls below the range of pH 6.75 to 7.25 recommended for optimal growing conditions. For exhibition work, the plants ought to be transplanted into rows with 460mm centres, while a spacing of 380mm is preferred for plant separation within the rows. On recommencement of free growth following transplantation, it is expedient to lightly dress the growth medium with sodium nitrate at a rate of 17 to 25g.m^2 every 2 to 3 weeks. During mid-August and if necessary in early September, a light dressing of potassium sulphate will further assist the hardening and ripening of the bulbs. Harvesting of the mature bulbs can normally be expected to commence in mid to late September.

1.2. Influence of various environmental factors on onion development

Growth of the onion plant from seed is composed of two morphologically distinct phases. The first phase is primarily concerned with the rapid proliferation of leaf tissue, while the second phase involves bulbing. Both phases are under strong environmental control with daylength, light intensity, light quality and temperature acting as major determinants. The following review will consider the available evidence supporting the role of assorted environmental factors on leaf development and bulbing.

1.2.1. Vegetative growth

Garner & Allard (1923), Kikuchi & Matsumoto (1954), Aura (1963), Kato (1964, 1965b), Butt (1968) and Ohkubo *et al* (1981) observed that the leaf extension rate and final height achieved in onion plants were increased with protraction of the daylength. In addition, Butt (1968) observed an augmentation in leaf blade diameter and leaf sheath length in response to long rather than short day treatments, while leaf fresh and dry weight were unaffected. However, as bulbing suppresses leaf production (Heath, 1945) and is initiated earlier under long daylengths (Kato, 1964), increasing the daylength invariably leads to a diminution in final plant height (McCelland, 1928). Cognizance should also be taken of the differential values obtained for plant height of various Japanese varieties grown under long days (Kato, 1964), for this

reflects an overriding degree of control by the genetic constitution of the varieties concerned.

In regard to light quality, Butt (1968) discerned that greater leaf extension rates, leaf blade diameters and leaf sheath lengths were produced as a result of irradiating onion plants with 8h natural daylight supplemented with a further 8h incandescent rather than fluorescent light, whereas the converse pertained with specific leaf weight. However, leaf fresh and dry weight were unaffected by the different supplemental light qualities. These results led Butt (1968) to tentatively suggest that long days with incandescent light produced increased cell expansion in preference to dry matter accumulation in the leaf blade. Since incandescent light emits a lower R:FR ratio than fluorescent light, Butt also inferred that R light was suppressive towards leaf blade and sheath enlargement, whilst FR light acted contrarily.

By using different grades of black and white muslin to produce a range of light intensities, Terabun (1971a) discerned an increase in plant height and leaf number as the percentage sunlight decreased from 100 to 30%, whilst below 30% both these characters were reduced. This restraint can be expected at low light intensities, since photosynthesis will be impaired, thus limiting the supply of photosynthates essential for leaf growth. Similarly, varying the light intensity within a controlled environmental cabinet, Butt (1968) demonstrated an increase in leaf length with light intensity from 93,700 to 31,200 $ergs.cm^{-2}.\ sec^{-1}$ and then a decrease below the latter light intensity. In contrast, leaf diameter, number, fresh weight and dry weight were augmented with increasing light intensities (Butt, 1968). However, Ahmed (1977) suggested that the decrease in plant height following irradiation with sunlight was due to enhanced senescence, whereas at 75 and 50% of full sunlight, the depression in height was progressively delayed as a result of delayed senescence.

In regard to temperature, a concurrent enlargement in the leaf extension rate (Kato, 1964; Butt, 1968), fresh weight, dry weight and area (Butt, 1968) pertained with a rise in temperature, reaching an optimum at $25^{\circ}C$, before decreasing at higher temperatures. However, a broader temperature optimum between

15 and 25°C yielded maximum leaf diameters, whilst temperatures of 10 and 30°C moderated this character (Butt, 1968). A corresponding enhancement of plant height and leaf number with a temperature rise from 15 to 30°C was also demonstrated by Ahmed (1977), while Kato (1964) established a minimum temperature of 10°C for observable growth. Furthermore, Kato (1964) established a temperature x photoperiod interaction, whereby reducing the temperature from 25 to 10°C under a 12 to 14h daylength evoked a rapid diminution in the leaf elongation rate, while a 24h daylength gave a slight retardation in the elongation rate and then only with the lowest temperature of 10°C.

Once bulbing commences, Nagai & Hanaoka (1967) reported a rapid diminution in leaf bud differentiation, successive reduction in the height of emerging leaves and cessation of leaf emergence two weeks after scale bud initiation. Similarly, Heath (1943b, 1945) and Heath & Holdsworth (1948) reported a cessation in leaf emergence and Butt (1968) observed a curtailment in the length of the longest leaf when bulbing commenced. However, when the temperature exceeds 27°C during the summer season in the arid tropical region of Sudan, Abdalla (1967) showed continued production of short leaves concurrent with retarded bulbing. Other reports suggesting that leaf development may still prevail after the onset of bulbing at lower temperatures was evident in the lowveldt of Zimbabwe, where leaf development continued for 3 to 4 weeks after incipient bulbing, as the temperature declined from 28°C in February to 17°C in July (Robinson, 1973). Similarly, Heath (1943a,b) established a concurrence of leaf production and bulbing of onion plants maintained at low temperatures of 14 to 15°C. Since slow rates of bulb expansion pertain at 15°C (Butt, 1968; Ahmed, 1977), this may permit a more favourable partitioning of metabolites to the leaves in preference to swelling leaf sheaths and scales.

In conditions unfavourable for bulbing such as short days (Garner & Allard, 1923 ; Thompson & Smith, 1938; Heath, 1943a,b; Heath & Holdsworth, 1948; Manuel & Velasco, 1962; Jones & Mann, 1963; Aura, 1963; Sinnadurai, 1970) or when the light source emits a high R:FR ratio (Paribok, 1956; Butt, 1968), continued leaf production prevails.

1.2.2. Bulbing

Generally, onion varieties grown in temperate regions require long days for the initiation of bulbing (Garner & Allard, 1923; McCelland, 1928; Magruder & Allard, 1937; Thompson & Smith, 1938; Heath, 1945; Abe et al, 1955; Aura, 1963; Jones & Mann, 1963; Austin, 1972). However, Abdalla (1967) and Robinson (1971) in Sudan and Zimbabwe respectively suggested that temperature was the major determinant regulating bulbing, since these countries lie in latitudes where the seasonal change in daylength is minimal, approximately 11 to 13h, but large seasonal changes in temperature pertains. Nevertheless, in Israel, where similar seasonal changes pertain, the onion variety Bet Alpha not only bulbs successfully as the temperature and daylength declines, but has a minimum photoperiodic requirement of 11h for bulbing (Levy & Kedar, 1972a; Kedar et al, 1975). Thus onion varieties best adapted to growing in Sudan & Zimbabwe may also have short day requirements for bulbing.

Magruder & Allard (1937), Abe et al (1955) and Austin (1972) reported substantial variation among and within varieties with regard to their minimum daylength requirement for bulbing. Furthermore, Abe et al (1955) proposed that ecological differentiation was the prime cause for variation in photoperiodic requirement for bulbing, since varieties demonstrated their abilities best when grown in regions where the minimum temperature and photoperiodic requirement coincide . Similarly, Jones & Mann (1963) reported that a cultivar was more likely to be adapted to different districts in the same latitude, because of uniformity in daylength, than to districts of similar climate in different latitudes. Hence, variable yields can be expected in the higher latitudes from the utilization of varieties with different photoperiodic requirements. Thus small bulbs are generally produced from short day varieties with a 10 to 12h minimum photoperiodic requirement, since the daylength and temperature requirements for bulbing should be acquired at a time of early seedling development, when there is a scarcity of leaf area. As leaf production curtails with onset of bulbing, only a limited amount of photosynthate production essential for bulbing can be

expected within the finite lifespan of the few leaves produced (Jones & Mann, 1963). The converse situation generally pertains with long day varieties requiring an excess of 12h to initiate bulbing. In addition, these explanations support the positive correlations between the plant size achieved prior to bulbing by varieties with different minimum photoperiodic requirements and the resulting magnitude of their mature bulbs (Magruder & Allard, 1937; Aoba, 1954; Kato, 1964; Butt, 1968). An extension of these points comes from the work of Woodbury & Ridley (1969) and Levy et al (1975) showing an earlier initiation, faster rate of bulb expansion and quicker time to maturity for short day varieties, whereas the converse applied to long day varieties.

Ahmed (1977) discerned that extending the daylength not only produced a corresponding diminution in the number of days from sowing to the point of incipient bulbing (PIB), but also incurred a direct correlation between bulb and neck diameter with the number of days from sowing to PIB. In addition, internal inspection of matured bulbs discerned a decrease in the number of swollen and unswollen scales produced by plants sown at later dates between February and July when the natural daylength had substantially increased (Heath & Mathur, 1944). Analysis of the photoperiodic stimulus by Terabun (1971b), ascertained that final bulb size was dependent on leaf area rather than age, following defoliation experiments, which left the plants with different aged leaves under conducive daylength conditions for bulbing. Furthermore, selective irradiation of leaves from the same plant with 8 or 24h daylength revealed enhanced bulbing when the number of leaves receiving 24h daylength was increased (Terabun, 1971b). However, transmission of the photoperiodic stimulus was not observed between different tillers of the same plant if they were given selectively 8 or 24h daylength, since only tillers receiving the latter daylength bulbed. Finally, the loop stage, reached 10 days after germination, represented the earliest physiological age receptive to bulbing (Terabun, 1971b).

Reversion from the bulbing phase to renewed leaf development can be accomplished by decreasing the daylength below the minimum photoperiodic requirement for bulbing (Aura, 1963; Kato, 1964;

Levy & Kedar, 1972a; Kedar et al, 1975). In addition, the number of days required for this transformation increased with the degree of bulbing attained, and restoration of leaf production was possible even at the late stage of top prostration (Kato, 1964).

Using various artificial light sources either alone or in conjunction with sunlight, bulbing was promoted by light rich in FR light, while R light antagonized this response (Paribok, 1956; Terabun, 1965; 1970; Butt, 1968; Woodbury & Ridley, 1969; Austin, 1972; Kedar et al, 1975). Austin (1972) observed that the R:FR ratio emitted by a particular light source was critical if bulbing was to be initiated. Thus sunlight, incandescent light and Philips Colour 37 fluorescent light with R:FR ratios of 1, 2, 3.7 respectively were conducive for bulbing, whilst Philips Colour 29 fluorescent light with a R:FR ratio of 22.7 was inhibitory. By irradiating onion seedlings with 12h fluorescent light with a high R:FR ratio followed by variable periods and intensities of incandescent light with a low R:FR, Butt (1968) showed that the duration of the light period was the overriding factor determining bulb initiation. Thus 8 but not 4 hours supplementary incandescent light ranging from intensities of 720 to 11,250 ergs. cm^{-2}. sec^{-1} were conducive to bulbing, though within a narrow range of supplemental light duration an interaction prevailed with light intensity. Hence 6h of supplementary incandescent light at intensities of less than 4,750 erg. cm^{-2}. sec^{-1} inhibited bulbing, but 8h at 3,200 ergs. cm^{-2}. sec^{-1} was conducive. Blue light may also promote bulbing and 8h irradiation with sunlight followed by 16h with a mixture of varying intensities of FR and blue light yielded a synergistic response to bulbing, which was further promoted when the fluence rate of both light sources was increased (Terabun, 1965, 1970).

Due to the regulatory role of daylength and light quality, Austin (1972) and Brewster (1977) proposed that bulbing was a phytochrome-mediated photoperiodic response. Lercari (1983) extended this argument by implicating the high irradiance reaction of phytochrome, since bulbing could be enhanced by interpolating an inductive photoperiod with monochromatic light at 714nm, which intimates an optimal photomorphogenetic response at low Pfr levels

and this effect could be augmented by increasing the fluence rate of the monochromatic light source. Although phytochrome absorbs in the blue region of the spectrum, Kendrick & Frankland (1976) and Wareing & Phillips (1981) suggest that another photoreceptor such as a flavoprotein or carotenoid may be implicated.

Using controlled environmental conditions and a 15.5h daylength conducive to bulbing, a temperature increase from 10 to 30°C produced a concomitant shortening in the time from sowing to bulb induction and enhanced the bulb expansion rate (Butt, 1968). Similarly, Ahmed (1977) showed a concurrent augmentation in the bulb expansion rate with temperature under a 16h daylength, but found the time taken to reach the point of incipient bulbing was unaffected by temperature. However, earlier work by Thompson & Smith (1938) and Heath (1943b) established that a temperature range 10 to 15.5°C inhibited bulbing, 15.5°C to 21°C delayed incipient bulbing and final maturity, while 21 to 26.5°C promoted bulbing and shortened the time to maturity. Although Thompson & Smith (1938) and Heath (1943b) demonstrated an inhibition of bulbing between 10 and 15.5°C, the converse was evident from the work of Kato (1964), Butt (1968) and Ahmed (1977). These discrepancies could be due to the time duration of the experiment, since a 16.5h daylength with a temperature of 24°C gave 100% bulbing after 5 weeks, whereas a temperature of 14°C yielded 7% bulbing after 10 weeks and 40% by 16 weeks (Heath & Holdsworth, 1943).

Evidence accrued by Jones & Mann (1963) and Robinson (1971, 1973) suggests that high temperatures produced earlier maturation and reduced bulb yields. Certainly in the latter study, premature bulbing and early dormancy was observed in onion plants transplanted at the beginning of the seasonal decline in temperature from 28.3°C in February to 17.8°C in June. In contrast, Ahmed (1977) and Butt (1968) obtained the largest bulb diameters from plants grown at high temperatures between 25 and 30°C under conducive photoperiods of 16 and 15.5h respectively for bulbing. These disparties may in part be explained by photoperiod x temperature interactions. Such interactions were discerned by Steer (1980a), whereby a low temperature regime of 18/10°C for the day and night period respectively moderated the bulbing

response normally elicited by increasing the photoperiod from 11 to 17h, whilst the converse applied when the temperatures were augmented to 22/14°C and 26/18°C. Furthermore, under the longest daylength of 17h a day/night temperature of 22/14°C produced the largest bulbs, whilst 26/18°C and 30/22°C hastened bulb expansion and time to maturity, but at the expense of bulb size. Similar photoperiod x temperature interactions were also obtained by Thompson & Smith (1938) and Kato (1964), whereby temperatures from 10 to 15°C depressed the bulbing response normally evoked when increasing the photoperiod, whilst the contrary applied to temperatures from 20 to 30°C. Furthermore, Steer (1980a) and Ohkubo et al (1981) demonstrated that the degree of the photoperiod x temperature interaction was also dependent on the variety examined.

Above 30°C and approaching temperatures normally associated with the summer season in tropical regions, bulbing was retarded (Abdalla, 1967; Steer 1980a) and leaf production maintained, even though the daylength requirement for bulbing was met (Abdalla, 1967). In these situations short day varieties are sown at the end of the summer season to enable bulbing to progress as the temperature and daylength decreases (Abdalla, 1967; Robinson, 1971; Kedar et al, 1975).

Increased night temperatures were also shown to enhance the bulbing response (Heath & Holdsworth, 1948; Steer, 1980b). Thus a 15°C rather than a 5°C drop from the day to the night temperature evinced a slower rate of bulbing, though increasing the daylength from 13 to 15h amplified the differences attained for bulb size between the two night temperatures (Steer, 1980b). To exacerbate the complexity of these responses, Steer (1980b) also observed a varietal effect controlling the degree of these environmental effects. In addition, a close inspection of the night temperature effect for plants maintained under a 13h daylength with a 26°C day temperature, revealed a faster rate of bulbing when the first half of the 11h night period was at 21°C and the second half at 11°C, than vice versa.

A reduction in light intensity had little effect on the commencement of bulbing (Kato, 1964; Ahmed, 1977), but markedly decreased the rate of bulb development (Kato, 1964; Butt, 1968; Terabun 1971a; Kedar et al, 1975; Ahmed, 1977). Furthermore, bulbing was completely inhibited when the light intensity was reduced to 100ft. candles (Kedar et al, 1975) or the natural daylight was reduced to between 30 and 40% using cheese cloth (Terabun, 1971a). Varietal differences were also evident with regard to the rate of bulbing under low light intensities, since Kedar et al (1975) discerned that short day varieties reached a bulbing ratio of 2 much earlier than longer day varieties under a light intensity of 250ft. candles. Furthermore, under a low light intensity, Butt (1968) disclosed a marked decrease in bulb sugar content, fresh weight, dry weight and length, whilst the converse applied to bulb length: diameter ratio, which indicated the development of long slender bulbs.

1.3. Influence of various plant growth regulators on onion development

1.3.1. Vegetative growth

Plant growth regulators reported to retard plant height are, amongst others, ethylene (Ahmed, 1977), CEPA (Levy & Kedar, 1970, 1972b; Levy, Kedar & Karacinque, 1973; Corgan, 1974; Saimbhi et al, 1974; Corgan & Montano, 1975; Lercari & Ceccarelli, 1975; Lipe, 1975, 1976 a, b; Corgan & Izquierdo, 1979), MH (Isenberg et al, 1951; Choudri & Bhatnagar, 1953; Terabun, 1967; Sinnadurai et al, 1971; Matlob, 1979) and N, N-diethylmorpholinium compounds (Knypl, 1979, 1980). With regard to CEPA, this releases ethylene by a base catalysed elimination reaction, when the pH conditions exceed 4.1, such as in the cytoplasm of the plant cells (Cooke & Randall, 1968).

Ethylene, CEPA and MH produce a rapid swelling of the leaf sheaths, which emulates the early stages of bulbing (Terabun, 1967; Levy & Kedar, 1970; Levy, Kedar & Karacinque 1973; Lercari & Ceccarelli, 1975; Ahmed, 1977) and in regard to the latter plant growth regulator, this can be attributed to a marked expansion in parenchymal cell size (Terabun, 1967). Furthemore, leaf blade injections (Brewster & Macadam, 1976) and foliar sprays (Lipe, 1975) of CEPA

also shortened the neck region of the plants, which implies a diminution in the length of the contributing leaf sheaths, a fact that was subsequently confirmed by Brewster & Macadam (1976). The ability of CEPA and MH to slow the rate of leaf production (Terabun, 1967; Levy, Kedar & Karacinque, 1973; Brewster & Macadam, 1976) accords with comparable findings in plants stimulated to bulb under inductive environmental conditions. Maximum retardation of leaf growth by foliar sprays of CEPA was best achieved by repeatedly applying at various leaf stages and ensuring that the sprays were given during the earlier rather than the later leaf stages, when bulbing was already initiated (Levy & Kedar, 1970; Lipe, 1976a, b). In addition, Levy & Kedar (1970) established a greater diminution in plant height with increasing concentrations of CEPA from 500 to 10,000 ppm. The efficiency of a particular CEPA concentration to promote swelling of the leaf sheaths and slow leaf production was also dependent on the method of application. Thus, to obtain these particular effects, immersion of roots and sheaths in a solution of CEPA required a concentration of only 1.5 ppm, soil drenches necessitated a concentration in excess of 300 ppm CEPA applied as 16 drenches, three times a week and foliar sprays of CEPA needed concentrations exceeding 600 ppm given 18 times at a rate of 2 treatments a week (Levy, Kedar & Karacinque, 1973).

Soil drench treaments with plant growth retardants DEOMC, CCC and Phosphon D increased the diameter and green colouration of the leaves, whereas the close structural analogues of DMOMC and DMMC were unresponsive. Later work by Knypl (1980) established that DEOMC and DEHEG applied as droplets to the base of the second leaf sheath, initially promoted leaf elongation, whilst strongly retarded the development of later leaves which became thicker and dark green in colour. As both retardants gave similar responses, Knypl (1980) suggested that DEHEG was the active ingredient, since DEOMC was hydrolysed by water to the betaine derivative DEHEG. Sinnadurai et al (1971) also indicated that CCC produced deep green leaves, but made no mention on whether leaf growth was modified. However, using foliar sprays of 1000 or 5000 ppm SADH, Lipe (1975) was unable to show leaf growth changes in a number of different onion cultivars, though a later study by Brewster & Macadam (1976) verified an increase in production and persistence of green leaf

blades when leaves were injected with SADH and ancymidol, while CCC was ineffectual.

Gibberellic acid (GA_3) generally enhanced the growth of various onion vegetative characters. Certainly an increase in plant height (Srivastava & Adhikari, 1972) and haulm length (Olivares & Manuel, 1962) was obtained following a 6h seed soak with either 30 or 50 ppm GA_3 and spraying with either 1, 10 or 100 ppm GA_3 respectively. However, the latter authors failed to determine whether the increased haulm length was attributable to an enlargement of leaf sheath length or number. Injecting the leaf blade with 10 ppm GA_3 every 5 days resulted in Kato (1965b) observing an augmented leaf blade : leaf sheath length ratio, which could be attributed to GA_3 enhancing the leaf blade length. Although El - Habbasha & Behairy (1977) failed to discern changes in leaf morphology following a single foliar spray of 100 ppm GA_3 alone or in conjunction with $MnSO_4$ and $MgSO_4$, leaf fresh weight was augmented with GA_3 in combination with these mineral salts. Furthermore, Corgan & Montano (1975) established that single and multiple foliar applications of 1000 and 500 ppm GA_3 respectively caused leaf growth of secondary buds. Lipe (1975) and Knypl (1980) also observed an increase in leaf number following GA_3 applications, but proposed that the response was either manifested by regrowth of normally dormant leaf blades in the centre of the mature bulb or of adventitious buds on the shoot axis.

Contradictory evidence purporting to show a suppression of vegetative growth by GA_3 is evident from the work of Knypl (1979), whereby two applications of 10µg GA_3 to the base of the third leaf moderated the diameter of the subsequent leaves. In contrast, Kathale et al (1975) elicited no modifications in plant height subsequent to a 14h seed soak in either 20, 40 or 60ppm GA_3.

Enhanced vegetative growth was generally reported for treatments involving IAA and various synthetic auxins. Thus a 6h seed soak with 50ppm IPA or 25ppm NOA (Srivastava & Adhikari, 1972), or a 14h seed soak with 20ppm NAA (Kathale et al, 1975) enhanced plant height. However, Kathale et al (1975) noted that the NAA effect was transient, since later assessments during the time course study revealed little difference between treatments. Dipping

onion plant roots in 10 or 20ppm IAA for 4h prior to transplanting improved leaf length, number, fresh weight and dry weight (Jauhari & Singh, 1960). Comparisons between the techniques involving either an 8h seed soak or root dip of 15cm high transplants in 1,10 or 100ppm IBA or NAA, disclosed for the former method, an increase in root and leaf dry weight by 1 and 10ppm IBA and NAA, whereas 100ppm was inhibory (Vaish, 1972). In contrast, a 1ppm NAA or IBA root dip markedly augmented the root and leaf dry weight, whilst 10ppm was ineffectual and 100ppm inhibitory. On the other hand plant height, leaf number and leaf fresh weight were promoted by foliar sprays of either IAA, IBA or NAA administered every two weeks at concentrations ranging from 100 to 300ppm (Mathur, 1971). More recent work by Brewster & Macadam (1976) employing leaf injections of IAA alone or combined with GA_3 and BA or NAA with GA_3 and BA revealed enhanced production and persistence of green leaf blades. Furthermore, Brewster & Macadam (1976) confirmed an earlier report by Terabun (1967) who showed that the synthetic auxin 2,4-dichlorophenoxyacetic acid, 2,4-D, produced longer leaf sheaths with small parenchyma cells within.

A few reports claiming that IAA retards leaf development were evident, since Lercari & Ceccarelli (1975) demonstrated a reduction in plant height and leaf number of onion plants grown in nutrient solutions containing 20ppm IAA. Similarly, Kato (1965a) established a reduction in plant height after 60 days of leaf blade injections with 10ppm IAA applied every 5 days, while Terabun (1967) demonstrated leaf epinasty following foliar sprays with 200ppm 2,4-D.

With regard to TIBA and morphactin purported to suppress IAA translocation in plant tissues (Hillman, 1984), foliar sprays of 17 to 1728ppm TIBA (Terabun, 1967) and foliar injections of 1.1 to 90ppm morphactin (Brewster & Macadam, 1976) were unable to influence vegetative development. In contrast, Lercari & Ceccarelli (1975) showed a diminution in plant height and leaf number when onion plants were grown in nutrient solutions containing 20ppm morphactin. Production and persistence of green leaf blades were also promoted by foliar injections of 0.37 to 30ppm BA, a synthetic cytokinin (Brewster & Macadam, 1976).

1.3.2. Bulbing

Although applications of ethylene (Ahmed, 1977) and CEPA (Levy & Kedar, 1970, 1972b; Montano, 1971; Levy, Kedar & Karacinque, 1973; Corgan, 1974; Saimbhi *et al*, 1974; Lercari & Ceccarelli, 1975; Lipe, 1975, 1976a,b; Brewster & Macadam, 1976) elicited earlier bulbing and enhanced bulb expansion in a variety of onion cultivars, this generally led to a premature cessation of bulbing and diminution in final bulb size and weight (Levy & Kedar, 1970; Bussell, 1972; Corgan, 1974; Saimbhi *et al*, 1974; Lipe 1975, 1976a,b). In addition ethylene and CEPA initiated bulbing under non-inductive short days (Levy & Kedar, 1972b; Levy, Kedar & Karacinque, 1973; Corgan, 1974; Lercari & Ceccarelli, 1975; Lipe, 1975; Brewster & Macadam, 1976; Ahmed, 1977). Since CEPA reduces the rate of leaf production and longevity (Levy & Kedar, 1970; Levy, Kedar & Karacinque, 1973; Brewster & Macadam, 1976), the production of sufficient photosynthates essential for the bulbing process may be impaired, thereby leading to a paucity in final bulb size. The reduction in final bulb size was found to be dependent on the concentration and timing of the CEPA treatments. Thus using foliar sprays Montano (1971) was unable to confirm a moderation in bulb size following 3 applications of 1000ppm CEPA applied 60,40 and 23 days before harvest, whereas Levy & Kedar (1970) established that low concentrations of 500 and 1000ppm initiated early expansion of bulbs without loss in final bulb weight, while 5000, and 10,000ppm lessened final bulb weight. Furthermore, when CEPA was applied at various individual leaf stages or combinations of these and using 3 different concentrations of 1000, 2000 and 3000ppm, Lipe (1976) concluded that high concentrations and repeated applications in conjunction or separately would ultimately yield small bulbs. Considering the effectiveness of various methods to administer CEPA, Levy, Kedar & Karacinque (1973) achieved bulbing from plants grown in solutions containing only 1.5ppm CEPA, whereas an excess of 300ppm was required to promote bulbing by soil drenches and 600ppm or more were a prerequisite for effective foliar sprays.

MH also promotes bulbing under non-inductive short days if applied in concentrations exceeding 500ppm (Terabun, 1967) and is apparently effective either as a soil drench or foliar spray when administered in concentrations ranging from 0.025% to 0.25% (Choudhri & Bhatnagar, 1953). However, foliar sprays of MH exceeding 300ppm produced puffy, distorted and light weight bulbs (Sinnadurai et al, 1971). A similar condition arose from spraying sprouted bulbs, which subsequently reswelled and developed a flabby appearance with large air spaces between the fleshy leaf sheaths (Isenberg et al, 1951). Furthermore injecting MH into young plants (Brewster & Macadam, 1976) or plants showing symptoms of incipient bulbing (Abdel-Rahman & Isenberg, 1974) evoked a reduction in bulb size and weight.

In regard to the effects mediated by GA_3 on bulbing, the evidence from the literature is contradictory. Thus Olivares & Manuel (1962) reported an increase in bulb diameter and weight following foliar sprays of 1,10 or 100ppm GA_3 to plants receiving long days of 12 and 15h, while GA_3 was unable to promote bulbing under the non-inductive daylength of 9h. Increases in bulb diameter and height were also observed following foliar injections of bulbing plants with 100ppm GA, alone or in combination with 100ppm Kinetin and IAA (Abdel-Rahman & Isenberg, 1974), whilst Chattopadhyay (1973) claimed increased bulb yields following a 24h root soak of 3 week old onion seedlings in 20ppm GA_3.

In contrast, injections of either 10ppm GA_3 every 5 days (Kato, 1965b) or a range of GA_3 concentrations from 3.3 to 270ppm on a weekly basis (Brewster & Macadam, 1976) restrained bulb development. In addition applications of 10µg GA_3 to the leaf bases was shown by Knypl (1979, 1980) to depress bulb diameter and fresh weight. However following foliar sprays of GA_3, both El-habbasha & Behairy (1977) and Lipe (1975) failed to obtain a regulation of bulbing by GA_3, though the former workers were able to discern an enlarged bulb weight when GA_3 was applied in conjunction with $MgSO_4$ and $MnSO_4$.

Bulbing can also be promoted by IAA and various synthetic auxins. Thus immersing the roots of onion transplants in 10 or 20ppm

IAA for 4h increased the final fresh weight, dry weight and volume of matured bulbs (Jauhari & Singh, 1960). Similarly foliar sprays of 100,200 or 300ppm IAA, IBA or NAA applied fortnightly (Mathur, 1971) or 1,10 or 100ppm NAA applied every other day (Olivares & Manuel, 1962) enlarged the bulb diameter. Furthermore, Olivares & Manuel (1962) and Terabun (1967) discerned that NAA and IAA were unable to promote bulbing under non-inductive short days. Following injections of onion plants with IAA, Brewster & Macadam (1976) demonstrated an increase in bulb weight, while Abdel-Rahman & Isenberg (1974) noted that 100ppm IAA enlarged the bulb height and diameter. Furthermore a 6h seed soak in various concentrations of synthetic auxins led Srivastava & Adhikari (1972) to demonstrate that 50ppm IPA and 25ppm NOA augmented the diameter, fresh and dry weight of the bulbs. Comparative studies between an 8h seed soak and root dip using either 1,10 or 100ppm NAA or IBA (Vaish, 1972) revealed that the former technique evoked an increase in bulb dry weight when 1 or 10ppm NAA or IBA were utilised, whilst 100ppm of either regulator was inhibitory. In contrast, the root dip method promoted bulb dry weight if 1ppm NAA or IBA was used, whereas concentrations of 10 and 100ppm yielded a progressively inhibitory response. When immersed in 10^{-4}M IAA with sucrose, excised leaf sheaths could swell in the dark, while intact seedlings bulbed perceptibly irrespective of whether long or short days were utilized (Clark & Heath, 1962). However, Lercari & Ceccarelli (1975) were unable to confirm the latter IAA response when growing onion seedlings in a solution of 20ppm IAA under either conducive or inhibitory daylengths for bulbing.

Evidence suggesting that auxins suppress bulbing was established when foliar sprays of 200ppm 2,4-D (Terabun, 1967) and foliar injections of 10ppm IAA every 5 days (Kato, 1965a) led to a diminution in bulb diameter under long days conducive for bulbing. Similarly 10g IAA administered to the base of the second leaf sheath reduced the fresh weight of harvested bulbs by 50% (Knypl, 1980).

With regard to plant growth retardants, Knypl (1979) demonstrated that 20ml soil drenches enlarged the bulb fresh weight and diameter by 100% with 0.01M DEOMC, 50% with 0.01M CCC and 0.1mM phosphon D and only 18% with 0.01M DMOMC, while 0.01M DMMC proved ineffectual. Similarly applications of 10 M DEOMC and DEHEG applied to the base of the second leaf sheath also elicited a 100% increase in bulb volume and fresh weight (Knypl, 1980). However 4 weekly foliar sprays of 500 to 4000ppm CCC (Sinnadurai et al, 1971), weekly foliar injections of 30 to 2430ppm CCC or 3.3 to 270ppm ancymidol (Brewster & Macadam, 1976), or overnight seed soaks in CCC concentrations ranging from 0 to 1.0M (Bussell, 1972) failed to influence bulbing, though the latter report mentioned that the time to maturity was evidently shortened and was independent of the concentration utilized. Similarly bulb yield and dimensions were unaffected by foliar sprays containing up to 5000ppm SADH (Montano, 1971; Corgan & Montano, 1975; Lipe, 1975) or foliar injections of 30 to 2430ppm SADH (Brewster & Macadam, 1976).

In regard to cytokinins, Terabun (1967) and Corgan & Montano (1975) showed that bulbing was unresponsive to foliar sprays of 10ppm Kinetin and 100ppm BA respectively, while bulb height and expansion were enhanced following injections into the leaf blade with either 0.45, 1.8 (Kato, 1965b) or 100ppm (Abdel-Rahman & Isenberg, 1974) Kinetin. Considering the auxin translocation inhibitor, TIBA, foliar sprays (Terabun, 1967) and foliar injections (Brewster & Macadam, 1976) at various concentrations of TIBA had little effect on bulbing. Similarly bulb diameter and fresh weight were unresponsive to morphactin applied either to a liquid growth medium to give a final concentration of 20ppm (Lercari & Ceccarelli, 1975), or foliar injected at concentrations ranging from 1.1 to 90ppm (Brewster & Macadam, 1976).

1.4. Aims of investigations.

A survey of the literature has failed to reveal any work concerned with the physiological determinants regulating growth in the large exhibition onion varieties. Although the genetic constitution is primarily responsible for the gigas effect within this

variety, environmental factors and exogenously applied plant growth regulators can be expected to modulate the various developmental stages characteristic of the onion plant.

The following investigation on the variety Kelsae is divided into 3 sections, with attention focused only on the period of vegetative growth following germination and the bulbing stage. The intention of the first chapter is to examine the role of light quality, photoperiod and to a lesser extent temperature on leaf and early bulb development, using controlled environmental conditions. In regard to light quality, attention will be focused on the role R and FR light has on the various characters assessed. In contrast, the second chapter is devoted entirely to establishing the presence of interactions between light quality and various exogenously applied plant growth regulators in modulating different gross morphological and cellular parameters of the developing onion plant under controlled environmental conditions. As with the first experimental chapter, the role of R and FR light represents the main feature considered in respect to the light quality effect. Since a number of plant growth regulators produced profound effects on onion plant development using controlled environmental conditions, the third chapter will consider their effectiveness under glasshouse and field conditions, where natural daylight is the sole light quality source. In this instance preferential attention will be focused on bulb development.

2. THE EFFECT OF LIGHT QUALITY AND DAYLENGTH ON VEGETATIVE GROWTH AND BULBING UNDER CONTROLLED ENVIRONMENTAL CONDITIONS

2.1. Introduction

As onion plant size prior to the onset of bulbing directly affects the bulb dimensions attained at maturity (Magruder & Allard, 1937; Jones & Mann, 1963), the importance of a long day requirement seems essential to provide sufficient time for an adequate photosynthetic canopy to develop, before bulbing curtails further leaf production (Aoba, 1964; Nagai & Hanaoka, 1967). Furthermore, a wealth of evidence has accumulated to suggest that phytochrome is implicated in the detection of shade light quality (Morgan, 1981; Smith, 1982) and mediation of photoperiodic responses (Vince-Prue, 1981). In these circumstances the ratio of R:FR light emitted by various light sources can be expected to modulate the growth of various morphological characters of the onion plant, as demonstrated for leaf (Butt, 1968) and bulb (Austin, 1972) development.

Since no work has been reported elucidating the physiological determinants regulating leaf and bulb development in the large exhibition onion variety Kelsae, information regarding the effect of photoperiod and light quality with different red: far red ratios will be considered on the aforementioned characters.

2.2. Materials and methods

2.2.1. Growth medium

To a growth medium consisting of 15 parts Irish moss peat, 7 parts loam and 2 parts flint hen grit, a further 115g of John Innes Base and 20g of ground lime was added to each $0.028m^3$ of growth medium. The growth medium was poured into paperpot honeycombs (Whalehide Company, Leigh on Sea, Essex) of dimensions 3cm (diameter) x 13cm (length) x 350 (pots) and compressed lightly. This procedure was repeated once more to give the required sowing depth of approximately 0.5cm. A single seed was sown in each pot, prior to a final addition of growth medium, which was lightly firmed and the excess scraped from the top of the paperpots. Soil moisture loss was reduced by sheathing the paperpot honeycomb sides with black polythene sheeting. A liberal application of water was given on the first day, while subsequent watering was as required.

2.2.2. Growth conditions

Germination and initial growth of onion seedlings was conducted in a Fison's growth cabinet (Model 600G/TTL) maintained at 20 and 10°C for the day and night period respectively. The plants received an 11h daylength with a light intensity of 141 ± S.D. 10 $\mu E.m^{-2}.sec^{-1}$ (P.A.R) from Atlas White fluorescent tubes. Later the temperature was lowered by day and increased by night at a rate of 1°C/day, until a final steady temperature of 15°C was achieved by the 24th day. From the 40th day onwards, Sangral Root and Foliar Feed (Lindsey & Kesteven, Saxilby, Lincoln) was applied at a rate of 1g/360 plants. Further description of the experimental conditions is divided into two sections, since different growth cabinets and temperature regimes were adopted.

2.2.2.1. Fison's growth cabinet

On the 47th day, 360 plants were selected from the paperpot honeycombs using similar lengths of the third leaf as the selection criterion. The plants, each retained in their own paperpot, were randomly assigned to one of 6 Hyware aquarium tubs of dimensions 35 x 25 x 20cm. These tubs had their exterior surfaces painted black and the interior subdivided by a varnished plywood crosswall to give four identical compartments, each holding 15 paperpots seated on a 3cm bed of moist vermiculite. To obtain two different light qualities, the interior of the growth cabinet was split into two sections using a movable aluminium foil divide. One section received light from Philips Colour 37 (C37 light) fluorescent tubes at an intensity of 103 ± S.D. 6 $\mu E.m^{-2}.sec^{-1}$ (P.A.R), while the other received light from Atlas White (AW light) fluorescent tubes at an intensity of 115 ± S.D. 13 $\mu E.m^{-2}.sec^{-1}$ (P.A.R). Three hyware aquarium tubs were allocated to each light quality compartment.

To achieve four daylengths of 11,14,17 and 20h, various compartments within the six tubs were darkened using cardboard hoods. During each 24h cycle, all daylength treatments commenced simultaneously, but at the end of a particular daylength, a hood was placed over one assigned compartment in each of the 6 tubs. No hoods were applied to plants receiving 20h, since this

coincided with the daylength setting of the growth cabinet. A temperature of 15°C was maintained throughout.

2.2.2.2. Tall growth cabinet

Seven days after the completion of the experiment in the Fison's growth cabinet, the same plants were transferred to the tall growth cabinet to accomodate for the growth in plant height. As the root system was already penetrating the walls and emerging from the base of the paperpots, the plants each retained in their own paperpot were transferred to polythene tubs of dimensions 15 x 23 x 15cm and entirely embedded in moist vermiculite. The wider plant spacing adopted within the polythene tubs was used to reduce the problems of low light intensities that will arise with the development of the leaf canopy. Each polythene tub received plants from a particular compartment of an aquarium tub. The tall growth cabinet, located in a heated greenhouse, was constructed of softboard with the interior split into two sections and the walls lined in aluminium foil. Due to the absence of temperature control, this ranged from a minimum of 17.5 ± S.D.3°C to a maximum of 34 ± S.D. 8°C during the night and day respectively. Each section of the tall growth cabinet received light from fluorescent tubes of either C37 light at an intensity of 70 ± S.D. 2 $\mu E.m^{-2}.\ sec^{-1}$ (P.A.R) or AW light at an intensity of 80 ± S.D. 3 $\mu E.m^{-2}.\ sec^{-1}$ (P.A.R). Identical procedures as previously adopted in the Fison's growth cabinet was used to obtain the same range of daylengths. In this instance black polythene hoods were used to cover the tubs. Plants were allocated the same daylength and light quality treatments that they had previously received in the Fison's growth cabinet.

2.2.3. Measurements

2.2.3.1. Light quality characteristics of fluorescent tubes

Spectral photon distributions (SPD) of the C37 and AW light were measured with a Gamma Scientific (San Diego) model 2400 digital photometer with the output traced on a XY recorder. Furthermore, a specially constructed 2.5m long flexible fibre optic tube fitted with a cosine-corrected receptor head (Gamma Scientific Model 700-8B) was used to capture the light for the SPD measurements.

Additional details concerning the spectroradiometer utilized and its calibration were adequately described by Holmes & Smith (1977) . SPD for C37 and AW light are illustrated in Fig.2.1.

The R: FR ratio (ξ) for AW and C37 light was calculated from the SPD curves and represents the ratio of the quantum flux in 10nm wide wavelength bands at 660 and 730nm for the R and FR wavelength bands respectively (Monteith, 1976; Holmes & Smith, 1977). Thus ξ was 5.17 ± S.D. 0.24 and 3.16 ± S.D. 0.10 for AW and C37 light respectively.

With regard to the phytochrome equilibria Pfr/P_{tot} (ϕ), earlier work by Smith & Holmes (1977) established a curvilinear relationship between ϕ and ξ. This was achieved by irradiating etiolated Phaseolus vulgaris hypocotyl hook sections with various light sources of known ξ and subsequent measuring the quantity of Pr and Pfr produced within these sections by dual wavelength spectrophotometry. Knowledge of the Pr and Pfr levels enabled ϕ to be calculated. Utilizing the above relationship derived by Smith & Holmes (1977) for ϕ and ξ, ϕ values can be estimated from the calculated ξ values of AW and C37 light and were observed to be 0.742 ± S.D. 0.003 and 0.710 ± S.D. 0.003 respectively.

2.2.3.2. Gross morphological determinations

2.2.3.2.1. Fison's growth cabinet

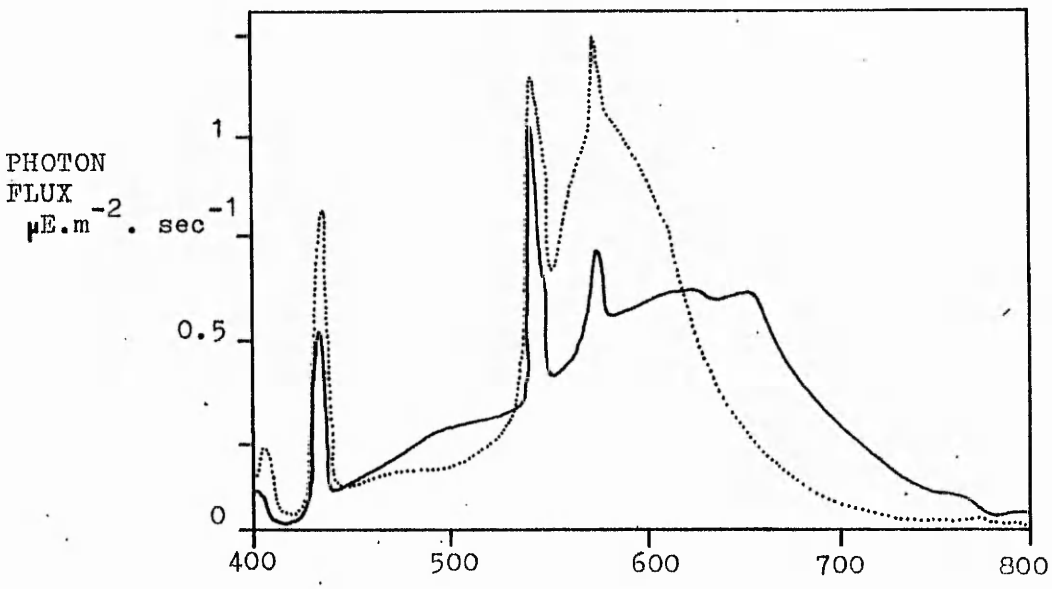
Two days after the introduction of the various treatments, measurements of leaf length were taken at 3 day intervals for 30 days. Measurements were only undertaken with the 3rd, 4th and 5th leaves, while on the final day of assessment, length of the 3rd leaf sheath was recorded. The criterion adopted for leaf length was the distance from the leaf tip to the pore of the previous leaf. With respect to leaf sheath length, the criterion was the divide between the leaf blade and leaf sheath to the pore of the previous leaf.

2.2.3.2.2. Tall growth cabinet

Seven days after the introduction of the plants to the tall growth cabinet and for a period of 60 days, measurements were

Fig.2.1.

Spectral Photon Distributions for AW and C37 fluorescent tubes.



KEY: _____ C37 light

..... AW light

CHARACTER	LIGHT QUALITY	
	AW light	C37 light
ξ	5.17 ± 0.24*	3.16 ± 0.10
ø	0.742 ± 0.003	0.710 ± 0.003

* ± STANDARD DEVIATION

taken of leaf length at 6 day intervals and bulb and neck diameters every 12 days. The criterion adopted for leaf length was previously described in Section 2.2.3.2.1. With maximum bulb or neck diameter, reliable estimates required two measurements to be taken at right angles and the mean calculated. From these measurements, the bulbing ratio was calculated in accordance with the method of Clark & Heath (1962).

2.2.4. Experimental design and statistics

2.2.4.1. Fison's growth cabinet

A split-plot design was adopted, where the 6 hyware tubs represent the main plots of which there are 3 to each light quality compartment. The 4 compartments within each hyware tub were in turn classified as the sub-plots and refer to the 4 different daylength treatments. A final partitioning of the sub-plots into sub-sub-plots accounted for the various leaf length measurements taken at 3 day intervals for plants in each sub-plot. The subdivision into sub-sub-plots was not required for the statistical analysis of the leaf sheaths of the third leaf. During the statistical analyses, daylength and day components were further partitioned using orthogonal polynomials to determine the presence of significantly different curvilinear trends for the various treatments.

2.2.4.2. Tall growth cabinet

A split-plot design was utilized, whereby the area within each light quality compartment was sectioned into 3 zones, which represent the main plots. In turn each zone was allocated 4 polythene tubs designated as sub-plots and relate to the 4 different daylength treatments. A final partitioning of the sub-plots into sub-sub-plots accomodates the various assessment times for each treatment with regard to length of the different leaves and also the bulbing ratio. Verification of curvilinear trends for different daylength and day responses were attempted by partitioning these components using orthogonal polynomials.

The various split-plot designs with superimposed regression analyses using orthogonal polynomials were analyzed according to the methods outlined in Snedecor & Cochrain (1967) and run

on the DEC system 20 computer (Digital Equipment Corporation, Maynard, Massachusetts) using the Genstat V (Mark 4.03) language (Lawes Agricultural Trust, Rothamsted Experimental Station). The Q method was used to test for significance between the appropriate treatments (Snedecor & Cochrain, 1967).

2.3. Results

2.3.1. Fison's growth cabinet

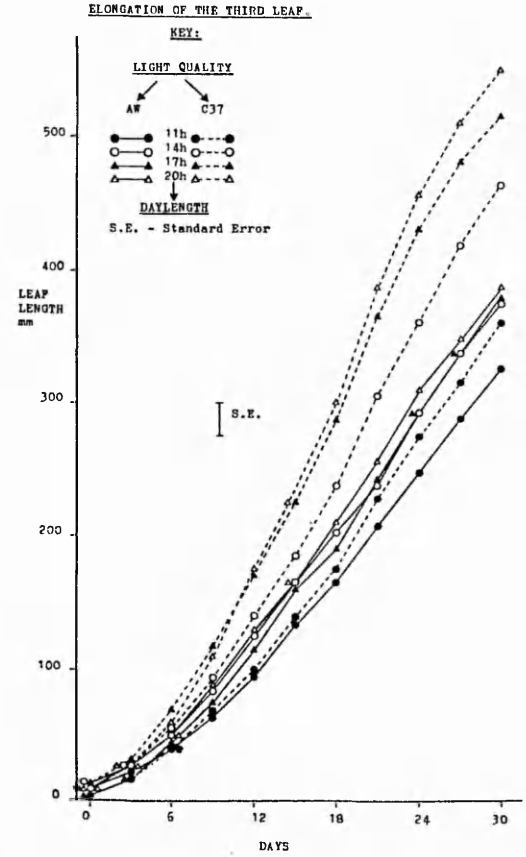
As illustrated in Fig.2.2, the extension of the third leaf rapidly increased with time, until approximately the 18th day, when the elongation rate became relatively steady, before declining by about the 27th day of the assessment period. This rate decrease was really only evident with plants receiving either 17 or 20h daylength with C37 light. Furthermore, these curvilinear trends were ratified by significant linear and cubic components partitioned from the day item (Appendix Table (A.T.) 2.1.). Since the fourth and fifth leaves emerged at successively later dates in the assessment period, their rates of extension were on the whole still accelerating by the 30th day of the assessment period (Fig. 2.2). In these circumstances the parabolic nature of the 4th and 5th leaf trends were subsequently validated by significant linear and quadratic components of the day item (A.T.2.2,2.3).

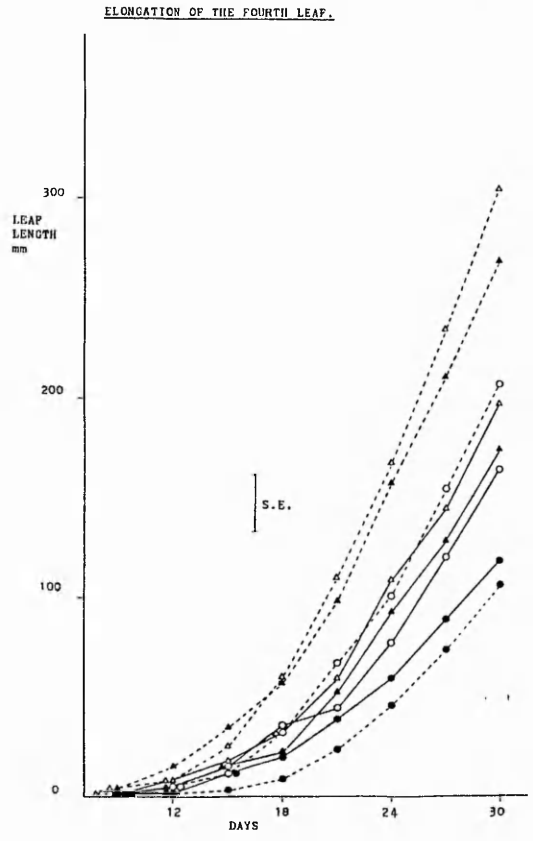
Both light quality and daylength influenced the development of the 3rd, 4th and 5th leaf through the promotion of different extension rates, that led to the digression in the leaf elongation trends depicted in Fig.2.2. These features were confirmed by significant light quality and daylength items and the presence of certain significant polynomial components extracted from the day item, light quality x day and daylength x day interaction items, which ratify the different curvilinear trends produced by the various treatments (A.T.2.1-2.3).

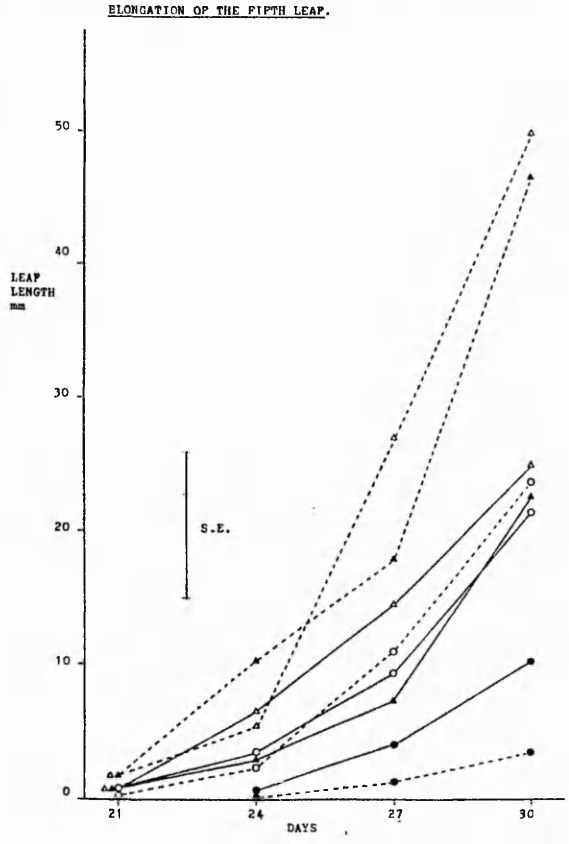
Close examination of these leaf elongation trends established a significant interaction between light quality and daylength (Fig. 2.1), whereby the faster elongation rates produced by C37 rather than AW light were amplified when the daylength was extended from 11 to 20h. With C37 light, this was achieved through a rapid increase in the leaf elongation rates with protraction of daylength,

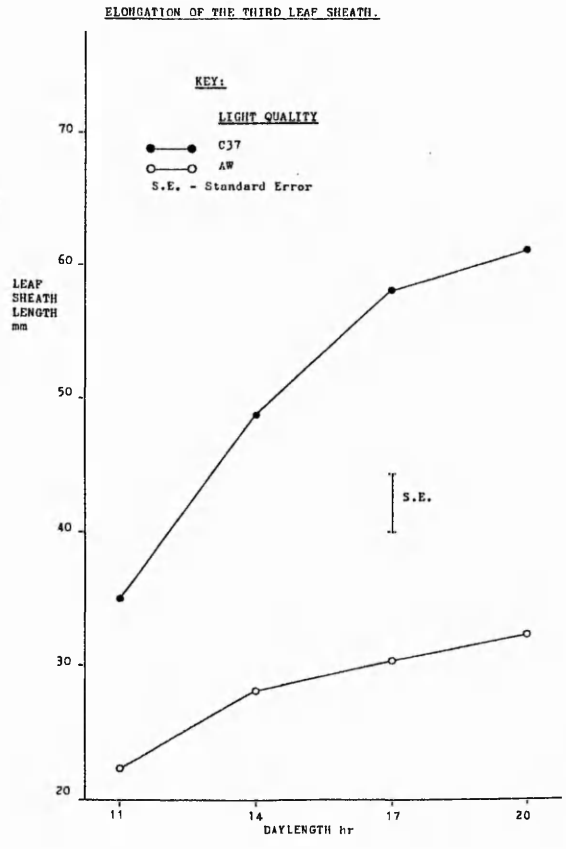
Fig.2.2.

EFFECT OF LIGHT QUALITY AND DAYLENGTH ON LEAF DEVELOPMENT PRIOR TO BULBING.









though the response was diminishing with each increment of daylength duration. In contrast, AW light only enhanced leaf elongation when the daylength was extended from 11 to 14h, while thereafter the rates remained relatively comparable irrespective of the daylength utilised. The parabolic regression evinced between leaf elongation and daylength was corroborated by significant linear and quadratic daylength components isolated from the daylength item (A.T.2.1-2.3). In addition, the control exerted by light quality alone and in combination with time on this association was validated by various significant polynomial combinations partitioned from the light quality x daylength and light quality x daylength x day interaction items (A.T.2.1-2.3). In summary, treating plants with a 11h daylength of either AW or C37 light yielded leaf elongation trends that were fairly comparable (Fig.2.2). Furthermore, the leaf elongation trends for plants receiving either 14,17 or 20h daylengths with AW light generally appeared between the trends obtained for the 11 and 14h daylength treatments with C37 light.

Most plants grown under AW light produced slightly wider leaves with a pronounced dark green colouration, whilst plants subjected to C37 light showed the converse symptoms. However, the disparity in leaf width of plants grown under the two different light qualities was less evident in the 11h daylength treatment.

The final length achieved by the leaf sheath of the third leaf after 30 days was markedly influenced by an interaction between light quality and daylength (Fig.2.2; A.T.2.4). Thus, C37 light substantially augmented the leaf sheath lengths, though the response decreased with each protraction of the daylength from 11 to 20h. In contrast, AW light mediated a more moderate and proportional increase in the leaf sheath length with daylength extension. Although this response was verified by a significant light quality x daylength interaction item, the differential C37 and AW light quality responses were corroborated by the isolation of significant linear and quadratic polynomial components and a significant linear polynomial component respectively (A.T.2.4).

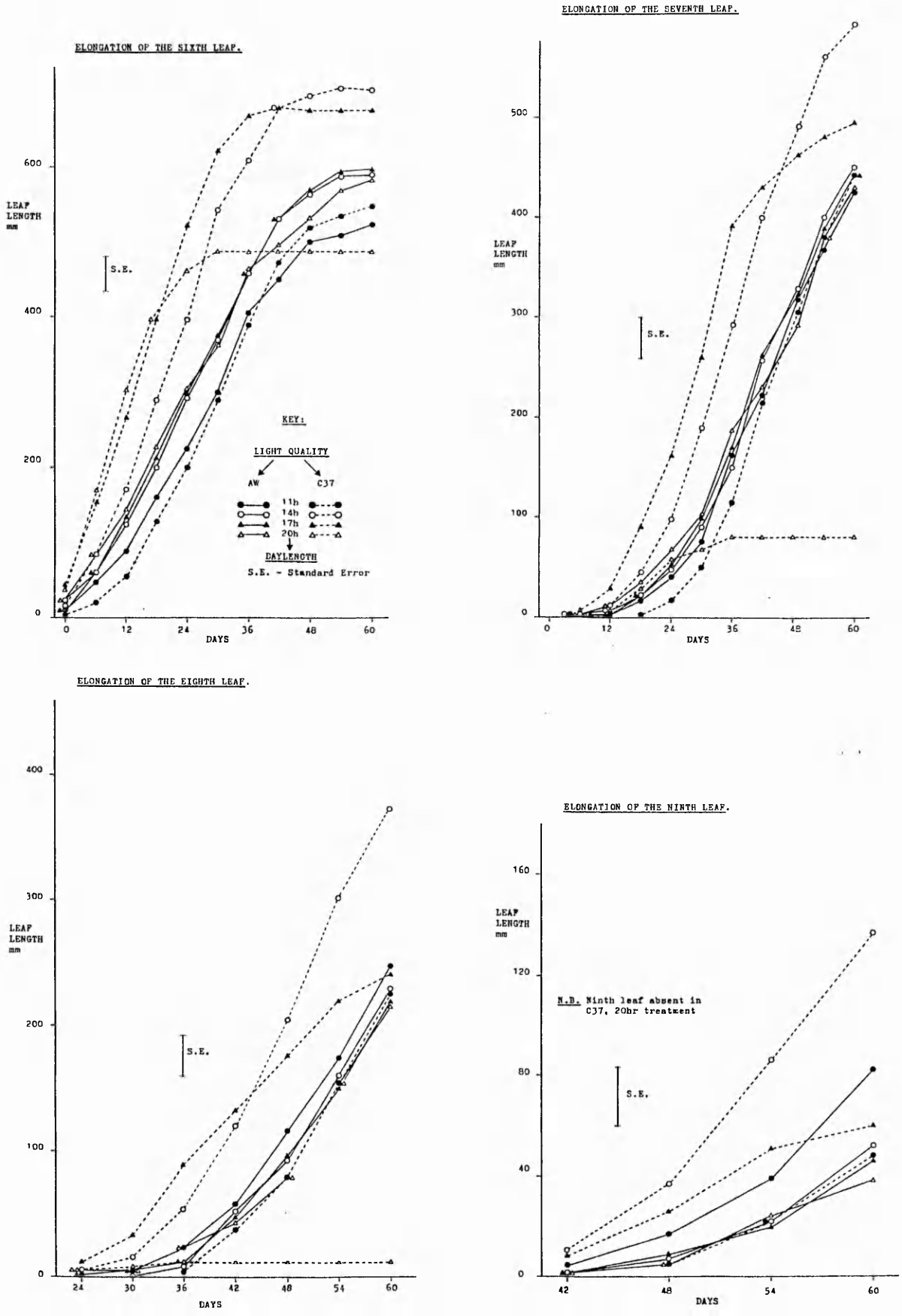
2.3.2. Tall growth cabinet

During the 60 day assessment period, elongation trends for the sixth leaf went through three phases, which were firstly a period of acceleration, followed by a relatively steady rate and finally a noticeable decline in the growth rate (Fig.2.3). In regard to the seventh, eighth and ninth leaf which emerged at successively later dates, the former leaf only showed the period of accelerated growth followed by the steady elongation rate (Fig.2.3), whereas the latter two leaves were still in the accelerating phase of leaf elongation (Fig.2.3). Nevertheless, for treatments involving a 17 and 20h daylength period with C37 light, these three younger leaves generally maintained a trend of leaf growth resembling that of the sixth leaf, though the ninth leaf failed to emerge under the longest daylength (Fig.2.3). These various curvilinear trends depicted above were corroborated by significant linear, quadratic and cubic components of the day item (A.T.2.5-2.8).

Since the extension rates for the sixth, seventh, eighth and ninth leaf were apparently controlled by both light quality and daylength, a digression in the various leaf elongation trends pertained, as illustrated in Fig.2.3. The observations were validated by significant daylength and light quality items, while the extraction of certain significant polynomial components from the day item, light quality x day and daylength x day interaction items substantiates the different curvilinear trends produced by these various treatments (A.T.2.5-2.8). Nevertheless, a close scrutiny of these different leaf elongation trends revealed a significant interaction between light quality and daylength. Thus irrespective of the daylength received, plants irradiated with AW light produced comparable leaf extension rates, which were also analogous to plants receiving a 11h daylength with C37 light (Fig.2.3). In contrast extending the daylength from 11 to 20h with C37 light, generally led to a rapid increase in the elongation rate, though the effect was observed to decrease with each successive incrementation in the daylength (Fig.2.3). However disparities were evident under C37 light, since the 20h and to a lesser extent the 17h daylength treatments led to an earlier decline in the leaf elongation

Fig. 2.3.

EFFECT OF LIGHT AND DAYLENGTH ON LEAF DEVELOPMENT DURING INCIPIENT BULBING.



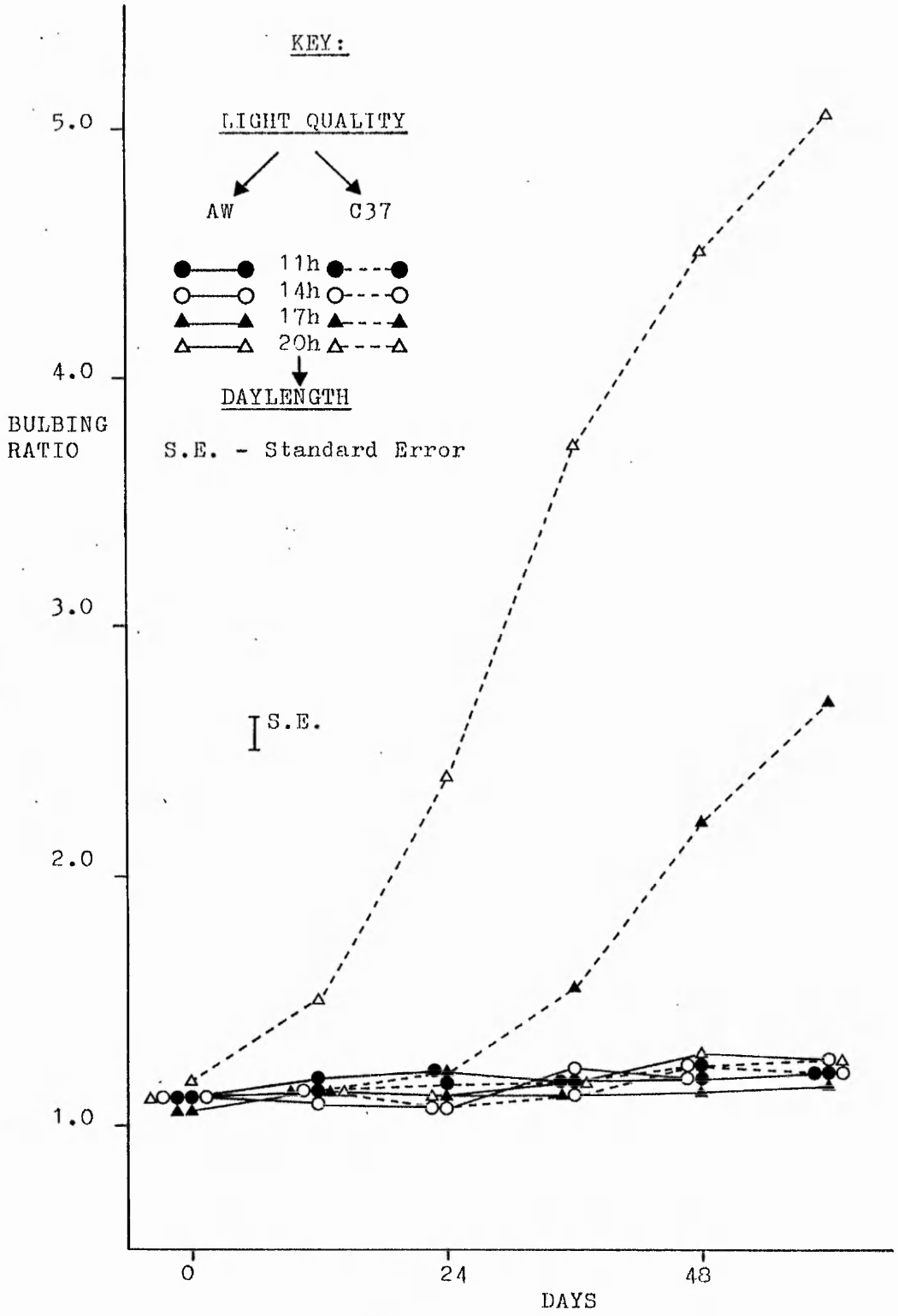
rate and the final height achieved at the end of the assessment period (Fig.2.3). Furthermore, with each successive leaf produced, the time period between leaf emergence and the extension rate decline became shorter and as a consequence the final height recorded on day 60 of the assessment period was reduced accordingly. Owing to the growing severity of the response under a 20h daylength treatment, the ninth leaf failed to emerge (Fig.2.3).

The parabolic relationship between leaf length and daylength was ratified by significant linear and quadratic daylength components extracted from the daylength item (A.T.2.5-2.8). In addition, the control exerted by light quality alone and in combination with time on this relationship was reflected by various significant polynomial combinations partitioned from the light quality x daylength and light quality x daylength x day interaction items (A.T. 2.5-2.8).

Inspection of the bulbing ratio trends disclosed a marked regulatory role by light quality and daylength with time as illustrated in Fig.2.4 and validated by the significant polynomial components extracted from the day item, light quality x day and daylength x day interaction items (A.T.2.9). Furthermore, an interaction was also evident between light quality and daylength, since irradiation with AW light suppressed bulbing irrespective of the daylength utilized, while C37 light only allowed bulbing to commence when the daylength exceeded 14h. Thus, the absence of bulbing under AW light was observed by the maintenance of similar bulbing ratios throughout the assessment period (Fig.2.4). A corresponding trend was also applicable for the 11 and 14h daylength treatments with C37 light (Fig.2.4). In contrast, the bulbing ratio increased after day 0 and day 24 for the 20 and 17h daylength treatments respectively and by day 60 when the experiment was terminated, the bulbing ratio was still increasing for both treatments (Fig.2.4). The interactive influence exerted by light quality and daylength on the various bulbing ratio trends was amply validated by the significant polynomial components partitioned from the light quality x daylength and light quality x daylength x day interaction items (A.T.2.9).

Fig.2.4.

EFFECT OF LIGHT QUALITY AND DAYLENGTH ON THE BULBING RATIO.



2.4. Discussion

Leaf elongation, leaf sheath length and bulbing were regulated by both light quality and daylength. Thus, extending the daylength from 11 to 20h enhanced the leaf extension rate and leaf sheath length of plants grown at 15°C and irradiated with C37 light. However, the increment in both characters was gradually decreased with each successive 3h increase in daylength. Certainly the results for leaf elongation confirm previous observations collated from the Japanese onion varieties by Kato (1964) using the criterion of plant height. On the other hand, exposure to AW light at a temperature of 15°C gave only a slight increase in leaf and leaf sheath length in response to longer days, whereas a temperature range of 17 to 34°C was apparently inhibitory towards the former character. However, this higher temperature range enabled bulbing to commence in plants receiving 17 and 20h daylength with C37 light. Despite conducive daylength and light quality conditions, Butt (1968) showed that bulbing was delayed by 40 days when the temperature was reduced from 20 to 15°C. This observation may explain the absence of bulbing in plants maintained at 15°C for 30 days, but receiving appropriate lighting conditions for bulbing.

Bulbing was completely suppressed by variable durations of AW light or short daylengths of 11 and 14h with C37 light, whilst the converse pertained under 17 and 20h daylengths with C37 light. Certainly, this long day requirement for bulbing would enable the plants to produce adequate leaf material to maintain a high assimilation rate necessary for the production of large bulbs, characteristic of the Kelsae variety. This is important, since two weeks after commencement of bulbing a reduction in height of emerging leaves became apparent and in the case of the 20h daylength treatment, emergence of the ninth leaf was completely suppressed. Similar evidence was also accrued by Nagai & Hanaoka (1967) from field studies on the onion variety Sapporoki. Furthermore Magruder & Allard (1937) discerned that bulb size and weight were dependent on the area of leaf produced by the time of incipient bulbing. Comparisons between 17 and 20h daylength treatments with C37 light revealed bulbing to be induced 2 weeks earlier for the latter daylength and validates an earlier report by Kato (1964)

claiming a similar 2 week delay between a 16 and 20h daylength treatment.

Since C37 and AW light have a R:FR ratio of 3.16 and 5.17 respectively, it is proposed that the increase in leaf blade and leaf sheath length and bulb induction only became apparent when the quantum flux density in the FR approached that in the R part of the spectrum. Certainly the above proposals lends support to the augmentations in the length of the longest leaf and bulb induction incurred by extending an 8h daylight period with 8h incandescent light emitting a low R:FR ratio in preference to fluorescent light emitting a higher ratio (Butt, 1968). A similar explanation may also justify the work of Paribok (1956), Woodbury & Ridley (1969) and Austin (1972)where long exposures to incandescent or fluorescent light with a low R:FR ratio were conducive to bulbing, whereas the contrary applied to fluorescent light delivering a high ratio.

A mixture of R and FR light was apparently necessary for bulb development, since exposing onion plants to 12h non-inductive fluorescent light followed by 12h R or FR light were inhibitory, whereas 8h incandescent light was conducive (Butt, 1968). Similarly, Terabun (1970) established a maximal bulbing response with a R:FR ratio of 1 when plants were exposed to 8h daylight extended with 16h R and FR light in different proportions. Either utilising the experimental approach adopted by Terabun (1970) above or simply irradiating the plants with light sources emitting different R:FR ratios, comparable reports of a concurrent enhancement in stem elongation as the R:FR ratio drops below 5 were disclosed for Fuchsia hybrida (Vince-Prue, 1975), Sinningia speciosa (Satter & Wetherell, 1968) and Chenopodium album (Holmes & Smith, 1975; Morgan & Smith, 1976, 1978, 1981; Morgan 1981).

The strong involvement of different R:FR ratios in modulating various morphological characters of the Kelsae onion plant and the ability of R light to reverse the promotive effect of a predominantly FR light source on bulbing (Terabun, 1965) indicates the participation of the photoreceptor phytochrome. Profound vegetative changes incurred by mixtures of R and FR light will

lead to the absorption of photons by both Pr and Pfr forms and phytochrome will cycle and come to a dynamic photoequilibrium, which can be expressed in terms of ϕ (P_{fr}/P_{tot}) (Morgan, 1981; Vince-Prue, 1981). Furthermore, by interpolating a 3h pulse of monochromatic light of different wavelengths, to produce certain ϕ values in the middle of an inductive 18h daylength, Lercari (1983) established that only wavelengths between 700 and 758nm, with an optimum of 714nm evoked bulbing symptoms. In addition, this response was enhanced by increasing the fluence rate (Lercari 1983). Thus, an optimum bulbing effect at 714nm and a fluence rate dependency indicate that the higher irradiance reaction of phytochrome was probably responsible (Schopfer, 1984).

Much evidence has accumulated showing relationships between ϕ and various physiological processes. Thus, an inverse linear associationship pertained with ϕ and $\log_{10}$ stem extension rate (Morgan & Smith, 1976, 1978, 1979) and petiole length, whilst a positive correlation was observed with leaf dry weight: stem dry weight ratio (Morgan & Smith, 1979). However, by employing only two light sources, AW and C37 light with ϕ of 0.742 and 0.710 respectively, only an equivocal ratification of a correlation between ϕ and a particular morphogenetic response can be obtained. A similar problem also pertains with the work of Lercari (1982) where irradiation with light emitting a R:FR of 1.2 (ϕ = 0.67) led to a faster bulbing rate than a R:FR of 1.8 (ϕ = 0.56). Nevertheless, the fact that bulbing occured under C37 rather than AW light implies that the upper threshold value of ϕ required for bulbing, lay between 0.747 and 0.710. If leaf length is correlated with estimated ϕ values, then a small change of ϕ from 0.747 to 0.710 for AW and C37 light respectively led to an increased leaf length of 150mm under a 20h daylength. In the light of this evidence considerable leaf extension should be expected under daylight and wheat canopy conditions, were ϕ values approach 0.605 and 0.33 respectively (Holmes & Smith, 1975). However, a linear relationship between ϕ and onion leaf length seems unlikely, since this would infer that under wheat canopy conditions, where a ϕ value of 0.33 pertains, an additional 1900mm of leaf extension is to be expected.

Aside from the aforementioned discrepancies between the R and FR spectra, C37 and AW light also showed other dissimilarities in their spectral photon distributions. Thus, C37 rather than AW light emitted a greater photon fluence rate between 455 and 530nm, whereas the converse pertained from 425 to 435nm and 550 to 630nm. Although the evidence for a blue light absorbing photoreceptor (BAP), possible a flavoprotein, is still equivocal in higher plants, anthocyanin synthesis, certain phototropic responses and hypocotyl growth appear in part to be regulated by blue light *per se* (Thomas, 1981). Nevertheless, the presence of a slightly larger fluence rate between 455 and 500nm for C37 light could imply a BAP effect, if the photoreceptor preferentially absorbed in this particular portion of the spectrum. Certainly, Terabun (1965, 1970) ascertained that a 4 and 16h blue light period following a non-inductive 11 and 8h daylight period respectively, promoted bulbing in onion plants. In contrast, interpolating an inductive 18h photoperiod at various times with 4h of blue light inhibited bulbing (Lercari, 1982). From these reports it is difficult to reach even a tentative conclusion on whether a BAP regulates bulbing or other morphological characters of the onion plant. This problem is further complicated by the fact that Pr and Pfr both absorb in the blue spectrum (Siegelman & Butler, 1965) and the action spectra of HIR of phytochrome can show considerable action in the blue spectrum (Thomas, 1981). However, Lercari (1982) established that interpolating an 18h photoperiod with 4h blue light producing a $\emptyset$ value of 0.35, which should have been conducive towards initiating bulbing, especially as the control 18h treatment with a combination of fluorescent and incandescent lights and a third treatment involving an intervening 4h FR light period not only gave $\emptyset$ values of 0.56 and 0.02 respectively, but also stimulated bulbing. The possibility that an irradiance dependency led to the differential bulbing response with blue light, although feasible, seems unlikely as Terabun (1965, 1970) used a lower fluence rate than Lercari (1982) to obtain bulbing.

Besides discrepancies in the blue spectrum, AW light also emitted a greater fluence rate between 550 and 630nm than C37 light. However, changes in this part of the light spectrum are more

likely to effectuate a shift in the phytochrome equilibria towards a higher proportion of Pfr than Pr and thus augment the inhibitory effect the R spectrum has on bulbing and vegetative development.

In regard to the photoperiodic control of bulbing and leaf elongation in the onion variety Kelsae, phytochrome appears to play an important role, since AW light containing a high R:FR ratio was clearly suppressive towards these two determinants irrespective of whether the photoperiod was of a suitable duration. Although the exact mechanism for photoperiodic timing in plants has still to be resolved, much evidence suggests that responses such as floral induction involve an endogenous circadian rhythm of phases with different sensitivities to light (Vince-Prue, 1975). Furthermore, phytochrome either promotes or inhibits flowering depending on the status of the endogenous oscillating circadian timer and the rhythm itself is probably phased by phytochrome (Vince-Prue, 1975). In regard to the photoperiodic control of bulbing in onions, current evidence has revealed a possible rhythmicity, whereby the optimum phytochrome equilibrium required to promote bulbing changed during the course of the daily light cycle. Certainly bulbing was inhibited when 2.25h or 1h of light of a low R:FR was given before and after a 14.5h (Austin, 1972) and after a 16h period (Woodbury & Ridley, 1969) respectively with light emitting a high R:FR ratio. Vince-Prue (1975) suggested that the above regimes probably established a high Pfr level during the 9th and 15th hour of the photoperiod at which time Pfr inhibited floral induction in Lolium temulentum and several other long day plants. This was tentatively ascertained in onion plants by interpolating 4.5h of FR light at different times during an 18h photoperiod conducive for bulbing (Lercari, 1982). Only between 4.5th and 13.5th hour of the daily photoperiod was FR light able to promote bulbing, whereas at other times FR light incurred an inhibitory response. However in a subsequent and similar experiment where the interpolation was conducted with dichromatic exposures of R and FR light to give a range of $\emptyset$ values, Lercari (1982) was unsuccessful in determining an endogenous rhythm of sensitivity to $\emptyset$ through possible changes in the optimum R:FR ratio required for bulbing during the day.

The ability of increasing daylengths under suitable light quality conditions to enhance the length of the onion leaves and hence leaf area, accords with similar results reported for leaf area of Beta vulgaris (Milford & Lenton, 1976) and Psophocarpus tetragonolobus (Herath & Ormrod, 1979) and also leaf length of Rubus chamaemorus (Kaurin et al, 1982) and Stevia rebaudiana (Metivier & Viana, 1979). Since an extension of the daylength will prolong the period of photosynthetic activity, the possible entailment of the latter factor in enhancing onion leaf expansion through increased availability of essential photosynthates cannot be ruled out. To study the effects of long days without the problem of photosynthesis, the technique of interpolating into the middle of a long night period a short pulse of generally incandescent light of low fluence rate, which is unsuitable for photosynthesis is often considered. This method assumes that a brief exposure to incandescent light maintains the presumed active phytochrome moiety Pfr for the photoperiodic response above a certain threshold value for the majority of the long night. In these conditions greater leaf areas and plant dry weights were obtained for Callistephus chinensis (Cockshull, 1966) and Circaea lutetiana (Frankland & Letendre, 1978). Thus the above results may imply that an independent photoperiodic control may regulate leaf elongation in onion plants. Cognizance should also be taken of the cyclic lighting technique which is also thought to depend for its effect on maintaining Pfr above some threshold value in the intervening period of darkness (Vince-Prue, 1975). Using this method, Terabun (1971a, 1980) established that retaining the total duration of incandescent light constant for a 16h night period, but increasing the number of cycles of incandescent light from 1 of 4h light / 4h dark to 32 of 15min light / 15min dark given directly after a 8h photoperiod of sunlight, increased the bulb size.

In view of the above facts, light quality appears to modulate the effectiveness of a photoperiodic response through a phytochrome mediated photoperiodic control of vegetative development and bulbing in the Kelsae onion plants as emphasized earlier by Terabun (1965, 1970) and Austin (1972). Nevertheless, from the above

discourse the phytochrome regulation of onion growth seems to centre on the involvement of Pfr and/or the maintenance of a dynamic equilibrium between Pfr and Pr. Unfortunately the control of various phytochrome moieties within the green plant can still not be accurately determined (Schäfer, 1981). In these circumstances the form of phytochrome participation must be held in abeyance.

3. THE EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VEGETATIVE GROWTH UNDER CONTROLLED ENVIRONMENTAL CONDITIONS

3.1. Introduction

This chapter is primarily concerned with elucidating the physiological role exerted by various plant growth regulators in combination with AW and C37 light on the vegetative development of onion plants prior to bulbing. To facilitate these experiments the plants were initially grown under AW light to prevent the changes associated with bulbing. In addition, during the experimental period the plants received a temperature of 15°C and a 20h daylength. The former prerequisite further delayed by at least one month the confounding morphological changes associated with bulbing under C37 light, whereas the utilisation of long daylengths ensured that differences in leaf development produced by AW and C37 light were maximised. These facets were previously established in Chapter 2.

In regard to the selection of the plant growth regulators, these basicially fell into two groups. The first group which consisted of IAA, $GA_{4/7}$ and ethylene, represent plant growth regulators that are indigenous to plants (Wareing & Phillips, 1981), though it must be stressed that ethrel C was substituted for ethylene for ease of handling. The second group was comprised of plant growth regulators which interfered with some aspect of the first group. Thus in Experiment A, IAA was compared alongside TIBA which purportedly suppresses IAA translocation (Morris *et al*, 1973; Goldsmith *et al*, 1974). Similarly, in Experiment C, $GA_{4/7}$ activity was examined side by side with the plant growth retardant phosphon D, which inhibits the cyclization of geranylgeranyl pyrophosphate by kaurene synthetase in the gibberellin biosynthetic pathway (Frost & West, 1977) and the retardant paclobutrazol alleged to lower endogenous gibberellin levels, though the mechanism has yet to be determined (Froggatt *et al*, 1981). Ethrel C was included in this experiment because of well documented evidence showing inhibition of leaf sheath elongation and leaf blade expansion (Levy & Kedar, 1970; Levy, Kedar & Karacinque, 1973) which was also synonymous of plant growth retardant activity on *Triticum vulgare* (Tolbert, 1960b) and *T. aestivum* (Humphries *et al*, 1965).

Preliminary experiments revealed that foliar sprays of GA_3 and the plant growth retardant CCC were ineffectual in modulating plant development. In these circumstances Experiment B was conducted to test the responsiveness of a range of gibberellins and plant growth retardants on plants maintained at a higher temperature of 25°C, previously reported to optimise onion plant growth (Butt, 1968) and irradiated with AW light to suppress bulbing. Comparisons between methods of application for plant growth retardants were also examined in Experiment B, especially as paclobutrazol was reported to be translocated preferentially in the xylem (Lever et al, 1982) and young onion leaf tissue, produced from a basally located intercalary meristem (Hoffman, 1933), appears to be more receptive to plant growth retardant activity.

3.2. Materials and Methods

3.2.1. Growth medium

To a growth medium consisting of 19 parts Irish moss, 3 parts loam and 2 parts flint hen grit, a further 115g John Innes Base and 45g ground lime was added to each $0.028m^3$ of growth medium. Differences between experiments in seedbed preparation are outlined below.

3.2.1.1. Experiment A

The growth medium was poured into paperpot honeycombs (Whalehide Company, Leigh on Sea, Essex) of dimensions 5cm (diameter) x 20cm (length) x 130 (pots) and compressed lightly. This procedure was repeated twice more to produce a sowing depth of approximately 0.5cm. Each paperpot received a single seed prior to a final addition of growth medium, which was lightly firmed and the excess scraped from the paperpot tops. Soil moisture loss was reduced by sheathing the paperpot honeycomb sides with black polythene. A liberal application of water was given on the first day, while subsequent watering was as required.

3.2.1.2. Experiment B

The growth medium was poured into 13cm Stewart plastic pots (R. Sankey & Son Ltd., Bulwell, Nottingham) and lightly compressed.

Ten seeds were sown in each pot prior to a further addition of growth medium to cover the seeds to a depth of approximately 0.5cm. A liberal application of water was given on the first day, while subsequent watering was as required.

3.2.1.3. Experiment C

Same procedure as outlined in Experiment A was adopted.

3.2.2. Growth Cabinets

Two types of growth cabinet were constructed by the author of these experiments:-

(i) Cool growth cabinet (15°C) - In this cabinet (Fig.3.1) the desired temperature of 15 ± 2°C was maintained by working the refrigeration system against the heat energy produced from the fluorescent lights and also the external temperature when this exceeded the internal temperature. The thermostat controlling the refrigeration unit and located directly above the evaporator, monitored the continuously circulating air within the cabinet.

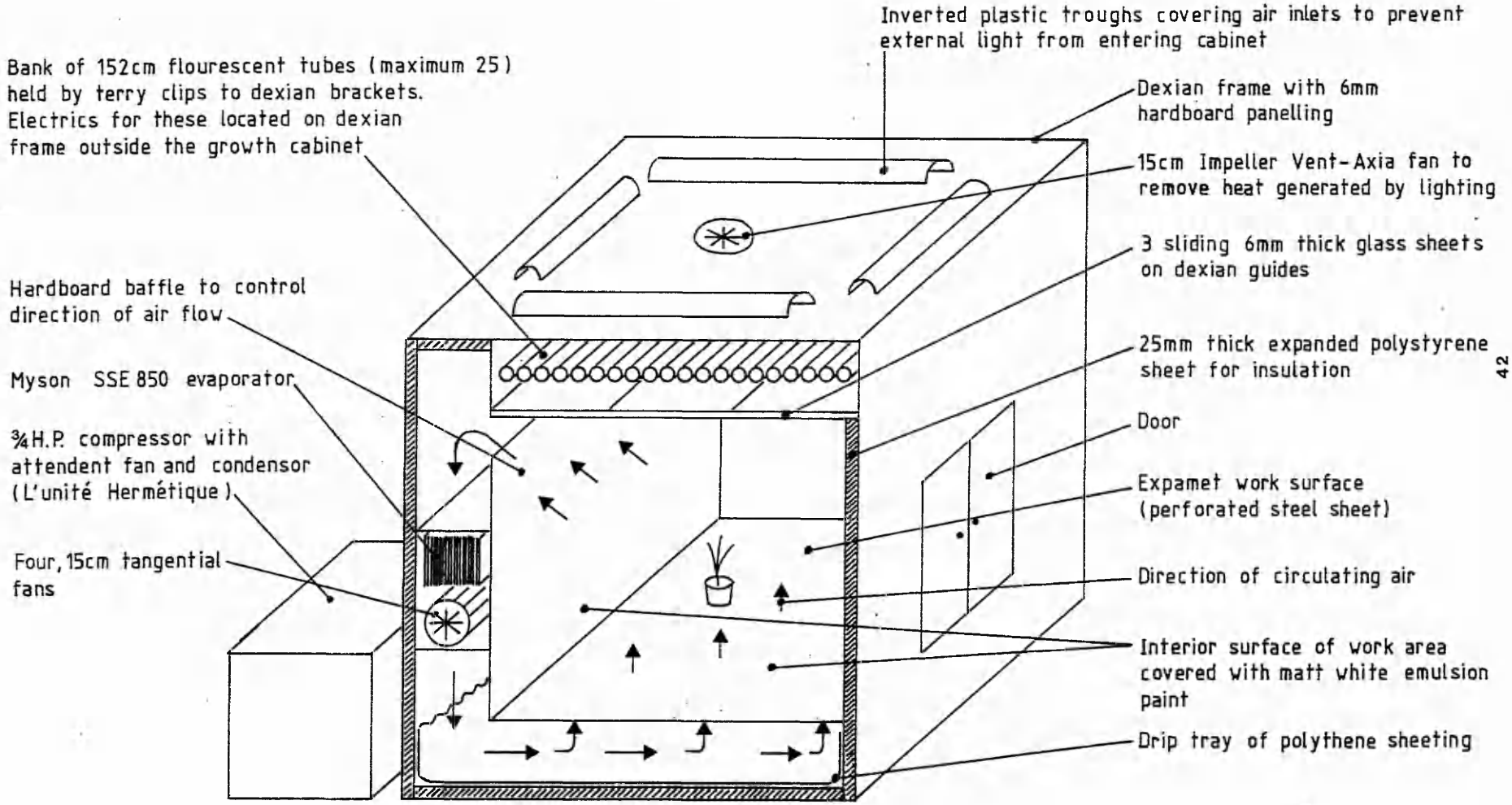
(ii) Warm growth cabinet (24°C) - A similar design to the cool growth cabinet was utilised. However instead of the refrigeration system, 2, 3 kilowatt Camplex greenhouse fanheaters (Simplex of Cambridge Ltd.) were located in the position of the evaporator. Furthermore the glass panels separating the fluorescent tubes from the growing area were omitted and the electrics for these fluorescent tubes were retained within the light fittings that were hung from dexian brackets located under the cabinet roof. To maintain the desired temperature of 24 ± 2°C, the thermostatically controlled fanheaters worked against the cooler air sucked in through the air inlets located in the cabinet roof.

3.2.3. Growth conditions

3.2.3.1. Experiment A

Germination and initial growth of onion seedlings were conducted in the cool growth cabinet. Plants received a 20h daylength from AW fluorescent tubes emitting a photon fluence rate of 163.67 ± S.D. 12.63 $E.m^{-2}.sec^{-1}$ (P.A.R). After 57 days, 390 plants were selected using similar lengths of the fourth leaf as the selection criterion. Groups of 13 selected plants, with

Fig. 3.1. Generalised diagram of the growth cabinet.



intact paperpots, were allocated to 30, 23cm diameter Stewart plastic pots ensuring that similar mean lengths were achieved for the fourth leaf between pots. The remaining space within the plastic pots was filled with vermiculite to provide structural support for the paper pots. Finally, the prepared plastic pots were divided into 3 groups of 10 pots, with each group receiving a particular plant growth regulator.

To obtain two different light quality treatments within the growth cabinet, alternating AW and C37 fluorescent tubes, ensheathed with aluminium foil for just over half their length, were inserted. Spatial separation of light qualities was achieved by positioning the exposed halves of either the AW or C37 fluorescent tubes to one side of the growth cabinet. Light quality mixing within the cabinet was prevented by hanging a aluminium foil divide from the glass panel directly below a 5cm band produced by the converging aluminium sheaths of the fluorescent tubes. Similarly a cardboard strip was inserted in the same position, but between the glass panel and the fluorescent tubes. The photon fluence rates produced in the AW and C37 light compartments were respectively 125 ± S.D. 4.21 and 125 ± S.D. 5.29 E. m^{-2}. sec^{-1} (P.A.R). The area within each light quality compartment was divided into 5 blocks, with each block receiving one randomly distributed pot from each of 3 plant growth regulator treatments. Watering of the plants was as required with Sangral Root and Foliar Feed applied at a weekly rate of 1g/360 plants.

3.2.3.2. Experiment B

Throughout this experiment the plants were grown in the warm growth cabinet and received a 20h daylength from AW fluorescent tubes emitting a photon fluence rate of 186.16 ± S.D. 22.69 E.m^{-2}. sec^{-1} (P.A.R). Twenty six days after sowing, plants were selected by using the criterion of similar lengths for the second leaf, thereby retaining 5 plants per pot with the remainder pricked out. Three pots were allocated to each of the 15 plant growth regulator treatment groups ensuring that a similar overall mean length of the second leaf was maintained between treatment groups. For ease of handling, the treatment groups were split into two separate units of 7 and 8 treatment groups, with each unit

occupying one half of the working space within the growth cabinet. Pots within a particular unit were redistributed randomly after each treatment or measurement time. Watering of plants was as required with Sangral Root and Foliar Feed applied at a weekly rate of 1g/360 plants commencing 14 days after plant selection.

3.2.3.3. Experiment C

Germination and initial growth of onion seedlings were conducted in the cool growth cabinet. Plants received a 20h daylength from AW fluorescent tubes emitting a photon fluence rate of 148.67 ± S.D. 9.87 $E.m^{-2}.\ sec^{-1}$ (P.A.R). After 53 days, 200 plants were selected using similar lengths of the fourth leaf as the selection criterion. Groups of 4 randomly chosen plants, each retained in their own paperpots, were assigned to 50, 13cm diameter Stewart plastic pots ensuring that similar mean lengths of the fourth leaf were obtained between all the plant groups. Finally these pots were randomly distributed into 5 plant growth regulator treatment groups of 10 pots each. To obtain the AW and C37 light quality treatments, the system utilised in Experiment A (Section 3.2.3.1) was adopted. Photon fluence rates produced under the AW and C37 fluorescent tubes were respectively 93.3 ± S.D. 4.93 and 98.3 ± S.D. 5.77 $E\ m^{-2}\ sec^{-1}$ (P.A.R). The area under each light quality compartment was divided into 5 blocks, with each block receiving one randomly placed pot from each 5 plant growth regulator treatments. Watering of the plants was required every alternate day with Sangral Root and Foliar Feed applied weekly at the rate of 1g/360 plants.

3.2.4. Plant growth regulator treatments

3.2.4.1. Experiment A

Plant growth regulators were administered 24h after plant selection. These were 2.86mM IAA and 1mM TIBA. IAA was dissolved in a small quantity of ethyl alcohol prior to addition of distilled water, while TIBA was first dissolved in 0.1N KOH followed by 0.1N HCl to reduce the alkalinity of the solution to pH.7, before adding distilled water. IAA, TIBA and the distilled water control were sprayed onto the onion plant foliage until run-off, using a Binks Bullows spray gun, Model L900, at an air

pressure of 10^6 dynes. cm^{-2}. All treatment solution were supplemented with the wetting agent Citowett (B.A.S.F. A.G.) to give a final concentration of 0.02% (V.V.). This quantity of Citowett was found sufficient to reduce the surface tension of distilled water to its minimum of 30 dynes. cm^{-2}. Foliar sprays were administered daily for 14 days.

3.2.4.2. Experiment B

Twenty four hours after selection, various plant growth regulator treatments were applied as listed below:-

TREATMENT	CONCENTRATION (mM)	METHOD OF APPLICATION
ANCYMIDOL	0.078	SOIL DRENCH
ANCYMIDOL	0.586	FOLIAR SPRAY
PHOSPHON D	5.03	SOIL DRENCH
AMO - 1618	5.63	SOIL DRENCH
AMO - 1618	2.82	FOLIAR SPRAY
MEPIQUAT CHLORIDE	36.36	FOLIAR SPRAY
SADH	62.50	FOLIAR SPRAY
CCC	31.65	FOLIAR SPRAY
CCC	37.97	SOIL DRENCH
PACLOBUTRAZOL	0.102	FOLIAR SPRAY
PACLOBUTRAZOL	0.034	SOIL DRENCH
GA_3	1.45	FOLIAR SPRAY
$GA_{4/7}$	1.52	FOLIAR SPRAY

Ancymidol and mepiquat chloride were received as liquid formulations and only required the addition of distilled water to achieve the correct concentration. Phosphon D, AMO-1618, SADH (wettable formulation, alar) and CCC readily dissolved and made up to the desired concentration using distilled water. Paclobutrazol and GA_3 were dissolved in a small quantity of absolute ethyl alcohol prior to the supplementation of distilled water to the required concentration. $GA_{4/7}$ (mixture of GA_4 and GA_7 in a ratio of 1:1 (W : W)) was initially dissolved in 0.1N NaOH and the alkalinity of the resultant solution reduced to pH 7 by supplementing with 0.1N HCl prior to the addition of distilled water to achieve the desired concentration.

The method previously described in Section 3.2.4.1. was used for these plant growth regulators and the distilled water control to be applied as foliar sprays. Plants to be sprayed had their growth medium covered by absorbent cotton wool to prevent contamination by run-off or foliar spray drift. For soil drench treatments, each pot received 50ml of the relevant plant growth regulator around the basal region of the plants. Two foliar sprays were administered 24 days apart, while only a single soil drench was applied.

3.2.4.3. Experiment C

Twenty four hours after plant selection the following plant growth regulators were applied:-

TREATMENT	CONCENTRATION	METHOD OF APPLICATION
$GA_{4/7}$	1.52 mM	FOLIAR SPRAY
ETHREL C	3.46 mM	FOLIAR SPRAY
PHOSPHON D	1.26 mM	SOIL DRENCH
PACLOBUTRAZOL	8.52 μM	SOIL DRENCH

Preparative methods for $GA_{4/7}$, phosphon D and paclobutrazol were previously described in Section 3.2.4.2. Ethrel C was received as a liquid formulation to which distilled water was added to obtain the desired concentration. For those plant growth regulators to be foliar sprayed, the method described in Section 3.2.4.1 was followed. Soil drenches of phosphon D and paclobutrazol were applied at a rate of 50ml/plant to the base of the plant. Foliar sprays and soil drenches were administered at fortnightly and four weekly intervals respectively.

3.2.5. Measurements

3.2.5.1. Gross morphological determinations

3.2.5.1.1. Experiment A

Gross morphological determinations were attempted at weekly intervals commencing on the same day as the plant growth regulator treatments. Plant sampling was based on the lengths of the fourth leaf originally used to aid plant distribution amongst the pots (Section 3.2.3.1). Thus for each pot, the plant having the

seventh longest leaf was assigned to the first harvest. The remaining 12 plants were split into 3 groups containing those with the four shortest fourth leaves, another the four intermediary and the final group the four longest. At each subsequent harvest, a plant was randomly selected from each leaf size group within a pot, making a total of 90 plants sampled from the 30 pots.

The scheme in Fig.3.2 depicts the various gross morphological determinations undertaken. Explanatory notes for determinations alphabetically indexed in the scheme are elaborated below:-

(A) Leaf blade length: The distance from the leaf tip to the junction between the leaf blade and leaf sheath or to the pore of the previous leaf if the leaf sheath has not emerged.

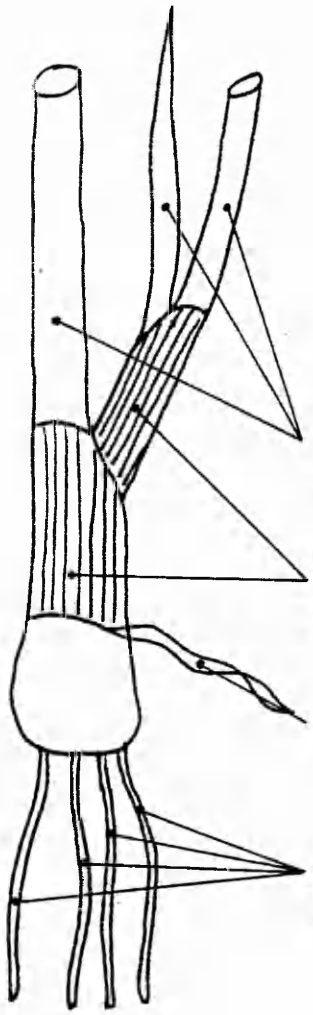
(B) Leaf blade width: Maximum distance across the flat face of the transversely D-shaped leaf.

(C) Leaf blade area: Calculated from leaf blade length and width values. A preliminary experiment was undertaken to determine whether a close correlation existed between the leaf product (leaf blade length x width) and leaf area. The latter was determined by slitting the leaf blade open along its longitudinal axis and flattening the blade between two sheets of glass. By illuminating the pinned leaf blade from below, outlines could be pencilled on to tracing paper and the area within these outlines calculated using an Apple II computer with a graphic tablet (Apple Computers 20525, Cupertino, California). Resultant leaf areas were graphed against their corresponding leaf products as illustrated in Fig.3.3. Two linear regression trends A and B, with correlation coefficients of 0.933 and 0.991 respectively, adequately defined the relationship between the leaf product and area. Leaf product values below 500 were used to formulate regression A, while regression B employed values exceeding this leaf product. Regression trends are described by the equation:-

$$\text{LEAF AREA} = (\bar{b} + (m \times (\text{LEAF PRODUCT} - \bar{x})$$

were m = regression coefficient, $\bar{b}$ = mean leaf area and $\bar{x}$ = mean leaf product. Inserting the relevant values for regression A this equation becomes:-

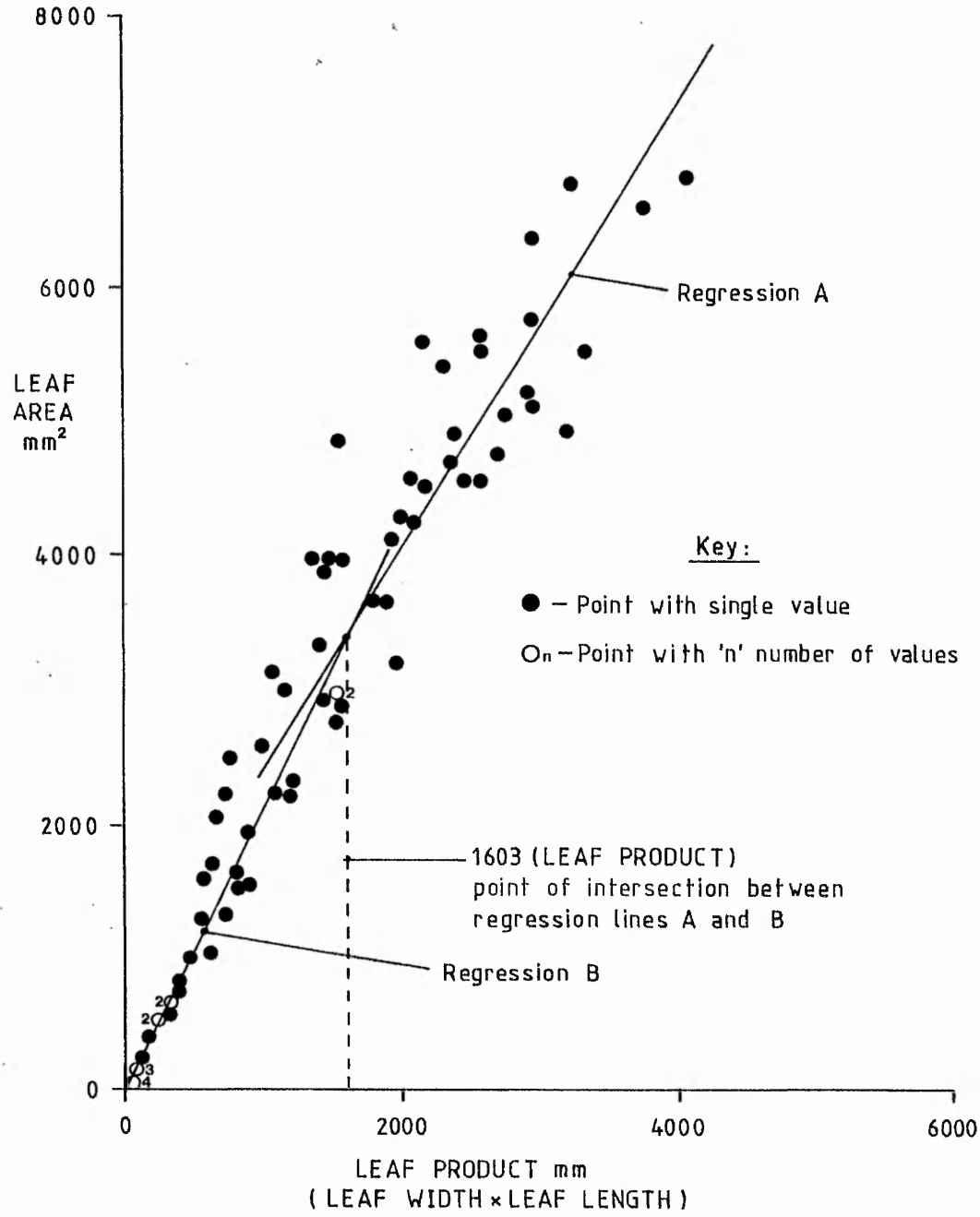
Fig. 3.2. Guide to gross morphological determinations for Experiment A.



Section A
Section B
Section C
Section D
Section E
Fourth leaf (D)
Individual section lengths
Individual section widths
Individual section fresh weights
Sections saved for cellular and dry weight determinations
Section fresh weights added
Number of leaves attained on final harvest
Green leaf blades
Leaf blade length (A)
Maximum leaf width (B)
Leaf blade area (C)
Total leaf fresh weight
Dry weight of fourth leaf sections calculated from dry weight: fresh weight ratios calculated for each section
Basal region and leaf sheaths
Combined fresh weight
80°C 3 days
Combined dry weight
80°C 3 days
Section dry weights combined to give fourth leaf dry weight
Senesced leaf material
80°C 3 days
Dry weight
Total leaf dry weight
Total plant dry weight (A similar calculation was also attempted for total plant fresh weight)
Roots (E)
Fresh weight
80°C 3 days
Dry weight

Fig. 3.3.

Relationship between the product of leaf length and width with leaf area.



(i) LEAF AREA = 3742.55 + (1.65 x (LEAF PRODUCT-1822.13))

Similarly for regression B:-

(ii) LEAF AREA = 376.33 + (2.11 x (LEAF PRODUCT - 181.06))

Subsequent leaf areas were calculated using equation (i) when the leaf product value was below the intersection value of 1603 (Fig. 3.3) and equation (ii) for those exceeding this value.

(D) Third leaf sections: Before each harvest, the third leaf of all plants were marked just above the pore of the previous leaf using an Edding 3000 permanent marker pen. This enabled a partitioning of the third leaf to be achieved, whereby section A represents growth attained before the first harvest, while sections B to E delineate various growth increments produced during consecutive weekly harvest times.

(E) Roots: These were gently shaken to remove the majority of the growth medium and then rinsed in tap water prior to surface drying with absorbent tissue.

Using the various fresh weight and dry weight determinations, the following additional growth analysis parameters were calculated:-

(i) Dry weight ratio (DWR) = x dry weight / Total plant dry weight

(ii) Relative growth rate (RGR) = $\ln W_2 - \ln W_1 \; / \; t_2 - t_1$

(iii) Unit leaf rate (ULR) = $(W_2 - W_1 \; / \; A_2 - A_1) \times (\ln A_2 - \ln A_1 \; / \; t_2 - t_1)$

(iv) Leaf area ratio (LAR) = Total leaf area / Total plant dry weight

(v) Specific leaf area (SLA) = Leaf area / Leaf dry weight

(vi) Specific water content (SWC) = (x fresh weight - x dry weight) / x dry weight

where x is either the leaf blades, combined basal region & leaf sheaths or roots. RGR and ULR were calculated according to the formulas described by Beadle (1982), where W_1 and W_2 represents the initial and final total plant dry weight, A_1 and A_2 represents the initial and final leaf area and $t_2 - t_1$ delineates the time interval of 14 days between harvests. Two consecutive assessments were conducted for the RGR and ULR, spanning the spray and post-spray period.

3.2.5.1.2. Experiment B

Gross morphological determinations commenced 24h before the various plant growth regulators were applied. The length and maximum width of the second, third and fourth leaf were measured every fourth day for a period of 36 days. Leaf sheath was determined on the 24th and 36th day for the second and third leaves. Criterion adopted for leaf length and width was the distance from the leaf tip to the pore of the previous leaf and the maximum distance across the flat face of the leaf respectively, while the distance from the pore of the previous leaf to the junction between the leaf sheath and blade represented the leaf sheath length.

3.2.5.1.3. Experiment C

Measurements of the length and maximum width of the fifth leaf were conducted soon after emergence and repeated every 6 days. Criterion adopted for leaf length and width determinations was previously described in Section 3.2.5.1.1. Forty three days after commencement of plant growth regulator treatments, all the plants were harvested and the remaining gross morphological determinations undertaken as depicted in Fig.3.4. Explanations for determinations which are alphabetically indexed in the guide are elaborated below:-

(A), (B), (C) and (I) : See Section 3.2.5.1.1

(E): See Section 3.2.5.1.2

(D) Haulm length : Distance from the bottom of the basal region to the end of the last leaf sheath

(F) and (G) Neck and bulb diameter : Two diameters were measured at right angles to each other and the mean calculated (Clark & Heath, 1962)

(H) Bulbing ratio : Calculated by dividing the mean bulb diameter by the mean neck diameter (Clark & Heath, 1962).

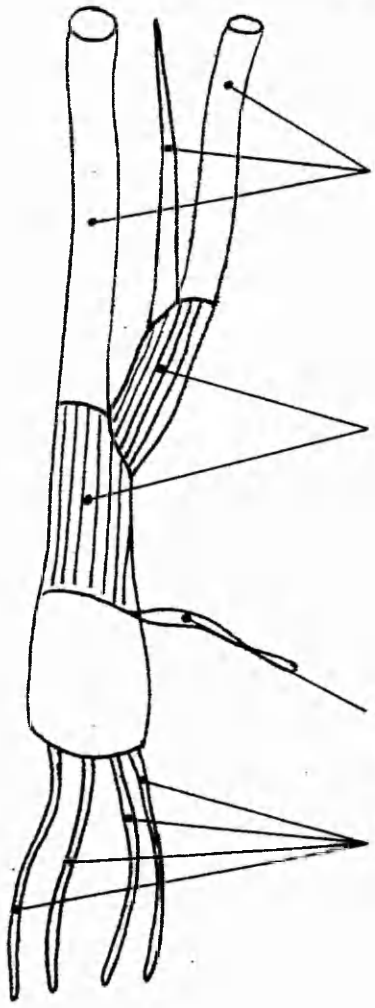
Calculations of the LAR, SLA and the various DWR and SWC follow the procedures described in Section 3.2.5.1.1.

3.2.5.2. Cellular determinations

3.2.5.2.1. Experiment A

The illustrated guide Fig.3.5 depicts the various cellular determinations conducted on the fourth leaf sections B, C and D, whilst the tip section A was omitted due to problems of senescence.

Fig. 3.4. Guide to gross morphological determinations for Experiment C.



Green leaf blades

Leaf number attained at harvest time → Fresh weight of fifth leaf blade → Saved for cellular measurements and dry weight : fresh weight ratio determinations

Leaf blade length (A)

Maximum leaf width (B)

Leaf blade area (C)

→ Combined fresh weight

Dry weight of fifth leaf calculated from dry weight : fresh weight ratios

Haulm length (D)

Length of fourth and fifth leaf sheath (E)

Basal region and leaf sheaths → Combined fresh weight

Neck diameter (F)

Bulb diameter (G)

Bulbing ratio (H)

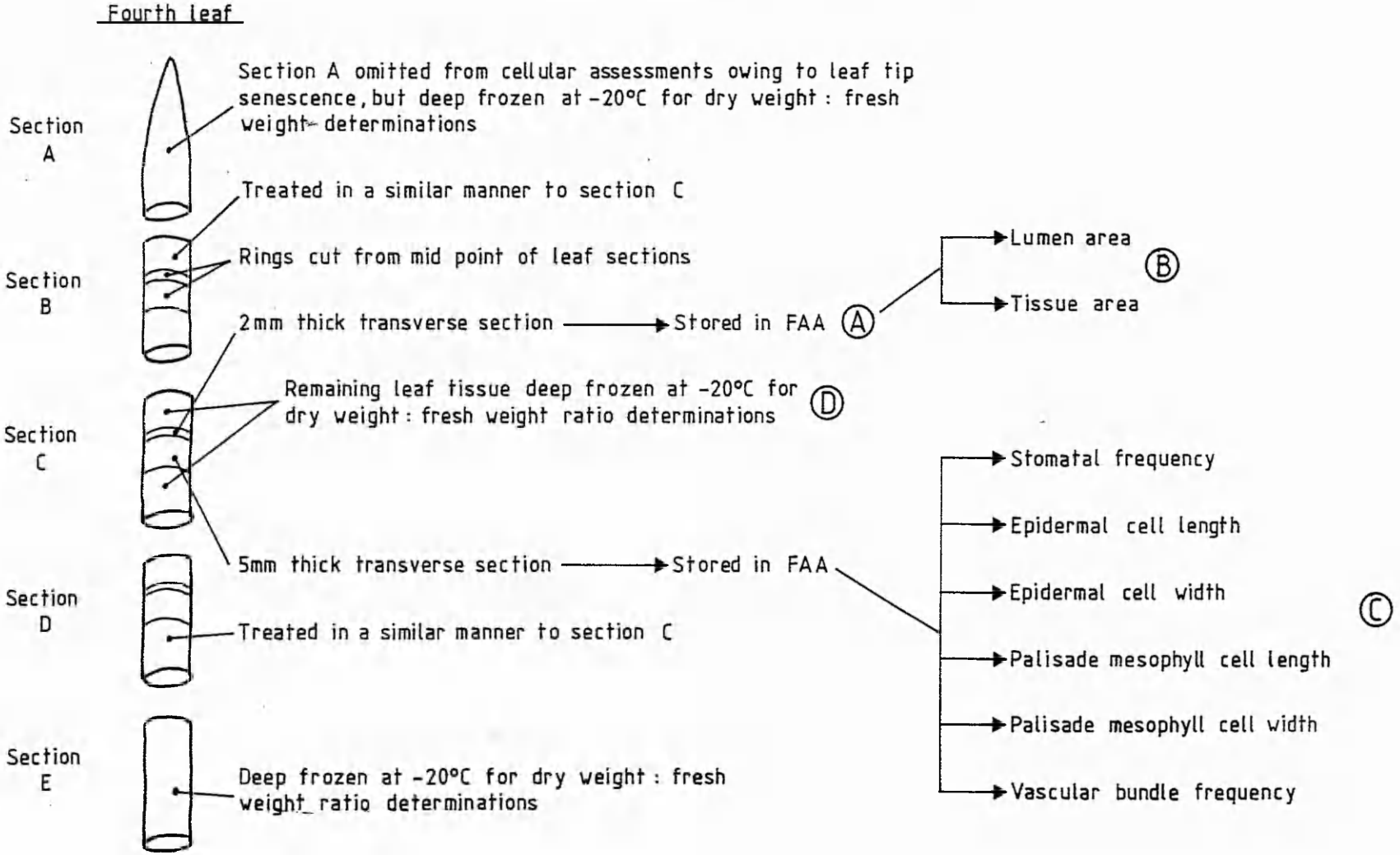
80°C 3 days → Combined dry weight

80°C 7 days → Combined dry weight

Senesced leaf material → 80°C 3 days → Dry weight

Roots (I) → Fresh weight → 80°C 3 days → Dry weight → Total plant dry weight (A similar calculation was also attempted for total plant fresh weight)

Fig.3.5. Guide to cellular determinations for Experiment A.



Explanatory notes for stages alphabetically indexed in the guide are outlined below:-

(A) FAA : Plant tissue fixative prepared by mixing (v/v) 100ml 50% aqueous ethyl alcohol with 6.5ml formalin and 2.5ml glacial acetic acid. Fixation in FAA enabled long term storage to be attempted without noticeable tissue shrinkage and facilitated masking pigment clearance.

(B) Two mm thick transverse sections : A single transverse section was submerged in FAA contained in a clear plastic tray mounted on the stage of a Carl Zeiss Standard 14 microscope. Using a Watson camera lucida, a magnified leaf section image could be projected on to adjacent white paper for the lumen and leaf perimeter outlines to be pencilled. By cutting along these perimeter lines, 2 pieces of paper representing the area covered by the leaf tissue and lumen were obtained for area determinations on a Li-Cor Area Meter Model LI-3000 (Lambda Instruments Corporation, Lincoln, Nebraska).

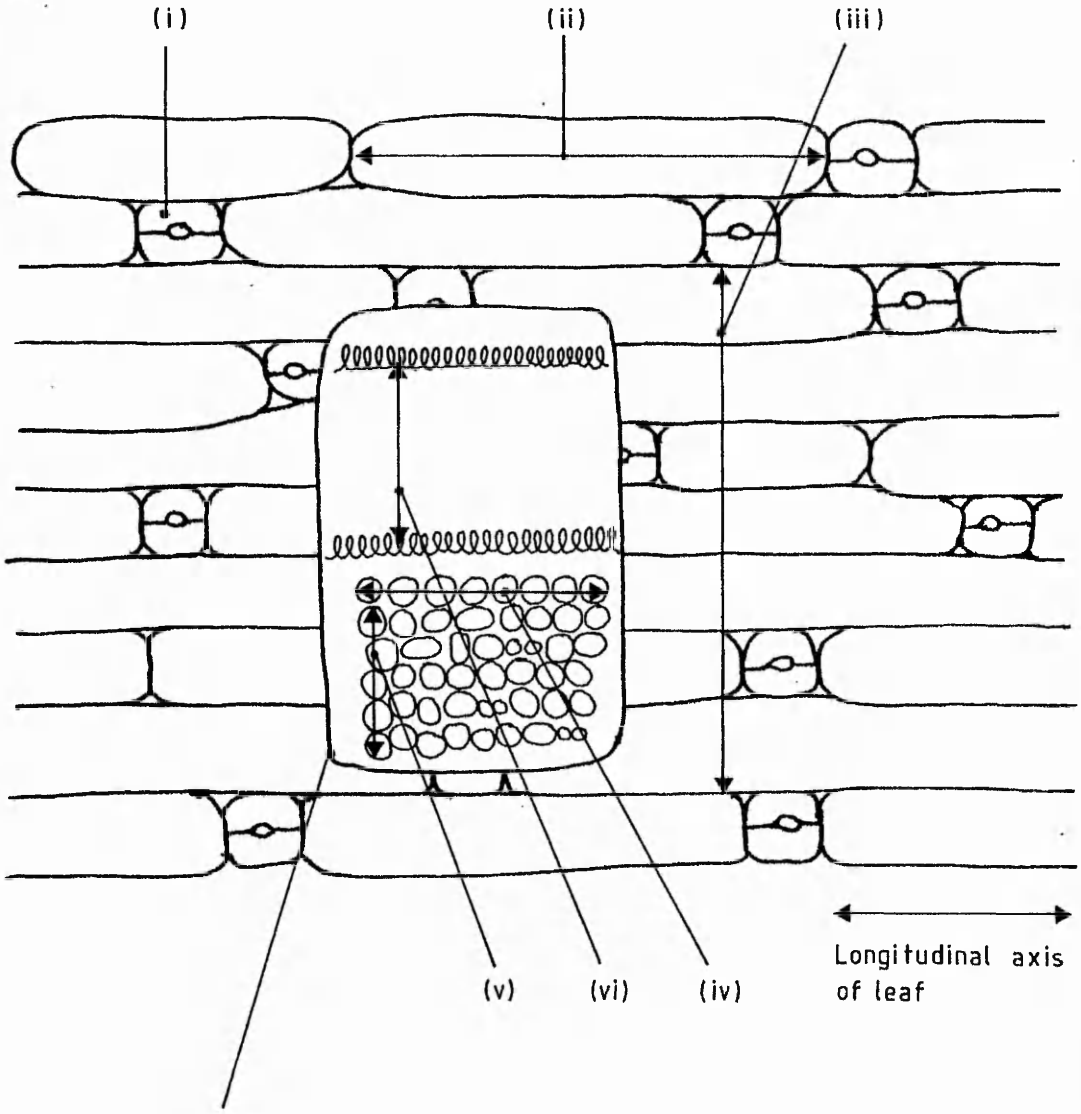
(C) Five mm thick transverse sections : Cellular determinations on these sections were only attempted on the fourth leaf segments B, C and D taken from one of the three plants sampled from each pot at a particular harvest time. The selection criterion adopted was the plant having the second longest leaf. Procedure entailed slitting open and spreading the preserved transverse section, epidermal cell layer uppermost, on the microscope slide. Safranin (1g safranin in 100ml 50% aqueous ethyl alcohol) was administered to stain the lignified tissues red and enhance the contrast of the cellular components. By focusing through the plant tissue using a Carl Zeiss Standard 14 microscope, estimates of various cell types could be obtained as illustrated in Fig.3.6. Explanatory details concerning cellular estimations which are indexed in the guide are elaborated below:-

(i) Stomatal frequency : Number of stomata counted within 10 random fields of view at x 240 magnification. Resultant figures were meaned and transformed to stomatal number. mm^{-2}.

(ii) Epidermal cell length : The individual lengths of 5 epidermal cells located end to end were measured with an ocular micrometer

Fig.3.6.

Guide depicting the various cell types used for the cellular determinations.



at x 240 magnification. This procedure was repeated at 8 random locations with the resultant figures grouped, meaned and transformed to epidermal cell length in mm.

(iii) Epidermal cell width : The transverse distance across 10 touching epidermal cells was measured with an ocular micrometer at x 240 magnification. Estimates obtained from 10 random locations were meaned and transformed to cell number. mm.

(iv) Palisade mesophyll cell length : The same procedure as (iii)

(v) Palisade mesophyll cell width : The same procedure as (iii)

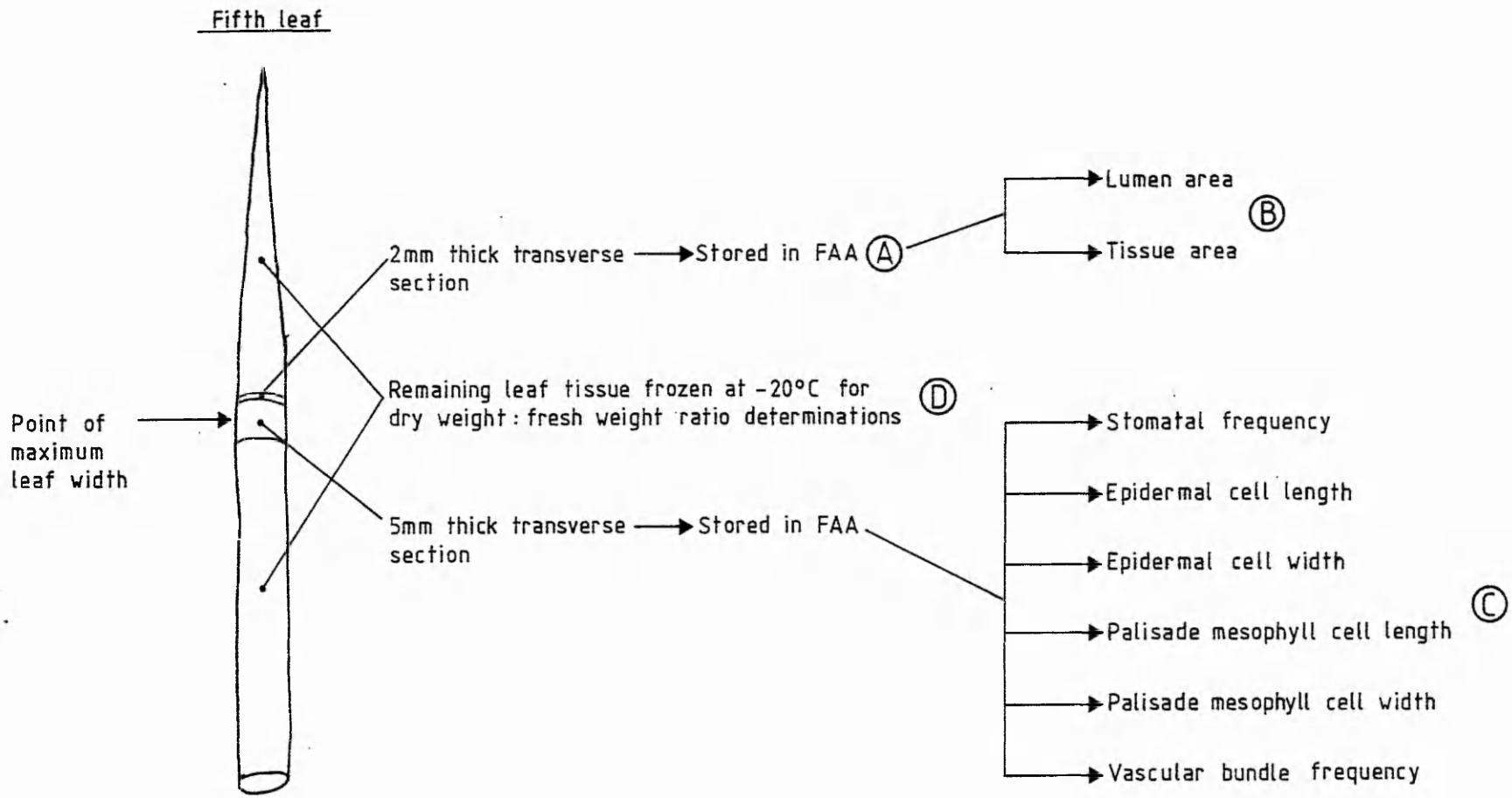
(vi) Vascular bundle frequency : For these estimates, the leaf section was required epidermal cell layer bottommost on the microscope slide. Measured distance from an arbitrarily designated first vascular bundle to the fifth in line. After collation of ten random estimates, the mean value of these was transformed to vascular bundle number. mm.

(D) Dry weight : fresh weight ratios : Of the 3 plants sampled from each pot at a particular harvest, the remaining leaf material from the fourth leaf sections A,B,C,D and E was bulked prior to freeze storage. The frozen remains of each leaf section of a particular harvest was diced and depending on the volume of material, 1 to 3 samples were taken for fresh weight determinations followed by dry weight measurements after drying at 80^{o}C for 3 days. From these estimations, mean dry weight : fresh weight ratios were calculated for each leaf section of a particular harvest. In turn the dry weight of a particular leaf section can be calculated from the product of its dry weight : fresh weight ratio and fresh weight. By these means the dry weight of the entire fourth leaf blade can be estimated and finally the total leaf dry weight of the plant.

3.2.5.2.2. Experiment C

Two and 5mm thick transverse sections were cut from the point of maximum leaf width for each fifth leaf sampled. The illustrated guide Fig.3.7 depicts the various measurements obtained from these sections. Explanatory notes for these stages alphabetically indexed in the guide are elaborated below:-

Fig. 3.7. Guide to cellular determinations for Experiment C.



(A) FAA : See Section 3.2.5.2.1

(B) Two mm thick transverse section : By submerging these sections in a clear plastic dish containing FAA and placing on a 3M Brand overhead projector (3M Company), a x 10.5 magnification of the projected image was obtained. Handling of the projected image and lumen and tissue area determinations are described in Section 3.2.5.2.1.

(C) Five mm thick transverse section : Cellular measurements were determined on only the plant having the second largest leaf width from the group of four plants allocated to each pot. Handling of the transverse sections and cellular determinations are described in Section 3.2.5.2.1.

(D) Dry weight : fresh weight ratios : From each pot of 4 plants the remaining fifth leaf blade tissue not used for cellular determinations was bulked prior to low temperature storage. Following the determination of dry weight : fresh weight ratios according to the method in Section 3.2.5.2.1, the dry weight of the fifth leaf was calculated from the product of the relevant ratio with the fresh weight of the fifth leaf and finally the total leaf dry weight of the plant can be estimated.

3.2.6. Experimental design and statistics

3.2.6.1. Experiment A

A split-plot design was selected, whereby the 5 blocks within each light quality compartment represented the main plots. In turn each main plot was partitioned into 3 sub-plots delineating the different plant growth regulator treatments. With the exception of leaf number attained, RGR and ULR, a final compartmentalization of each sub-plot into a variable number of sub-plots accounted for the weekly observations undertaken on the other parameters.

3.2.6.2. Experiment B

For each of the experimental units 1 and 2, a fully randomised design was adopted for the replicates of the plant growth regulator treatments. Since repeated measurements on various characters were undertaken at intervals of time, a two-way analysis of variance was utilized. The day and plant growth regulator x day interaction

items were further partitioned using orthogonal polynomials to test for differential curvilinearity in the rates of leaf and width expansion. Owing to a single assessment only a one-way analysis of variance was utilized on the estimates for leaf sheath length.

3.2.6.3. Experiment C

A split-plot design was selected, whereby each light quality compartment was partitioned into 5 main plots delineating the replicate blocks. In turn the individual blocks were subdivided into 5 sub-plots representing the 5 different plant growth regulator treatments. In the case of length and width determinations of the fifth leaf, a time course study was superimposed leading to a further sub-division of the sub-plots into sub-sub-plots to cater for the seven measurement periods attempted at 4 day intervals. Furthermore, a regression analysis employing orthogonal polynomials was included to test for disparities amongst the curvilinear growth trends for the above two characters of the fifth leaf.

The various split-plot designs, one and two-way analyses of variance and regression analyses employing orthogonal polynomials in the 3 experiments were analysed according to the methods outlined by Snedecor & Cochrain (1967) and run on the DEC system 20 computer (Digital Equipment Corporation, Maynard, Massachusetts) using the Genstat V (Mark 4.03) language (Lawes Agricultural Trust, Rothamsted Experimental Station). The Q method was used to test for significance between the appropriate treatments (Snedecor & Cochrain, 1967).

3.3. Results

3.3.1. Gross morphological determinations

3.3.1.1. Experiment A

Of the various gross morphological characters considered, irradiation with C37 rather than AW light generally enhanced their size (Fig.3.8-3.10; Table 3.1; Appendix Table (A.T.) 3.2, 3.3, 3.5 - 3.10, 3.14, 3.22, 3.23). However a few instances were obtained of AW light preferentially enlarging certain characters in respect to C37 light as observed for root and senesced leaf material dry weight and root DWR (Fig.3.8, 3.9; A.T. 3.8, 3.12, 3.15).

Fig. 3.8.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS GROSS MORPHOLOGICAL CHARACTERS.

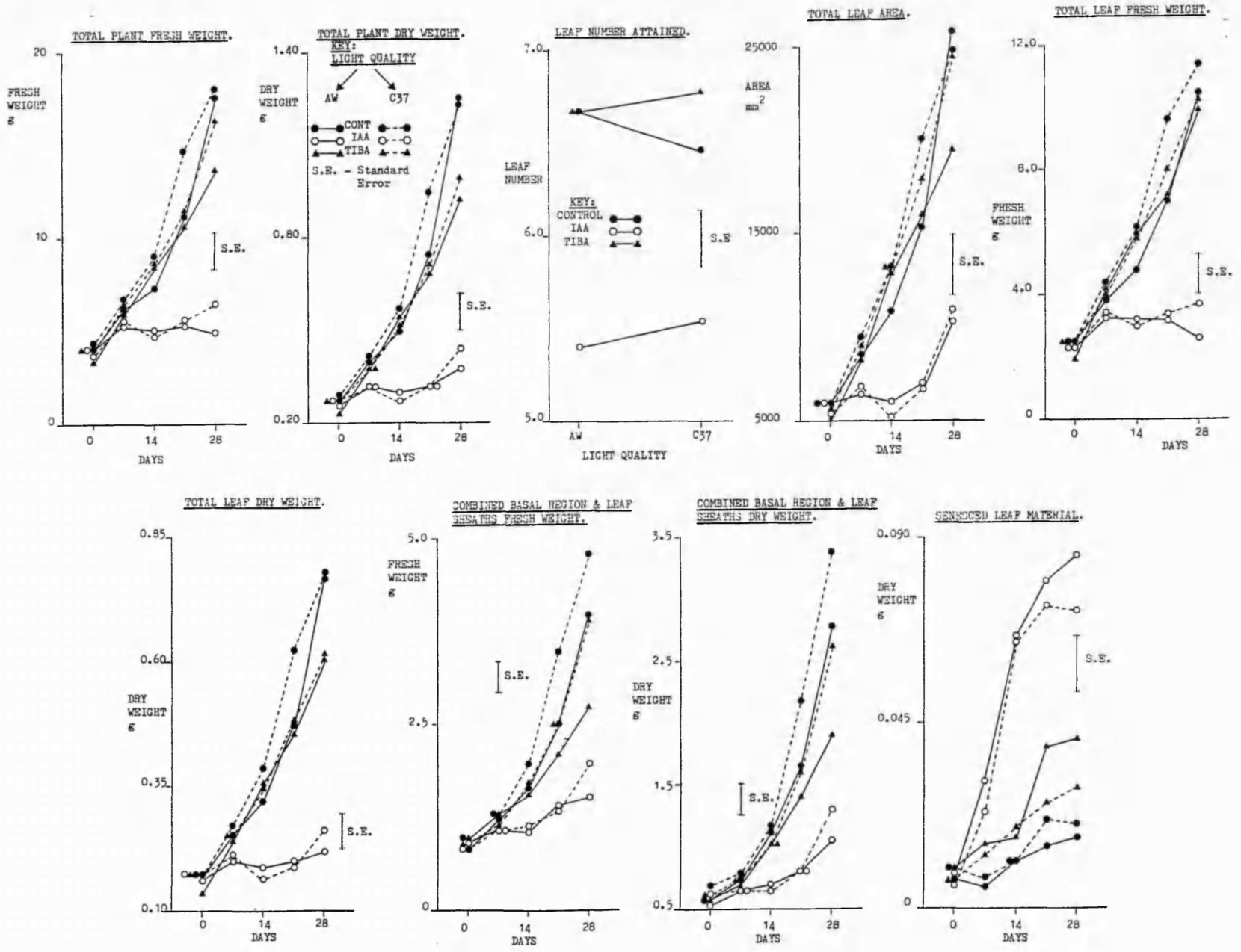


Fig. 3.9.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS GROSS MORPHOLOGICAL CHARACTERS.

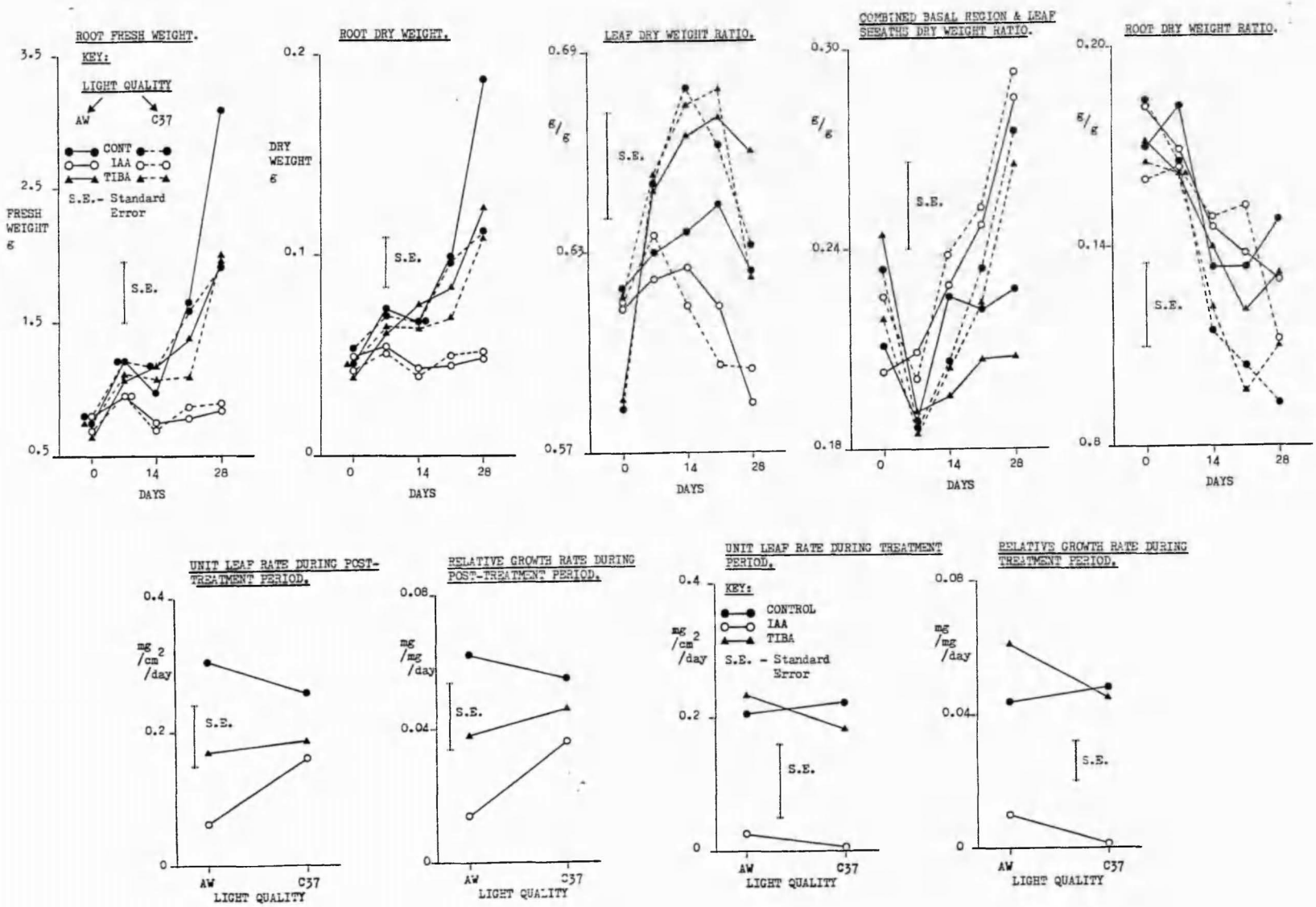


Fig. 3.10.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS GROSS MORPHOLOGICAL CHARACTERS.

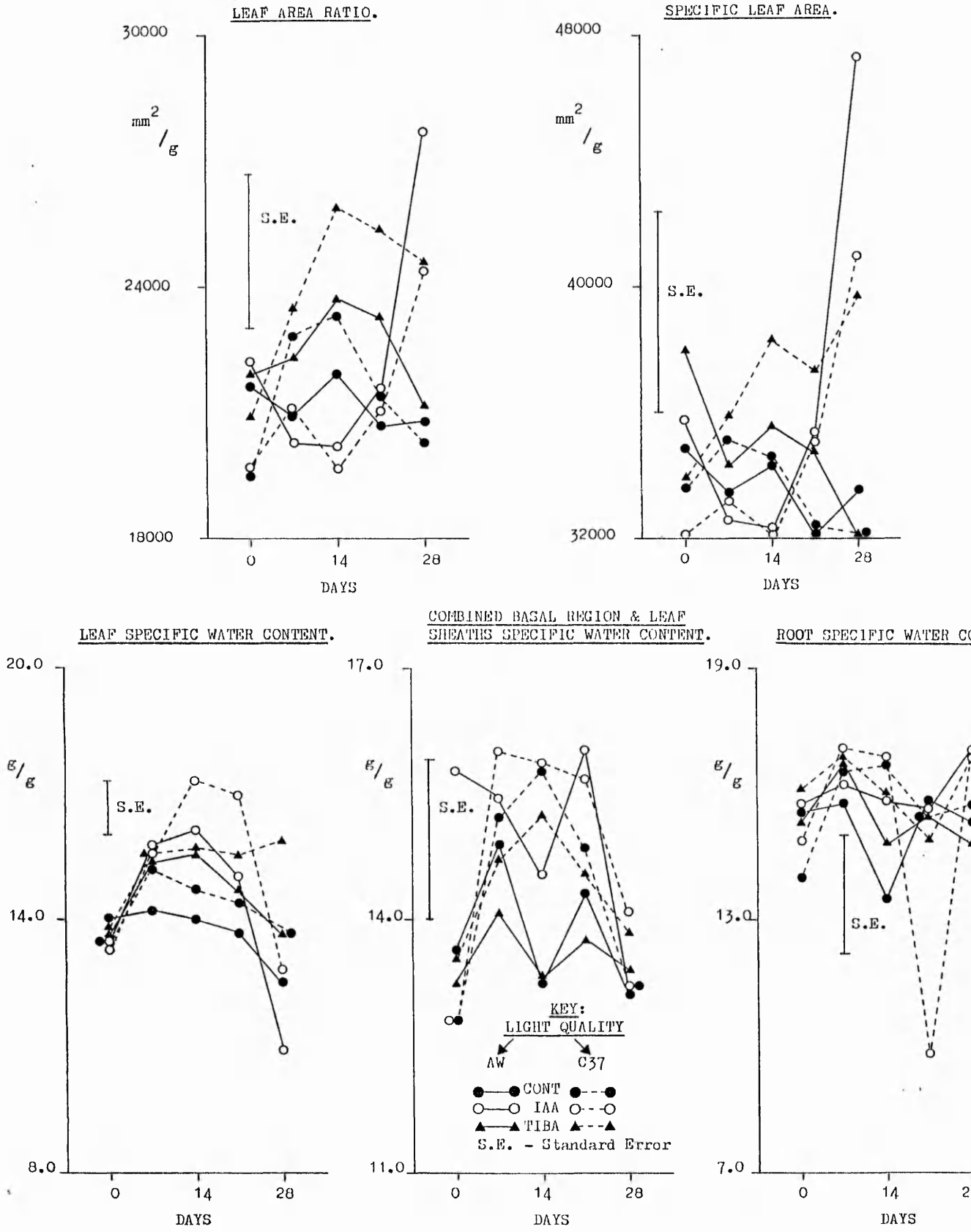


Table 3.1.

Summary of gross morphological effects incurred by light quality and plant growth regulators in Experiment A.

CHARACTER	TREATMENT			
	AW LIGHT	C37 LIGHT	IAA	TIBA
Plant fresh weight	↓	↑	↓	↓
Plant dry weight	↓	↑	↓	↓
Leaf number	0	0	↓	0
Total leaf area	↓	↑	↓	0
Total leaf fresh weight	↓	↑	↓	0
Total leaf dry weight	↓	↑	↓	↓
Senesced leaf material dry weight	↑	↓	↓	↓
Combined basal region & leaf sheaths fresh weight	↓	↑	↓	↓
Combined basal region & leaf sheaths dry weight	↓	↑	↓	↓
Root fresh weight	0	0	↓	↓
Root dry weight	↑	↓	↓	↓
Leaf DWR	0	0	↓	0
Combined basal region & leaf sheaths DWR	↓	↑	↑	0
Root DWR	↑	↓	0	0
ULR (Spray period)	0	0	↓	0
ULR (Post-spray period)	0	0	↓	↓
RGR (Spray period)	0	0	↓	0
RGR (Post-spray period)	0	0	↓	0
LAR	0	0	↑	↑
SLA	0	0	↑	↑
Leaf SWC	↓	↑	↑	↑
Combined basal region & leaf sheaths SWC	↓	↑	↑	0
Root SWC	0	0	0	0

Key: ↑ - increased; ↓ - decreased; 0 - no change.

Furthermore light quality had a negligible effect on leaf number, root fresh weight, leaf DWR, ULR, RGR, LAR, SLA and root SWC (Fig. 3.8 - 3.10; A.T. 3.4, 3.11, 3.13, 3.16 - 3.21, 3.24).

Effects evoked by the plant growth regulators IAA and TIBA (Table 3.1) revealed the former and to a lesser extent the latter were for the most part inhibitory (Fig.3.8, 3.9; A.T. 3.2 - 3.13, 3.16 - 3.19). Exceptions were evident, since both IAA and TIBA augmented the LAR, SLA and leaf SWC, whilst IAA alone enhanced the DWR and SWC of the combined basal region & leaf sheaths (Fig.3.9, 3.10; A.T. 3.14, 3.20 - 3.23). The rather poor response exacted by TIBA on various gross morphological characters was highlighted by a negligible change in the number, fresh weight and area of the leaves, all DWR, RGR and the SWC of the combined basal region & leaf sheaths and roots (Fig. 3.8 - 3.10; A.T. 3.4 - 3.6, 3.13 - 3.16, 3.18, 3.19, 3.23, 3.24).

Whereas the majority of gross morphological characters increased in magnitude with time, different trends pertained with the various DWR and SWC. Thus with the former parameters, the leaf DWR increased to a maximum between day 14 and 21 before decreasing, while the contrary applied to the combined basal region & leaf sheath DWR, though in this instance the minimum ratio was reached by about the seventh day (Fig.3.9). In regard to the root DWR, this decreased from a maximum on day 0 to a minimum on day 21 to day 28 (Fig.3.9). Inspection of the SWC for the leaves and combined basal region & leaf sheaths established the presence of a curvilinear trend which enlarged to a maximum between day 7 and 14 of the assessment period and declined thereafter (Fig.3.10). Although the root SWC showed a significant day item (A.T. 3.24), the erratic nature of the trend coupled with a spurious moderation observed on day 21 for plants receiving C37 light and IAA tends to question the validity of this significance (Fig.3.10). Certainly difficulties encountered in separating the fragile roots from the growth medium, may be responsible for the large standard error (Fig.3.10), which will confound possible modifications exerted by the treatments.

Non-significant interactions between light quality and plant growth regulators were obtained for the majority of gross morphological characters considered and may imply that these two factors acted independently on the characters in question (A.T. 3.2 - 3.8, 3.11 - 3.24). Exceptions were evident since significant light quality x plant growth regulator interactions were obtained for the combined basal region & leaf sheaths fresh and dry weights (A.T.3.9, 3.10). In this instance, IAA not only moderated the incrementation of these characters below the level achieved by the control plants, but also decreased their expected augmentation under C37 light to the level attained under AW light (Fig.3.8). Barring a few instances, the extraction of significant plant growth regulator x day interaction items generally substantiates the marked suppressive role effectuated by IAA with time on the multifarious gross morphological characters, when compared with control and TIBA treatments (A.T. 3.2, 3.3, 3.5 - 3.13). Although IAA chiefly incurred an inhibitory response, the period following the curtailment of IAA application has in certain circumstances yielded perceptibly faster growth rates, suggesting that IAA regulation was only transient. This facet was observed with leaf area, total plant and leaf dry weight, LAR, SLA and combined basal region & leaf sheaths fresh weight, dry weight and DWR (A.T. 3.3, 3.5, 3.7, 3.9, 3.10, 3.14, 3.20, 3.21). In contrast the exiguous inhibition exacted by TIBA often became notable during the post-spray period, indicating the development of a gradual but progressive restraint (Fig.3.8, 3.9). Non-significant plant growth regulator x day interaction items were observed for the SWC of the roots and combined basal region & leaf sheaths (A.T. 3.23, 3.24), whilst the omission of the day factor in the analysis of leaf number, ULR and RGR precludes determinations of the relevant interaction item (A.T. 3.4, 3.16 - 3.19). Finally the presence of a few significant light quality x day interaction items may intimate a continued control exerted by AW and C37 light with time on certain gross morphological characters. Such trends were observed for the SWC, DWR, dry and fresh weight of the combined basal region & leaf sheaths and leaf SWC, in which C37 rather than AW light produced a faster augmentation, whilst the contrary applied to the root dry

weight (Fig.3.8 - 3.10; A.T. 3.9, 3.10, 3.12, 3.14, 3.22, 3.23).

The remaining part of this section will consider the various determinations attempted on the fourth leaf and its individual segments B, C and D, which emerged during the experimental period. In general, irradiation with C37 rather than AW light enhanced the length, width, area, fresh weight and dry weight of the fourth leaf (Fig.3.11; Table 3.25; A.T. 3.26 - 3.30). Although similar attributes were for the most part applicable to the topmost section B and the middle section C of the fourth leaf, a light quality effect on section C width was not established (Fig.3.11, 3.12; Table 3.25; A.T. 3.31 - 3.38). With the bottom section D, light quality had little influence on the length, fresh weight and dry weight, whereas width was enhanced by AW in preference to C37 light (Fig.3.11, 3.12; Table 3.25; A.T. 3.39 - 3.42).

Considering the plant growth regulators IAA and TIBA, the former substantially reduced all the parameters of the fourth leaf and its various sections, whereas the latter was generally ineffectual (Fig.3.11, 3.12; Table 3.25; A.T. 3.26 - 3.42). Exceptions were evident, since TIBA reduced the dry weight of the fourth leaf (Fig. 3.12; Table 3.30) and in regard to the leaf sections, enhanced the length and fresh weight of topmost section B, while decrementing the dry weight of mid-section C and length, fresh weight and dry weight of bottom section D (Fig. 3.11, 3.12; A.T. 3.31, 3.33, 3.38, 3.39, 3.41, 3.42). These findings suggest a gradual inhibition by TIBA which became more pronounced with the emergence of later fourth leaf sections.

Although most fourth leaf parameters increased with time as ratified by significant day items (Fig. 3.11, 3.12; A.T. 3.26 - 3.42), the individual sections showed only an increase in length, width, fresh weight and dry weight for 7 to 14 days after emergence before ceasing (Fig.3.11, 3.12).

Light quality x plant growth regulator interaction items were obtained for the fourth leaf length, area and fresh weight determinations and may reflect the ability of IAA to suppress the dissimilar responses incurred on the fourth leaf by the two different light qualities (Fig.3.11; A.T. 3.26, 3.28, 3.29).

Fig.3.11.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS GROSS MORPHOLOGICAL CHARACTERS OF THE FOURTH LEAF.

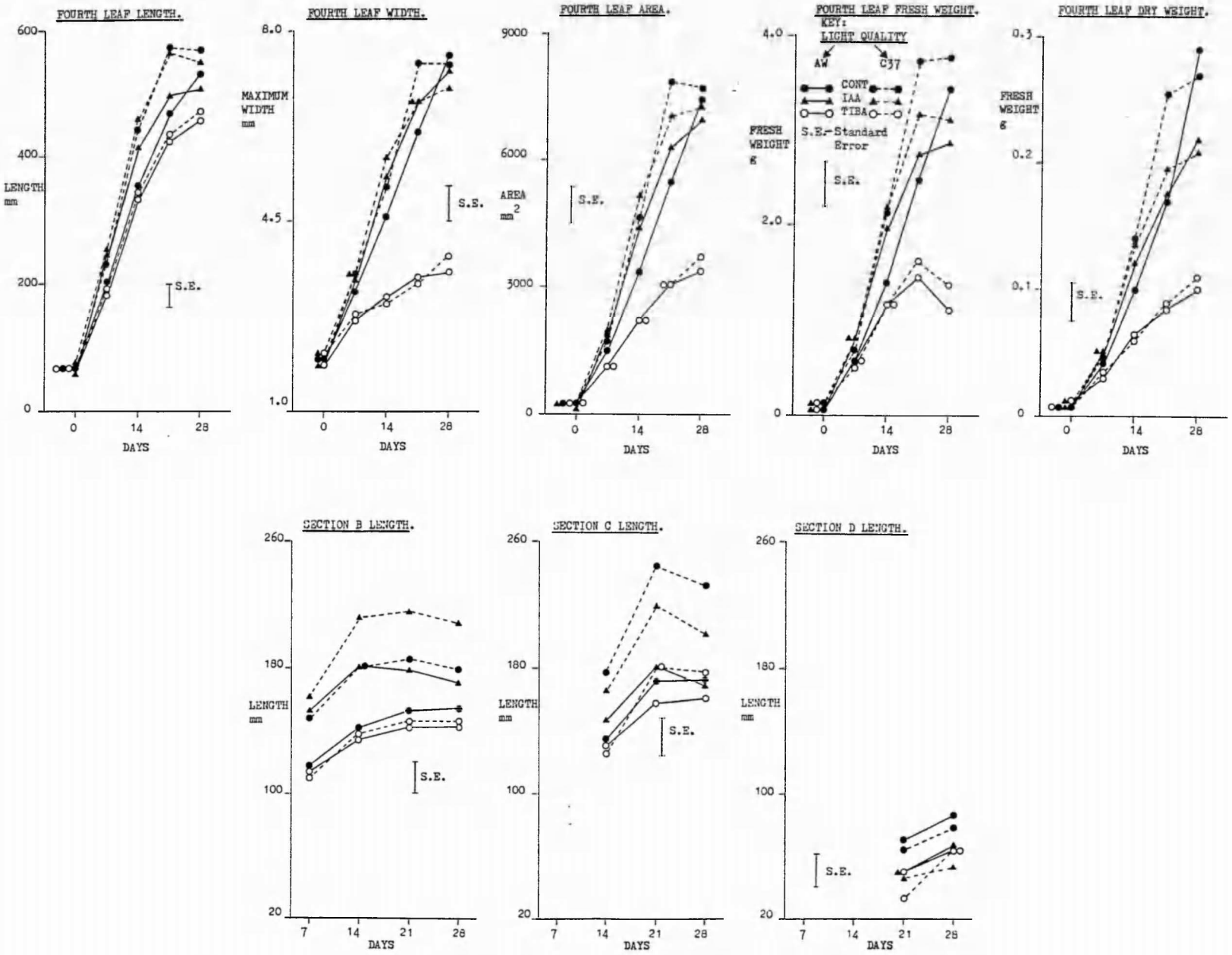


Fig. 3.12.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS GROSS MORPHOLOGICAL CHARACTERS OF THE FOURTH LEAF.

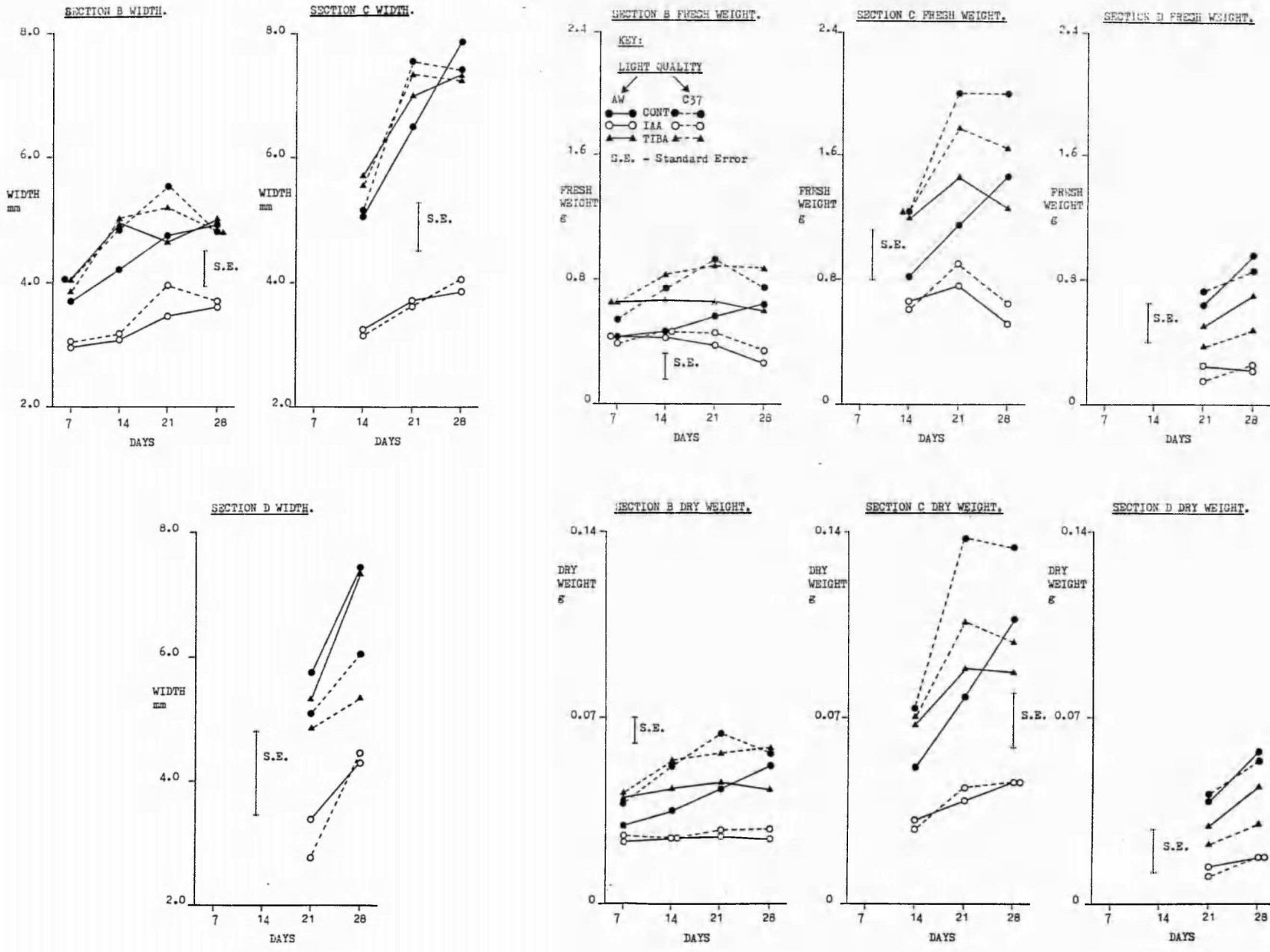


Table 3.25.

Summary of gross morphological effects incurred by light quality and plant growth regulators on the fourth leaf in Experiment A.

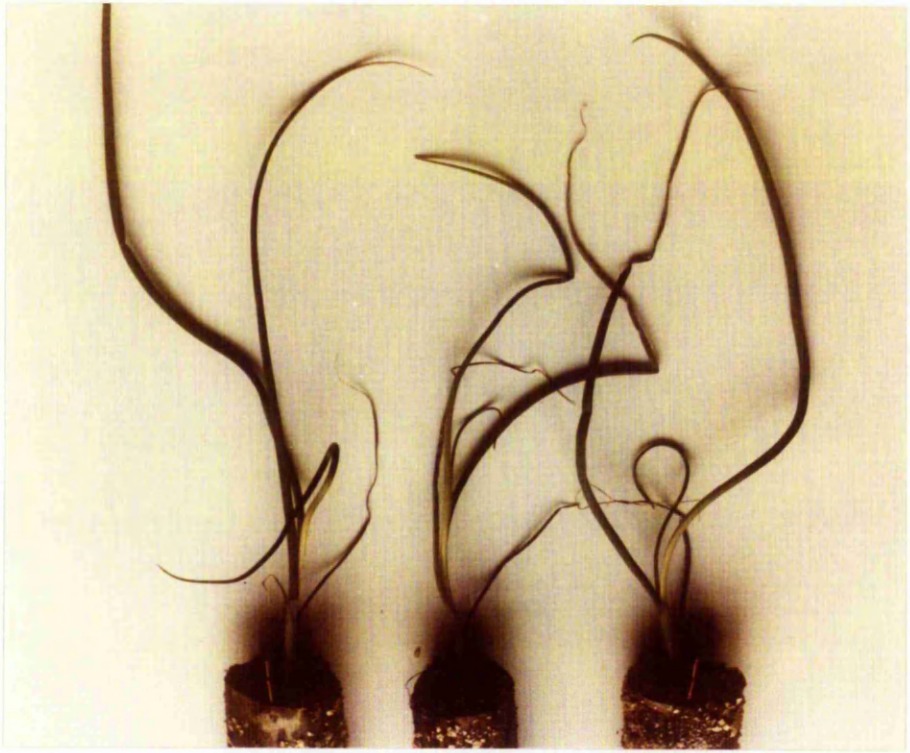
CHARACTER	TREATMENT			
	AW	C37	IAA	TIBA
Leaf length	↓	↑	↓	0
Leaf width	↓	↑	↓	0
Leaf area	↓	↑	↓	0
Leaf fresh weight	↓	↑	↓	0
Leaf dry weight	↓	↑	↓	↓
Leaf section B - length	↓	↑	↓	↑
- width	↓	↑	↓	0
- fresh weight	↓	↑	↓	↑
- dry weight	↓	↑	↓	0
Leaf section C - length	↓	↑	↓	0
- width	0	0	↓	0
- fresh weight	↓	↑	↓	0
- dry weight	↓	↑	↓	↓
Leaf section D - length	0	0	↓	↓
- width	↑	↓	↓	0
- fresh weight	0	0	↓	↓
- dry weight	0	0	↓	↓

Key: ↑ - increased; ↓ - decreased; 0 - no change;
AW - AW light; C37 - C37 light.

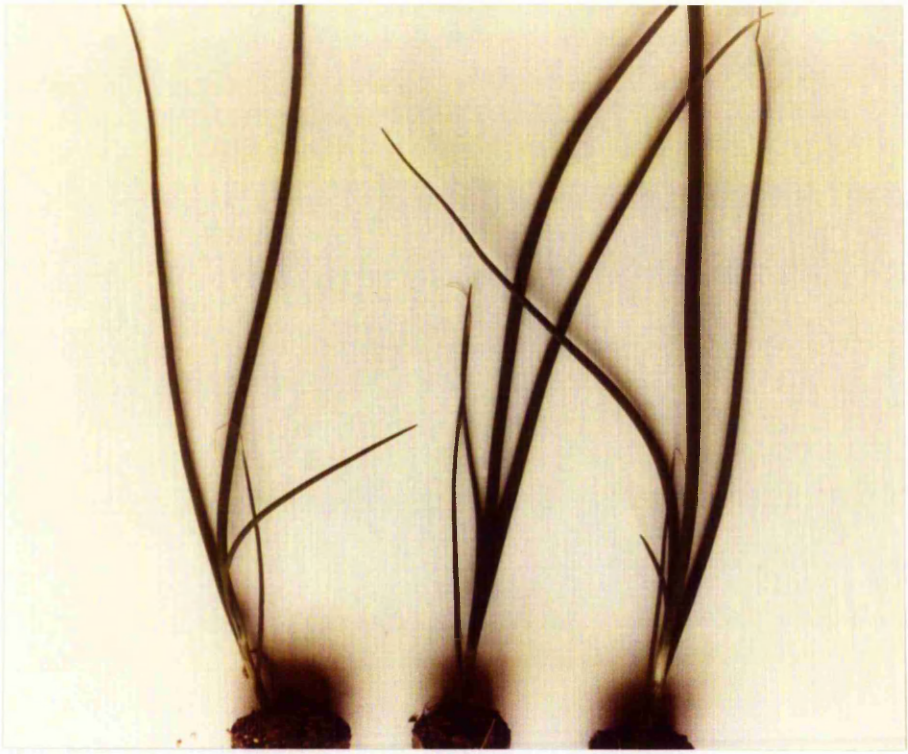
Similar explanations were also applicable for the length, fresh weight and dry weight parameters of fourth leaf sections B and C, whereas section D was unresponsive (Fig.3.11, 3.12; A.T. 3.31, 3.33 - 3.35, 3.37 - 3.42). However the absence of significant light quality x plant growth regulator interaction items for the width determinations may imply that these treatments acted independently on this character, while in the case of section D, only the plant growth regulators exerted an influence (Fig.3.11, 3.12; A.T. 3.27, 3.32, 3.36, 3.40). The presence of significant light quality x day interaction items tend to substantiate the observation that C37 rather than AW light led to a faster increase in the length, area, fresh weight and dry weight, but not width of the fourth leaf (Fig.3.11; A.T. 3.26 - 3.30). Similar findings were only perceived in the various sections for the width and length determinations of fourth leaf sections B and C respectively (A.T. 3.31, 3.35). In contrast the inhibition exacted by IAA with time on the multifarious fourth leaf characters were for the most part verified by significant plant growth regulator x day interaction items (A.T. 3.26 - 3.30, 3.33, 3.34, 3.36 - 3.38). Some exceptions were evident, as evinced for length and width of section B, section C length and all parameters of section D (A.T. 3.31, 3.32, 3.35, 3.39 - 3.42). This may infer that the influence exerted by IAA on leaf tissue development was manifested prior to the emergence of a particular fourth leaf section. A similar argument may also apply to some of the responses engendered by TIBA and the light qualities.

Aside from the various quantitative measurements considered, certain visual differences were also evident. Thus IAA produced severe epinasty (Plate 3.1), succulence, brittleness and pale green colouration in the developing fourth leaf. A similar but less pronounced pale green colouration was only evident from the leaves of TIBA treated plants. Although no wax determinations were attempted, the shiny surface accredited to the IAA treated fourth leaf suggests possible changes in the wax deposits on the cuticle. With TIBA treated plants, the number of adventitious roots emanating from the basal plate seemed greater than with the control or IAA treated plants. With plants receiving IAA, the

Plate 3.1.



Marked epinasty and paling of the fourth leaf coupled with senescence in the older leaves were produced in response to treatment by IAA.



Two outer plants received treatment with TIBA, whilst the central plant represents the control treatment. A lack of leaf malformations and a slight paling of the leaves characterizes the TIBA response.

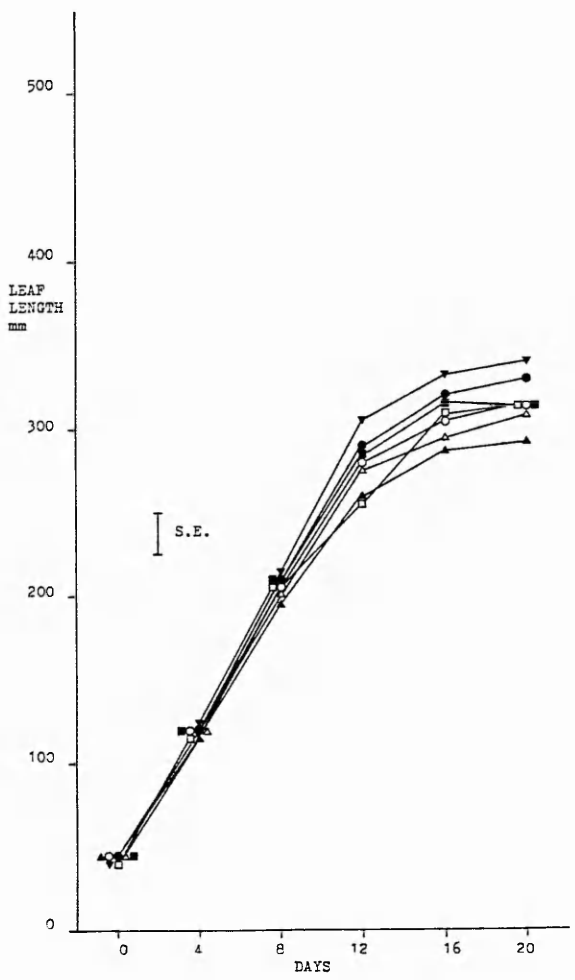
amount of root matter was always noticeably less than the control plants. Finally, the increased senescence following IAA treatment was due to rapid yellowing of the older first and second leaves, and could imply a greater sensitivity in the form of toxicity symptoms on the older leaves in response to frequent IAA applications (Plate 3.1).

3.3.1.2. Experiment B

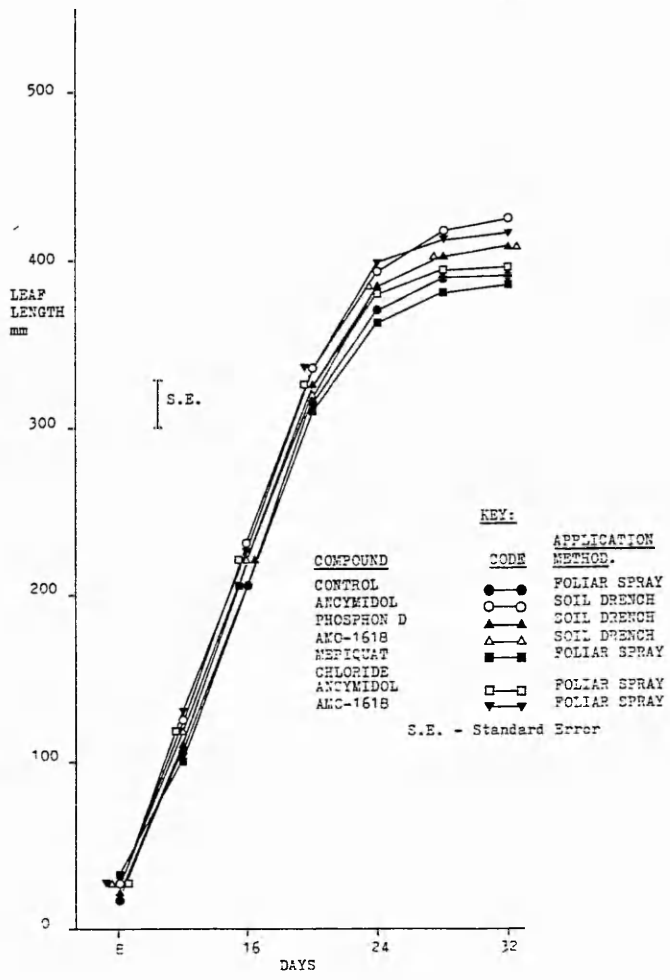
Of the various plant growth regulators examined, only a few significantly influenced the elongation and expansion in width of the leaves and regulated leaf sheath length (Fig.3.13 - 3.17; Table 3.43; A.T. 3.44 - 3.70). Thus soil drenches of paclobutrazol produced a small reduction in the second and third leaf length, while severely decreasing this parameter in the fourth leaf (Fig. 3.14; A.T. 3.46, 3.55, 3.64). In contrast, the response manifested by $GA_{4/7}$ was slow and transient, since a marked moderation in leaf elongation was only observed with the third leaf, whereas the fourth leaf was unaffected (Fig.3.14; A.T. 3.46, 3.55, 3.64). The expansion in leaf width was enhanced following soil drench treatments with paclobutrazol, phosphon D and AMO-1618, while the converse applied to foliar spray administrations of $GA_{4/7}$ and GA_3 (Fig. 3.15, 3.16; A.T. 3.49, 3.58, 3.67). Furthermore it must be stressed that the symptoms were only manifested during the growth of the later third and fourth leaves and in the case of GA_3, only tentatively with the fourth leaf. Plant growth retardants paclobutrazol, phosphon D and AMO-1618 evoked a strong inhibition of the second, third and fourth leaf sheaths (Fig.3.17; A.T. 3.52, 3.61, 3.70). On the other hand, $GA_{4/7}$ stimulated leaf sheath elongation of the second leaf and although the mean length of the third and fourth leaf sheaths of plants receiving $GA_{4/7}$ were greater than the control plants, statistical significance was not achieved (Fig. 3.17; A.T. 3.52, 3.61, 3.70).

Significance was also obtained for the effects of a number of other plant growth regulator treatments, though their importance appears questionable. Thus although soil drenching with ancymidol and foliar spraying with CCC and AMO-1618 led to a small but significant change in leaf length, the non-significant plant

SECOND LEAF.



THIRD LEAF.



KEY:

COMPOUND	CODE	APPLICATION METHOD.
CONTROL	●—●	FOLIAR SPRAY
ANCYMIDOL	○—○	SOIL DRENCH
PHOSPHON D	▲—▲	SOIL DRENCH
AMO-1618	△—△	SOIL DRENCH
MEPIQUAT CHLORIDE	■—■	FOLIAR SPRAY
ANCYMIDOL	□—□	FOLIAR SPRAY
AMO-1618	▼—▼	FOLIAR SPRAY

S.E. - Standard Error

FOURTH LEAF.

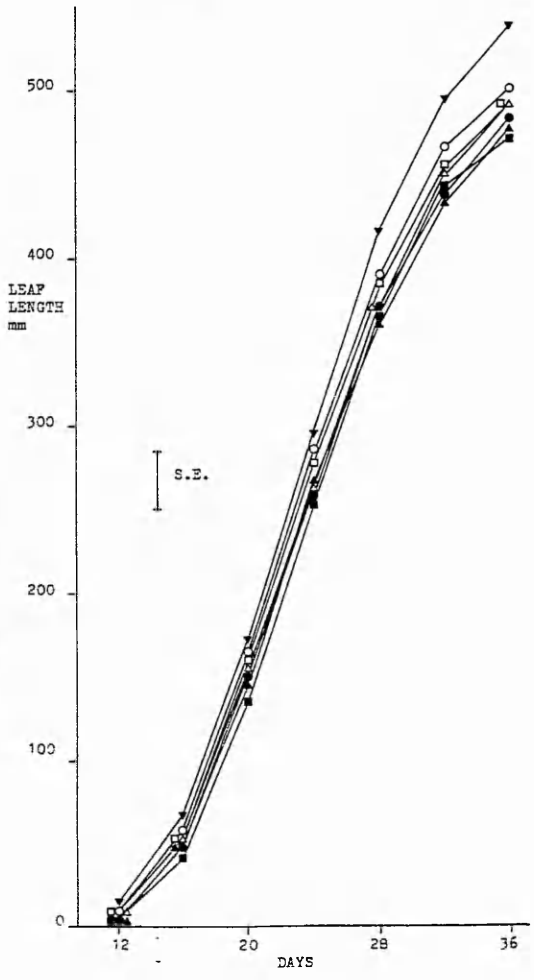


Fig. 3.14.

UNIT 2 - EFFECT OF PLANT GROWTH REGULATORS ON LEAF LENGTH.

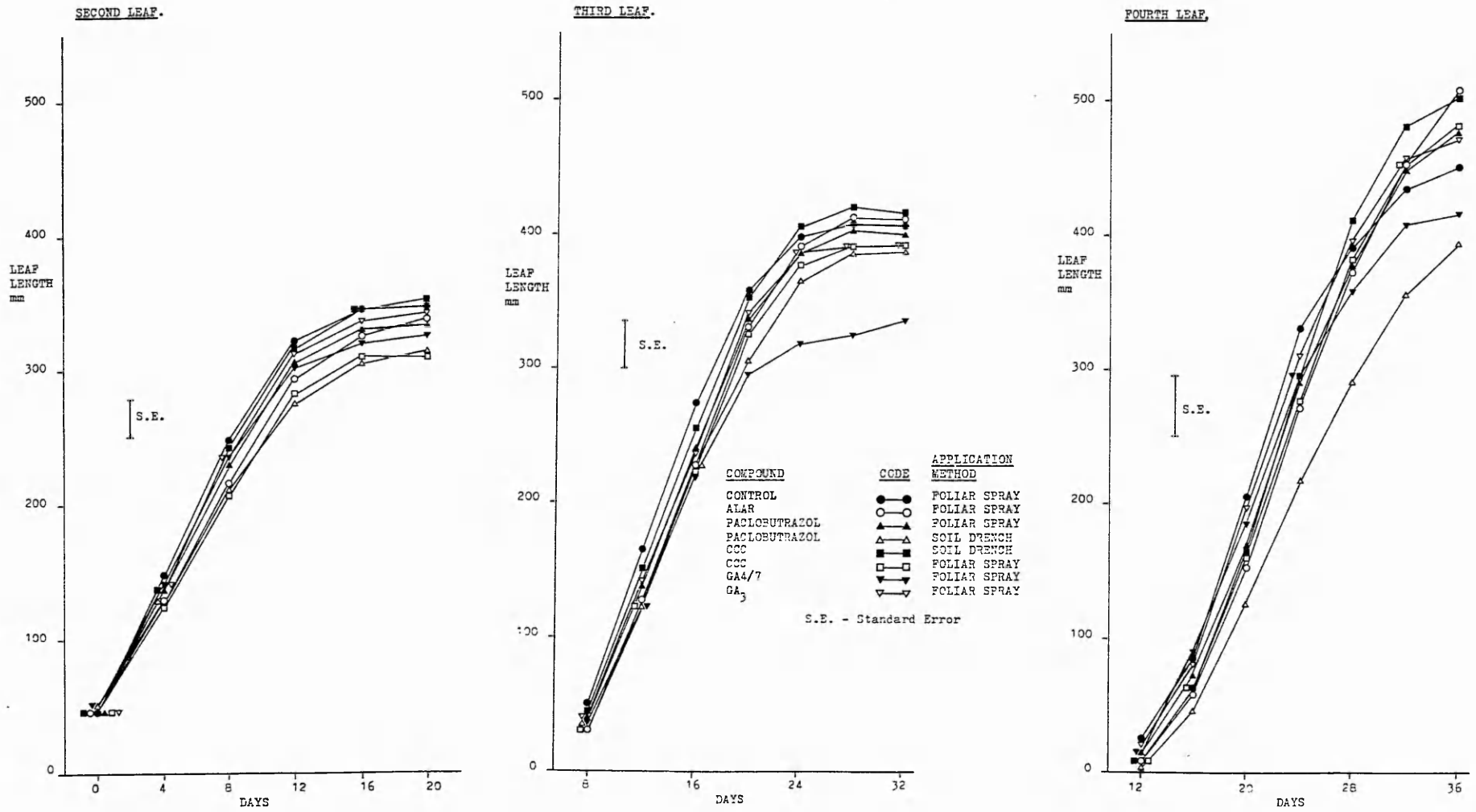


Fig. 3.15.

UNIT 1 - EFFECT OF PLANT GROWTH REGULATORS ON MAXIMUM LEAF WIDTH.

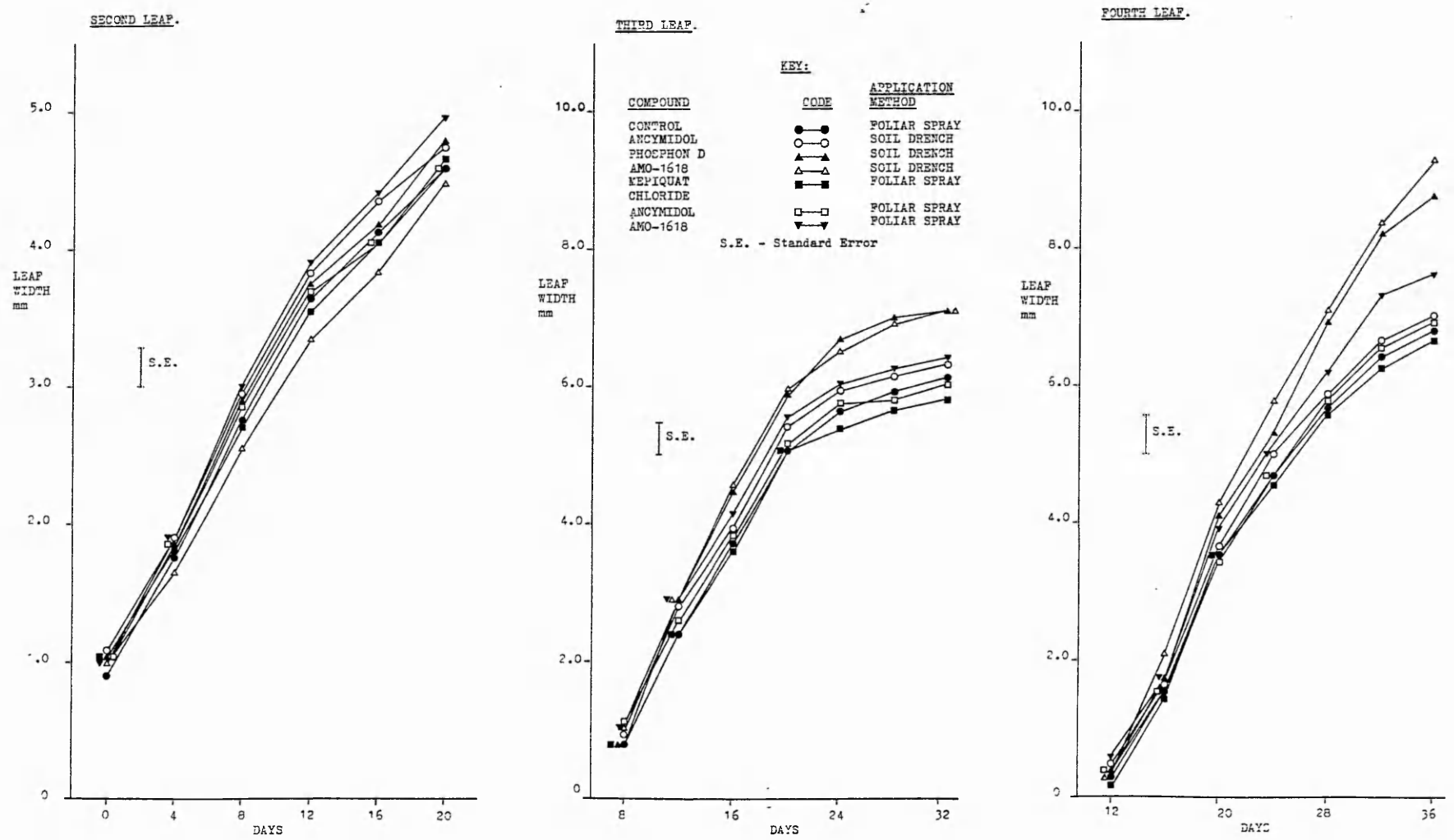


Fig. 3.16.

UNIT 2 - EFFECT OF PLANT GROWTH REGULATORS ON MAXIMUM LEAF WIDTH.

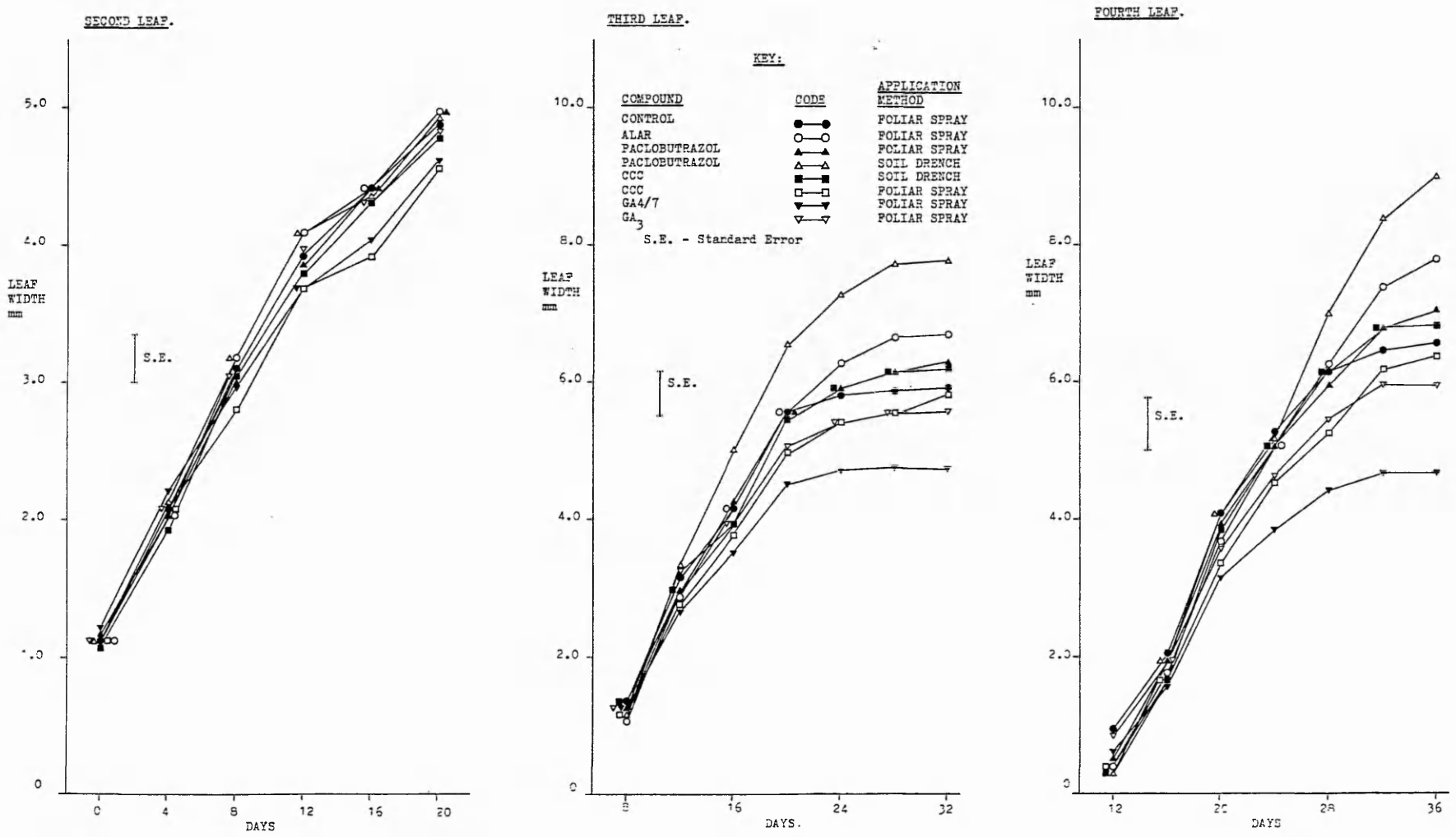


Fig. 3.17.

EFFECT OF VARIOUS PLANT GROWTH REGULATORS ON LEAF SHEATH LENGTH.

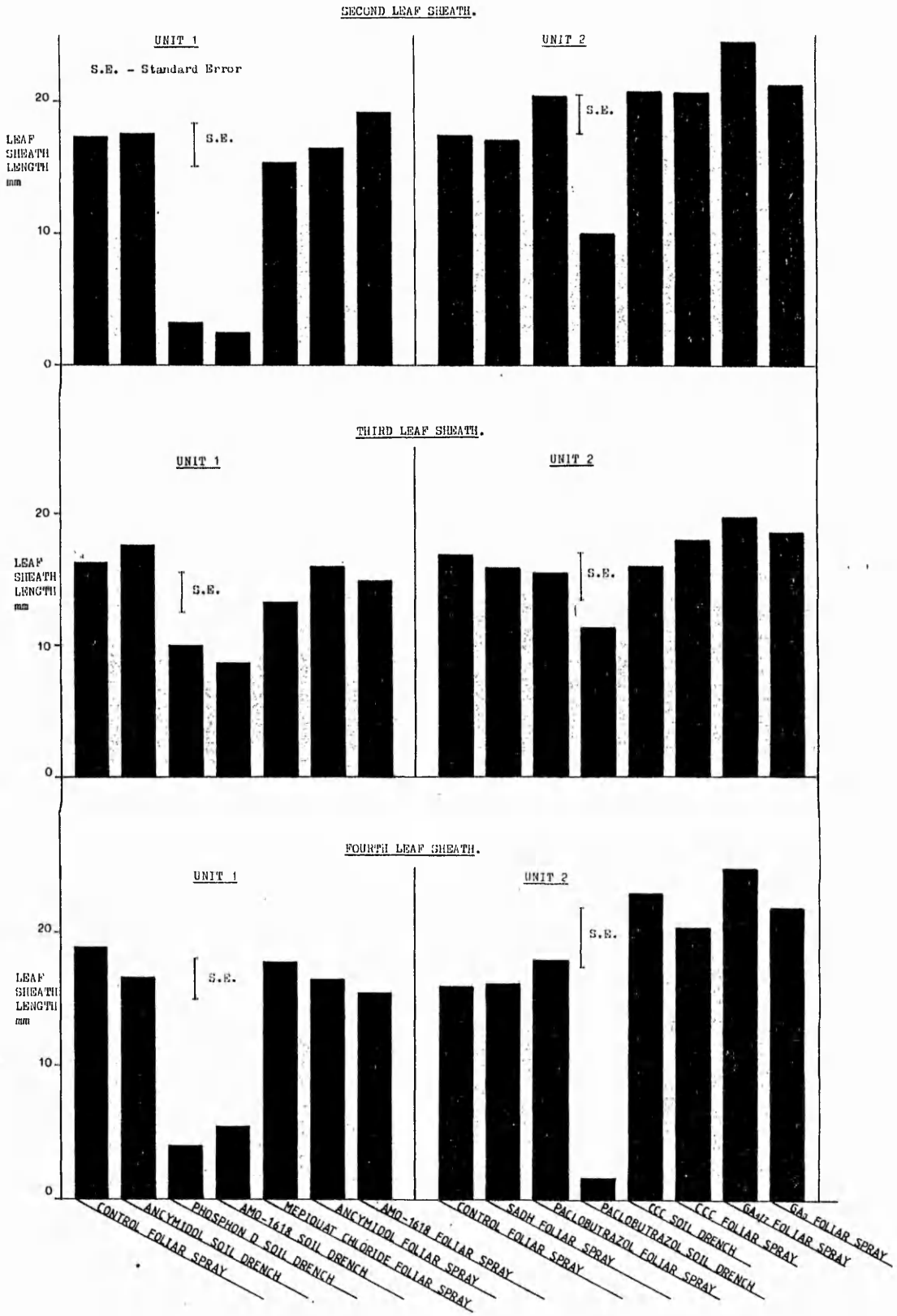


Table 3.43.

Summary of gross morphological effects incurred by plant growth regulators in Experiment B.

TREATMENT	METHOD OF APPLI-CATION	CHARACTER								
		SECOND LEAF			THIRD LEAF			FOURTH LEAF		
		LEAF LENGTH	LEAF WIDTH	LEAF SHEATH LENGTH	LEAF LENGTH	LEAF WIDTH	LEAF SHEATH LENGTH	LEAF LENGTH	LEAF WIDTH	LEAF SHEATH LENGTH
UNIT 1										
Ancymidol	SD	0	0	0	↑	↑	0	0	0	0
Phosphon D	SD	↓	0	↓	0	↑	↓	0	↑	↓
AMO-1618	SD	0	0	↓	0	↑	↓	0	↑	↓
Mepiquat chloride	FS	0	0	0	0	0	0	0	0	0
Ancymidol	FS	0	0	0	0	0	0	0	0	0
AMO-1618	FS	0	↑	0	↑	↑	0	↑	↑	0
UNIT 2										
SADH	FS	0	0	0	0	0	0	0	0	0
Paclobutrazol	FS	0	0	0	0	0	0	0	0	0
Paclobutrazol	SD	↓	0	↓	↓	↑	↓	↓	↑	↓
CCC	SD	0	0	0	0	0	0	0	0	0
CCC	FS	↓	↑	0	↓	0	0	0	↓	0
$GA_{4/7}$	FS	0	0	↑	↓	↓	0	0	↓	0
GA_3	FS	0	0	0	0	0	0	0	↓	0

Key: ↑ - increased
↓ - decreased
0 - no change
SD - soil drench
FS - foliar spray

growth regulator x time interaction item suggests due caution (Fig.3.13, 3.14; A.T. 3.45, 3.46, 3.53, 3.55, 3.62, 3.64). Justification for this cautionary note relies on the fact that the treatments were initiated on plants known to have similar leaf widths and lengths and any control excercised by these plant growth regulators should be ratified by a digression in the graphed trends for the treatments in question. A similar explanation may also tentatively apply to significant increases in second leaf width incurred by foliar sprays of AMO-1618 (Fig.3.15; A.T. 3.47, 3.49). However a comparable increase for the third leaf width followed by a substantial incrementation in the fourth leaf width may imply that AMO-1618 applied via the leaf surface requires a longer time interval before becoming visibly effective (Fig.3.15; A.T. 3.56, 3.58, 3.65, 3.67). Significant changes in leaf width and length were also observed following soil drench treatments with ancymidol, phosphon D and foliar sprays of CCC (A.T. 3.46, 3.49, 3.58, 3.67). However the merits of these cases are debateble owing to the small change effectuated and their transient nature.

Aside from the various quantitative measurements, soil drenching especially with paclobutrazol and to a lesser extent phosphon D and AMO-1618 were observed to increase the rate of senescence in the older leaves. The outcome of this phenomenon was a visual reduction in green leaf tissue quantity.

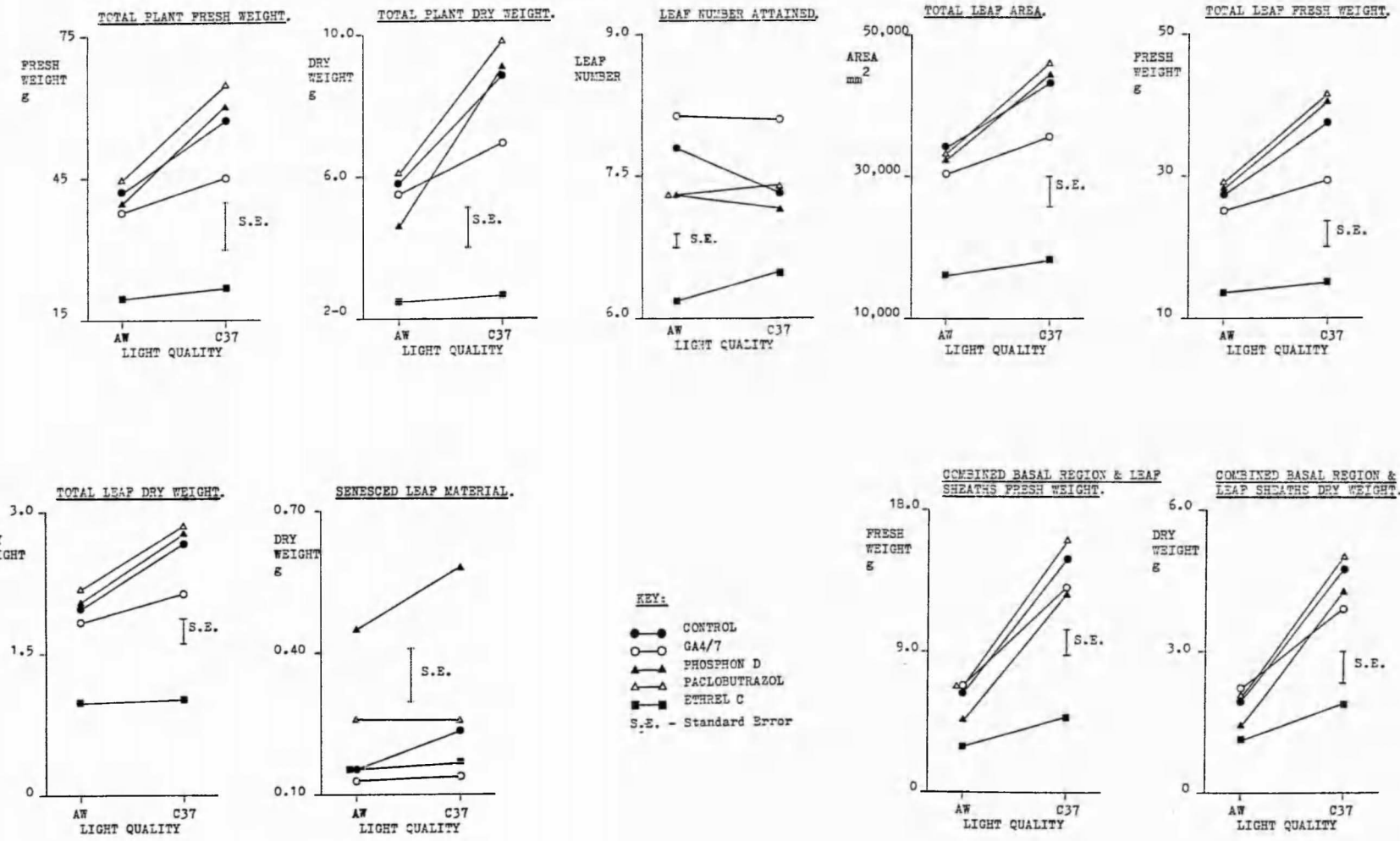
3.3.1.3. Experiment C

Predominantly C37 light mediated a faster increase in the various gross morphological characters than AW light (Fig.3.18, 3.19; Table 3.71; A.T. 3.72, 3.73, 3.75 - 3.80, 3.83 - 3.88, 3.90, 3.94; Plate 3.2). Exceptions were evident, since AW in preference to C37 light incremented the root fresh weight, DWR and SWC, leaf DWR and LAR (Fig. 3.19, 3.20; A.T. 3.81, 3.89, 3.91, 3.92, 3.96) while neither light quality regulated leaf number, root dry weight, SLA and combined basal region & leaf sheaths SWC (Fig. 3.18 - 3.20; A.T. 3.74, 3.82, 3.93, 3.95).

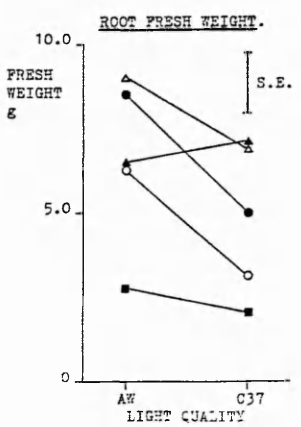
In regard to the plant growth regulators, ethrel C and to a lesser extent $GA_{4/7}$ for the most part suppressed onion plant development (Fig. 3.20 - 3.22; Table 3.71, A.T. 3.72 - 3.77, 3.79 - 3.84, 3.86

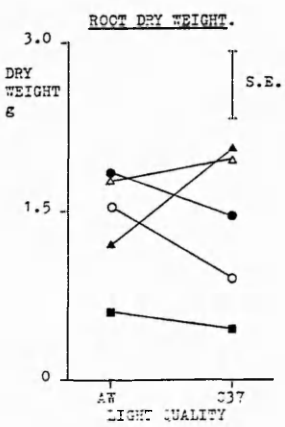
Fig. 3.18.

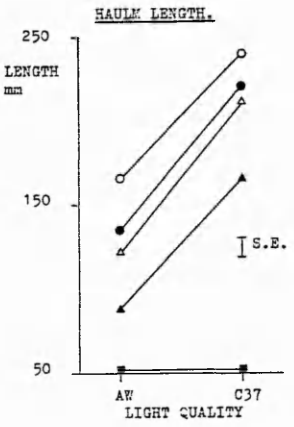
EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS MORPHOLOGICAL CHARACTERS.

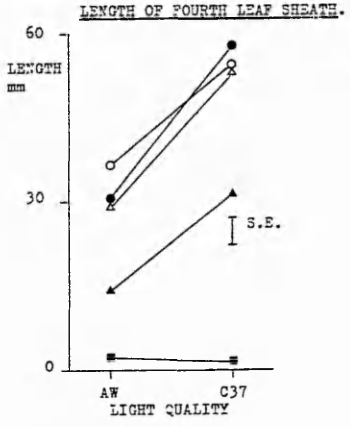


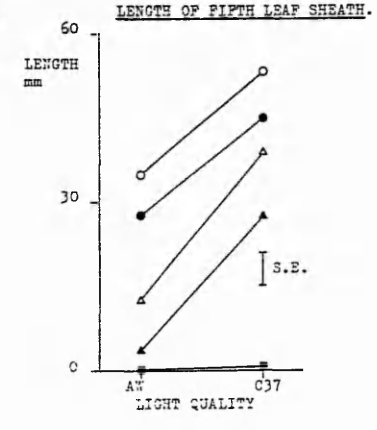
EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS GROSS MORPHOLOGICAL CHARACTERS.

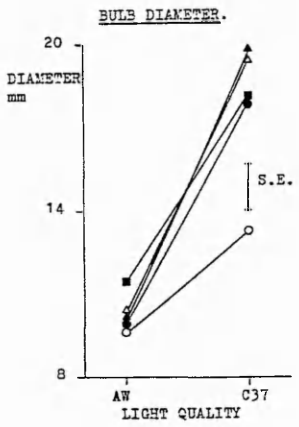


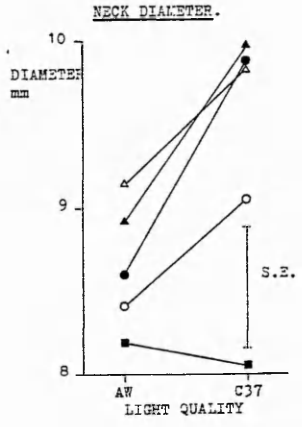


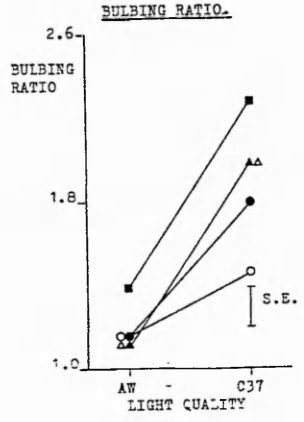












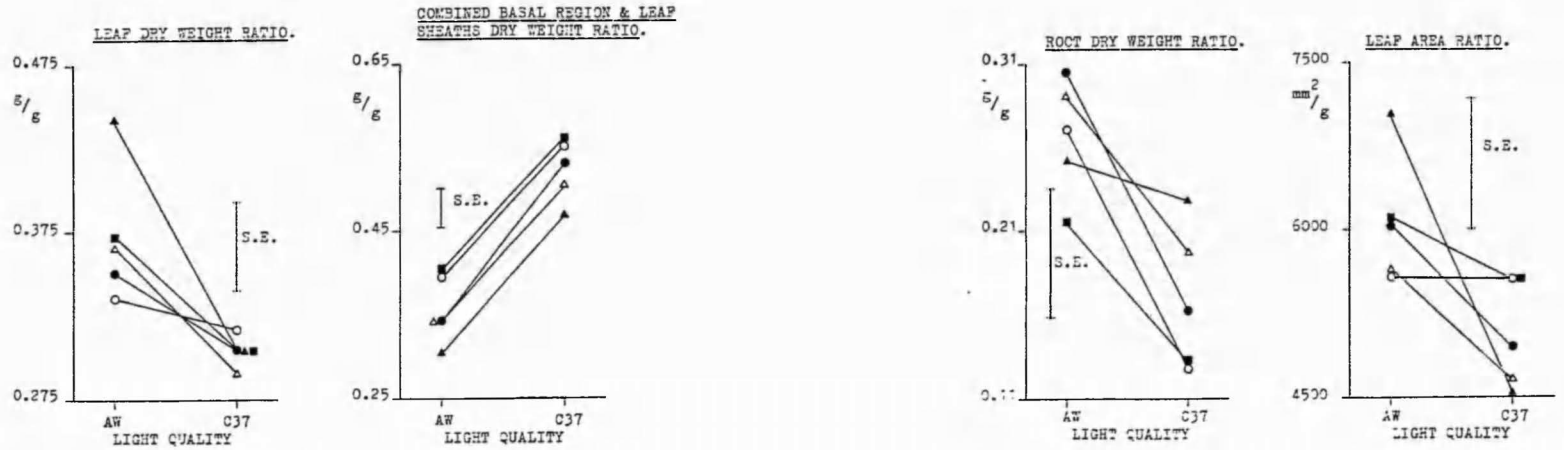
KEY:

- CONTROL
- GA4/7
- PHOSPON D
- PACLOBUTRAZOL
- ETHREL C

S.E. - Standard Error

Fig.3.20.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS GROSS MORPHOLOGICAL CHARACTERS.



KEY: CONTROL ●—●, $GA_{4/7}$ ○—○, PHOSPHON D ▲—▲, PACLOBUTRAZOL △—△, ETHREL C ■—■,

S.E. - Standard Error

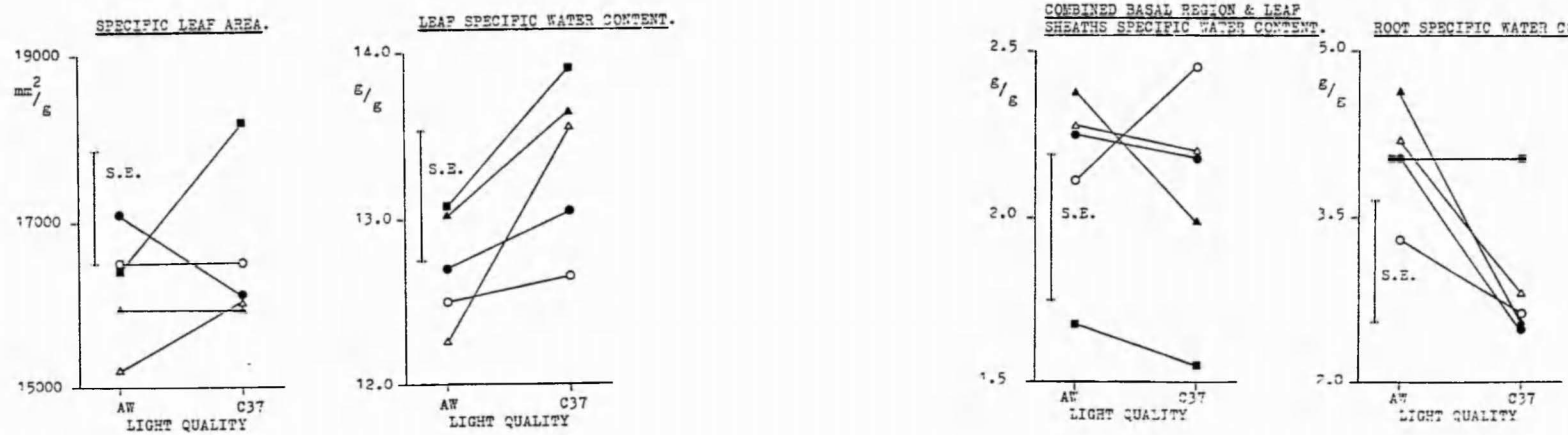


Table 3.71.

Summary of gross morphological effects incurred by light quality and plant growth regulators in Experiment C.

CHARACTER	TREATMENT					
	AW LIGHT	C37 LIGHT	$GA_{4/7}$	PD	PP333	ETH
Plant fresh weight	↓	↑	↓	0	0	↓
Plant dry weight	↓	↑	0	0	0	↓
Leaf number	0	0	↑	↓	0	↓
Total leaf area	↓	↑	↓	0	0	↓
Total leaf fresh weight	↓	↑	↓	0	0	↓
Total leaf dry weight	↓	↑	↓	0	0	↓
Senesced leaf material dry weight	↓	↑	0	↑	0	0
Combined basal region & leaf sheaths fresh weight	↓	↑	↓	↓	0	↓
Combined basal region & leaf sheaths dry weight	↓	↑	0	0	0	↓
Root fresh weight	↑	↓	↓	0	0	↓
Root dry weight	0	0	0	0	0	↓
Bulb diameter	↓	↑	↓	0	0	0
Neck diameter	↓	↑	0	0	0	↓
Bulbing ratio	↓	↑	0	0	0	↑
Haulm length	↓	↑	↑	↓	0	↓
Fourth leaf sheath length	↓	↑	0	↓	0	↓
Fifth leaf sheath length	↓	↑	↑	↓	↓	↓
Leaf DWR	↑	↓	0	0	0	0
Combined basal region & leaf sheaths DWR	↓	↑	0	↓	0	↑
Root DWR	↑	↓	0	0	0	0
LAR	↑	↓	0	0	0	0
SLA	0	0	0	0	0	0
Leaf SWC	↓	↑	0	0	0	0
Combined basal region & leaf sheaths SWC	0	0	0	0	0	↓
Root SWC	↑	↓	0	0	0	↑

Key: ↑ - increased; ↓ - decreased; 0 - no change; PD - phosphon D; PP333 - paclobutrazol; ETH - ethrel C.

- 3.88, 3.95; Plate 3.2, 3.4). Nevertheless $GA_{4/7}$ produced negligible changes in the dry weight of the total plant, root and combined basal region & leaf sheaths, quantity of senesced leaf material, neck diameter, bulbing ratio, fourth leaf sheath length, the various DWR and SWC, LAR and SLA, whereas ethrel C was unaffective on the quantity of senesced leaf material, bulb diameter, leaf and root DWR, LAR, SLA and the SWC of the leaves and roots (Fig. 3.18 - 3.20; Table 3.71; A.T. 3.73, 3.78, 3.80, 3.82 - 3.85, 3.87, 3.89 - 3.96). However $GA_{4/7}$ was observed to promote leaf number, haulm length and the length of the fifth leaf sheath (Fig. 3.18, 3.19; A.T. 3.74, 3.86, 3.88). In addition the fact that ethrel C reduced the neck diameter, but had a negligible effect on bulb diameter suggests that the enlarged bulbing ratio, attributable to ethrel C, was due to a diminution in the neck diameter (Fig. 319; A.T. 3.83 - 3.85). Morphological alterations were generally not manifested by paclobutrazol and only in a few instances by phosphon D. Considering the latter retardant, this reduced the leaf number, combined basal region & leaf sheath fresh weight and DWR, haulm length and length of the fourth and fifth leaf sheaths, while increasing the quantity of senesced leaf material (Fig. 3.18 - 3.20; Table 3.71; A.T. 3.74, 3.78, 3.79, 3.86 - 3.88, 3.90).

Significant light quality x plant growth regulator interactions were obtained and in general reflect the ability of ethrel C and to a lesser extent $GA_{4/7}$ to reduce the disparity produced by C37 over AW light on specific gross morphological characters. Thus this particular feature was evoked by ethrel C and $GA_{4/7}$ on the fresh and dry weight of the total plant and leaf and leaf area (Fig. 3.18; A.T. 3.72, 3.73, 3.75 - 3.77), while bulb diameter and the bulbing ratio were affected by $GA_{4/7}$ alone and combined basal region & leaf sheath fresh and dry weight, haulm length, fourth and fifth leaf sheath lengths by ethrel C specificially (Fig. 3.18, 3. 19; A.T. 3.79, 3.80, 3.83, 3.85 - 3.88). Exceptions were also observed, since ethrel C augmented the root SWC for plants irradiated with C37 light to the level attained under AW light (Fig. 3.20; A.T. 3.96). In a similar vein phosphon D reduced the root fresh and dry weight under AW light, whilst the converse symptoms pertained under C37 light (Fig.3.19; A.T. 3.81, 3.82).

Instances of plant growth regulators and light quality acting independently were established for phosphon D, which increased the amount of senesced leaf material and decreased the combined basal region & leaf sheath fresh weight and DWR, haulm length and length of the fourth and fifth leaf sheaths irrespective of the light quality used to irradiate the plants (Fig. 3.18 - 3.20; A.T. 3.78, 3.79, 3.86 - 3.88, 3.90). Similar attributes were observed for the diminution in root fresh weight and incrementation in haulm length and length of the fifth leaf sheath by $GA_{4/7}$ (Fig. 3.19; A.T. 3.81, 3.86, 3.88) and the enhanced bulbing ratio evoked by ethrel C (Fig. 3.19; A.T. 3.85).

The following section will be concerned primarily with the gross morphological determinations attempted on the fifth leaf. Thus length, width, area, fresh weight and dry weight of the fifth leaf werepreferentially enhanced by C37 rather than AW light (Fig. 3.21, 3.22; Table 3.97; A.T. 3.98 - 3.102). Furthermore these same characters were enhanced by phosphon D and reduced by $GA_{4/7}$ and ethrel C (Fig. 3.21, 3.22; Table 3.97; A.T. 3.98 - 3.102; Plate 3.2 - 3.4). The only exception was leaf length, which was enlarged by phosphon D under C37 light (Fig. 3.22; A.T. 3.101). In contrast soil drenching with paclobutrazol was for the most part unresponsive, barring leaf fresh weight, which was perceptibly augmented (Fig. 3.21; A.T. 3.99).

The presence of significant light quality x plant growth regulator interactions ratify the ability of ethrel C and $GA_{4/7}$ to negate the increase expected for leaf area, fresh weight, dry weight and length under C37 rather than AW light (Fig. 3.21, 3.22; A.T. 3.98 - 3.101). In addition, the same interaction also substantiates the further incrementation in leaf area and length engendered by phosphon D on plants receiving C37 in preference to AW light (Fig. 3.21, 3.22; A.T. 3.98, 3.101). On the other hand, non-significant light quality x plant growth regulator interactions for leaf width implies that the diminutions produced by $GA_{4/7}$ and ethrel C and the promotion by phosphon D were independent of the light quality effect (Fig. 3.22; A.T. 3.102).

Fig.3.21.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON GROSS MORPHOLOGICAL CHARACTERS OF THE FIFTH LEAF.

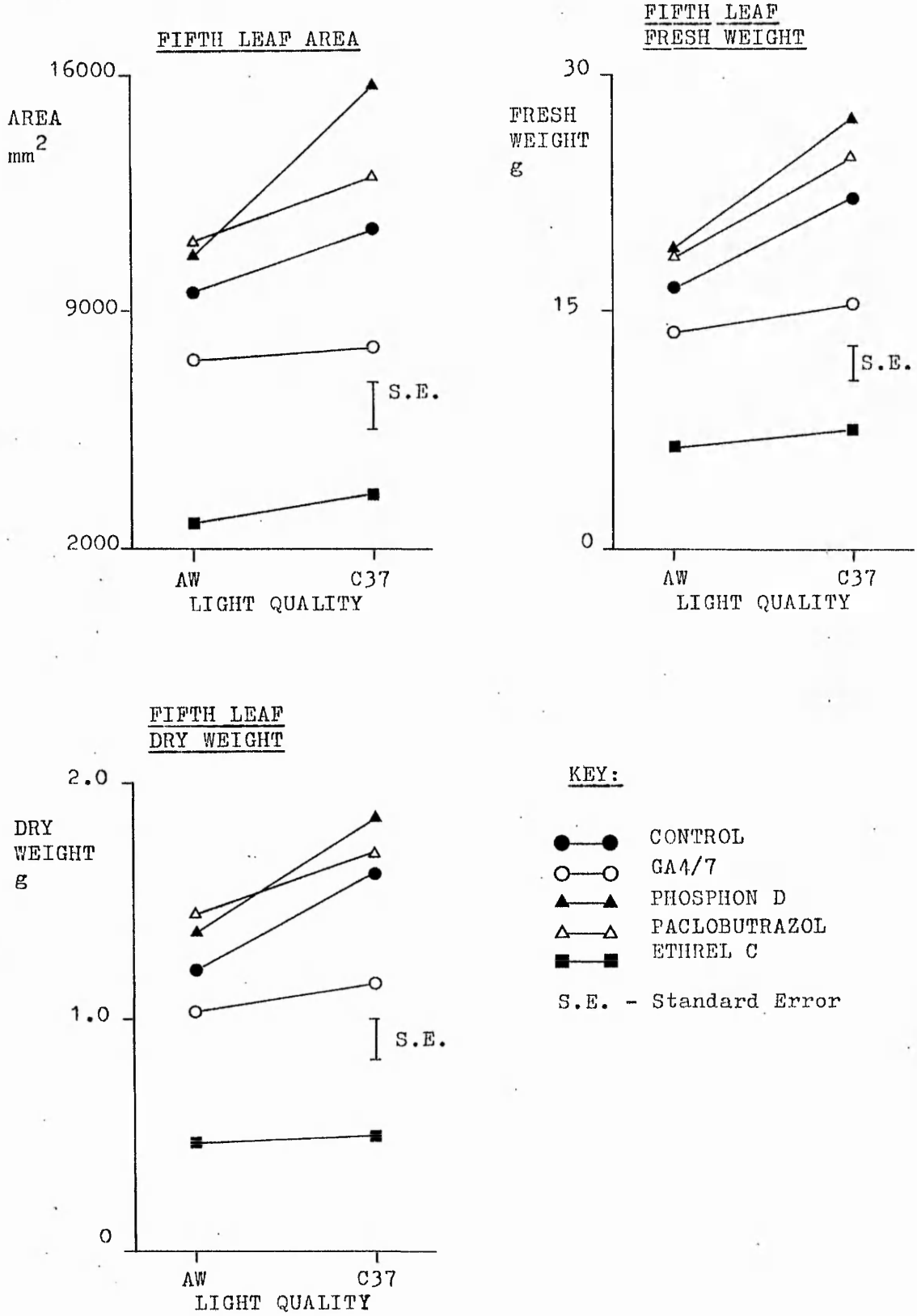


Fig. 3.22.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON GROSS MORPHOLOGICAL CHARACTERS OF THE FIFTH LEAF.

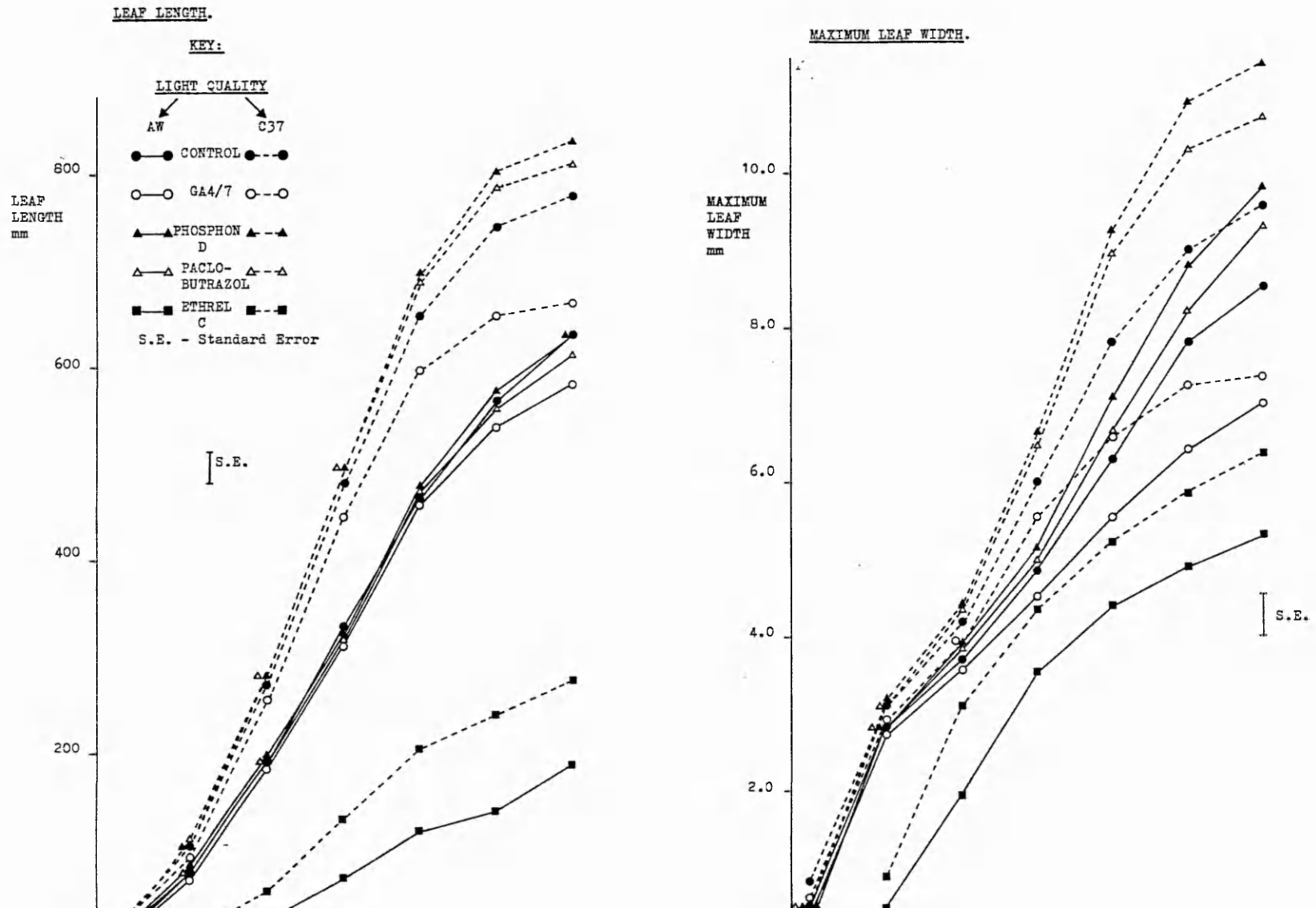


Table 3.97.

Summary of gross morphological effects incurred by light quality and plant growth regulators on the fifth leaf in Experiment C.

CHARACTER	TREATMENT					
	AW LIGHT	C37 LIGHT	$GA_{4/7}$	PD	PP333	ETH
Fifth leaf area	↓	↑	↓	↑	0	↓
Fifth leaf fresh weight	↓	↑	↓	↑	↑	↓
Fifth leaf dry weight	↓	↑	↓	↑	0	↓
Fifth leaf length	↓	↑	↓	0	0	↓
Fifth leaf width	↓	↑	↓	↑	0	↓

Key: ↑ - increased

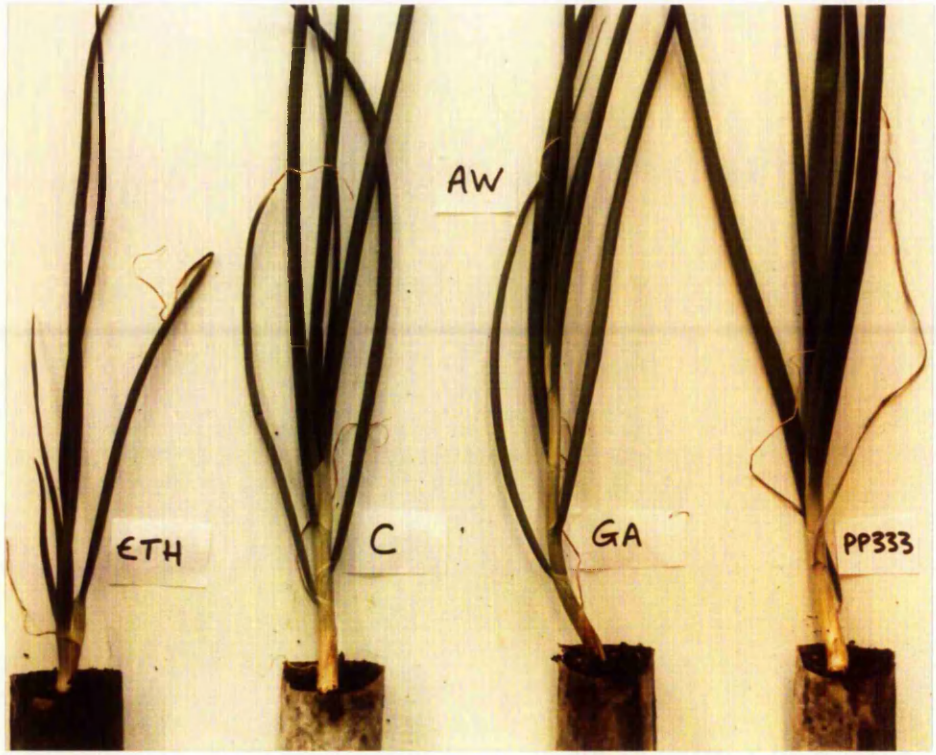
↓ - decreased

0 - no change

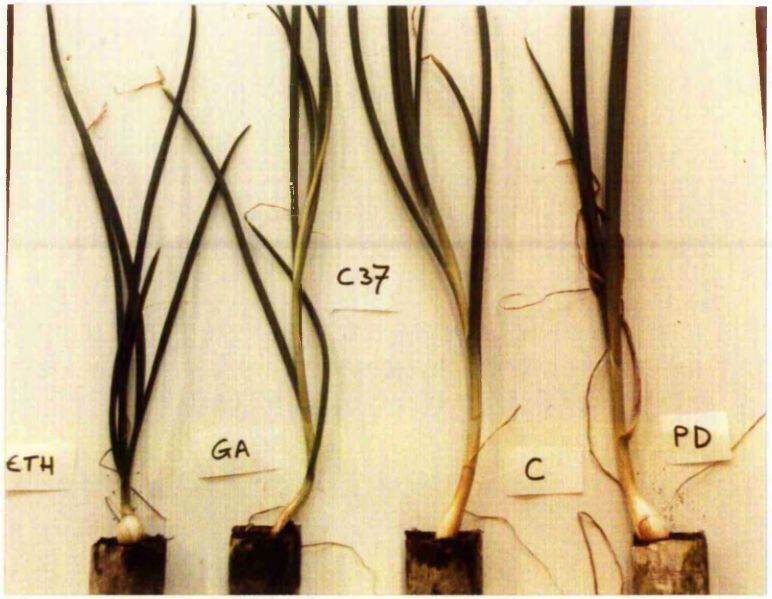
PD - phosphon D

PP333 - paclobutrazol

ETH - ethrel C

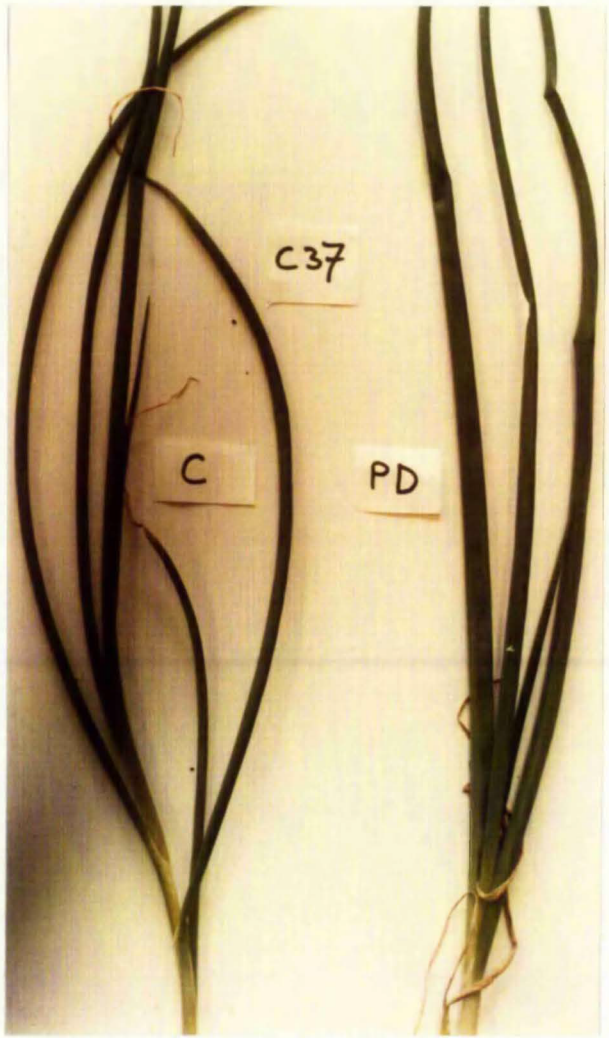


Effect of various plant growth regulators in combination with AW light quality on vegetative development. Comparisons with the control treatment (C) showed that ethrel C (ETH) reduced the haulm length, whereas the contrary pertained with $GA_{4/7}$ (GA). Furthermore paclobutrazol (PP333) yielded wider leaves in some instances, whilst ethrel C promoted exiguous bulb swelling under AW light quality.



Effect of various plant growth regulators in combination with C37 light quality on vegetative development. Comparisons with the control treatment (C) revealed ethrel C (ETH) and phosphon D (PD) reduced haulm length whereas the converse applied to $GA_{4/7}$ (GA). Furthermore, phosphon D incurred greater senescence in older leaves and augmented leaf width, while bulbing was depressed by $GA_{4/7}$.

Plate 3.3.



Both plates exemplify the ability of the plant growth retardants phosphon D (PD) and paclobutrazol (PP333) to produce a wider leaf in respect to the control plants (C). Furthermore the response was independent of whether AW or C37 light quality was used to irradiate the plants.

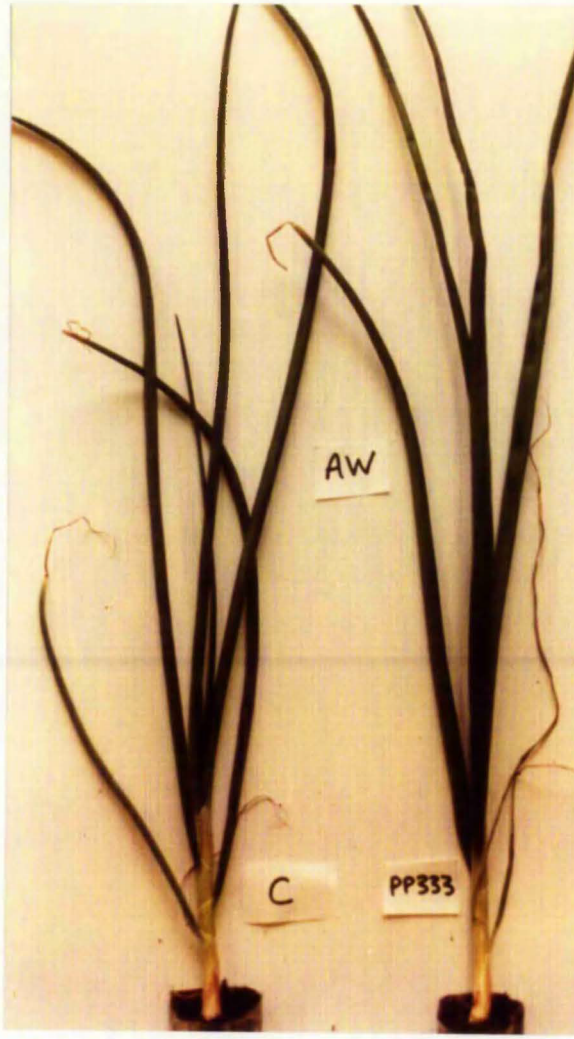
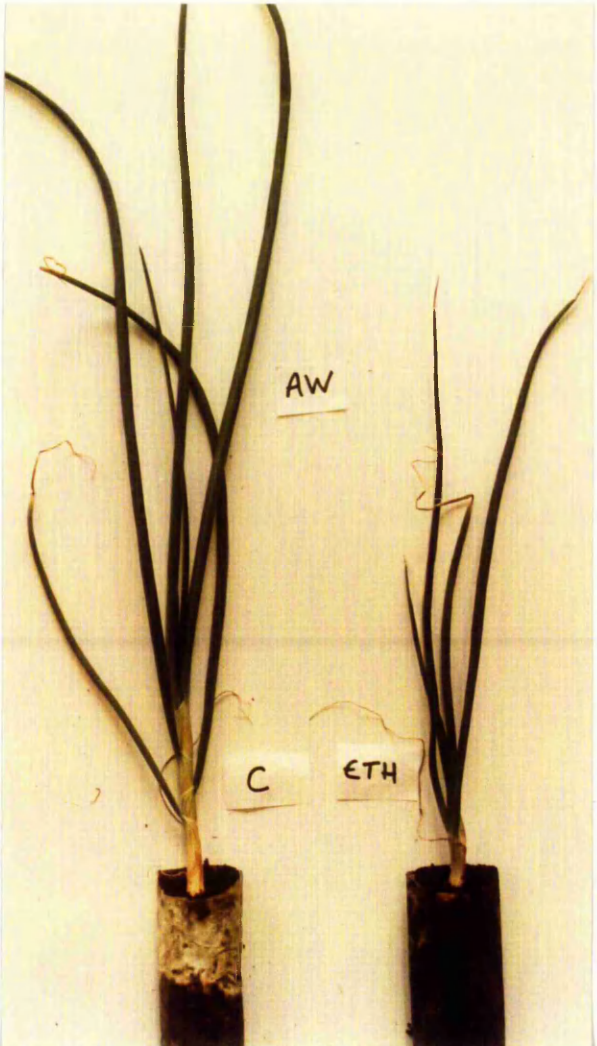
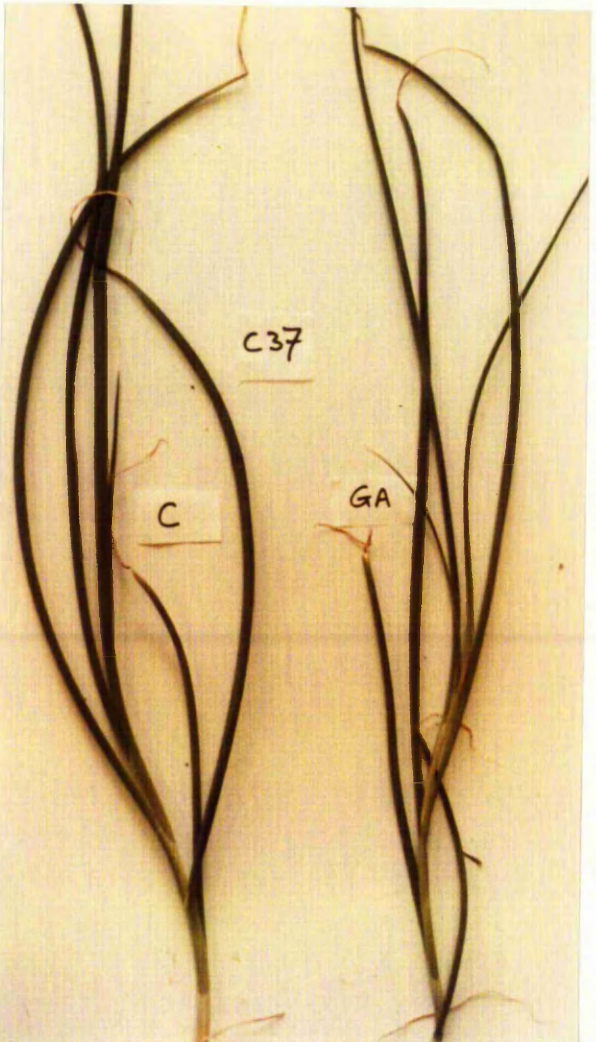


Plate 3.4.



Left hand plate shows the reduction in haulm length and plant height manifested by treatment with ethrel C (ETH). Although the plants shown were irradiated by AW light quality the same response was also pertinent for plants exposed to C37 light quality.

Right hand plate reveals the marked reduction in leaf width and elongation in haulm length which were characteristic features of $GA_{4/7}$ (GA) activity irrespective of the light quality used to irradiate the plants. Control plants represented by symbol (C).



In regard to the time course study attempted on the fifth leaf length and width assessments, the isolation of significant light quality x time and plant growth regulator x time interactions along with their significant polynomial components substantiates the continuing divergence of the various treatment trends with time (Fig. 3.22; A.T. 3.101, 3.102).

3.3.2. Cellular determinations

3.3.2.1. Experiment A

For section B, C and D of the fourth leaf, irradiation with C37 rather than AW light increased the stomatal frequency and length and width of the epidermal and palisade mesophyll cells (Fig.3.24, 3.25; Table 3.103; A.T. 3.110 - 3.124; Plate 3.5). The augmentations relating to the latter 3 parameters were observed as a decrease in the number of cells per unit length. On the other hand, the lumen area and vascular bundle frequency were increased and decreased respectively under C37 light when compared to AW light in leaf section B for the former parameter and similarly for the latter in the bottommost leaf section D (Fig. 3.23, 3.25; Table 3.103; A.T. 3.104, 3.106, 3.108, 3.125 - 3.127). Irrespective of which leaf section was examined, light quality had a negligible effect on tissue area (Fig. 3.23; Table 3.103; A.T. 3.105, 3.107, 3.109).

Of the two plant growth regulators considered, only IAA produced changes in all 3 sections of the fourth leaf, while for the most part an exiguous influence was manifested by TIBA in the topmost leaf section B (Table 3.103). Thus IAA decreased the lumen (Plate 3.6) and tissue area, epidermal cell length and width (Plate 3.7) and palisade mesophyll width (Plate 3.8), whilst promoting stomatal and vascular bundle frequency (Fig. 3.23 - 3.25; A.T. 3.104, 3.106 - 3.111, 3.113, 3.115 - 3.118, 3.122 - 3.127). The major exception concerned palisade mesophyll length, since IAA inhibited cell length expansion in section B, whereas the contrary applied to section C and to a greater extent, section D (Fig. 3.25; A.T. 3.119 - 3.121; Plate 3.8, 3.9). Promotion of cell expansion in section C and D may be attributed to a rapid decline in IAA activity, especially as the cells in these particular

Fig. 3.23.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS CELLULAR CHARACTERS OF THE FOURTH LEAF.

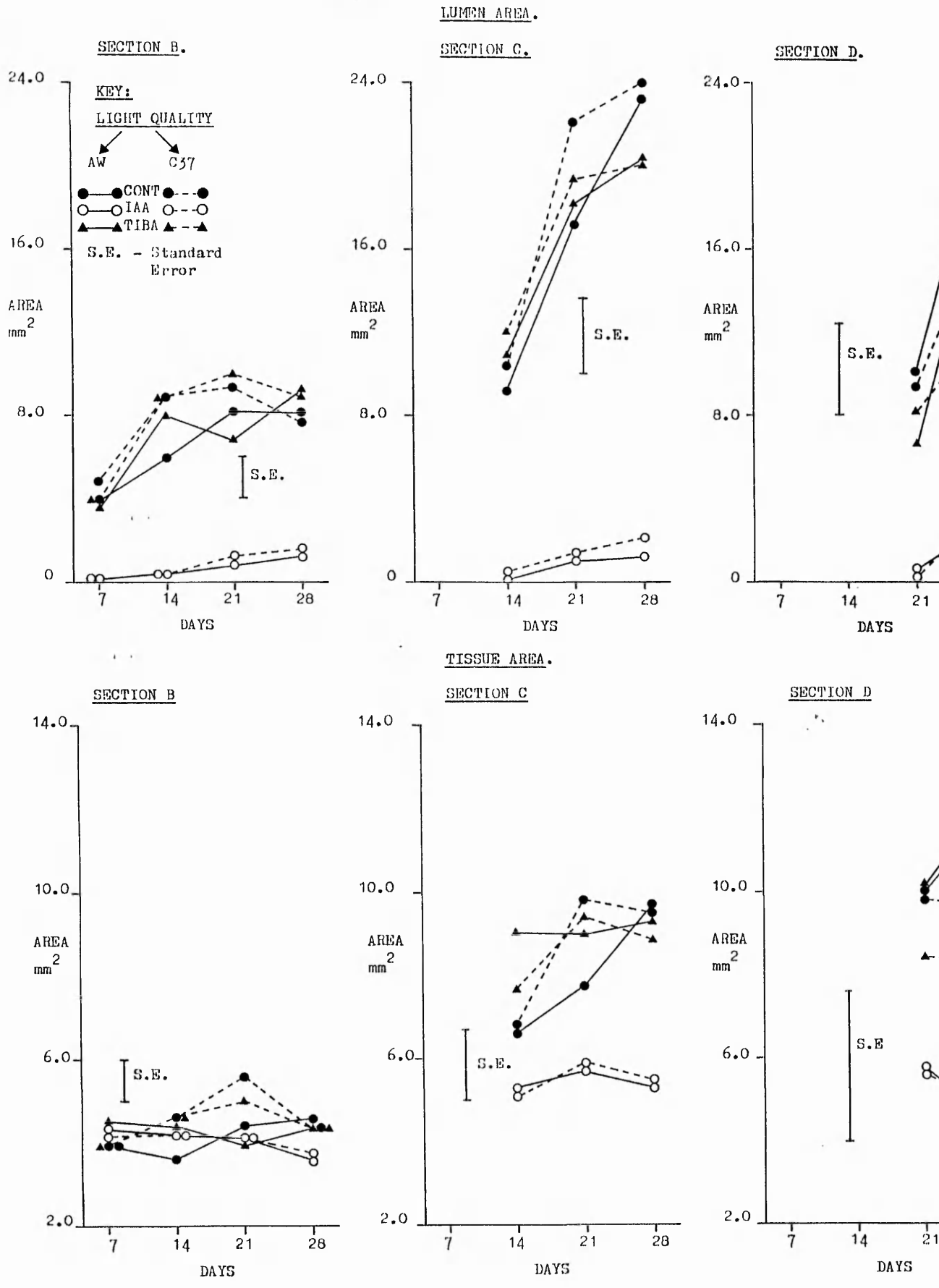


Fig. 3.24.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS CELLULAR CHARACTERS OF THE FOURTH LEAF.

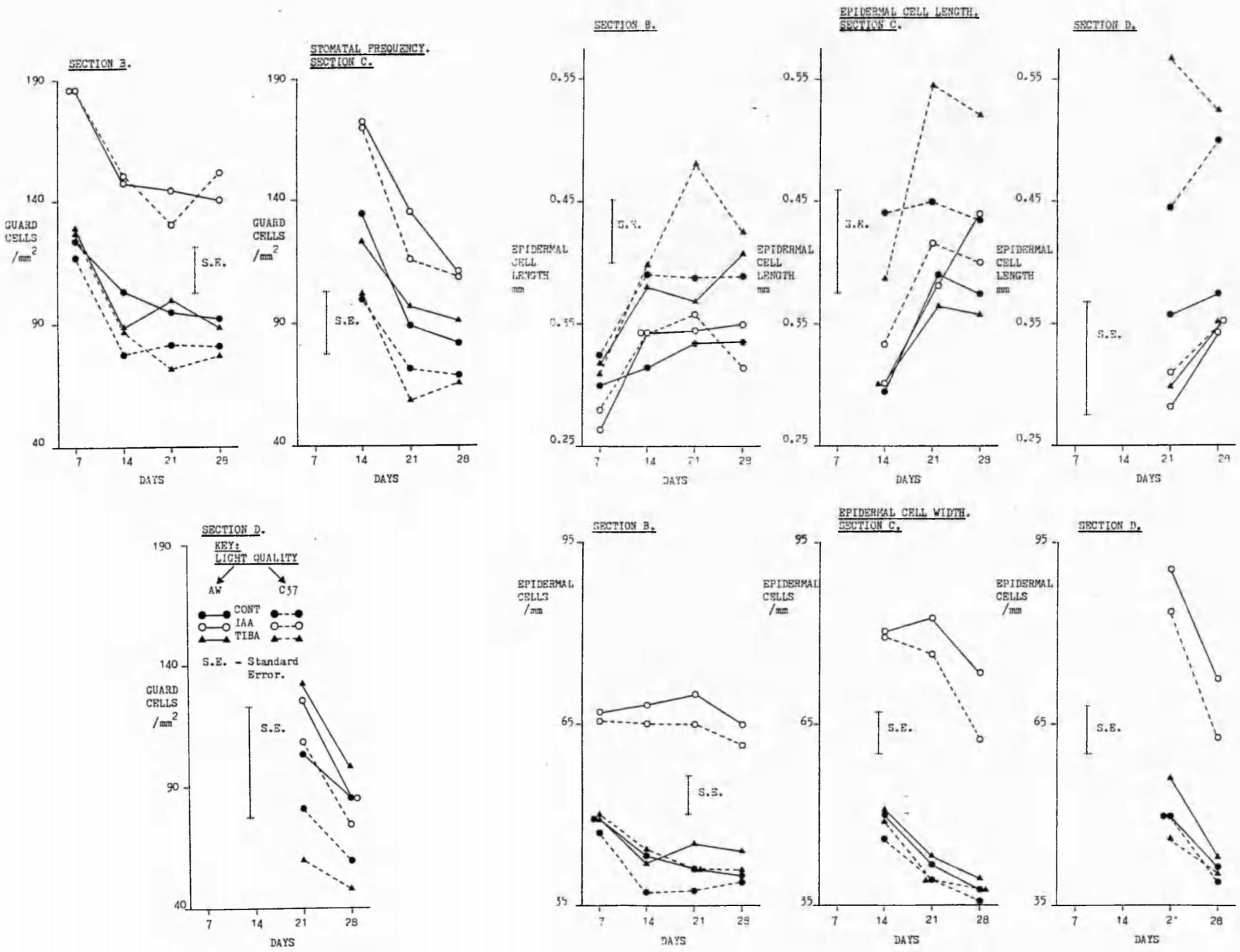


Fig. 3.25.

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS CELLULAR CHARACTERS OF THE FOURTH LEAF.

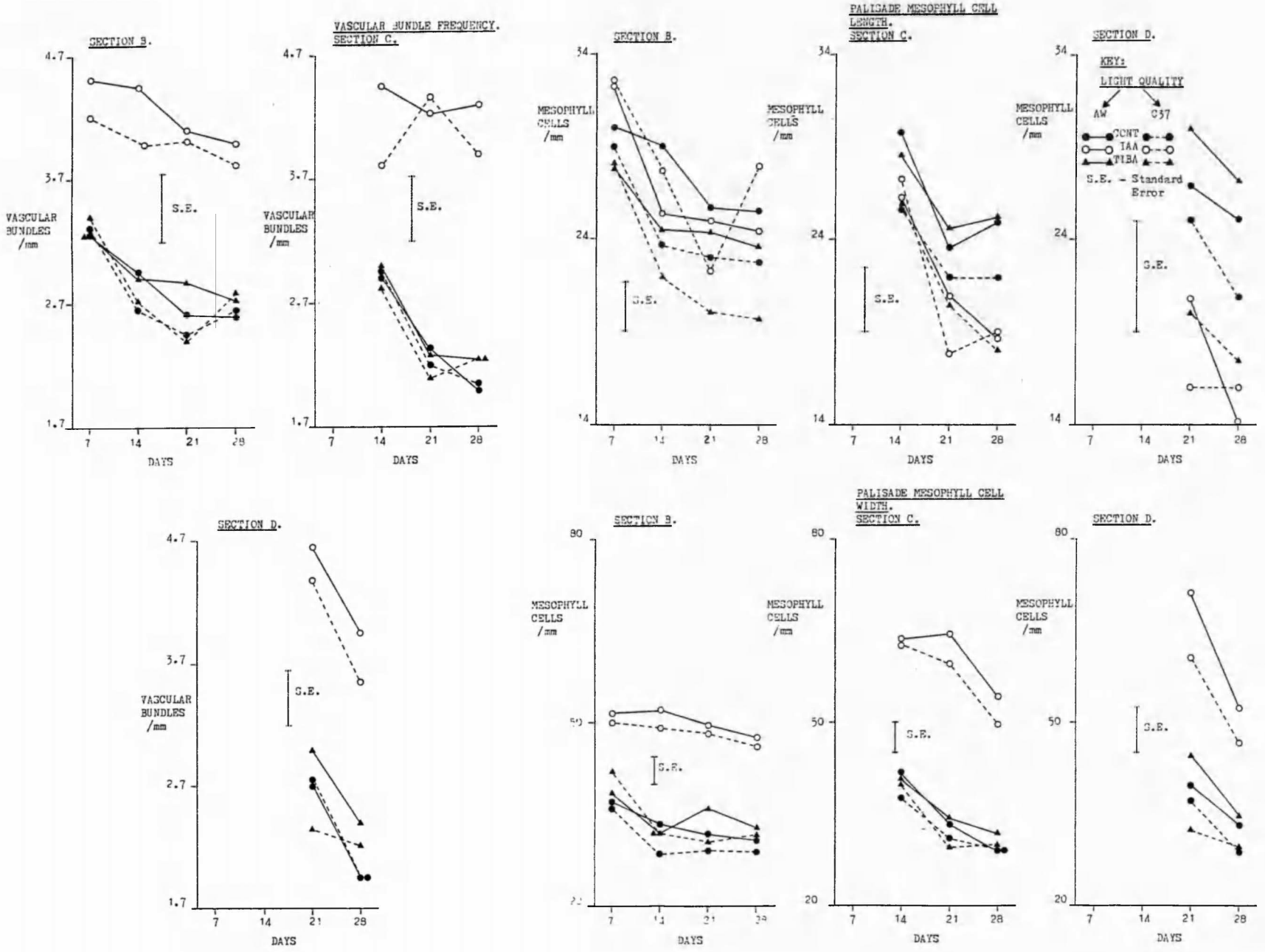


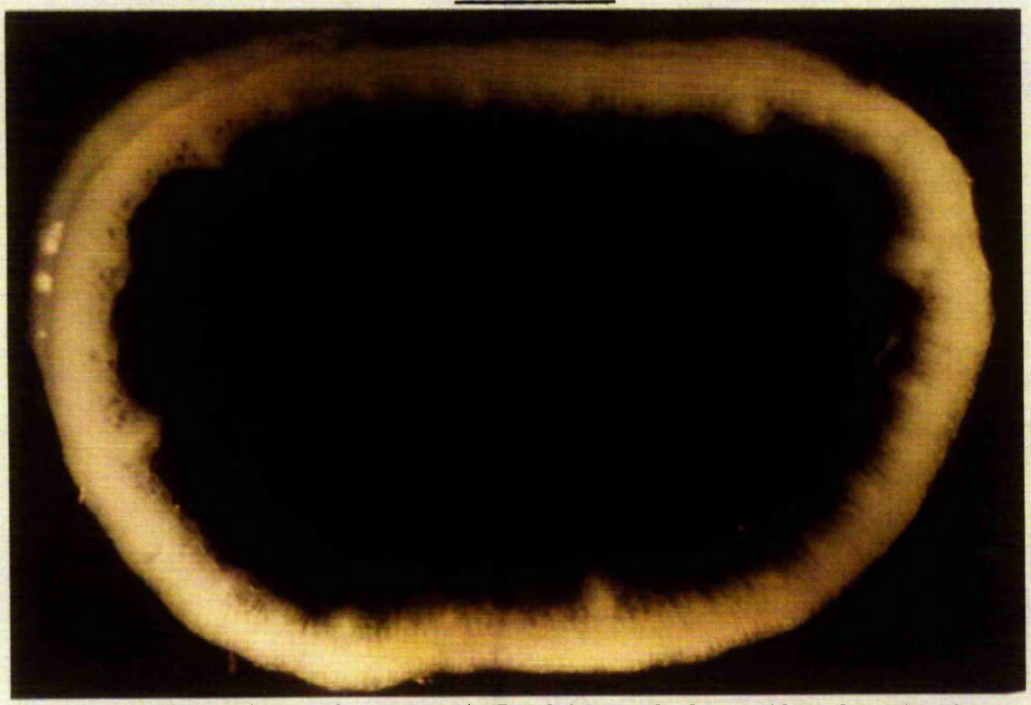
Table 3.103.

Summary of the cellular effects incurred by light quality and plant growth regulators on the various fourth leaf sections in Experiment A.

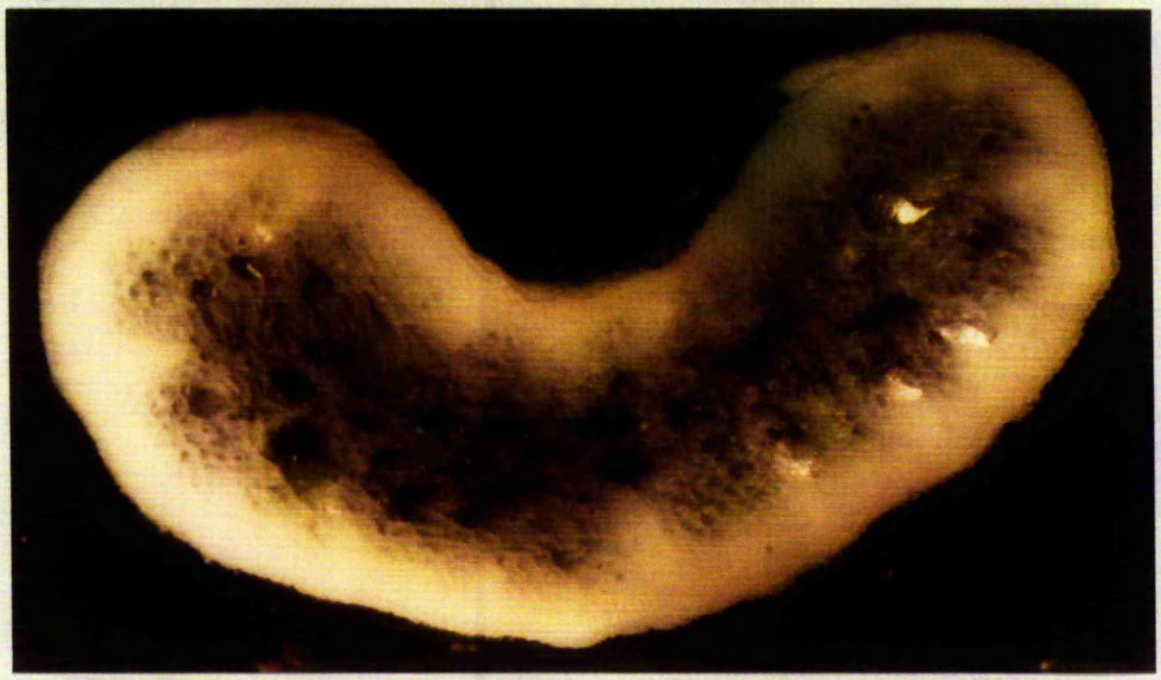
CHARACTER		TREATMENT			
		AW LIGHT	C37 LIGHT	IAA	TIBA
Section B - lumen area		↓	↑	↓	0
- tissue area		0	0	0	0
Section C - lumen area		0	0	↓	0
- tissue area		0	0	↓	0
Section D - lumen area		0	0	↓	↓
- tissue area		0	0	↓	0
Stomatal frequency	- section B	↑	↓	↑	0
	- section C	↑	↓	↑	0
	- section D	↑	↓	0	0
Epidermal cell length	- section B	↓	↑	↓	↑
	- section C	↓	↑	0	0
	- section D	↓	↑	↓	0
Epidermal cell width	- section B	↓	↑	↓	↓
	- section C	↓	↑	↓	0
	- section D	↓	↑	↓	0
Palisade mesophyll length	- section B	↓	↑	↓	↑
	- section C	↓	↑	↑	0
	- section D	↓	↑	↑	0
Palisade mesophyll width	- section B	↓	↑	↓	↓
	- section C	↓	↑	↓	0
	- section D	↓	↑	↓	0
Vascular bundle frequency	- section B	0	0	↑	0
	- section C	0	0	↑	0
	- section D	↑	↓	↑	0

Key: ↑ - increased; ↓ - decreased; 0 - no change.
Epidermal cell width, palisade mesophyll length and width based on individual cell size.

Plate 3.5.

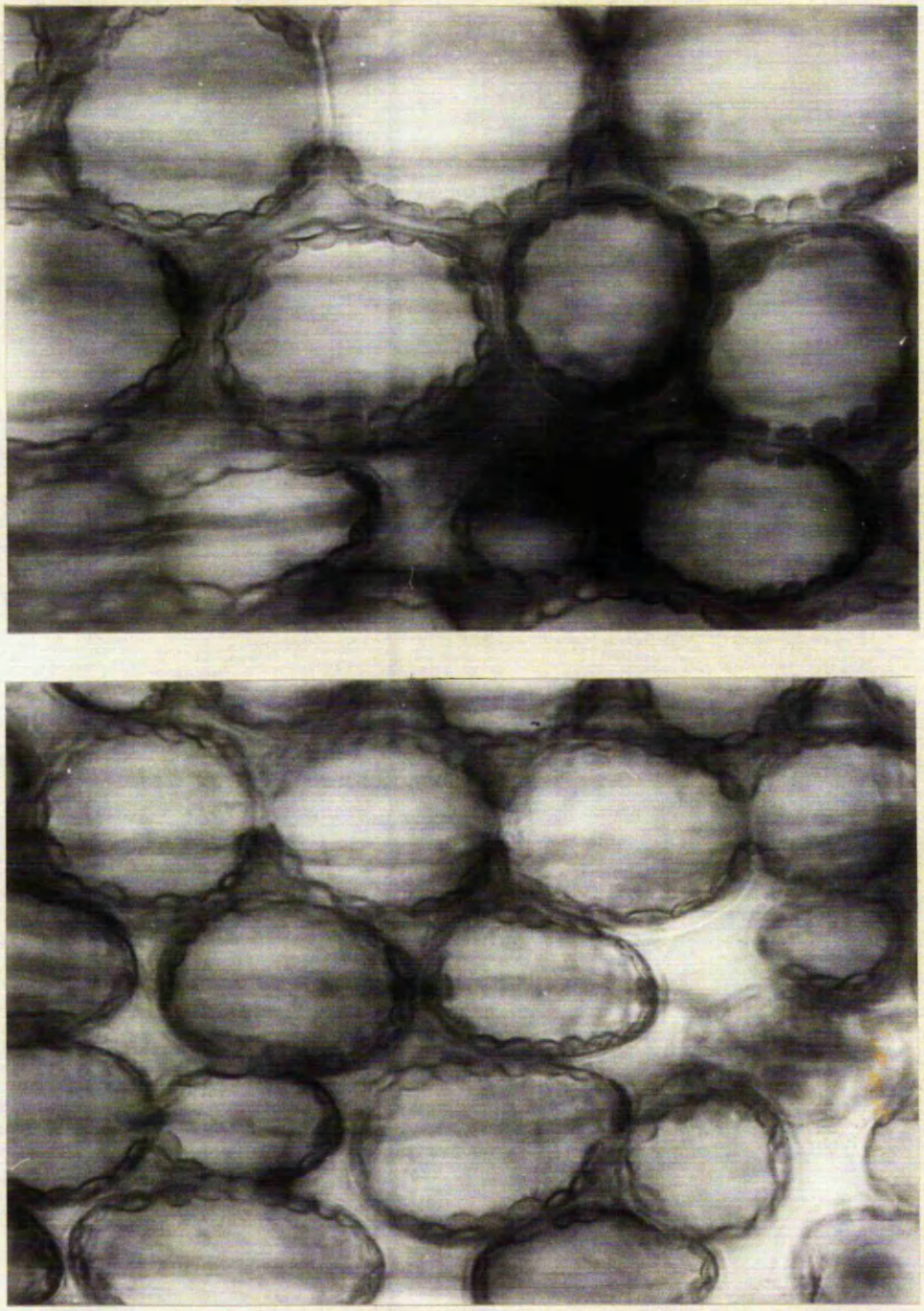


Transverse section of segment B obtained from the fourth leaf of a control plant. Segment shows a large lumen and a thin leaf guage. Magnification x 45.



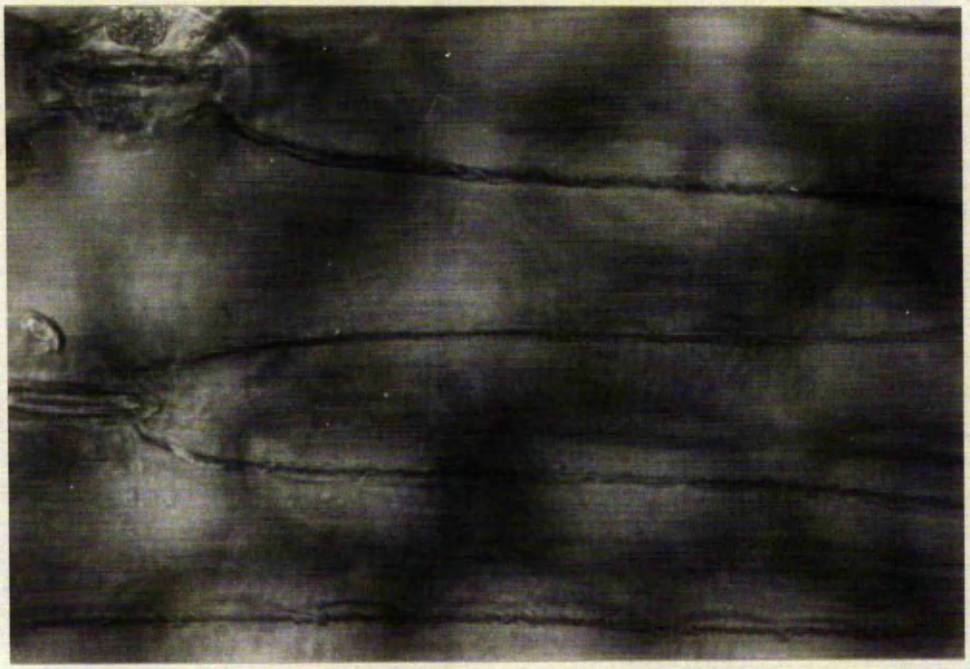
Transverse section of section B obtained from the fourth leaf of an IAA treated plant. Segment reveals the occlusion of the lumen by unruptured parenchymatous tissue. Magnification x 150.

Plate 3.6.



Comparison between the effects of C37 and AW light quality on palisade mesophyll cell development in section C of the fourth leaf, ascertained that C37 light quality (Top Plate) led to a greater expansion in celllength and width when compared to AW light quality (Bottom Plate). Magnification x 900.

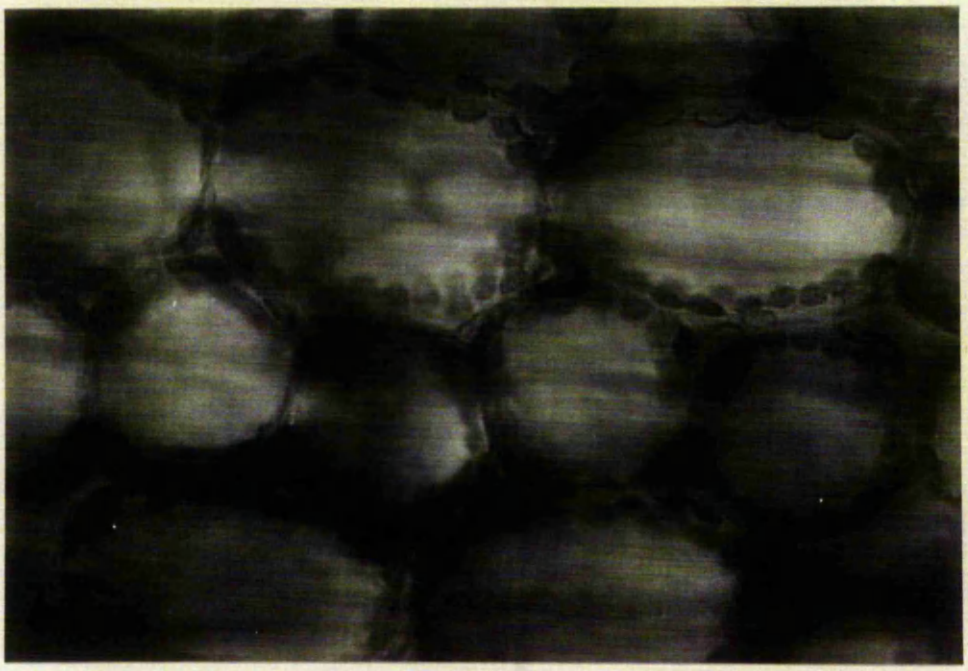
Plate 3.7.



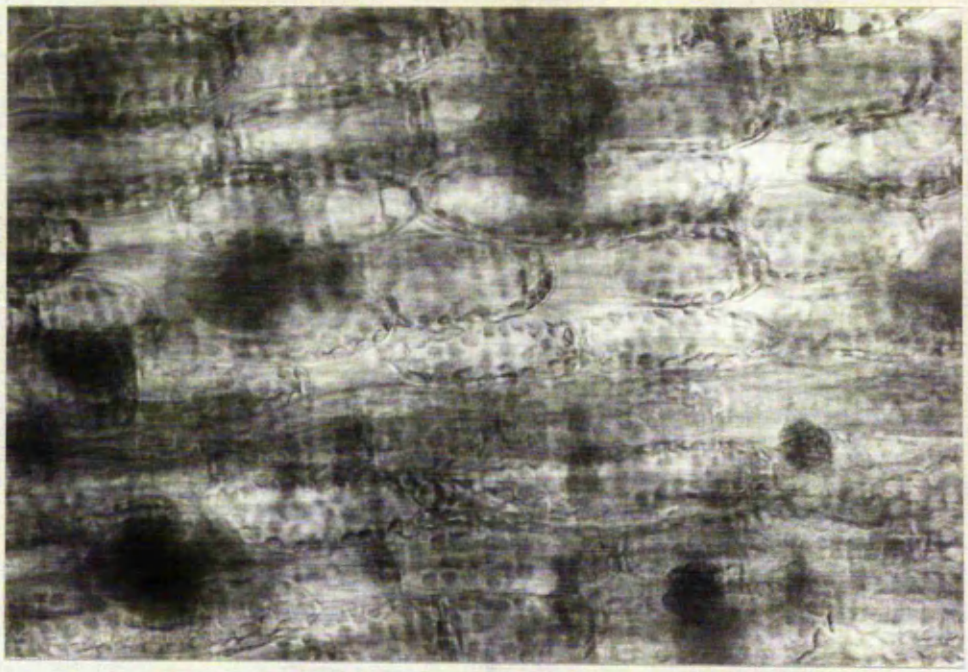
Surface view of epidermal cells of leaf section C taken from control plants showing enlargement in cell width. Magnification x 900.

Surface view of epidermal cells of leaf section C from plants that had just finished receiving a 14 day spray program with IAA. Epidermal cells reveal a severe moderation in width. Magnification x 900.

Plate 3.8.



Surface view of palisade mesophyll cells of leaf section D from control plants showing an increase in both the length and width of the cells. Magnification x 900.



Surface view of palisade mesophyll cells of leaf section C taken from plants that had just finished receiving a 14 day spray program with IAA. Palisade mesophyll cells show severe curtailment in cell width. Magnification x 900.

Plate 3.9.

Surface view of palisade mesophyll cells of leaf section D taken from IAA treated plants 14 days after the cessation of spraying. Palisade mesophyll cells show considerable expansion in length and to a lesser extent width. Complete occlusion of intercellular air spaces can be discerned. Magnification x 900.

sections were still expanding subsequent to the cessation of IAA application. A few instances were obtained of IAA being unable to influence cellular changes, as evinced for tissue area, stomatal frequency and epidermal cell length in sections B, C and D respectively (Fig. 3.23, 3.24; A.T. 3.105, 3.112, 3.114). Considering TIBA, this augmented epidermal and palisade mesophyll cell length, while reducing the width of these particular cell types in section B (Fig. 3.24, 3.25; A.T. 3.113, 3.116, 3.119, 3.122). Furthermore TIBA also enlarged the lumen area of section D (Fig. 3.23; A.T. 3.108).

Generally the significant day items verify the rapid changes produced by the various cellular parameters with time (Fig. 3.23 - 3.25; A.T. 3.104, 3.106 - 3.108, 3.110 - 3.114, 3.116 - 3.127). Usually the magnitude of these alterations were most prominent during the first 7 days after emergence, though in the case of the middle section C evidence indicated cellular changes persisting up to the fourteenth day, while IAA evoked a faster enlargement between day 7 and day 14 in the epidermal and palisade mesophyll cell width (Fig. 3.23 - 3.25).

Significant light quality x plant growth regulator interactions observed for epidermal and palisade mesophyll cell length can be ascribed to IAA reducing the ability of C37 light to promote a greater extension of these particular cells when compared to AW light (Fig. 3.24, 3.25; A.T. 3.113 - 3.115, 3.119 - 3.121). In turn the non-significant light quality x plant growth regulator interaction items for lumen area of section B, stomatal frequency of section B and C, vascular bundle frequency of section D and epidermal and palisade mesophyll cell width of all sections, intimates that light quality and the plant regulators acted independently on these characters (A.T. 3.104, 3.110, 3.111, 3.116 - 3.118, 3.122 - 3.124, 3.127). For those cellular parameters regulated by light quality, the effects were probably manifested prior to the emergence of the relevant leaf sections, since non-significant light quality x day interaction items imply an absence of a continuing divergence in the various cellular parameter trends of the emerged leaf sections under the different light qualities (A.T. 3.104, 3.110 - 3.124, 3.127). In contrast differential rates

of enlargement were apparently still being imposed by the plant growth regulators on some of the cellular parameters subsequent to the emergence of the relevant fourth leaf sections. Such activity was ratified by the extraction of significant plant growth regulator x day interaction items and reflect the marked moderation incurred by IAA on lumen area of all leaf sections, tissue area and vascular bundle frequency of section C, while increasing the rate of expansion during the latter part of the experimental period for palisade mesophyll cell width of all leaf sections and epidermal cell width of leaf section D (Fig. 3.23 - 3.25; A.T. 3.104, 3.106 - 3.108, 3.118, 3.122 - 3.124, 3.126). In spite of these exceptional instances, the general impression was that the majority of cellular parameters were influenced by the plant growth regulators prior to the emergence of the relevant leaf sections (A.T. 3.109 - 3.111, 3.113, 3.115 - 3.117, 3.119 - 3.121, 3.125, 3.127).

3.3.2.2. Experiment C.

Comparisons between the effects elicited by C37 and AW light on cellular parameters, determined at the point of maximum width of the fifth leaf, established that the former led to a greater promotion of the lumen area and epidermal and palisade mesophyll cell length and width than the latter, while the converse applied to tissue area (Fig. 3.26; Table 3.128; A.T. 3.129 - 3.135). Augmentations in epidermal cell width and palisade mesophyll cell length and width were observed as a decrease in the cell number per unit length. In contrast vascular bundle frequency was apparently unaffected by light quality (Fig. 3.26; Table 3.136).

In regard to the plant growth regulators, $GA_{4/7}$ and in particular ethrel C (Plate 3.10) decreased the lumen and tissue area, whilst phosphon D increased these particular parameters (Fig. 3.26; Table 3.128; A.T. 3.129, 3.130). In addition $GA_{4/7}$ moderated the epidermal cell width, whereas ethrel C decreased the epidermal and palisade mesophyll cell length and increased the vascular bundle and stomatal frequency (Fig. 3.26; Table 3.128; A.T. 3.131 - 3.134, 3.136). Of the different plant growth regulators considered, only paclobutrazol was found to be ineffective on the various cellular parameters (Fig. 3.26; Table 3.128; A.T. 3.129 - 3.136).

EFFECT OF LIGHT QUALITY AND PLANT GROWTH REGULATORS ON VARIOUS CELLULAR CHARACTERS OF THE FIFTH LEAF.

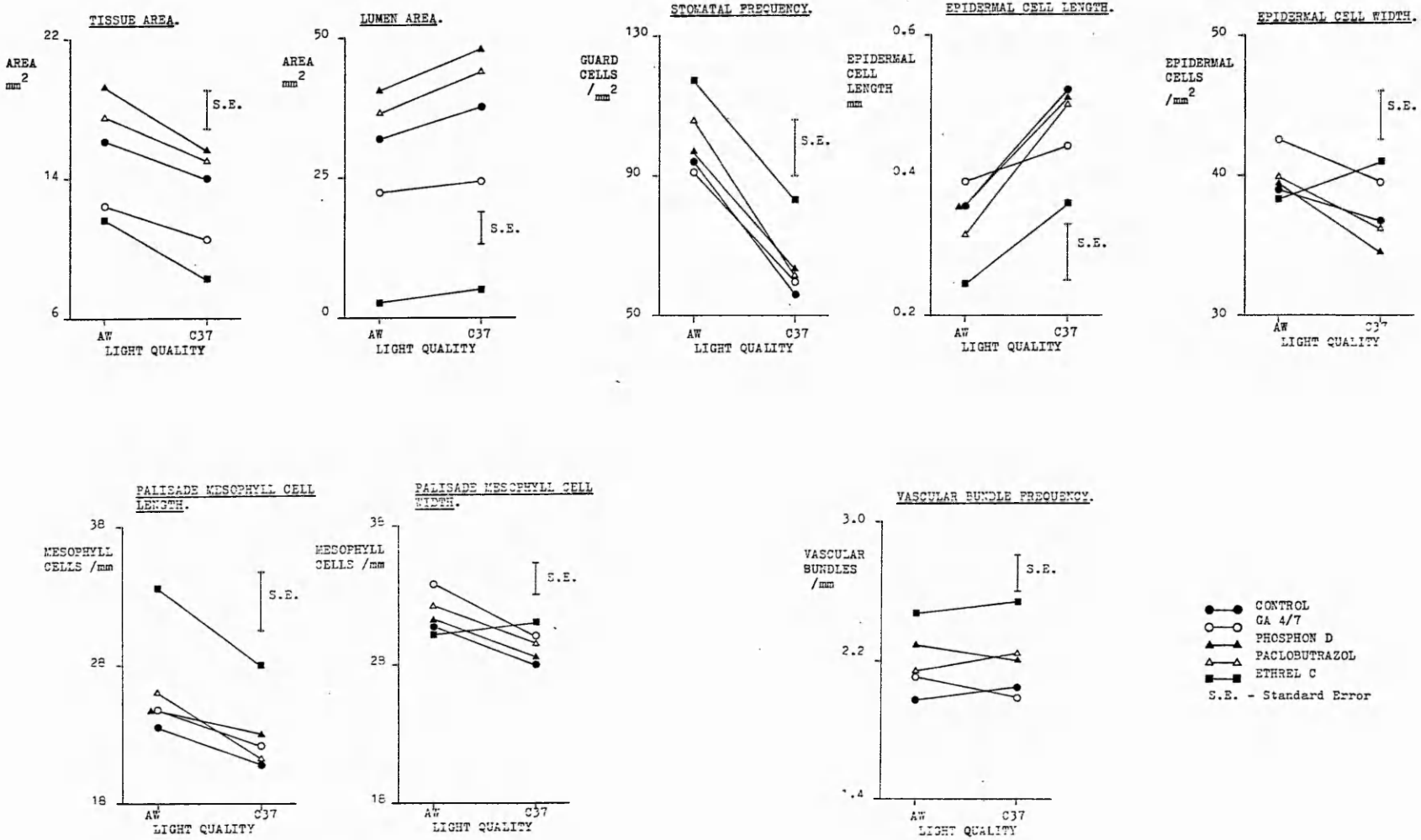


Table 3.128.

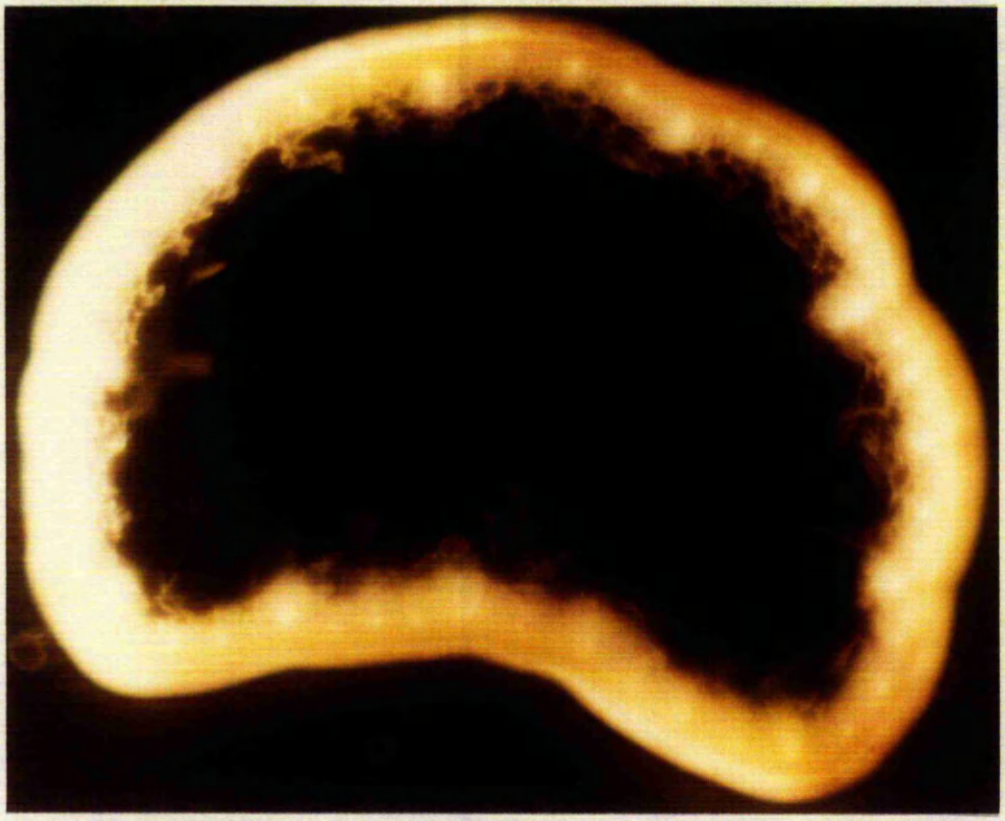
Summary of cellular effects incurred by light quality and plant growth regulators on the fifth leaf in Experiment C.

CHARACTER	TREATMENT					
	AW LIGHT	C37 LIGHT	$GA_{4/7}$	PD	PP333	ETH
Fifth leaf						
- lumen area	↓	↑	↓	↑	0	↓
- tissue area	↑	↓	↓	↑	0	↓
- stomatal frequency	↑	↓	0	0	0	↑
- epidermal cell length	↓	↑	0	0	0	↓
- epidermal cell width	↓	↑	↓	0	0	0
- palisade mesophyll length	↓	↑	0	0	0	↓
- palisade mesophyll width	↓	↑	0	0	0	0
- vascular bundle frequency	0	0	0	0	0	↑

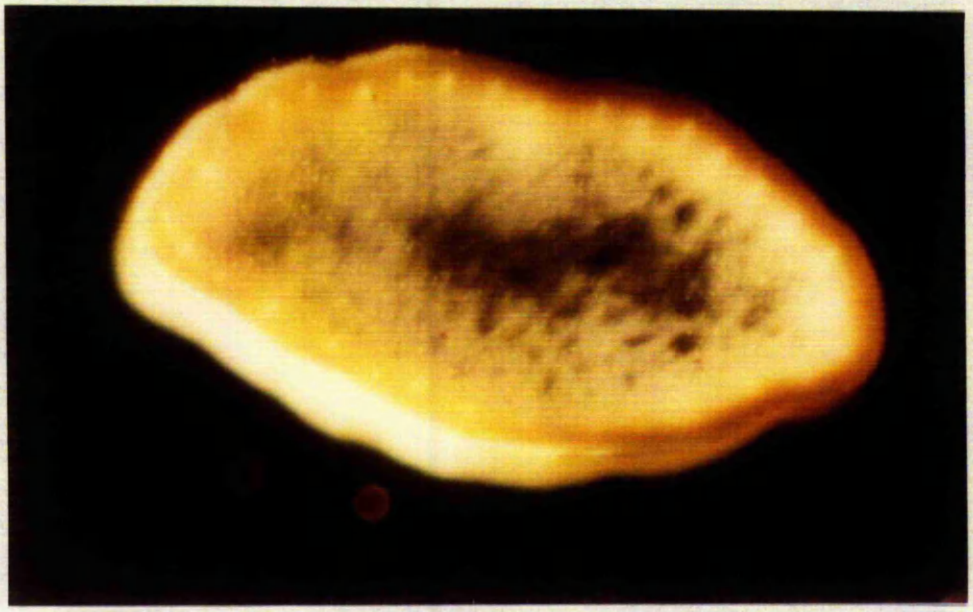
Key: ↑ - increased
↓ - decreased
0 - no change
PD - phosphon D
PP333 - paclobutrazol
ETH - ethrel C

Epidermal cell width, palisade mesophyll length and width based on individual cell size.

Plate 3.10.



Transverse section of the fifth leaf from a control plant disclosing an enlarged lumen and thin leaf guage. Magnification x 20.



Transverse section of the fifth leaf from plants treated with ethrel C revealing an occluded lumen attributable to unruptured parenchymatous tissue. Magnification x 50.

Significant light quality x plant growth regulator interactions were only observed with ethrel C, which decreased the epidermal cell width of plants receiving C37 light to the level attained by plants irradiated by AW light (Fig. 3.26; A.T. 3.133). In contrast the control mediated by $GA_{4/7}$, phosphon D and ethrel C on tissue and lumen area, $GA_{4/7}$ on epidermal cell width and ethrel C on stomatal frequency, epidermal and palisade mesophyll cell length were probably manifested independently of the light quality effects, owing to the extraction of non-significant light quality x plant growth regulator interaction items (A.T. 3.129 - 3.134).

3.4. Discussion

3.4.1. Light quality effects

From Experiment A and C, C37 rather than AW light enhanced the leaf area through an expansion in both leaf length and width. However in Experiment A, the C37 light mediated expansion of the fourth leaf was only observed in the two topmost leaf sections B and C for the length determinant and section B for the width determinant, while the width of the bottommost section D was enhanced by AW light.

In Chapter 2 emphasis was placed on the disparity in the R:FR ratio emitted by AW and C37 light as a possible advocate regulating leaf elongation in onion plants through a modulation of the phytochrome equilibrium $\emptyset$. A similar hypothesis is also proposed for leaf expansion and other onion plant characters influenced by C37 and AW light in Chapter 3. However the enhancement of leaf area by C37 light emitting a low R:FR ratio was contrary to the reduced leaf area effectuated in Circaea lutetiana (Frankland & Letendre, 1978) and Rumex obtusifolius (McLaren & Smith, 1978).

In view of the fact that AW rather than C37 light increased the root dry weight, while the converse pertained with the other onion organs, due consideration was given to possibilities of a light quality influence on dry matter distribution. Thus Experiment A revealed an increase and decrease in the combined basal region & leaf sheaths DWR and root DWR respectively under C37 rather than AW light, whereas the leaf DWR was unresponsive. Nevertheless cognizance should be taken of the general curvilinear course adopted by the leaf and

combined basal region & leaf sheaths DWR and the declination of the root DWR during the time course study. Whether these trends depict a possible ontogenetic drift, variability in the growth conditions or sampling variation remains an open question. In contrast Experiment C revealed that C37 light decremented both the leaf and root DWR and amplified the combined basal region & leaf sheaths DWR, whilst AW light acted contrariwise. Although C37 light produced no bulbing symptoms in Experiment A, the rise and fall in the combined basal region & leaf sheath DWR and root DWR respectively, could represent an initial step towards incipient bulbing, whereby assimilates translocated from the leaves were preferentially acquired by the combined basal region & leaf sheaths at the expense of further root development. Once bulbing has commenced, as ratified by the increased bulb diameters and bulbing ratios, the assimilate requirement for this process may be such that little will be available to sustain further root and leaf production. Certainly the reported decline in the leaf (Heath & Holdsworth, 1948; Aoba, 1964; Nagai & Hanaoka, 1967) and root (Kato, 1963) growth soon after incipient bulbing lends support to the above proposals.

The ability of light sources emitting different R:FR ratios to alter dry matter distribution in other species was observed as a positive correlation between Ø (Pfr/Ptotal) and leaf dry weight: stem dry weight ratio (Morgan & Smith, 1978, 1979, 1981) and also by light emitting a low R:FR ratio promoting stem length on a unit plant rather than a stem dry weight basis (Corré, 1983). Besides a possible reallocation of available assimilates to promote stem elongation at the expense of leaf development, light sources emitting a low R:FR ratio also retarded root growth in favour of enhanced growth in other plant organs as evinced in Nicotiana tabacum (Kasperbauer, 1971) and Rumex obtusifolius (Mclaren & Smith, 1978).

Although improved photosynthetic gains may be inferred from the ability of C37 in preference to AW light to augment the total plant dry weight, negligible changes were effectuated by light quality on the ULR, RGR and LAR in Experiment A. Nevertheless a degree of variability was experienced between samplings of plant dry weight and total leaf areas and this may have constituted a confounding

factor masking small changes in the ULR, RGR and LAR attributable to the light qualities. This proposal was further heightened in Experiment C by C37 light producing a smaller LAR than AW light, though the effect on the ULR and RGR could not be contemplated owing to a single harvest attempted. In addition the C37 light mediated bulbing response in Experiment C was probably responsible for the reduced LAR, since a diminution in the leaf DWR component of the LAR (Evans, 1972) coupled with an increase in the combined basal region & leaf sheath DWR intimates a dry matter distribution favouring bulbing rather than leaf development. In other species, light sources emitting a low R:FR ratio were observed to reduce the ULR in various shade tolerant and intolerant species (Corré, 1983), whilst the LAR was increased in Circaea lutetiana (Frankland & Letendre, 1978) and remained unchanged in Veronica persica and V. montana (Fitter & Ashmore, 1974).

Although the different R:FR ratios of C37 and AW light produced a negligible change in the SLA of onion leaves, which is consistent with findings from Chenopodium album (Morgan & Smith, 1981), Veronica persica and V. montana (Fitter & Ashmore, 1974), greater SLA were attained in Impatiens parviflora (Young, 1976) and Circaea lutetiana (Frankland & Letendre, 1978) receiving light emitting a low R:FR ratio. However under controlled environmental conditions, Child et al (1981) observed that the enhanced stem elongation produced by light emitting a low R:FR ratio brought the leaves closer to the light sources and as a consequence of receiving higher fluence rates the SLA was reduced. Since a constant distance between the onion leaf tips and the fluorescent tubes was not maintained, the possibility of a light intensity effect on other aspects of onion plant development besides the SLA cannot be exempted.

Since C37 rather than AW light augmented the various fresh weight determinations, possible changes in the SWC may be envisaged. Certainly in Experiment A, C37 light incremented the leaf and combined basal region & leaf sheaths SWC, whilst the root SWC was unaffected. Nevertheless cognizance should be taken of the general change with time of the various SWC trends, which could reflect either some form of ontogenetic drift, a response to uncontrolled

variability in the growth conditions or possible sampling variation. Furthermore, the intervention of a bulbing phase under C37 light in Experiment C, increased and decreased the leaf and root SWC respectively, but failed to alter the combined basal region & leaf sheaths SWC when compared to AW light. Thus a corresponding augmentation of leaf area and SWC by C37 light intimates that leaf enlargement could in part be attributed to enhanced cell expansion. A comparable argument may also justify the augmented combined basal region & leaf sheaths SWC in Experiment A, since the leaf sheaths were visibly elongated by C37 rather than AW light. Although the leaf sheath length was also promoted by C37 light in Experiment C, the accumulation of dry matter in the developing bulbs probably masked the expected change in the combined basal region & leaf sheaths SWC. In turn the C37 light mediated reduction of the root SWC in Experiment C could reflect alterations in the root development pattern, especially as Kato (1963) discerned that bulbing reduced the number of new roots being produced and attaining a branched condition, whereas the number of old roots decreased. The ability of light sources emitting different R:FR ratios to influence the water content of plant tissues was demonstrated in Circaea lutetiana (Frankland & Letendre, 1978) and Rumex obtusifolius (Mclaren & Smith, 1978), where a low R:FR ratio incremented the SWC and fresh weight: dry weight ratio respectively. However these authors omitted to ascertain whether the changed water content was ubiquitous for all plant organs or specific to those organs such as the stem, which rapidly enlarged in response to a low R:FR ratio.

In Experiment C, transverse leaf sections revealed that C37 light increased and decreased the lumen and tissue area respectively and as a consequence depressed the leaf guage, whilst the converse applied to AW light. A similar appraisal of various fourth leaf sections in Experiment A could only confirm a comparable light quality response for the lumen area of the topmost section B. Without a doubt, an implied reduction of the leaf guage by C37 light suggests a compensatory growth change, whereby cell expansion at right angles was replaced by expansion parallel to the leaf surface, thereby enabling the length and width and hence the area of leaf to increase.

Certainly the suggestion that C37 light manifested a greater cell expansion parallel to the leaf surface than AW light was ratified by significant promotions in the epidermal and palisade mesophyll cell length and width. The converse situation applied to Rumex obtusifolius receiving light emitting a low R:FR ratio where a diminution in the various cell type dimensions accounted for the decreased leaf area (Mclaren & Smith, 1978). In addition, C37 in preference to AW light decreased the stomatal frequency, whilst producing a negligible effect on the vascular bundle frequency. However the response on stomatal frequency could be an indirect result of light quality decreasing the epidermal cell length and width and thereby increasing stomatal propinquity. However Child et al (1981) ascertained that the augmentation in stomatal number per unit leaf area in Chenopodium album irradiated with light containing a high R:FR ratio was not accompanied by changes in epidermal cell size. In addition the inability of light quality to influence the distance between the vascular bundles in onion leaves means that the greater leaf width exacted by C37 light, also augmented the total number of vascular bundles within the cylindrical leaf.

3.4.2. Plant growth regulator effects

Interpretation of effects incurred by exogenous applications of plant growth regulators are fraught with problems besides the more obvious considerations of whether they are indigenous or their action is indicative of the role exerted by their endogenous counter parts. These problems include the degree of penetration, speed of translocation to sites of activity, inactivation through photo-oxidation, metabolism and conjugation, stimulating the synthesis of other active endogenous plant growth regulators or toxic effects of supra-optimal concentrations.

Certainly GA-(Kato, 1965b; Thomas, 1969; Tsukamoto et al, 1969) and IAA-(Clark & Heath, 1962; Kato, 1965a; Tsukamoto et al, 1969; Thomas, 1969) like activity were demonstrated in onion plants using bioassay techniques. However unequivocal confirmation is still required to determine which GA are present and those actively involved in regulating onion plant growth. This problem was

further highlighted by Aung & Peterson (1974) showing that trimethylsilylation and subsequent gas liquid chromatography of GA-like substances, previously separated using paper chromatography, produced retention times that were dissimilar to GA_1, GA_3, GA_4, GA_7 and GA_{13} standards. Nevertheless Experiment B established that $GA_{4/7}$ incurred a greater control over leaf development than GA_3. Assessment of structure-activity relationships for C-19 GA indicate that 3β hydroxylation, 3β,13-dihydroxylation and α1,2-unsaturation generally confer high activity (Wareing & Phillips, 1981). Certainly GA_4, GA_7 and GA_3 were 3β - hydroxylated, whereas GA_4 and GA_3 also had α1-2 unsaturation and 3β, 13-dihydroxylation respectively. Furthermore studies on GA metabolism in Gibberella fujikuroi revealed a biosynthetic pathway which converted GA_4 to GA_3 via the intermediate GA_7 (Hedden et al, 1978). Thus further work seems essential to clarify the presence of GA_4, GA_7 or both within onion plant tissue and whether they represent the GA responsible for modulating growth, while GA_3 could be a less active intermediary in a biosynthetic pathway leading to GA inactivation. In a similar vein the presence of endogenous IAA needs to be accurately verified, especially as indole-3-acetonitrile, 4-chloro-indole-3-acetic acid and phenylacetic acid may also produce auxin - like activity (Wareing & Phillips, 1981). In contrast ethylene production in onion plants was confirmed using gas chromatography (Levy & Kedar, 1972b; Levy, Kedar & Goldschmidt, 1973; Levy et al, 1979).

Penetration of onion leaf tissues appears not to be a problem, since all the plant growth regulators considered produced morphological alterations. Since most of the plant growth regulator effects were manifested in the actively growing parts of the leaves located proximal to the intercalary basal meristem, the question arises as to whether these regulators were actually translocated to the sites of active growth or operated at a distance by activating a possible intermediary which was translocated. Of the two options the former appears likely as a rapid non-polar movement of IAA was observed through the phloem of intact plants of Coleus (Goldsmith et al, 1974), Lycopersicon esculentum (Maldiney, et al, 1982) and Cucurbita maxima (Sabnis & Watson, 1982). Thus foliar

applied IAA probably enters the phloem and moves basipetally through the leaf to the basal plate, prior to acropetal distribution into the younger emerging leaves, again via the phloem. As GA can also be translocated through the phloem and xylem (Wareing & Phillips, 1981), the proposed route suggested for IAA translocation may also apply. In regard to exogenous applications of ethrel C, available evidence suggests that the active ingredient ethylene is translocated in a conjugated form with glucose or fructose and without loss in activity (Giulivo et al, 1981a,b). Of the various plant growth retardants examined, vegetative changes in the onion variety Kelsae were only effectuated by paclobutrazol and AMO-1618 applied as soil drenches rather than foliar sprays. Although phosphon D was effective as a soil drench, a similar dependence on the method of administration cannot be contemplated until foliar spray treatments are assessed. These results imply that basipetal translocation of plant growth retardants in the phloem appears blocked, whilst uptake and transport acropetally in the xylem is readily undertaken. However it must be emphasized that leaf penetrance, translocation to the vascular system and uptake into the phloem were not investigated. Nevertheless paclobutrazol appears to be exclusively translocated in the xylem (Lever et al, 1982) and a similar mode of transport may also apply to phosphon D and AMO-1618 in onion plant tissue. However the general lack of activity produced by paclobutrazol on onion plants in Experiment C when compared to Experiment B, may predominantly reside with the dryish nature of the growth medium observed at harvest time, since a high soil moisture content appears essential for maximum uptake of paclobutrazol by the roots (Shearing & Batch, 1982; Froggatt et al, 1981). Although Thomson et al (1973) demonstrated that TIBA movement was polar and basipetal in Zea mays coleoptile sections, this movement was one fifth of the speed attained by IAA polar movement and the possibility of translocation in the phloem and xylem of intact plants cannot be excluded.

Another problem associated with exogenously administered plant growth regulators is that the concentration utilized may not necessarily reflect the endogenous levels required to evoke the desired response. This situation may well be further exacerbated

by the ability of the onion plants to inactivate the applied plant growth regulators. Thus 2β -hydroxylation and conjugation with glucose represent two methods used to deactivate GA, whilst photo-oxidation, enzymatic degradation by IAA oxidase and conjugation with certain sugars, proteins and amino acids lowers IAA activity (Wareing & Phillips, 1981). Certainly tentative support for a possible regulatory control of IAA levels within the Kelsae onion plant comes from the observed rapid acceleration in mesophyll cell length and leaf area, subsequent to the cessation of daily IAA applications.

The enhanced production of other endogenous regulators as a result of exogenous applications of certain plant growth regulators could confound the interpretation of the results obtained. Certainly IAA appears to stimulate ethylene production when applied at supra-optimal concentrations exceeding 10^{-6}M (Lieberman, 1979). Although the possibility of IAA augmented ethylene production cannot be excluded in Kelsae onion plants, the fact that IAA inhibited bulbing, enhanced leaf senescence and reduced the width of the leaf and its constituent cells were contrary to the effects evoked by exogenous applications of ethrel C.

The premature senescence evoked by IAA and the retardants paclobutrazol AMO-1618 and phosphon D could be interpreted as toxicity symptoms. Nevertheless when considering the possibility that supra-optimal concentrations of a plant growth regulator could produce toxicity symptoms, the problem arises as to what form and to what level of physiological change constitutes a toxic response and whether the impairment should be permanent, reversible or lead to eventual plant death. This situation is further exacerbated by the lack of experimental data assessing the influence these plant growth regulators have on respiration, photosynthesis and nucleic, protein and lipid metabolism. Thus for plant growth regulators indigenous to the species under consideration, the term supra-optimal concentration should ideally be contemplated in terms of its level exceeding the maximal endogenous content in a particular locality of the plant being considered. Furthermore the use of a range rather than a single "effective" concentration of an applied plant growth regulator could disclose certain growth changes being incurred at low concentrations that may be indicative of the role

played by its endogenous counterpart, whereas the development of a progressively inhibitory response at higher applied concentrations may signify the emergence of toxicity symptoms. Certainly foliar administrations of 10ppm NAA and IBA stimulated vegetative growth and bulbing in Allium cepa, whereas 100ppm proved inhibitory (Vaish, 1972). A similar response also prevailed with Phaseolus vulgaris, whereby foliar sprays of 0.5 and 1ppm 2,4-D enhanced various growth parameters, whilst concentrations exceeding 10ppm became steadily more suppressive (Miller et al, 1962).

When considering the rate of leaf expansion, this was reduced by IAA, $GA_{4/7}$ and ethrel C and increased by plant growth retardants phosphon D, paclobutrazol and AMO-1618. Although TIBA had little effect on the fourth leaf and total leaf area, a significant expansion in length was observed for the topmost section B of the fourth leaf indicating a transient promotion of leaf development. Certainly the inhibition evoked by IAA on the fourth leaf length and area corroborates comparable claims of IAA mediated reductions in plant height of other onion varieties (Kato, 1965a; Lercari & Ceccarelli, 1975) and primary leaf area of Sinapis alba (Wild et al, 1981). Furthermore the ability of IAA to elicit nastic symptoms coupled with severe reductions in onion leaf width appear consistent with similar onion leaf malformations reported by Terabun (1967) and the curled strap-like leaves produced in the broad leaved species Gossypium hirsutum (Gifford, 1953) and Phaseolus vulgaris (Burton, 1947; Watson, 1948) using 2,4-D.

The general unresponsiveness of TIBA on onion leaf expansion contrasts sharply with the notable diminutions exacted on leaf area of Phaseolus vulgaris (Whiting & Murray, 1948) and Vicia faba (Chapman & Sadjadi, 1981) and also symptoms of leaf epinasty in Phaseolus vulgaris (Kraus & Mitchell, 1947; White & Hillman, 1972) and Glycine max (Galston, 1947). These results may imply the presence of species specificity in relation to TIBA sensitivity.

In spite of the fact that $GA_{4/7}$ moderated both onion leaf length and width and hence total leaf area, the wealth of evidence concerning GA activity on leaf development revealed a mode of activity which was not ubiquitous among different species. Thus

comparable reductions to this achieved in the Kelsae onion plants were observed with individual leaf areas of Xanthium pennsylvanicum (Maksymowych & Maksymowych, 1973) and area of the first three trifoliate leaves of Phaseolus vulgaris (Felippe & Dale, 1968), whilst the contrary pertained for leaf area of Lycopersicon esculentum (Bora & Selman, 1969; Briant, 1974) and Solanum tuberosum (Humphries & French, 1960, 1963; Wheeler & Humphries, 1963). Similarly the restraint produced by $GA_{4/7}$ on leaf width ratifies analogous findings ascertained for Allium cepa var.Wolska (Knypl, 1979) and Triticum aestivum (Brian et al, 1954), whilst the opposite applied to leaf length which was enhanced in Zea mays (Phinney, 1956) and Lolium perenne (Cooper, 1958).

The capability of plant growth retardants phosphon D, AMO-1618 and paclobutrazol to increase onion leaf width substantiates comparable effects by DEOMC (Knypl, 1979, 1980) and CCC (Knypl, 1979). The fact that CCC appeared ineffectual on the onion variety Kelsae may intimate the presence of varietal specificity. Nevertheless comparisons with other species yielded both similarities and disparities, since the enhanced individual leaf area sustained by phosphon D on onion plants supported comparable increases in total leaf area of Sinapis alba (Humphries, 1963) and Brassica oleracea (Van Emden & Cockshull, 1967) receiving CCC, whilst paclobutrazol moderated leaf area of Beta vulgaris (Jaggard et al, 1982) and Helianthus annus (Wample & Culver, 1983).

The effects elicited by ethrel C on fifth leaf growth were suppressive with leaf area being decreased through a diminution in both leaf width and length. Certainly CEPA, the active ingredient of ethrel C moderated leaf extension in other species such as Poa pratensis (Van Andel, 1970) and Ananas comosus (Norman, 1981). Since CEPA breaks down to release ethylene within the plant tissues (Cooke & Randall, 1968; Yang, 1969), the ability of ethylene to produce identical diminutions in leaf size were ratified in Dianthus caryophyllus (Piersol & Hanan, 1975) and Cucumis sativus (Abeles, 1973).

Generally IAA, $GA_{4/7}$, ethrel C and to a lesser extent TIBA reduced the total plant, leaf, combined basal region & leaf sheaths and

root dry weight gains, whilst the plant growth retardants phosphon D and paclobutrazol were for the most part ineffective. However an examination of the DWR suggests that with the exception of TIBA, the other plant growth regulators produced compensatory growth changes through a redistribution of dry matter between and within the different plant organs.

Although IAA reduced and augmented the leaf and combined basal region & leaf sheaths DWR respectively, a quantity of senesced leaf material was also produced from the older first and second leaves. Thus an enlarged combined basal region & leaf sheaths DWR could be interpreted as a substantial loss of leaf material exceeding the overall decline in growth exacted by IAA on the leaf and combined basal region & leaf sheaths. The fact that IAA specifically reduced the leaf DWR in preference to other plant organ DWR substantiates comparable DWR estimated from tabulated dry weight data of Phaseolus vulgaris (Miller et al, 1962) and Lycopersicon esculentum (Tognoni et al, 1967) receiving 2,4-D and NAA respectively.

The inability of TIBA to influence the various DWR of the onion plant contrasted with the decremented stem DWR and augmented leaf and root DWR calculated from tabulated dry weight data of Glycine max (Galston, 1947) treated with TIBA. Since TIBA appears to suppress apical dominance and thereby stimulate lateral bud outgrowth (Jewiss, 1972; Isbell & Morgan, 1982), the commensurate reduction in stem length with axillary bud growth observed in Glycine max (Galston, 1947; Anderson et al, 1965) and Phaseolus vuglaris (Yeang & Hillman, 1981) implies that TIBA directed a greater proportion of available assimilates destined for the stems and leaves to the axillary bubs. This argument was ratified by allowing Lolium temulentum leaves to photosynthesize in an atmosphere containing labelled CO_2 (Jewiss, 1972). Only TIBA treated plants concentrated a higher proportion of ^{14}C in the axillary buds proximal to the leaf receiving the labelled CO_2 and the quantity of accumulated ^{14}C in the buds was correlated with their increase in length and weight.

Although $GA_{4/7}$ failed to evoke changes in the various DWR, the increase in the number of leaves, tillers (Chapter 4) and length

of the haulm and leaf sheaths with a forfeiture in leaf size may represent a compensatory growth change specific to leaf development. A similar justification may also apply to the decreased leaf area concurring with enhanced leaf production reported for GA_3 treated Xanthium pennsylvanicum (Maksymowych et al, 1976) and Syringa vulgaris (Juntilla, 1970). Furthermore the polarized longitudinal growth exacted by $GA_{4/7}$ on the onion leaf sheath was probably also at the expense of lateral expansion, especially as reduced bulb diameters and bulbing ratios were incurred under C37 light. Certainly this enhancement in the leaf sheaths, corroborates the GA_3 mediated extension of Zea mays (Brian et al, 1964) and Oryza sativa (Hashimoto & Yamaki, 1960; Suge, 1974) leaf sheaths and haulm length of the onion variety Granex (Olivares & Manuel, 1962). Whereas $GA_{4/7}$ produced negligible changes in the various DWR of the Kelsae onion plant, GA_3 decreased the root and leaf DWR and augmented the stem DWR in Lycopersicon esculentum (Bora & Selman, 1969; Tognoni et al, 1967) and Ipomoea caerulea (Njoku, 1958). The major reallocation of assimilates to the stem by GA_3 was verified by allowing Helianthus annus leaves to fix labelled CO_2 (Umoessien & Forward, 1982). Although GA_3 had little influence on the initial basipetal translocation of ^{14}C from the leaf, the majority of re-exported ^{14}C from the roots was transferred to the shoot tips to meet the increased energy demands of GA_3 stimulated shoot growth.

Since the plant growth retardant phosphon D only decreased the combined basal region & leaf sheaths DWR, this change could either be inferred as spurious or the lack of significance accorded to the leaf and root DWR were attributable to experimental variation confounding their small but real increase. Certainly a diminution in the combined basal region & leaf sheaths DWR could account for the phosphon D mediated suppression of the haulm and leaf sheath length. However this response was not accompanied by a compensatory growth change favouring lateral expansion of the leaf sheaths irrespective of whether bulbing was induced or negated under AW and C37 light respectively, as verified by bulb diameter and bulbing ratio determinations. The ability of plant growth retardants to reduce onion leaf sheath length ratifies similar observations in Zea mays

(Wittwer & Tolbert, 1960), Avena sativa and Hordeum vulgare (Tolbert, 1960a). Plant growth retardant modulation of the DWR was also apparent in the root crops, since treating Daucus carota (Dyson, 1972; Currah & Thomas, 1979) and Beta vulgaris (Jaggard et al, 1982) with SADH and paclobutrazol respectively enhanced assimilate accumulation in the storage roots and depressed top growth. Assessment of species lacking a major storage root "sink" revealed a general decrease in the estimated stem DWR, while the root and/or leaf DWR may increase, as ratified from tabulated dry weight data from Nicotiana tabacum (Humphries, 1963) and Brassica oleracea (Van Emden & Cockshull, 1967). Certainly the diminutions in the stem DWR substantiates the decrease produced in the stem length, which is a characteristic feature of plant growth retardant action (Cathey & Stuart, 1961; Cathey, 1975). Phosphon D may also have produced another form of compensatory growth change in the Kelsae onion plant, whereby the fifth leaf expansion was accompanied by moderated leaf production and accelerated senescence of the older leaves. This may imply that leaves stimulated to expand greatly could become active sicks for available metabolites to sustain their growth rate and thereby hasten metabolite depletion of the older leaves and reduce metabolite allocation for further leaf production.

The moderation in leaf production and early swelling of the leaf sheaths under C37 light, that was symptomatic of a bulbing response (Corgan, 1974; Lipe, 1975, 1976a, b) may represent a compensatory growth change elicited by ethrel C. Although an augmented combined basal region & leaf sheaths DWR may support this proposal, an unchanged leaf and root DWR could either infer a conjectural enhancement of the combined basal region & leaf sheaths DWR by ethrel C or the lack of significance in the other two DWR were ascribable to experimental variation confounding their real but exiguous diminution. The proposed greater allocation of assimilates to the leaf sheaths may also apply under AW light as well, since ethrel C promoted some swelling of the leaf sheaths. Whereas the bulb diameter of control and ethrel C treated plants receiving C37 light were comparable, the bulbing ratio actually increased in response to ethrel C due to the development of

thinner necks. Since expanding leaf blades and sheaths influence the magnitude of the neck diameter, reduced leaf production evoked by ethrel C probably accounted for the decreased neck diameter. In addition, ethrel C also produced a compensatory growth change in the leaf sheaths, since the marked lateral expansion concurred with a suppression of longitudinal extension. Changes in dry matter distribution may also be inferred from the tabulated dry weight data of CEPA treated Poa pratensis, since the estimated root and leaf DWR was reduced and the tiller and stem DWR increased (Van Andel, 1973). These DWR changes infer a greater allocation of assimilates to sustain the CEPA enhanced growth in stem length and tiller production at the expense of leaf blade and root development. In contrast CEPA increased and decreased the leaf and root dry weight respectively in Raphanus sativus and by applying labelled sucrose to the leaf, Adedipe (1973) not only observed a greater retention of labelled sucrose within the leaves than translocated to the roots, but confirmed the change in assimilate redistribution by CEPA.

Reductions in the total plant dry weight by IAA, ethrel C, to a lesser extent TIBA and possibly $GA_{4/7}$ may imply reduced photosynthetic gains. Certainly the depressed ULR, RGR, LAR and SLA for the period of IAA administration lends credence to an impairment in plant growth, whereas the converse situation pertaining to the post-spray period indicates symptoms of recovery, as also ratified by incrementations in the total plant dry weight, leaf area and dry weight, combined basal region & leaf sheaths fresh and dry weight. Cognizance should be taken of the IAA mediated senescence of the mature leaves and reduced leaf size and production, since these will reduce light energy interception and moderate assimilate production. Furthermore the reduced LAR for the period of IAA treatment can be ascribed to a reduction in the SLA and leaf DWR, Whilst the post-spray period increase in the LAR involves mainly an augmentation in the SLA. Certainly this enlargement of the SLA may be attributed to accelerated expansion in the younger leaves, since the older leaves had either senesced or reached maturity. The ability of IAA to reduce the ULR and RGR in onion plants corroborates similar results obtained from treating

Lycopersicon esculentum and Phaseolus vulgaris with the synthetic auxin NAA (Tognoni et al, 1967). However discrepancies were evident with the LAR, since this was apparently unchanged in Lycopersicon esculentum, whilst being decremented in Phaseolus vulgaris (Tognoni et al, 1967).

TIBA had little influence on the ULR and RGR during the period of application, whereas the post-spray period led to a diminution in the ULR and possibly the RGR. In contrast TIBA produced a gradual increase in the LAR during the spray period and the disparity was maintained throughout the following post-spray interval. Although the invariability of the RGR and ULR during the spray period may question the validity of this progressive rise in the LAR, the maintenance of an enlarged LAR with a reduced ULR during the post-spray period could be justified on the grounds that the RGR showed indications of declining.

Although the single harvest attempted in Experiment C precludes the calculation of ULR and RGR, the unresponsiveness of the LAR to $GA_{4/7}$ and ethrel C treatment implies that diminutions could be expected in these rates, owing to an exiguous and large decrease in the dry matter content by the former and latter regulators respectively. Certainly a suppression of leaf area by CEPA and $GA_{4/7}$ can be expected to lower the amount of solar radiation intercepted with consequent reductions anticipated in assimilate production. Nevertheless available evidence concerning other species has revealed a variety of responses, since GA_3 yielded negligible changes in the RGR, ULR and LAR of Lycopersicon esculentum and Phaseolus vulgaris (Tognoni et al, 1967), decreased the ULR of Solanum tuberosum (Humphries, 1958) and increased and decreased the ULR and LAR respectively without a concurrent change in the RGR of Syringa vulgaris (Juntilla, 1970).

Treatment with the plant growth retardant phosphon D effectuated little change in the LAR nor modified the total plant dry weight to indicate possible changes in the ULR and RGR of the onion variety Kelsae, and in these circumstances the gross morphological changes incurred could be attributed to assimitate redistributions. In other species plant growth retardants yielded a diverse range of responses, since CCC decremented the ULR and LAR in Raphanus

sativus, decreased and increased the ULR and LAR respectively in Sinapis alba (Humphries, 1963). Some of this variation could be attributed to effects manifested by plant growth regulators on leaf morphology. Thus in paclobutrazol treated Beta vulgaris, the depressed dry matter yield obtained under field conditions was probably due to an augmented photosynthetic rate being unable to compensate for the reduced leaf area and hence decreased light interception (Jaggard et al, 1982). In contrast the 30% increase in yield of Glycine max following treatment with BTS 44584 could be attributed to an enhanced net photosynthetic rate, brought about by the retardant decreasing the leaf area of the upper leaves and thereby augmenting light penetration to the lower leaves and also enhancing stomatal and residual CO_2 conductances (Hewitt et al, 1982).

Aside from postulating possible changes in assimilate distribution and photosynthetic gains, some of the gross morphological alterations incurred by the plant growth regulators utilized may also be evoked through modifications in the SWC. Certainly the high leaf SWC incurred by IAA not only validates the increased succulence of emerging leaf tissue, but suggests that the augmentations in the SLA and total leaf area during the post-spray period was due to an incrementation in water rather than dry matter content and hence increased cell expansion. A similar argument may also apply to the concurrence of incremented SLA and leaf SWC engendered by TIBA and also the enhanced combined basal region & leaf sheaths SWC by IAA. The ability of IAA to increase the water status of the onion leaves corroborates a similar augmented relative water content in IAA treated primary leaves of Sinapis alba (Wild et al, 1981).

Despite the fact that $GA_{4/7}$ and phosphon D influenced the development of certain morphological characters, these effects did not produce commensurate changes in the SLA and the various SWC. The converse situation prevailed with Lycopersicon esculentum (Bora & Selman, 1969), whereby an enhanced stem SWC accounted for the considerable stem elongation effectuated by GA_3. Later work on the same species by Briant (1974) established that GA_3 gave a transient increase in the leaf water content, which coincided

with the period of rapid leaf expansion. In regard to the plant growth retardants, Van Emden & Cockshull (1967) confirmed that CCC promoted the water content of the leaves and stems but not the roots of Brassica oleracea. The contrary applied to Pisum sativum leaves, since Nieden & Neumann (1978) revealed little change in the dry weight: fresh weight ratios irrespective of the reduced area and augmented thickness incurred by CCC on the leaves.

Although ethrel C suppressed onion leaf expansion, the SLA and leaf SWC were unchanged. However the combined basal region & leaf sheaths SWC was depressed and as the bulb represents the major storage organ of the onion plant, a decline in this SWC by ethrel C may indirectly reflect an accumulation of assimilates as verified by the increased combined basal region & leaf sheaths DWR. Ethrel C also augmented the root SWC of those plants irradiated with C37 light and this could indicate symptoms of increased cell expansion.

Assessment of transverse leaf sections discerned a negligible effect by TIBA on the lumen and tissue area expansion. In contrast IAA and to a lesser extent ethrel C reduced the lumen area to a greater extent than the tissue area and thereby increased the leaf guage. Although cellular measurements were not undertaken on these transverse leaf sections, the substantial reduction in leaf width by these two plant growth regulators infers either a diminution in cell number and/or a possible curtailment in epidermal and palisade mesophyll cell expansion parallel to the leaf surface. Certainly decrementations in either of these proposals could justify the reduced expansion in tissue area of the transverse sections and minimize the traction on the centrally located parenchymatous packing cells to part and form the lumen. On the other hand the reduction and increase in leaf width mediated by $GA_{4/7}$ and phosphon D respectively were apparently manifested through a proportional decrease by the former regulator and an augmentation by the latter regulator on the lumen and tissue areas. This led to an unchanged leaf guage and the possibility of increased cell expansion or number at right angles to the leaf surface unlikely.

Appraisal of transverse sections from other species receiving plant growth retardants, established the development of thicker leaves

due to extensions in the longitudinal axis of the palisade mesophyll cells, as observed in Malus domestica (Halfacre & Barden, 1968; Eaton & Liu, 1970) and Gossypium hirsutum (Schott & Rittig, 1982) treated with SADH and mepiquat chloride respectively.

In regard to cellular determinations, IAA led to reductions in cell expansion at right angles and to a lesser extent parallel to the longitudinal axis of the leaf for both epidermal and palisade mesophyll cells. Certainly these diminutions can account for IAA mediated reductions in length and especially width of the fourth leaf. However the increase in mesophyll cell length of the bottom-most fourth leaf sections C and D could be associated with a decline in IAA activity, as they expanded subsequent to the cessation of IAA application. Since an analogous expansion was not observed in the epidermal cell length of sections C and D to accomodate for the palisade mesophyll enlargement, a decrease in their number by IAA may be inferred. Furthermore a moderation in the epidermal and palisade mesophyll cell width and length by IAA may explain the observed concomitantincrease in stomatal and vascular bundle frequency and hence their propinquity. Comparable results were also evident in Gossypium hirsutum (Gifford, 1953) and Phaseolus vulgaris (Watson, 1948) where a severe curtailment in lateral growth of the lamina by 2,4-D produced closely apposed veins. Besides suppressing cell expansion, IAA also produced rectangular rather than isodiametric shaped palisade mesophyll cells as viewed from the leaf surface and inhibited the formation of intercellular air spaces between these cells. Certainly the lack of intercellular air spaces ratifies analogous observations from Phaseolus vulgaris (Burton, 1947; Watson, 1948) and Cyperus rotundus (Eames, 1949) treated with 2,4-D. Whether the absence of these intercellular air spaces can be attributed to poor lysis between the cells as suggested by Watson (1948) or be due to a physical constraint engendered by the limited epidermal cell expansion remains debatable. The depletion observed in chloroplast number of IAA treated mesophyll cells may intimate the possible formation of "replacement tissue" that resembles parenchymatous cells, but with thicker walls and few if any chloroplasts (Watson, 1948; Gifford, 1953). Certainly the development of brittle and succulent leaves combined with

enlarged palisade mesophyll cells in the bottommost fourth leaf sections of IAA treated onion plants were comparable to the crisp nature of 2,4-D treated Phaseolus vulgaris leaves containing a preponderance of replacement tissue (Watson, 1948).

On the other hand TIBA increased the epidermal and palisade mesophyll length and decreased their width in only the topmost section B of the fourth leaf which emerged during the period of treatment. Certainly an augmentation in cell length could account for the increased elongation of leaf section B of TIBA treated plants. TIBA has also been shown to regulate cell size in Phaseolus vulgaris (Whiting & Murray, 1948), though in this instance the mesophyll cells became smaller and rectangular in shape, while intercellular airspaces were occluded. In regard to vascular bundles and stomatal frequency in onion leaves, these were apparently unresponsive to TIBA treatment.

Surface examination of the various cell types ascertained that $GA_{4/7}$ decremented the epidermal cell width. Although significance was not established for palisade mesophyll cell width, the slightly higher number of these cells incurred by $GA_{4/7}$ per unit leaf width suggests an over-all diminution in lateral expansion of the various cell components by $GA_{4/7}$. However longitudinal development of epidermal and palisade mesophyll cells and also vascular bundle and stomatal frequency were unaffected by $GA_{4/7}$. Since the length of the fifth leaf was substantially reduced, unchanged epidermal and palisade mesophyll cell length infers that $GA_{4/7}$ may have moderated the rate of cell division. A similar argument may also explain the unaltered vascular bundle and stomatal frequency when the leaf width was substantially moderated. However the method by which GA regulates cell development in other species appears to vary. Thus a decrease in epidermal cell number and volume and palisade mesophyll cell volume accounted for the GA_3 mediated reduction in leaf area of Xanthium pennsylvanicum (Maksymowych et al, 1976), whilst in Fragaria species (Arney & Ovenden, 1965) a gradual decline in the area of successive leaves concurred with a similar fall in the number but not size of adaxial epidermal cells. Since GA_3 also increased the area devoted to intercellular air spaces in Glycine max (Bostrack & Struckmeyer, 1964) and

Trigonella foenum-graecum (Desai & Pathak, 1965), further information on whether $GA_{4/7}$ influences the area devoted to intercellular air spaces and palisade mesophyll cells would be beneficial in the onion variety Kelsae.

The plant growth retardant phosphon D apparently had a negligible effect on epidermal and palisade mesophyll cell length and width and also vascular bundle and stomatal frequency. In view of these results, the expansion mediated by phosphon D on leaf width may be accounted by increased cell division of the various cell types considered, though with the palisade mesophyll cells, an incrementation in intercellular air spaces in respect to mesophyll cell number may also be conceivable. Certainly the reduction in the number of palisade mesophyll cells per leaf area following treatment of Malus domestica with SADH led Halfacre & Barden (1968) to show a concurrent enlargement of palisade mesophyll cells with intercellular air space area. Nevertheless in Brassica oleracea (Van Emden & Cockshull, 1967) and Glycine max (Hewitt et al, 1982) stomatal frequency appears to be indirectly related to the effects evoked by the plant growth retardant on leaf area, since in the former species CCC mediated an increase and decrease in the leaf area and stomatal frequency respectively, whereas the converse was engendered on the latter species by BTS 44584.

Surface views of the various leaf cellular components disclosed that ethrel C decremented both the epidermal and palisade mesophyll cell lengths, whereas cell width was apparently unresponsive. In the light of this evidence, the depression in lateral leaf expansion may be attributed mainly to ethrel C suppressing cell division, whilst the inhibition of leaf elongation implies a decrease principly in the expansion of the epidermal and palisade mesophyll cells. Certainly in Poa pratensis (Van Andel, 1973) and Pisum sativum (Apelbaum & Burg, 1972) receiving CEPA and ethylene respectively, the curtailment of leaf elongation apparently entailed a diminution in cell division activity. Although vascular bundle and stomatal frequency were increased by ethrel C, the augmentation in the latter could be attributed to a diminution in epidermal cell length increasing stomatal propinquity, while the enhancement in the former was probably due to a reduced leaf width augmenting the vascular

bundle propinquity. Nevertheless a report by Funke et al (1938) observed that ethylene prevented a normal expansion of Helianthus annus leaf cells and changed the ratio of epidermal cells to stomates, such that the ratio increased and decreased on the adaxial and abaxial sides of the lamina respectively.

3.4.3. Light quality x plant growth regulator interactions

Of the various gross morphological and cellular characters influenced by TIBA and light quality, the absence of significant interactions implies that these two factors probably acted independently. On the other hand, specific morphological and cellular parameters summarized in Table 3.191 were apparently regulated through an interaction between light quality and the four plant growth regulators IAA, $GA_{4/7}$, ethrel C and phosphon D. For the former three plant growth regulators, this was generally achieved through the regulator depressing the expected enhancement by C37 light on the character in question to a level approaching that attained with AW light in combination with the same regulator (Table 3.191). The converse applied to phosphon D, which produced an additional augmentation of certain gross morphological and cellular characters under C37 light, while having a negligible or inhibitory effect under AW light (Table 3.191).

Since the different R:FR ratios of C37 and AW light appear responsible for producing the various photomorphogenetic responses through a change in the phytochrome equilibrium Ø (Smith, 1982), the purported active form of phytochrome, Pfr, probably interacted with the relevant plant growth regulator or certain steps in the sequence of biochemical and physiological events leading to the response being examined. Marmé (1977) suggested that the various membranes of the cell may be one of the primary sites of phytochrome action, especially as Pfr seems capable of binding in vivo to undefined subcellular structures within a few seconds of being formed and can therefore account for the fastest physiological effects related to membranes. Evidence supporting the hypothesis that phytochrome may interact with IAA at the membrane level was the decrease effectuated by R light on the number of binding sites for the synthetic auxin NAA in Zea mays mesocotyls and that these sites were apparently located on the endoplasmic reticulum (Walton & Ray, 1981).

Table 3.137.

Summary of interactive effects incurred by light quality and plant growth regulators in Experiment A and C.

CHARACTERS	PLANT GROWTH REGULATORS			
	IAA	$GA_{4/7}$	PHOSPHON D	ETHREL C
1. Gross morphological characters				
Total plant fresh weight		x		x
Total plant dry weight		x		x
Total leaf area		x		x
Total leaf fresh weight		x		x
Total leaf dry weight		x		x
Combined basal region & leaf sheaths fresh weight	x			x
Combined basal region & leaf sheaths dry weight	x			x
Root fresh weight			▲	
Root dry weight			▲	
Bulb diameter		x		
Bulbing ratio		x		
Haulm length				x
Leaf sheath length				x
Root SWC				△
2. Measurement of particular leaf developing during treatment				
(i) Gross leaf measurements				
Leaf area	x	x	●	x
Leaf length	x	x	●	x
Leaf fresh weight	x	x		x
Leaf dry weight		x		x
(ii) Leaf cellular measurements				
Epidermal cell length	x			
Epidermal cell width				x
Palisade mesophyll length	x		●	

Table 3.137 cont.

KEY:

x - reduced expected enhancement under C37 light to value attained under AW light.

Δ - increased value under C37 light to value equivalent to unchanged estimate under AW light.

▲ - increased value under C37 light, decreased value under AW light.

● - additional augmentation under C37 light, small or no increase under AW light.

Similarly Blakeley *et al* (1983) discerned a R light induced swelling of protoplasts from etiolated *Triticum aestivum* primary leaves, which could be attributed to a change in membrane permeability. In addition, the red light response was not only FR light reversible, implying a control by phytochrome, but the effect could be replaced by GA_3 intimating that this regulator probably acted as an intermediate to phytochrome induced protoplast swelling. Work on apple tissue and mung bean seedlings suggests that the ethylene synthesizing system was probably located on the plasma membrane surface (Lieberman, 1979). Furthermore a R light pulse administered to etiolated *Pisum sativum* seedlings increased ACC (1-aminocyclopropane -1- carboxylic acid), an intermediate in the ethylene biosynthetic pathway, prior to a rise in ACC oxidase activity and ethylene production and the response was FR light reversible implying a possible phytochrome control (Rohwer & Schierle, 1982). Although phosphon D may block the conversion of transgeranylgeranyl pyrophosphate to ent-kaurene by kaurene synthetase (Frost & West, 1977) and thereby impair GA biosynthesis and moderate endogenous GA levels, phosphon D also suppresses the increase of mevalonic acid into dimethylsterols that are important components of membrane lipids (Douglas & Paleg, 1974, 1981). In these circumstances membrane lipid changes may influence phytochrome binding to membranes or ability to effectuate membrane permeability, whilst reduced GA biosynthesis could impair those responses elicited by phytochrome, which may depend on GA as intermediaries.

Cognizance should be taken of the interactive control exerted by IAA or phosphon D with light quality on the various determinants of the particular onion leaf developing during the period of treatment, whilst these same factors appeared to act independently on the total leaf determinants (Table 3.191). Since these treatments mainly influenced the young emerging leaf tissue and had a negligible effect on leaf tissue approaching maturity, the latter may have confounded the isolation of an interactive control by statistical means on the total leaf characters. This proposal may also be pertinent to a number of other gross morphological determinants which apparently showed independent control by light quality and the different plant growth regulators utilized. In

spite of this problem, light quality with either IAA or phosphon D interacted over the control of longitudinal expansion of the leaf blade and constituent epidermal and palisade mesophyll cells, whereas independent action was demonstrated on the lateral expansion of these characters (Table 3.191). However the interactive control exerted on leaf length by $GA_{4/7}$ and ethrel C was not reflected in the leaf cellular determinants of epidermal and palisade mesophyll cell length and may therefore imply that cell division was the factor under interactive control (Table 3.191). Although $GA_{4/7}$ seemed to act independently of light quality in regulating the width of the leaf blade and constituent epidermal and palisade mesophyll cells, a similar argument may only apply in part to ethrel C, since this plant growth regulator interacted with light quality on epidermal cell width (Table 3.191).

Certainly the interactive control exerted by different R:FR ratios of C37 and AW light with various plant growth regulators on onion plant growth corroborates similar interactions observed in other species were R and FR light were preferentially used. Thus prior illumination with R light on eliolated Oryza sativa coleoptiles (Furuya et al, 1969) and Zea mays mesocotyls (Iino, 1982) depressed the sensitivity of these plant organs to elongate in response to applied IAA. Although Iino (1982) failed to confirm a FR reversible phytochrome control in Zea mays mesocotyl elongation, this was ratified in Oryza sativa (Pjon & Furuya, 1967) and Avena sativa (Schopfer et al, 1982) coleoptiles. Similarly exogenously applied GA_3 appeared to interact with R light by releasing the inhibition imposed on elongation by a pulse of R light on etiolated Pisum sativum seedlings (Lockhart, 1959). Furthermore the R light response could be reversed by a subsequent pulse of FR light thereby implicating a phytochrome mediated control (Lockhart, 1959). In addition R light appears to interact with ethylene, since R light induced opening of excised hooks of etiolated bean hypocotyls was prevented by ethylene (Kang et al, 1967) and Samimy (1978) and Goeschl et al (1967) confirmed a FR reversible phytochrome control of the R light response in Glycine max hypocotyls and Pisum sativum epicotyles respectively. Finally Virgin (1962) established that the unrolling of etiolated Triticum aestivum leaf sections

was a phytochrome - controlled reaction and applications of the plant growth retardants AMO-1618 and CCC interacted with R light by inhibiting the stimulated unrolling produced by this particular light quality (Loveys & Wareing, 1971).

4. THE EFFECT OF PLANT GROWTH REGULATORS ON BULBING UNDER GREENHOUSE AND FIELD CONDITIONS.

4.1. Introduction

In view of the profound morphological changes exacted by the various plant growth retardants on vegetative growth and incipient bulbing under controlled environmental conditions (Chapter 3), these same compounds were applied to plants under greenhouse and field conditions, to verify whether comparable responses could be manifested when there was little control over the environmental conditions. Such an investigation was deemed necessary, since a survey of the literature revealed a great deal of disparity as to whether auxins or gibberellins were able to stimulate or inhibit vegetative development and bulbing under various growth conditions.

As with the experiments of Chapter 3, the plant growth regulators adopted fell into two groups. The first group consisted of IAA, GA_3, $GA_{4/7}$ and ethylene (derived from ethrel C) which are natural plant growth regulators, whereas the second group was composed of plant growth regulators purported to antagonize various aspects of the first group. Thus, IAA was compared with TIBA, which actively inhibits IAA translocation (Morris *et al*, 1973; Thomson *et al*, 1973) and correspondingly GA with its alleged biosynthetic inhibitors CCC, DMMC, phosphon D and paclobutrazol (Dicks, 1979). Similarly ethrel C was assessed alongside silver cations and silver thiosulphate anions which are claimed to suppress ethylene biosynthesis, bind to ethylene receptor sites or bind to the ethylene molecule (Veen, 1983).

4.2. Method and materials

4.2.1. Growth medium

To a growth medium containing 19 parts Irish moss peat, 3 parts loam and 2 parts hen grit, a further 115g John Innes Base and 45g ground lime was added to each $0.028m^3$ of growth medium. The growth medium was poured into paperpot honeycombs (Whalehide Company, Leigh on Sea, Essex) of dimensions 5cm (diameter) x 20cm (length) x 130 (pots) and compressed lightly. This procedure was repeated twice more to give the required sowing depth of approximately 0.5cm.

Each pot received a single seed prior to a final supplementation of growth medium, which was lightly compressed with the excess scraped from the paperpot tops. Finally, the paperpot honeycomb sides were sheathed with black polythene to reduce soil moisture loss from the peripheral paperpots. A liberal application of water was given on the first day while subsequent watering was as required.

4.2.2. Growth conditions

The germination and early growth of the seedlings were performed in the warm growth cabinet maintained at 24 ± 2°C (Section 3.2.2). Onion seedlings for the greenhouse and field experiments received light from AW fluorescent tubes at a photon fluence rate of 170.56 ± S.D. 15.70 and 186.16 ± S.D. 22.69 $\mu E.m^{-2}.\ sec^{-1}$ (P.A.R) respectively. During the last two weeks of using the growth cabinet, intermittant high external temperatures forced the temperature within the growth cabinet to levels approaching 30 to 35°C, though no observable stress symptoms developed amongst the onion seedlings. The following part of the growth condition section will consider the greenhouse and field experiments separately.

4.2.2.1. Greenhouse experiment

Sixty-two days after sowing, 140 plants were selected according to the presence of the sixth leaf. Each plant separated from its paperpot was transplanted into 23cm diameter Stewart plastic pot (Richard Sankey & Son Ltd., Nottingham) containing J.Arthur Bower's Seed and potting compost (Lindsey & Kesteven, Saxilby, Lincoln). Ten transplants were randomly assigned to each of 14 plots located in a line down one side of an unheated greenhouse. These plots were in turn split into two adjacent blocks of 7 plots each and 7 different plant growth regulator treatments were randomly allocated to the plots within each block. Watering of plants was as required and no additional nutrient feeding was attempted. Thrip infestations were controlled by intermittant applications of Tumblebug (Murphy Chemical Ltd.) containing the active ingredients 3% (w/v) heptenophos and 0.75% (w/v) permethrin.

4.2.2.2. Field experiment

Fifty-two days after sowing, 360 plants were selected according to

the presence of the fifth leaf. The plants, separated from their paperpots were transplanted directly into the field site consisting of a heavy clay soil recently rotovated, prior to a liberal application of ground lime and a general fertilizer raked into the soil. The site was partitioned into 4 blocks, each containing 10 plots alined end to end, with each pot receiving a group of 9 randomly chosen plants. The plants and plots were separated from each other by a gap of 20 and 30cm respectively, while paths of 46cm in width, separated the individual blocks. Ten plant growth regulator treatments were randomly allocated to the plots within each block. Although no nutrient feeding was undertaken, one heavy drenching with water from a hose was deemed necessary to alleviate water stress during the dry summer of 1983.

4.2.3. Plant growth regulator treatments

4.2.3.1. Greenhouse experiment

Plant growth regulators 2.86mM IAA, 1mM TIBA, 3.16mM CCC, 1.45mM GA_3, 3.46mM ethrel C and 2.94mM $AgNO_3$ were applied 24h after the plants were transplanted. IAA and GA_3 were prepared by dissolving in a small quantity of absolute ethyl alcohol prior to the addition of distilled water. TIBA was dissolved in a small volume of 0.1N NaOH, followed by 0.1N HCl to reduce the alkalinity to pH.7 before distilled water was finally added. CCC, $AgNO_3$ and the liquid formulation ethrel C only required the addition of distilled water to achieve the desired concentration. All treatment solutions had the wetting agent Citowett (B.A.S.F. A.G.) incorporated to give a final concentration of 0.02%. This quantity of Citowett was deemed sufficient to diminish the surface tension of distilled water to its minimum of 30 dynes. cm^{-2}. Foliar spraying of the plant growth regulators and distilled water control were conducted with a 500ml hand operated Mist Spray (Boots Co., Nottingham) having the nozzle adjusted to give the finest spray. Spraying was continued until run-off and spray drift onto the other plots was prevented by using portable hardboard shields. Foliar sprays were administered on a weekly basis for 14 weeks.

4.2.3.2. Field experiment

Plant growth regulators 2.86mM IAA, 1mM TIBA, 1.45mM GA_3, 1.52mM

$GA_{4/7}$ (GA_4 and GA_7 in a ratio of 1:1 (W:W)), STS (silver thiosulphate - contributing $AgNO_3$ component at concentration of 1.47mM), 3.46mM ethrel C, 3.30mM DMMC, 1.26mM phosphon D and 8.52 µM paclobutrazol were applied directly after the plants were transplanted. Preparative methods for IAA, TIBA, GA_3 and ethrel C were described earlier in Section 4.2.3.1. $GA_{4/7}$ was first dissolved in 0.1N NaOH and the alkalinity of the resulting solution reduced to pH.7 with 0.1N HCl, prior to the addition of distilled water. Paclobutrazol was dissolved in a small quantity of absolute ethyl alcohol subsequent to supplementation with distilled water. Phosphon D and the liquid formulation DMMC only required the addition of distilled water to achieve the desired concentration. STS preparation required the separate solubilization of $AgNO_3$ and $Na_2S_2O_3$ in distilled water prior to their mixing in the ratio of 1 M silver to 8 M sodium thiosulphate.

Wetting agent addition and spraying technique were previously described in Section 4.2.3.1. To prevent spray drift a portable polythene hood mounted on a dexian box frame was placed over the plot to be sprayed. A slit in one side of the polythene hood gave access for purposes of spraying. IAA, TIBA, GA_3, $GA_{4/7}$, STS, ethrel C and DMMC were foliar sprayed. With regard to soil drenching 450mls of 5.03mM phosphon D and 8.52 µM paclobutrazol were poured around the basal region of all 9 plants within each plot. Over a 9 week period, foliar sprays were applied on a weekly basis while soil drenches were given every fourth week.

4.2.4. Measurements

4.2.4.1. Greenhouse experiment

Twenty-eight and 63 days after commencement of plant growth regulator treatments, bulb and neck diameters were measured by taking two estimates at right angles to each other and calculating the mean value. The bulbing ratio was subsequently derived by dividing the mean bulb diameter by the mean neck diameter (Clark & Heath, 1962). On the 125th day, by which time the majority of onion bulbs had matured, they were harvested and the leaves and roots excised prior to taking the fresh weights. The bulbs were stored in wooden crates at a room temperature ranging from approximately 18 to 25°C

for a further 87 days before the following final measurements were taken:-

(i) Bulb diameter: Methodology explained above

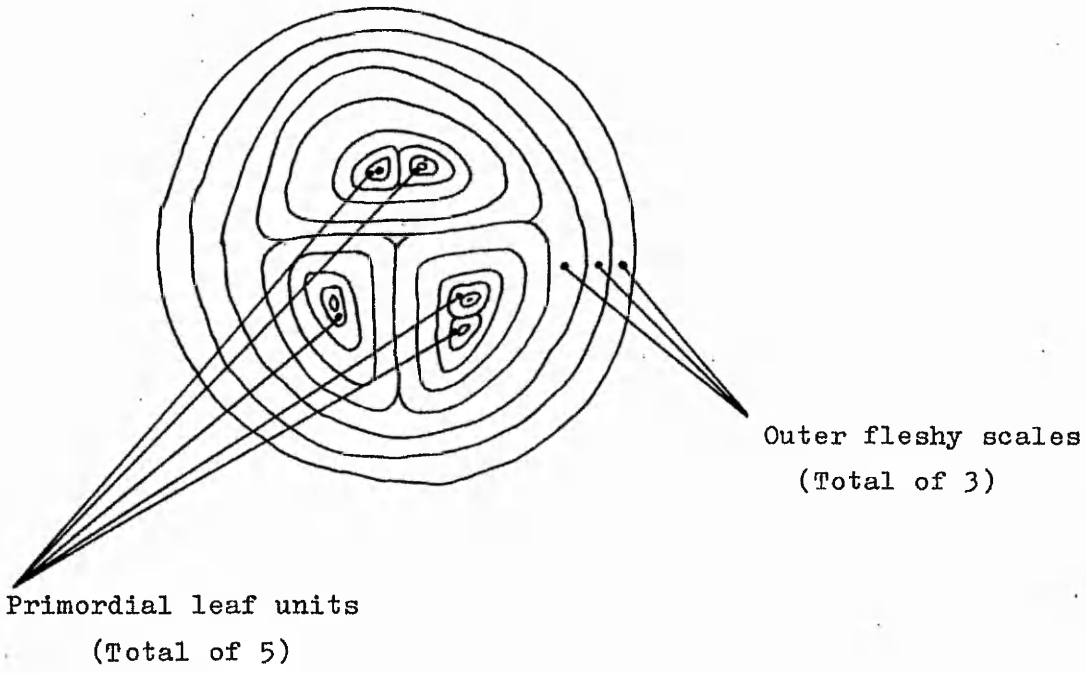
(ii) Bulb height: Distance from the basal plate to the point of inflexion, which delineates the demarkation point between the neck and the bulb.

(iii) Bulb height: diameter ratio: Bulb height divided by bulb diameter

(iv) Number of primordial leaf units and outer fleshy scales: A transverse cut through the point of maximum diameter of the bulb enabled an assessment of these characters to be attempted as illustrated in Fig.4.1.

Fig. 4.1.

Determination of number of primordial leaf units and outer fleshy scales



4.2.4.2. Field experiment

One hundred and sixteen days after the initiation of the plant growth regulator treatments, the following measurements of bulb diameter, neck diameter, bulbing ratio, bulb height, bulb height: diameter ratio and bulb fresh weight were taken as described in section 4.2.4.1. Additional measurements included the haulm length, which represented the distance from the basal plate to the end of the last leaf sheath and the number of tillers produced per plant.

4.2.5. Experimental design and statistics

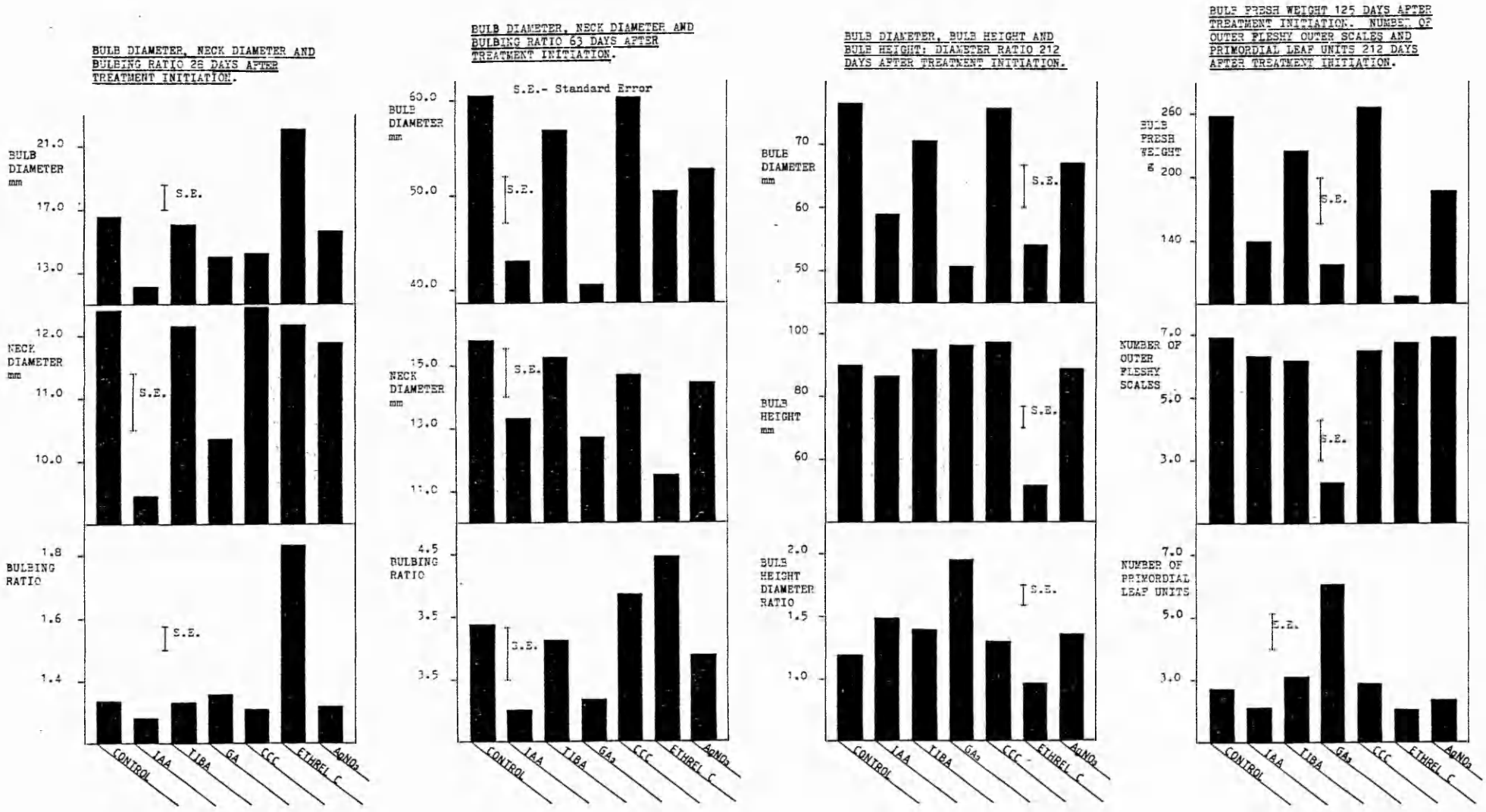
A randomized block design was utilized in both the greenhouse and field experiments. In the former experiment the design consisted of 2 replicate blocks each containing 7 plots of 10 plants apiece, whilst the latter experiment entailed 4 replicate blocks each holding 10 plots with 9 plants apiece. The various plant growth regulator treatments were randomized amongst the plots in each block. The analysis of variance for these designs were conducted according to the methods outlined in Snedecor & Cochrain (1967) and run on the DEC system 20 computer (Digital Equipment Corporation, Maynard, Massachusetts) using the Genstat V (Mark 4.03) language (Lawes Agricultural Trust, Rothamsted Experimental Station). The Q method was used to test for significance between plant growth regulator treatments (Snedecor & Cochrain, 1967).

4.3. Results

4.3.1. Greenhouse experiment

Twenty-eight days after the commencement of plant growth regulator treatments, ethrel C was observed to augment the bulb diameter, while IAA and to a lesser extent GA_3 produced a reduction in both the bulb and neck diameter (Fig.4.2; Appendix Table (A.T.) 4.1, 4.2). Only ethrel C increased the bulbing ratio through a major incrementation in the bulb diameter, whereas the inability of GA_3 and IAA to alter this ratio could be attributed to a proportional decrease in both the bulb and neck expansion (Fig.4.2; A.T.4.3). In contrast TIBA, CCC and $AgNO_3$ were apparently unresponsive on the various bulb determinants (Fig.4.2; A.T.4.1 - 4.3).

EFFECT OF VARIOUS PLANT GROWTH REGULATORS ON DIFFERENT GROSS MORPHOLOGICAL CHARACTERS DURING BULBING UNDER GREENHOUSE CONDITIONS



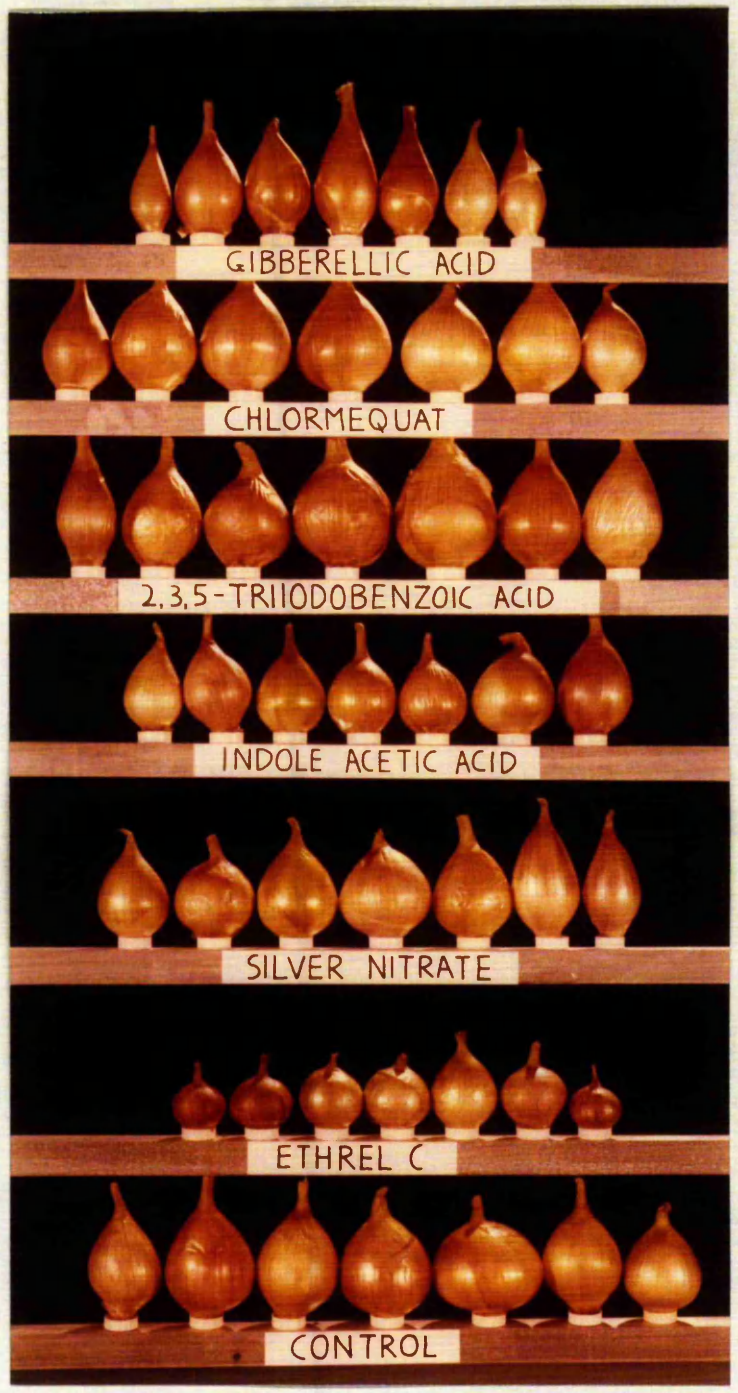
Although 63 days after initiation of plant growth regulator treatments revealed a continued but greater restraint by IAA and GA_3 on the bulb diameter and to a lesser extent the neck diameter, significant reduction were now also evident for the bulb and neck diameters of ethrel C treated plants and bulb diameter of plants receiving $AgNO_3$ (Fig.4.2; A.T. 4.4, 4.5; Plate 4.1). On the other hand, treatment with CCC and TIBA remained ineffective (Fig.4.2; A.T. 4.4, 4.5). Following the computation of the bulbing ratios, ethrel C was observed to significantly increase the ratio due to the development of a thin neck with a large bulb diameter, whereas the greater restraint in bulb diameter rather than neck diameter expansion were symptomatic of the reduced bulbing ratios incurred by GA_3 and IAA (Fig.4.2; A.T. 4.6). $AgNO_3$, TIBA and CCC had a negligible effect on the bulbing ratios (Fig.4.2; A.T. 4.6).

Fresh weight determinations of bulbs harvested 125 days after the commencement of plant growth regulator treatments revealed substantial diminutions by $AgNO_3$, IAA, GA_3 and ethrel C, while treatments with CCC and TIBA were unresponsive (Fig.4.2; A.T. 4.7).

Irrespective of whether the bulb diameter was assessed 63 or 212 days after the commencement of plant growth regulator treatments, the effects elicited by the plant growth regulators were generally comparable, even though the later assessment time included a 78 day storage period at room temperature, which can be expected to reduce bulb volume through dehydration. This observation was validated in the later assessment time by significant moderations in bulb diameter by IAA, GA_3 and ethrel C, while TIBA, $AgNO_3$ and CCC were ineffectual (Fig.4.2; A.T. 4.8; Plate 4.1).

Although inspection of the bulb height established a diminution by ethrel C and negligible effects by the other plant growth regulators (Fig.4.2; A.T. 4.9), bulb height : diameter ratios were enhanced by IAA and GA_3 and decremented by ethrel C (Fig.4.2; A.T. 4.10). The small bulb diameters produced by IAA and GA_3 were mainly responsible for the large bulb height : diameter ratios and hence account for the formation of torpedo shaped bulbs, whereas the low ratio evoked by ethrel C could be attributed to the severe reductions in bulb height leading to the development of round to flat shaped bulbs

Plate 4.1.



The effect of various plant growth regulators on bulb development. Notable features include the formation of torpedo and small flat shaped bulbs by GA_3 and ethrel C respectively, whilst IAA and silver nitrate reduced bulb size. CCC (chlormequat) and 2,3,5-triiodobenzoic acid had no apparent effect on bulbing.

(Plate 4.1, 4.3). Close scrutiny of the bulb internal structure ascertained that GA_3 incurred a substantial increase in the primordial leaf unit number and a reduction in the number of outer fleshy scales, while treatments employing IAA, TIBA, ethrel C and CCC were deemed unresponsive (Fig.4.2; A.T. 4.11, 4.12; Plate 4.2). Bulbs showing symptoms of sprouting were omitted from these two determinations, since they showed a marked deterioration and collapse in the outer fleshy scales, through depletion of their food reserves for the developing shoots. In these circumstances the remaining replicate bulbs for each plant growth regulator treatment within a block were meaned before the analysis of variance was attempted (A.T. 4.11, 4.12).

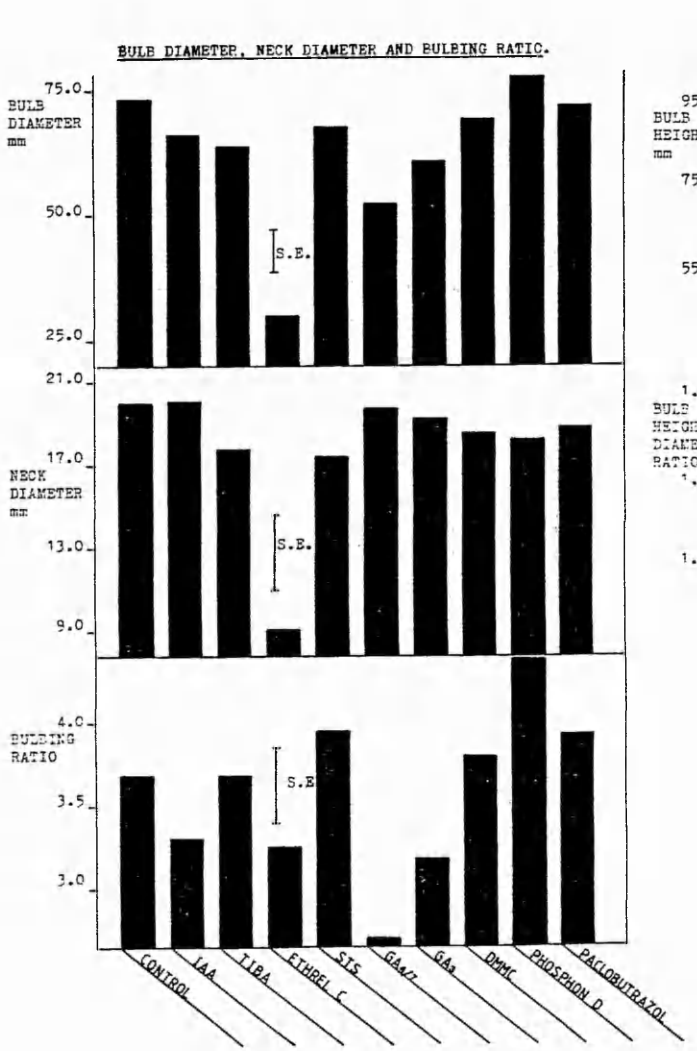
Aside from the various quantitative measurements, a number of visual observations were also noted. Thus, ethrel C treatment led to the slow development of short leaves with a notable dark green colouration (Plate 4.3), whilst GA_3 produced a preponderance of thin leaves, a number of which belonged to tillers similarly induced by GA_3 (Plate 4.3). Tillering was not observed in any of the other plant growth regulator treatments. Weekly foliar treatments with IAA were not observed to reduce the green colouration or produce epinastic symptoms in the leaves as evinced under controlled environmental conditions in Chapter 3.

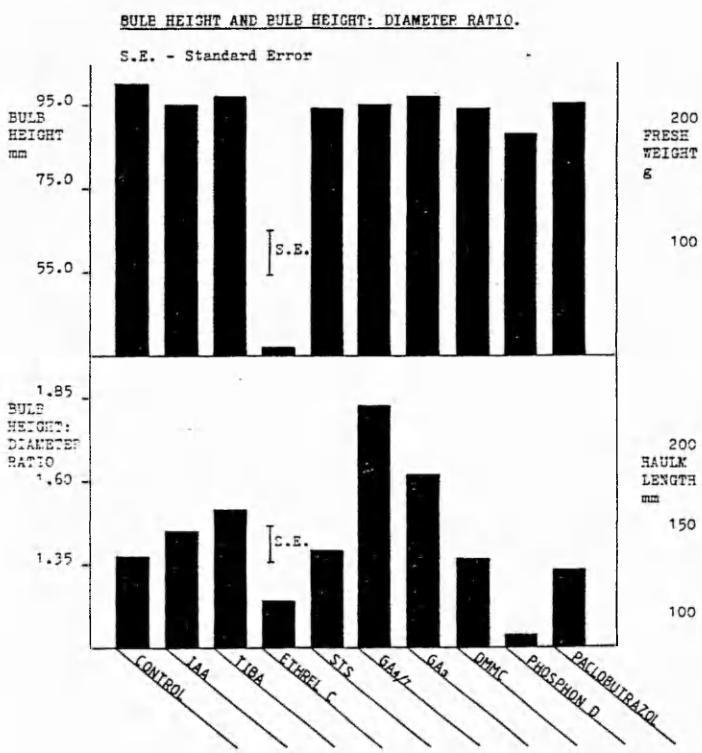
4.3.2. Field experiment

Treatment with ethrel C led to a significant diminution in the bulb and neck diameter and bulb height, while a similar response by $GA_{4/7}$ was only effectuated on the former character (Fig.4.3; A.T. 4.13, 4.14, 4.16; Plate 4.4, 4.5). None of the other plant growth regulators were deemed responsive (A.T. 4.13, 4.14, 4.16). Calculation of the bulbing ratio revealed that $GA_{4/7}$ reduced the ratio by producing a slower expansion in the bulb diameter, whereas no significant changes in the ratio could be discerned by the other plant growth regulators (Fig.4.3; A.T. 4.15; Plate 4.5).

With regard to the bulb height : diameter ratio, $GA_{4/7}$ and GA_3 substantially increased the ratio by moderating the expansion in bulb diameter, whereas the reduction in bulb height accounts for the decreased ratio elicited by phosphon D (Fig.4.3; A.T. 4.17).

EFFECT OF VARIOUS PLANT GROWTH REGULATORS ON DIFFERENT GROSS MORPHOLOGICAL CHARACTERS DURING BULBING UNDER FIELD CONDITIONS.





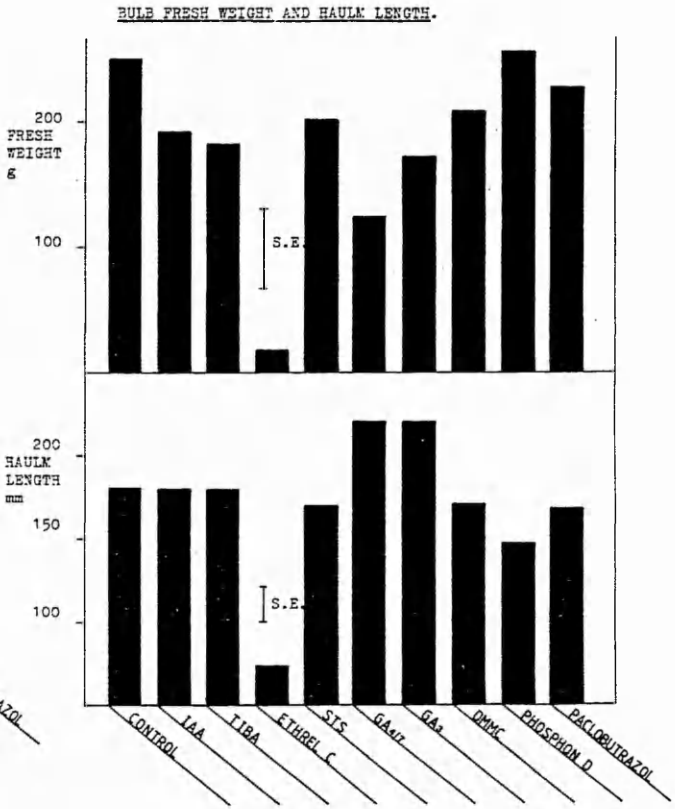
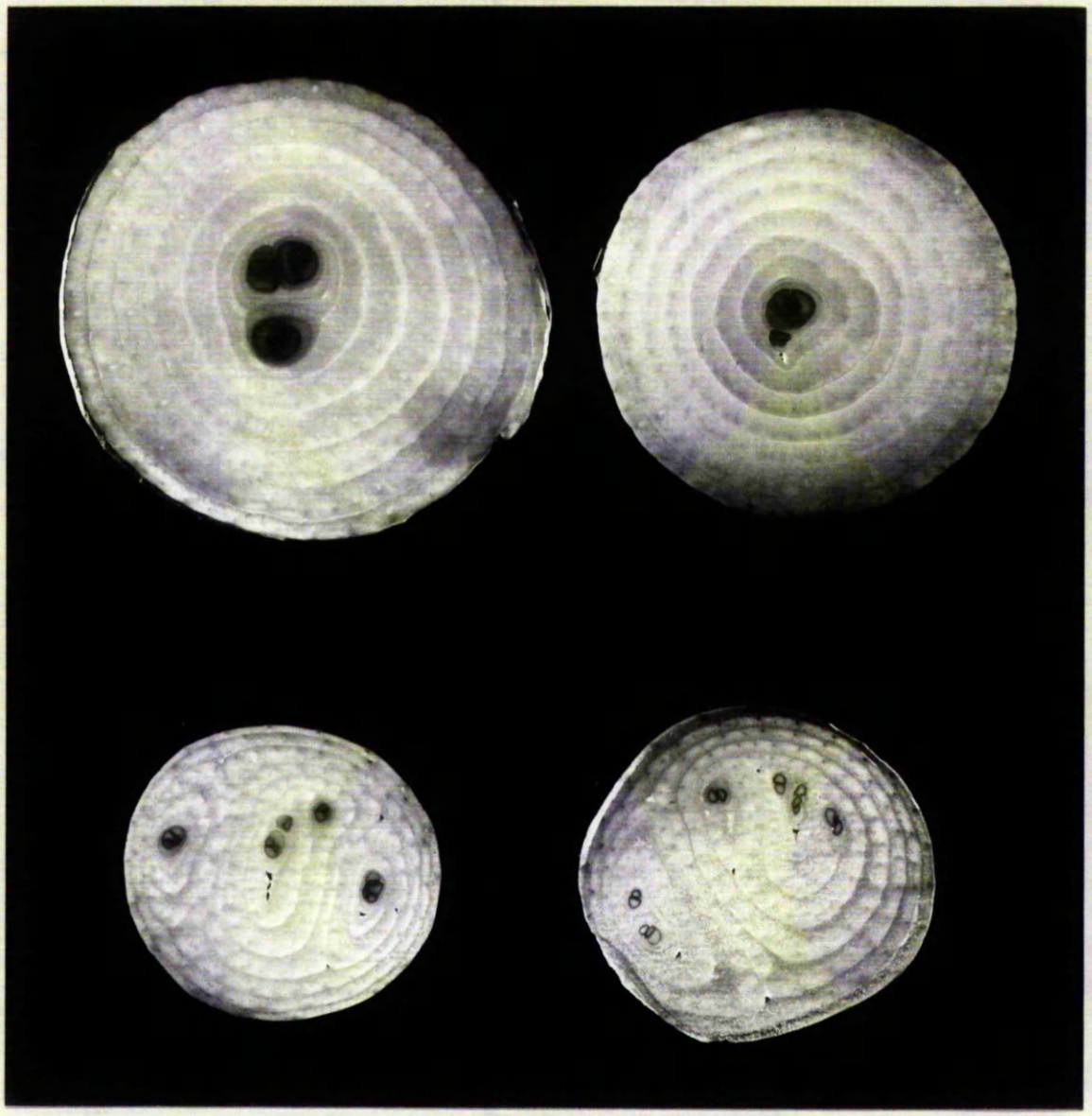


Plate 4.2.



Transverse sections through the widest part of bulbs from control (upper two sections) and GA_3 treated (lower two sections) plants. Plants receiving GA_3 produced bulbs with a preponderance of primordial leaf units and a reduction in the number of outer fleshy scales.

Plate 4.3.

Comparisons between the control (left), ethrel C (middle) and GA (right) treatment on Kelsae onion plants. Ethrel C incurred small flat shaped bulbs, short necks and reduced leaf length, whereas GA_3 evoked tiller development, thin leaves and torpedo shaped bulbs.

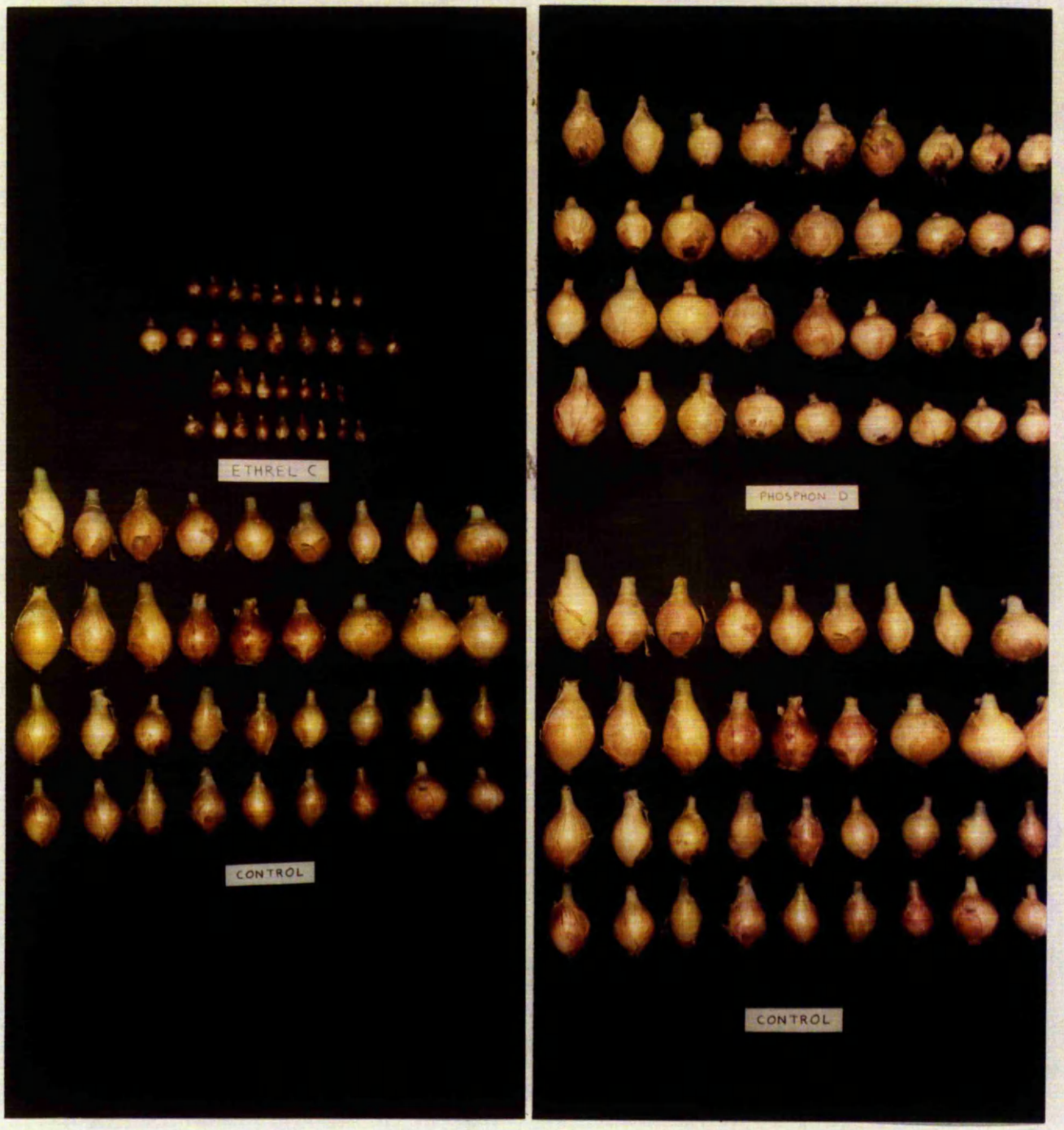
The outcome of these regulatory constraints on bulbing were the development of torpedo shaped bulbs and round bulbs following treatments with GA and phosphon D respectively (Plate 4.4, 4.5). Of the other plant growth regulators utilized, none were found to influence the bulb height : diameter ratio (A.T. 4.17).

Both $GA_{4/7}$ and GA_3 produced significant increases in the haulm length (Fig.4.3; A.T. 4.18; Plate 4.6) and since these GA were unable to influence bulb height, the enhancement in haulm length can be assigned to a regulation of leaf sheath development. Whether this regulation was attributable to an incrementation in length or number of leaf sheaths was not determined quantitatively, although visually the leaf sheaths were notably longer. In contrast, ethrel C restrained the haulm length (Fig.4.3; A.T. 4.18; Plate 4.8), through a discernable diminution in both the bulb height and the individual leaf sheath length. Remaining plant growth regulators not discussed above, produced non-significant changes with regard to the haulm length (Fig. 4.3; A.T. 4.18).

Only ethrel C and $GA_{4/7}$ led to a significant depression in bulb fresh weight (Fig.4.3; A.T. 4.19). Furthermore both $GA_{4/7}$ and GA_3 promoted extensive tillering by producing on average 2.11 ± S.D. 0.75 and 1.69 ± S.D. 0.71 tillers respectively per plant (Plate 4.7). Two plants from the IAA treatment also tillered and in each case only one tiller emerged. This phenomenon was not visualized in any of the other plant growth regulator treatments.

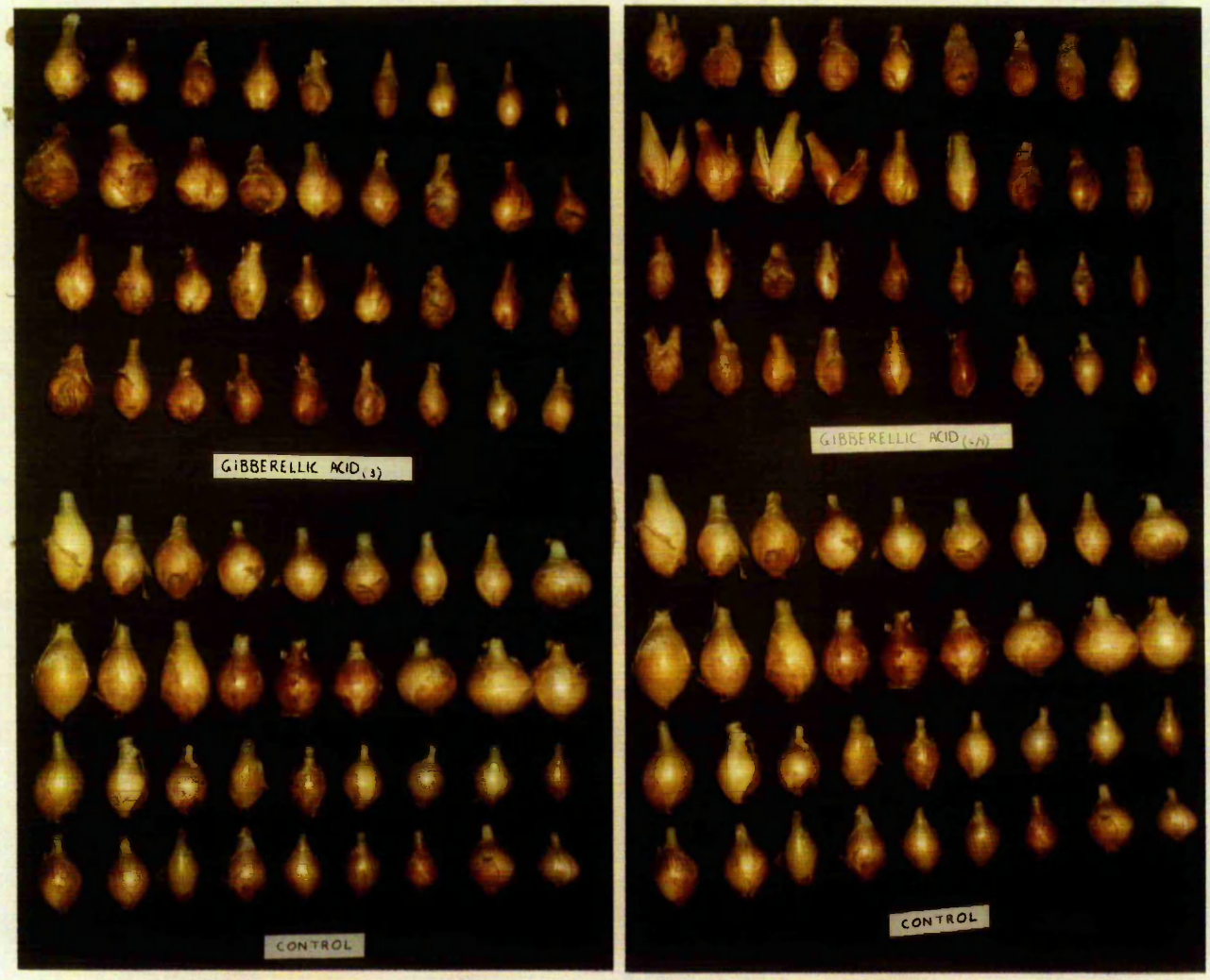
Aside from the various quantitative assessments undertaken, a number of visual differences were also observed amongst the treatments. Thus, ethrel C led to a slower production of very short leaves, whereas GA_3 and $GA_{4/7}$ produced many thin leaves, though a large proportion of these were attributable to the emerging tillers (Plate 4.6, 4.7, 4.8). In addition, $GA_{4/7}$ also led to a number of the bulbs splitting into smaller units due to the outer fleshy scales being unable to accommodate the rapid bulbing response of the individual tillers and the primary shoot (Plate 4.7). On the other hand phosphon D promoted the growth of discernably wider leaves (Plate 4.6), a response that was not visualized with the other plant growth retardants paclobutrazol and DMMC. As in the

Plate 4.4.



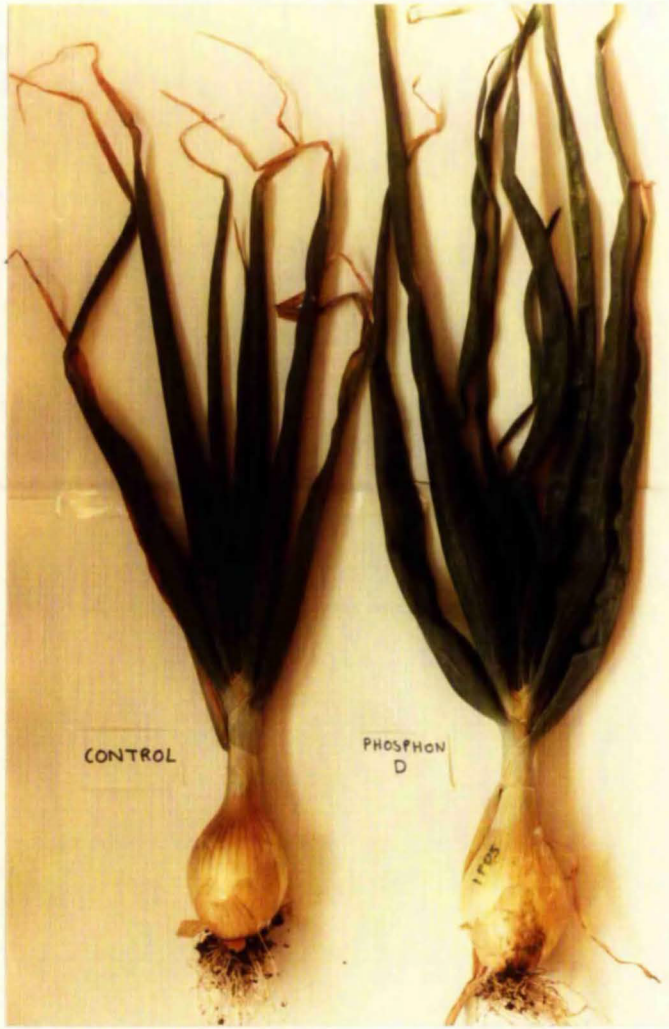
Comparisons between control (bottom two groups), ethrel C (top left group) and phosphon D (top right group) treatments on bulbing. Phosphon D treatment produced rounder bulbs without affecting bulb size, whilst ethrel C led to marked diminution in bulb size and a negligible change in bulb shape.

Plate 4.5.

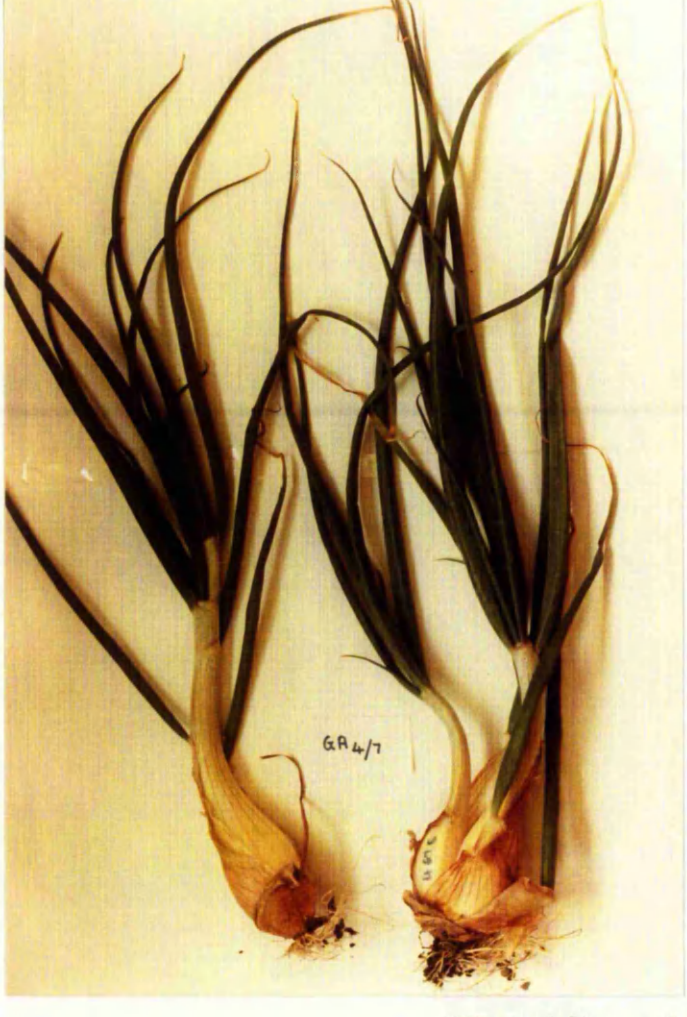


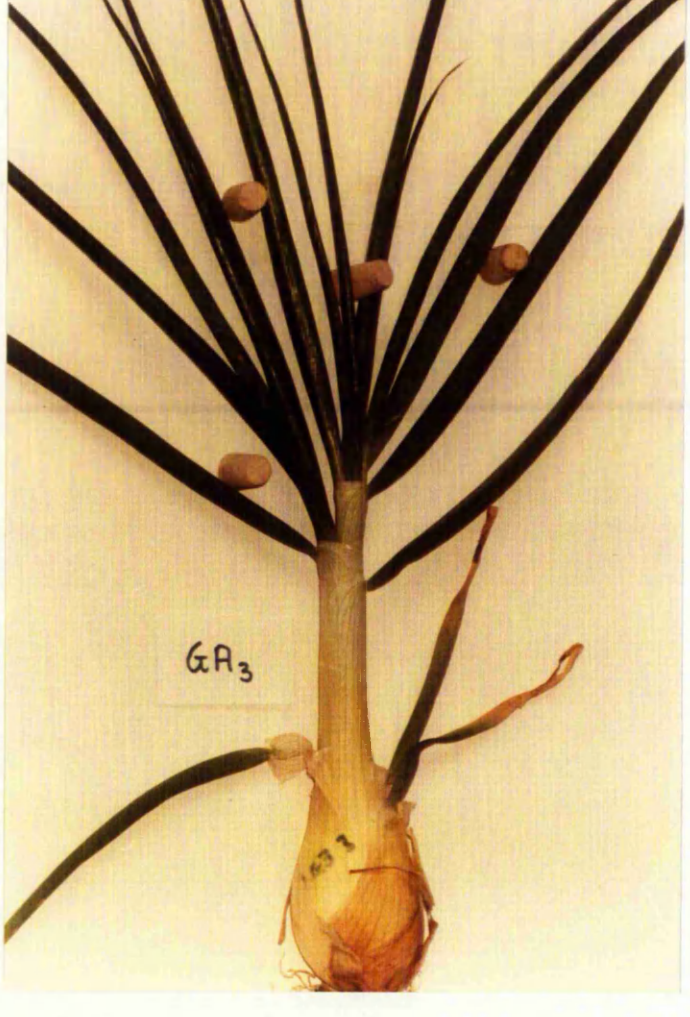
Comparisons between control (bottom two groups), GA_3 (top left group) and $GA_{4/7}$ (top right group) treatments on bulbing. Both GA_3 and $GA_{4/7}$ evoked torpedo shaped bulbs, whilst $GA_{4/7}$ also reduced bulb diameter and caused splitting into smaller bulb units.

Plate 4*6.



Effect of $GA_{4/7}$ and phosphon D on the vegetative development of kelsae onion plants. Thin leaves, increased leaf production through tillering and extended haulm length characterize the responses mediated by $GA_{4/7}$, whereas phosphon D expanded leaf width.





Effect of $GA_{4/7}$ and GA_3 on leaf and bulb development. Both plant growth regulators led to the production of thin leaves, tillers and torpedo shaped bulbs. In addition $GA_{4/7}$ also facilitated splitting of the original bulb into smaller units.

Plate 4.8.

Comparison between the control and ethrel C treated plants. Reduced bulb size, leaf sheath length, leaf blade length and leaf number characterize the responses evoked by ethrel C.

greenhouse experiment, weekly applications of IAA failed to produce a reduction in the green colouration nor symptoms of epinasty in the leaves, which characterised IAA activity in the controlled environmental experiments. (Section 3.3.1.1).

4.4. Discussion

(i) IAA mediated effects

Foliar applications of IAA under greenhouse rather than field conditions inhibited bulb development, though an increase in the bulb height : diameter ratio reflected the formation of torpedo shaped bulbs. Irrespective of whether IAA was administered to plants maintained under greenhouse or field conditions, epinastic symptoms in the leaves were not produced as previously discerned under controlled environmental conditions (Section 3.3). Although the IAA concentration of 2.86mM was a common factor, the frequency of applications varied with daily foliar sprays being utilized for the controlled environmental experiment and weekly sprays under either greenhouse or field conditions. Since IAA can be readily photo-oxidised by sunlight (Bleasdale, 1973) or metabolized within the plant (Wareing & Phillips, 1981), frequent applications may be required to develop and sustain IAA mediated effects.

The inhibition elicited by IAA on bulb fresh weight under greenhouse conditions ratifies comparable reports from other onion varieties (Kato, 1965a; Knypl, 1979). Similarly the production of torpedo shaped bulbs (Macadam, 1976) and diminutions in bulb and neck diameter and bulbing ratio (Terabun, 1967) by the synthetic auxin 2,4-D corroborate identical responses in greenhouse grown Kelsae onion plants receiving IAA. Although Brewster & Macadam (1976) and Terabun (1967) reported excessive sheath elongation by 2,4-D, this response was not verified by incrementations in the haulm length of field grown Kelsae onion plants treated with IAA.

Nevertheless reports in the literature have revealed augmentations in vegetative and bulbing characters following treatment with NAA, IPA, IBA, NOA and IAA (Jauhari & Singh, 1960; Mathur, 1971; Vaish, 1972; Srivastava & Adhikari, 1972; Kathale *et al*, 1974).

A possible explanation for the disparity amongst the effects exhibited by IAA and the synthetic auxins may depend on the con-

centration and duration of active auxin at the sites most responsive to auxin action. Certainly Vaish (1972) using either root or seed soaks of NAA or IBA observed that concentrations of 1 and 10 ppm were stimulatory, whereas 100ppm was suppressive towards dry weight gains of the onion plants. Similarly Miller, et al (1962) reported that a single foliar spray of 0.5 and 1ppm 2,4-D stimulated growth of Phaseolus vulgaris, whilst higher concentrations became progressively inhibitory.

(ii) TIBA mediated effects

Negligible changes incurred by weekly foliar sprays of TIBA on various bulb and vegetative parameters under greenhouse and field conditions were contrary to the small transient promotion in certain vegetative characters followed by a general inhibition of plant growth produced by daily foliar sprays of TIBA under controlled environmental conditions (Sections 3.3.1.1). Thus the decreased frequency of applications required to maintain an optimal level of TIBA at sites most responsive to TIBA activity may be responsible for the inactivity of TIBA under greenhouse and field conditions. Nevertheless Terabun (1967), Brewster & Macadam (1976) and Macadam (1976) diserned a lack of influence by TIBA on various aspects of onion development in other varieties.

Although TIBA appears to negate IAA translocation (Morris et al, 1973; Thomson, et al, 1973), the possibility that IAA depletion by TIBA in certain plant organs may confer an opposite effect to that manifested by IAA was not realized in regard to bulb development or the ability to promote secondary bud growth as observed in Wintex barley, Chalco teosinte (Leopold, 1949) and Lolium temulentum (Jewiss, 1972). The latter findings are based on the fact that IAA may have a central role in maintaining apical dominance over the development of the axillary buds (Wareing & Phillips, 1981).

(iii) GA mediated effects

Treatment of Kelsae onion plants with GA_3 and $GA_{4/7}$ under greenhouse and field conditions respectively decreased the bulb fresh weight and the bulbing ratio through a greater restraint on the expansion of the bulb rather than the neck diameter. Indubitably

the GA inhibition of bulb size and weight in the Kelsae variety supports comparable results from other onion varieties receiving GA_3 (Kato, 1965b; Lipe, 1975; Brewster & Macadam, 1976; Macadam, 1976; Knypl, 1980). Nevertheless GA_3 was also reported to increase the bulb diameter, fresh weight, dry weight and volume in certain onion varieties (Olivares & Manuel, 1962; Srivastava & Adhikari, 1972; Chattopadhyay, 1973; El-Habbasha & Behairy, 1977). In summary it is difficult to reconcile these differences, since the workers varied greatly in the concentrations of GA_3 they used, the frequency and method of application and also the variety chosen.

GA_3 and $GA_{4/7}$ mediated augmentations in bulb height : diameter ratios reflect the formation of torpedo shaped bulbs and substantiates the reports of reduced bulb width : length ratios (Macadam 1976) and the photographical presentations of long thin bulbs (Knypl, 1979) in other onion varieties receiving GA_3. Similarly an incrementation in the haulm length by GA_3 and $GA_{4/7}$ accords with similar observations in the Granex onion plants (Olivares & Manuel, 1962) and verifies the increased leaf sheath length : bulb fresh weight ratio of Autumn Spice onion plants (Macadam, 1976) foliar sprayed with GA_3. The capacity of GA_3 and $GA_{4/7}$ to induce tiller development in Kelsae onion plants confirms the GA_3 enhanced secondary bud growth reported by Corgan & Montano (1975). However, an increase by GA_3 on leaf number, led Lipe (1975) and Knypl (1980) to suggest either a stimulation of normally dormant leaf blades in the bulb centre or development of adventitious buds on the shoot axis. Nevertheless an examination of axillary bud development in the variety Excell by Abdalla & Mann (1963) revealed the formation of these buds in the axils of the 7,8, 9 and 10th leaf after bulb inception. Assuming a similar growth pattern in the Kelsae onion, GA applications could have exacerbated early formation and growth of these axillary buds. Certainly cross sectional examination of mature GA_3 treated bulbs from the greenhouse experiment, ascertained that early axillary bud growth led to a number of small bulbs forming which were enclosed by a few outer fleshy scales. These smaller bulbs appeared to be comprised of swollen sheaths encircling a number of primordial bladed leaf units. In extreme cases the rapid

swelling of these small bulbs may be responsible for the splitting of the outer fleshy scales as observed in bulbs treated with $GA_{4/7}$.

The fact that $GA_{4/7}$ and GA_3 stimulated secondary bud growth in onion disagrees with reports on Sorghum bicolor (Morgan et al, 1977; Isbell & Morgan, 1982) and Lolium perenne (Jewiss, 1972), where GA_3 inhibited tiller production. However, work by Clifford & Langer (1975) and Sharif & Dale (1980) on Lolium multiflorum var. Westerwoldicum and Hordeum vulgare respectively disclosed that GA_3 could promote elongation and dry weight gains of tiller buds, thereby suggesting GA promotion of sinkactivity in the buds. A similar proposal may also be tenable in onion plants receiving either GA_3 or $GA_{4/7}$, since tiller bud development was apparently at the expense of bulb and leaf expansion. Indubitably, the characteristic development of thin leaves attributable to GA treatment ratifies similar findings in other onion varieties (Corgan & Montano, 1975; Knypl, 1979).

(iv) Plant growth retardant mediated effects

Irrespective of the environmental conditions, onion plants treated with CCC, phosphon D, DMMC or paclobutrazol led to negligible changes in bulb and neck diameter, bulbing ratio and bulb fresh weight. The inability of plant growth retardants to facilitate changes in bulb size and weight was also evinced using SADH, ancymidol, CCC and DMMC on other onion varieties (Sinnadurai et al, 1971; Bussell, 1972; Corgan & Montano, 1975; Lipe, 1975; Lercari & Ceccarelli, 1975; Brewster & Macadam, 1976; Macadam, 1976; Knypl, 1979). In contrast, DEHEG, DEOMC, DMOMC, CCC and phosphon D enhanced bulb fresh weight and diameter (Knypl, 1980). Since these workers used different types and concentrations of plant growth retardants, methods of application and various onion varieties, the possibility of varietal specificity and sensitivity to these retardants cannot be overlooked.

The presence of dry soil conditions in the field experiment, may have reduced the effectiveness of paclobutrazol, especially as Shearing & Batch (1982) and Levy et al (1982) discerned that a high soil moisture content was required for maximal uptake of this retardant. A similar argument may also apply to phosphon D, for

although leaf width was considerably increased, changes in the bulb weight and diameter were not attained as previously reported by Knypl (1979) for this retardant. However, phosphon D was able to produce a smaller bulb height : diameter ratio that reflected the formation of rounder bulbs. Although paclobutrazol and phosphon D reduced the haulm length under controlled environmental conditions (Section 3.3), similar attributes were not disclosed under field conditions. Furthermore, the inability of CCC, phosphon D, paclobutrazol and DMMC to induce secondary bud growth was contrary to reports of enhanced tillering in Triticum vulgare (Tolbert, 1960a,b) and Poa pratensis (Van Andel, 1973) treated with CCC.

(v) Ethrel C mediated effects

Under greenhouse conditions, the CEPA (active ingredient of ethrel C) mediated promotion of bulb development prior to a diminution in final bulb size and fresh weight, also observed under field conditions, corroborates comparable findings by Levy & Kedar (1970), Bussel (1972), Corgan (1974), Saimbhi et al (1974), Lipe (1975, 1976a,b) and Brewster & Macadam (1976). Similarly the decreased neck diameter accords with analogous effects mediated by CEPA in combination with SADH on Yellow Sweet Spanish and El Capitan onions (Montano, 1971) and probably reflects the reduced production of leaves normally expected to expand the neck. Without a doubt, CEPA severely depressed vegetative growth as exemplified by moderations in haulm length and overall plant height and thereby confirms similar diminutions reported by Corgan (1974), Saimbhi et al (1974) and Lipe (1975, 1976a,b). Although leaf number estimations were not attempted on Kelsae onion plants treated with CEPA, an examination of Plate 4.8 infers a suppressive role which was ratified previously by Levy, Kedar & Karacinque,(1973) and Lipe (1975). Since leaf height, top fresh and dry weight were significantly correlated with bulb yield (Pande & Mundra, 1971; Sabota & Downs, 1981) and bulb dry matter yields were linearly related to total radiation intercepted during bulb growth (Brewster, 1982), diminutions incurred by CEPA on total leaf area, through moderations in leaf number and height, can therefore be expected to moderate bulb yields at maturity. However, it must be stressed

that the reduced bulb yields may involve the action of two processes, one mediated by CEPA and the other initiated by the bulbing phase, since bulbing promoted by conducive environmental conditions can also suppress further leaf development. The possibility that the latter process may be controlled by endogenous ethylene levels was investigated by Levy et al (1979). Although these workers tentatively demonstrated increased endogenous ethylene levels during bulbing under field conditions, bulbing was not associated with a rise in the endogenous ethylene levels when conducive long daylengths and light quality containing low R:FR ratios were given under controlled environmental conditions (Levy et al, 1979). CEPA also decreased the bulb height : diameter ratio, thereby promoting the development of flatter bulbs for plants grown under greenhouse conditions, whereas a similar effect was not observed in the field. Nevertheless the development of flat bulbs under greenhouse conditions supports the enhanced bulb width : length ratio incurred by CEPA in Autumn spice onions (Macadam, 1976).

(vii) Silver mediated effects

Foliar applications of $AgNO_3$ to onion plants grown in the greenhouse led to a gradual depression in the bulb diameter and fresh weight, while having a negligible effect on the other bulb and vegetative characters. The cation Ag^+ is believed to interfere with either the binding sites for ethylene action, inhibit synthesis of ethylene from 1-amino cyclopropane-1-carboxylic acid (ACC), production of ACC by ACC synthetase (Veen, 1983) or form diethylene complexes ($Ag(C_2H_4)_2$) (Kasai et al, 1980). In these circumstances an enhancement of bulbing in onion plants by ethylene may be moderated by Ag^+. Certainly the immersion of onion plant roots in a solution containing $AgNO_3$ has led to the suppression of bulbing under inductive long day conditions (Levy et al, 1979). However these workers were unable to equivocally establish a correlation between endogenous ethylene levels and the process of bulbing. This problem is further complicated by the fact that $AgNO_3$ is phytotoxic and acts as a general non-competitive enzyme inhibitor (Veen, 1983). Thus diminutions produced by $AgNO_3$ on the bulb diameter and fresh weight of the onion variety Kelsae

may represent phytotoxic symptoms.

Due to the phytotoxic nature of the Ag^+ cation, the anionic complex $Ag(S_2O_3)_2^{3-}$ (STS) was utilized in the field experiment, since Veen *et al* (1980) ascertained that for a concentration of 2.0mM STS only 0.46pmol.l^{-1} Ag will be present in the toxic cationic form. However foliar sprays of STS on onion plants produced negligible changes in the various bulb and vegetative characters, intimating either photo-oxidation by sunlight, absence of an interaction between endogenous ethylene and STS over the regulation of bulbing or there were problems in leaf penetration and/or subsequent translocation to relevant receptor sites. The latter suggestion appears tentative, since Beyer (1976) showed that foliar applied $AgNO_3$ must have penetrated the plant tissues to prevent ethylene mediated senescence in *Gossypium hirsutum* leaves and growth retardation, stem swelling and horizontal growth in etiolated *Pisum sativum* seedlings. Similarly Veen & Van de Geijn (1978) observed that STS was transported through the xylem at a greater speed than Ag^+ in *Dianthus caryophyllis* cut stems immersed in the treatment solutions. Although the work of Veen & Van de Geijn (1978) implies that STS and Ag^+ can be translocated through the xylem, comparable movement within the phloem of onion leaf blades to the leaf sheaths may be prevented.

5. GENERAL DISCUSSION

5.1. Critism of experimental techniques

Cognizance should be focused on the control of various environmental factors in the cool (15°C) and warm (24°C) growth cabinets utilized in Chapter 3 and 4. Thus thermohydrograph recordings established a ± 2°C differential inside the cool growth cabinet, which could be attributed to external fluctuations in the temperature. Generally a slightly higher temperature prevailed within the cabinet when the external temperature fell below 15°C, while the converse applied at higher external temperatures. However when the external temperatures approached and exceeded 24°C, maintenance of a constant temperature within the warm growth cabinet became impossible and higher temperatures prevailed. This situation was to be expected, since the warm growth cabinet relies on air outside the cabinet to cool the heat emissions of the fluorescent tubes. As the warm growth cabinet was located in an unheated greenhouse, the temperature problem was negated by conducting the majority of experiments during the cooler part of the year. Although the refrigeration system works against the heat emissions of the fluorescent tubes in the cool growth cabinet, the utilization of a 4h night period invariable led to a temperature drop of between 1 to 2°C, according to thermohydrograph readings. A similar temperature drop prevailed in the warm growth cabinet, irrespective of the fact that the thermostatically controlled fan-heaters operated throughout the night period. In addition, there was no control over the atmospheric humidity levels in either the Fison's, warm or cool growth cabinets and intermittent checks revealed highly variable relative humidity values. Although temperature (Butt, 1968) and humidity (Milthorpe & Moorby, 1979) variations can be expected to influence plant growth, the application and assessment of various treatments at similar times in these cabinets enable all the onion plants for a particular experiment to receive identical environmental conditions. However this assumption will only hold if the various treatments act independently of the effects evoked by temperature and humidity fluctuations. In the light of this evidence, improvements to the

growth cabinets should entail the instalment of humidifiers, besides the introduction of heating elements and a refrigeration unit in the cool and warm growth cabinets respectively. Furthermore a slightly faster circulation of air may further moderate temperature fluctuations within the warm and cool growth cabinets.

Of the various experiments conducted in the growth cabinets where light quality represented one of the treatments under investigation, replication of C37 and AW light compartments was impracticable owing to the small size of the growth area. Nevertheless the incorporation of replicate blocks in each light quality compartment enable the light quality effects to be partitioned from changes produced by subtle environmental differences within the compartments. However the replicate blocks cannot account for possible differential heat and UV emissions of C37 and AW fluorescent tubes, nor variable temperature and humidity fluctuations between light quality compartments, since these will be confounded with the light quality effects. To some extent the undesirable fluorescent tube emissions will be dissipated in the Fison's and cool growth cabinets by the presence of a glass sheet barrier located directly below the light source, though this will not apply to the tall growth cabinet utilized in Chapter 2. The incorporation of specific filters and a water bath to reduce the level of UV and heat radiation respectively, may solve the above problem. Such measures can be expected to decrease the light intensity, though this may be overcome by installing a double bank of the appropriate fluorescent tubes. To isolate the possible effects of dissimilar temperature and humidity fluctuations between light quality compartments, the experiments must be repeated with the fluorescent light exchanged between the light quality compartments. Since temperature and humidity measurements were generally comparable between light quality compartments, the value of repeating these time consuming experiments is questionable, especially when there is a time limit on the research project. The converse situation may apply to the field experiment in Chapter 4, since weather conditions can be expected to vary between years. In these circumstances repetition of the field experiment in subsequent summer seasons will show whether the different plant growth regulators can exert the same

degree of influence irrespective of the weather conditions. This requirement gains further support when soil drench treatments of paclobutrazol are considered, for paclobutrazol activity is dependent on a high soil moisture content (Lever et al, 1982) and the dry soil conditions experienced during the summer of 1983 were probably responsible for the paclobutrazol inactivity.

Despite utilizing similar growing conditions in each experiment, a fair degree of heterogeneity persisted between the onion seedlings in regard to plant size. By selecting plants on the criterion of similar leaf lengths and ensuring that the mean leaf length between treatments were approximately the same at the start of the experiment, treatment differences were generally obtained with a minimum of interference from between plant variation. Since plant heterogeneity may in part be attributed to genetic variation, vegetative propagation to obtain plants of the same genotype may improve plant uniformity and hence increase the resolution of the treatment effects. This proposition appears feasible as Hussey (1978) has developed an in vitro propagation technique, whereby axillary and adventitious shoot proliferation with associated root formation can be obtained from shoot and scale base explants dissected from a single bulb and grown on nutrient agar.

Due to the incorporation of moss peat into the growth medium, total removal of peat particles from the brittle roots was impractical without incurring a substantial loss in root material. As a result, great variation was observed between replicate means of the various root determinants and this probably accounted for the lack of resolution between some treatment means. Although this difficulty may be overcome by replacing moss peat by sedge peat, thereby maintaining the soil water retentive properties of the growth medium, further experiments will be required to determine its suitability for handling in paperpots, for onion growth and removal during root cleansing.

Although the leaf area determinations adequately highlight the different areas produced by the various light quality and plant growth regulator treatments, the accuracy of these estimations can be questioned. This is because the leaf area formulas were derived

from leaf width and length measurements attempted on leaves grown only under AW light and assumes that the modifications produced under other light quality and plant growth regulator treatments will lead to either a proportional decrease or increase in leaf length and width. Leaf area differences produced by C37 and AW light quality probably follow the above assumptions fairly closely, but discrepancies can be expected from the plant growth regulator treatments, since they preferentially increased or decreased leaf width or length. Improvements in the accuracy and speed of leaf area determinations could be achieved by using a Li-Cor area meter (Lambda Instruments Corporation, Lincoln, Nebraska) previously utilized for tissue and lumen area determinations. However maximal effectiveness of the area meter is dependent on having an absolutely flat leaf and doubts are still entertained as to whether the more solid IAA and ethrel C treated leaves will flatten sufficiently even when cut longitudinally into halves.

Preliminary experiments revealed that leaf samples stored in FAA for 1 week showed negligible shrinkage when the number of palisade mesophyll cells per unit distance was estimated. However doubts may be raised as to whether some cell shrinkage will develop during the 1 to 2 month storage period required in Experiment A of Chapter 3. This problem was partially overcome by analysing the various leaf samples after they had been stored in FAA for approximately the same period of time. The same problem was not encountered in Experiment C of Chapter 3, since only 4 consecutive days were required to analyse the small number of leaf samples for their various cellular determinants.

In outlining lumen and tissue perimeters of transverse leaf sections, problems were encountered with the irregular breakage of the parenchymatous tissue to form the lumen area. Generally this was associated with recently emerged leaf tissue and leaves treated with IAA or ethrel C and took the form of either severe and irregular sized corrugations or the formation of several small lumens. The former difficulty was overcome to some extent by drawing the perimeter line through approximately the mid-height of each corrugation. In the latter case a rough approximation was achieved by encompassing only those adjacent lumens, whose partitions

were virtually 1 cell thick, within a single lumen perimeter.

Accurate assumptions can be generally made on whether the various treatments affected individual palisade mesophyll cell expansion from estimating palisade mesophyll cell number per unit distance. However the usefulness of such data must be treated with caution in deciding if a concurrent lack of cell expansion with enlargement or moderation of leaf blade dimensions can be attributed to changes in cell division. This is because estimates of cell number per unit distance were based on the length covered by a specific number of adjacent touching cells and does not take into account the intercellular air spaces that often occur between groups of palisade mesophyll cells. This problem could be resolved in future experiments, by calculating what percentage of length is taken up by intercellular air spaces within the distance covered by a specific number of cells. In contrast determinations of epidermal cell dimensions will give a more accurate indication on whether a particular treatment impaired cell division due to the absence of intercellular air spaces in the epidermal cell layer. Furthermore an accompanying check showing that the epidermal : stomatal cell number ratio was not changed during each treatment would add further weight to a proposal implying a change in cell division activity.

5.2. Overview and theories for physiological effects incurred.

The present investigation was conducted to determine in detail what influence light quality, photoperiod and plant growth regulators have on various gross morphological and leaf cellular parameters of onion seedlings prior to and during the bulbing phase. Available evidence in the literature concerning the effects of light quality and plant growth regulators appears fragmentary, lacks resolution and was often contradictory, especially when the latter was considered. In addition, the absence of published data concerning the influence of different environmental factors and plant growth regulators on large exhibition onion varieties needs to be rectified, so comparisons can be confidently drawn with smaller onion varieties, and techniques developed to improve existing methods of propagating exhibition varieties.

When considering the effect of light quality on onion seedling development, it was evident that irradiation with C37 rather than AW light increased the leaf blade and sheath dimensions, fresh and dry weight of the whole plant, leaves and combined basal region & leaf sheaths, while the converse applied to the root fresh and dry weight. Since the major difference between C37 and AW light was the lower R:FR ratio emitted by the former light source, the various photomorphogenetic alterations were attributed to changes in either the phytochrome equilibria (P_{tot}/Pfr) (Smith, 1982) or the quantity of the presumed active moiety Pfr (Schäfer, 1981). However neither theory can be confirmed unequivocally owing to the inability to monitor Pr and Pfr levels in green plants (Smith, 1982) and the lack of complete evidence on how phytochrome triggers the various biochemical events leading to the observed photomorphogenetic responses (Marmé, 1977; Schopfer, 1977). In spite of this problem phytochrome appears to have some control over dry matter distribution and cellular expansion in the onion plant, though doubts exist with photosynthetic efficiency. Thus from an inspection of the DWR, it was apparent that C37 light emitting a lower R:FR ratio than AW light promoted a greater accumulation of dry matter in the combined basal region & leaf sheaths at the expense of the roots. Once sufficient time has elapsed to enable bulbing to commence under the inductive C37 light, both the leaf and root DWR decreased, thereby implying a major transfer of metabolites to the swelling combined basal region & leaf sheaths. Certainly incipient bulbing led to an observable diminution in leaf elongation of the Kelsae onion variety and is consistent with reports of reduced leaf (Nagai & Hanaoka, 1967) and root (Kato, 1963) production in other onion varieties. However a different situation prevails with dicotyledenous plants, since irradiation with light sources containing a low rather than a high R:FR ratio increased the stem DWR at the expense of the leaf and root DWR and thereby accounted for the augmentation in stem length concurrent with a reduction in leaf area and root matter (McLaren & Smith, 1978; Corré, 1983).

Although plant dry weight and leaf area were enhanced by C37 rather than AW light during the pre-bulbing phase, these changes were not

ratified by promotions in either the ULR or RGR to indicate photosynthetic gains through increased light interception and/or photosynthetic efficiency. In contrast light emitting a low R:FR ratio apparently lowered the ULR of Rumex obtusifolius (McLaren & Smith, 1978), though this response could be attributed to a commensurate reduction in both leaf area and Chl content per unit leaf area, thereby impairing light interception and utilization. During incipient bulbing, the diminution in the LAR was likely to be a direct result of the decline in leaf development, whilst bulb dry weight was rapidly increasing.

Prior to bulbing, C37 light enhanced the fresh weight of the leaves and combined basal region & leaf sheaths to a greater extent than AW light and the response was corroborated by an augmentation in the SWC of these organs. Thus a C37 light mediated enlargement of the leaf blades and sheaths along with a high SWC corroborates the marked expansion elicited by C37 light on epidermal and palisade mesophyll cell length and width. As a result of the cell expansion evoked by C37 light parallel to the leaf surface rather than at right angles, a commensurate increase and decrease was observed in the lumen and tissue areas respectively and accordingly led to a decrease in the leaf gauge. The converse situation was applicable under AW light. In addition the epidermal cell expansion produced by C37 in preference to AW light was presumed responsible for the reduction in stomatal propinquity, while the constant distance between vascular bundles intimates an increase in their number owing to the augmentation in leaf width by C37 light. A different situation pertained in the dicotyledenous species Rumex obtusifolius, where light emitting a low R:FR ratio moderated epidermal and palisade mesophyll cell expansion (McLaren & Smith, 1978). However this result was probably due to the available assimilates being directed away from leaf development to meet the energy demands of enhanced stem extension also promoted by this particular R:FR ratio.

Exposure of onion plants to different daylengths showed a progressive increase in the leaf blade and leaf sheath length with extension of daylength from 11 to 20h. However an interaction pertained between light quality and daylength whereby the above responses

were observed for plants receiving C37 light, whilst AW light evoked only an exiguous augmentation with extension of daylength. A similar light quality x daylength interaction was evident for bulbing, though in this instance leaf sheath swelling was only promoted when the daylength exceeded 14h and the plants were irradiated with C37 rather than AW light. In addition a 20h daylength initiated bulbing 2 weeks earlier than a 17h daylength. Although the exact mechanism for photoperiodic timing in plants has still to be resolved, the photoperiodic control of various morphological determinants may involve an endogenous circadian rhythm of phases with different sensitivities to light, as envisaged by Vince-Prue (1975) for floral induction in other species. In view of the fact that the different R:FR ratios of C37 and AW light could control these photomorphogenetic responses in the onion plant, it is quite possible that the envisaged circadian rhythm was phased by phytochrome. A certain rhythmicity appears to control bulbing, since interpolation with light emitting a low R:FR ratio during a photoperiod inductive towards bulbing was only inhibitory at the beginning and end of the photoperiod, while promoting bulbing during the mid portion of the photoperiod (Lercari, 1982).

When examining the effects of the plant growth regulators IAA, GA and ethrel C, due consideration was also given to their purported antagonists. Thus the effects of IAA were compared with those of the IAA transport inhibitor TIBA (Morris et al, 1973), $GA_{4/7}$ and GA_3 with various plant growth retardants presumed to interfere with GA and/or lipid biosynthesis (Dicks, 1979) and ethrel C in relation to $AgNO_3$ and STS which may modulate ethylene biosynthesis or block ethylene binding sites (Veen, 1983).

Comparisons between the effects engendered by IAA and TIBA during the pre-bulbing phase of development revealed that the former and to a lesser extent the latter moderated the dry weight of the total plant and constituent organs. Only IAA changed the dry matter distribution by increasing the combined basal region & leaf sheaths DWR and decreasing the leaf DWR. Nevertheless the faster senescence rate observed in the old leaves was probably responsible for the disparity in the DWR due to dry matter accumulation in the

leaves and combined basal region & leaf sheaths being slower than the loss of leaf tissue through senescence. However the DWR results were consistent with findings obtained from treating Phaseolus vulgaris with 2,4-D concentrations exceeding 1ppm (Miller et al, 1962), since the estimated leaf DWR was preferentially reduced in respect to stem and root DWR.

A possible impairment in photosynthetic gains may also be intimated, since IAA and during the post-spray period, TIBA, depressed the ULR and RGR. Certainly the severe curtailment in light interception through a diminution in leaf expansion and a reduction in the light energy harvesting pigment, Chl, (data not presented) adds further credence to a postulated impairment of photosynthetic capacity. A similar argument may also apply to TIBA since the Chl content (data not presented) was depressed, though the leaf area was not affected.

Besides producing severe epinasty, IAA also elicited a greater succulence in the leaf blades and sheaths which was corroborated by increased leaf and combined basal region & leaf sheaths SWC. In these circumstances, the rapid increase observed in the LAR and SLA during the post-spray period and attributed to a decline in IAA activity, may imply a higher water content through augmented cell expansion. Certainly the marked increase in palisade mesophyll cell length observed in IAA treated plants during the post-spray period lends support to this theory. Although TIBA produced a greater SLA, LAR and leaf SWC during the spray and post-spray period, the results were not ratified by noticeable leaf succulence nor a continued enlargement of successive epidermal and palisade mesophyll cells.

In general the marked reductions incurred by IAA on leaf area and in particular leaf width can be assigned to diminutions in the epidermal and palisade mesophyll cell length and width. This contrasts sharply with the majority of evidence indicating that IAA produces an increase in cell size through a cascade effect which involves changes in membrane permeability and enzymatic regulation of protein, cellulosic and hemicellulosic matrix of the cell wall (Bandurski & Nonhebel, 1984). Nevertheless the possibility exists for a differential sensitivity to IAA, whereby low

concentrations are stimulatory, while high concentrations became inhibitory towards cell expansion. Certainly foliar sprays of 10ppm NAA or IBA (Vaish, 1972) and 0.5 to 1ppm 2,4-D (Miller et al, 1962) stimulated growth of Allium cepa and Phaseolus vulgaris plants respectively, whereas higher concentrations became progressively inhibitory. In response to the restraint evoked by IAA on epidermal cell expansion, the leaf lumen remained generally occluded and hence accounted for the thicker leaf gauge incurred. Furthermore this same constraint presumably forced the palisade mesophyll cells to maintain their rectangular shape after cell division and thereby negated the formation of intercellular air spaces, which normally arise from the palisade mesophyll cells taking on a isodiametric shape. A similar occlusion of intercellular air spaces was evident from Phaseolus vulgaris (Burton, 1947) and Cyperus rotundus (Eames, 1949) leaves treated with 2,4-D. In addition the inhibition in epidermal cell expansion was also responsible for the increased stomatal propinquity, whereas the reduction in epidermal and palisade mesophyll cell width accounted for the close proximity between vascular bundles. Furthermore this explanation lends credence to the development of closely apposed veins in Gossypium hirsutum (Gifford, 1953) leaves receiving 2,4-D.

On the other hand the TIBA induced elongation of the topmost fourth leaf section could be attributed to a concurrent increase in the epidermal and palisade mesophyll cell length, while the width of these cell types was decreased to compensate for this polarized growth pattern. Aside from this transient effect evoked by TIBA, the majority of responses elicited by TIBA on various cellular and gross morphological characters were comparable to those of IAA. Thus it is difficult to envisage TIBA producing the converse symptoms to those of IAA in onion plants on the assumption that TIBA appears to inhibit the polar movement of IAA.

The bulbing response of onion plants receiving weekly foliar sprays of IAA under greenhouse conditions was the development of small torpedo shaped bulbs. Since the synthetic auxin 2,4-D produced excessive sheath elongation (Terabun, 1967; Brewster & Macadam, 1976), a similar response by IAA may be responsible for changing

the direction of parenchymal cell expansion in the swelling leaf sheaths so elongated bulbs were formed. However the failure to obtain comparable results in field conditions could be associated with the rapidity by which IAA is photo-oxidised(Wareing & Phillips, 1981). In contrast weekly foliar sprays of TIBA produced negligible effects on bulbing, irrespective of whether the onion plants were maintained under greenhouse or field conditions.

In regard to the effects elicited by various GA and plant growth retardants, use of the former group revealed that foliar sprays of $GA_{4/7}$ engendered a faster moderation of leaf width than GA_3. Such a response intimates that GA_4 and/or GA_7 could represent GA actively regulating onion plant development, whereas GA_3 is a less active intermediary in the pathway leading to GA deactivation. Since this assumption was based on the GA biosynthetic pathway of Gibberella fujikuroi (Jones & MacMillan, 1984), it must be treated with due caution until a similar pathway is confirmed in Allium cepa. Of the various plant growth retardants assessed, paclobutrazol, AMO-1618 and phosphon D were deemed active and then only when applied as soil drenches rather than foliar sprays on the onion plants. Since Lever et al (1982) demonstrated that paclobutrazol was exclusively translocated through the xylem, a similar route may also be pertinent to AMO-1618 and phosphon D.

When comparing the responses manifested by phosphon D and $GA_{4/7}$ on various onion plant characters during incipient bulbing, the former had a negligible effect on the dry weight of the total plant and its constituent organs, whilst the latter reduced the total plant dry weight mainly through a diminution in total leaf dry weight. However both $GA_{4/7}$ and phosphon D effectuated changes in dry matter distribution. Thus the diminution produced by phosphon D on the combined basal region & leaf sheaths DWR implies that less assimilates were directed to the leaf sheaths and thereby accounted for their reduced growth in length. Certainly the expected high energy demands required to produce the enlarged leaves incurred by phosphon D was probably responsible for this decrease in leaf sheath length, besides depressing overall leaf production and accelerating senescence in the older leaves. However plant growth retardants appear to produce a range of dry matter

distribution patterns since Daucus carota (Dyson, 1972) and Beta vulgaris (Jaggard et al, 1982) yielded low leaf and high root DWR, suggesting that assimilates were preferentially diverted to the roots. In contrast a specific reduction in the stem DWR (whilst the converse applied to the leaf and root DWR) was observed in the dicotyledenous species Nicotiana tabacum (Humphries, 1963) and Brassica oleracea (Van Emden & Cockshull, 1967) and reflects the characteristic diminution generally promoted by plant growth retardants on stem extension (Cathey, 1975).

Although $GA_{4/7}$ produced no significant alterations in the DWR to indicate dry matter distributions between the leaf, combined basal region & leaf sheaths and roots, $GA_{4/7}$ appeared to enhance leaf production, leaf sheath length and with time, tiller development. Since individual leaf areas were substantially reduced, available assimilates may be directed towards promoting leaf production and leaf sheath growth. The influence exerted by GA on assimilate distribution in onion plants appears to be at variance with other species, since in Lycopersicon esculentum (Bora & Selman, 1969) and Ipomoea caerulea (Njoku, 1958) the stem DWR was specifically enhanced at the expense of the root and leaf DWR. However in Daucus carota GA_3 engendered an increase in the shoot/root dry weight ratio (Currah & Thomas, 1979).

A compensatory growth change by $GA_{4/7}$ favouring longitudinal rather than lateral expansion of the leaf sheaths probably explains why torpedo shaped bulbs were obtained under controlled environmental, greenhouse and field conditions. The converse situation may pertain with phosphon D, since the restraint on leaf sheath extension was later manifested in the formation of spherical bulbs under field conditions.

Although phosphon D was unable to modify the total plant dry weight, a small but non-significant reduction by $GA_{4/7}$ tentatively infers a diminution in photosynthetic gains. Certainly the ability of $GA_{4/7}$ to reduce light interception through a moderation in the leaf area may explain the reduced photosynthetic capacity. This argument is reinforced by the fact that onion bulb yields were positively correlated with leaf height (Pande & Mundra, 1971)

and bulb dry matter yields were linearly related to total radiation intercepted during bulb growth (Brewster, 1982).

The marked reduction produced by $GA_{4/7}$ on leaf width could be attributed to a decrementation in the epidermal and possibly the palisade mesophyll cell width. However the absence of a similar association in regard to leaf length with epidermal and palisade mesophyll cell length, suggests that the diminution was through a suppression in cell division. The same proposal may apply to stomatal and vascular bundle frequency, since these determinants failed to increase when the leaf width and length was moderated. In spite of the fact that leaf width was decreased, a proportional reduction in the lumen and tissue area was sustained by $GA_{4/7}$ and intimates a negligible alteration in the leaf gauge. This implies that a compensatory growth change favouring cell expansion at right angles rather than parallel to the leaf surface was unlikely and further emphasizes the possible impairment in cell division. Evidence gleaned from the literature suggests that GA affects the process of cell division in higher plants by increasing the size of the meristematic region and the number of cells undergoing division (Jones & Macmillan, 1984). Thus it may be argued that $GA_{4/7}$ promoted cell division activity in specific meristematic zones of the onion plant, thereby enabling increases in leaf production and tiller initiation to be manifested. In turn the implied impairing of cell division in the individual leaves may simply be due to depressed assimilate availability, since the zones of increased growth initiated elsewhere by $GA_{4/7}$ will act as strong sinks for the available assimilates. Although $GA_{4/7}$ apparently increases cell extensibility in a variety of species (Jones & Macmillan, 1984), the converse situation apparently applies to epidermal and palisade mesophyll cells of the onion leaf blades, since their expansion in width was moderated.

When considering the role of phosphon D on leaf cellular development, an enhanced rate of cell division appears to account for the enlarged leaf width, as epidermal and palisade mesophyll cell width was unaffected. Similarly the fact that the stomatal and vascular bundle frequencies failed to decrease with the expansion in leaf width also intimates increased production of these determinants. In

contrast the expansion in leaf width led to a proportional augmentation in the lumen and tissue areas, thereby implying little change in the leaf gauge and presumably a lack of cell division and /or cell expansion at right angles to the leaf surface. If phosphon D inhibits GA biosynthesis (Dicks, 1979), then a reduction can be expected in the proposed GA levels required to promote cell division in certain meristematic zones of the onion plant. Thus the outcome of this action may be responsible for the suggested increase in cell division activity and the development of a strong assimilate sink in the enlarged individual leaves produced by phosphon D.

Under controlled environmental conditions, foliar sprays of ethrel C reduced the size and number of leaves and also the dry weight of the total plant, leaves, combined basal region & leaf sheaths and roots. The effect elicited by ethrel C on the former three gross morphological parameters of the onion variety Kelsae ratifies similar attributes produced by CEPA on other smaller onion varieties (Levy, Kedar & Karacinque, 1973; Corgan, 1974; Lercari & Ceccarelli, 1975; Lipe, 1975). A closer examination revealed that ethrel C evoked a change in the dry matter distribution, whereby the combined basal region & leaf sheath DWR was specifically enhanced. Certainly a marked reduction in the leaf and root dry weight tends to support the proposed dry matter accumulation in the basal region of the leaf sheaths following ethrel C induced bulbing. Similarly Nagai & Hanaoka (1967) and Kato (1963) observed diminutions in leaf and root development respectively on incipient bulbing. In addition a growth change favouring lateral rather than longitudinal leaf sheath expansion, that was observed under controlled environmental conditions, may further substantiate the early bulbing and formation of flat shaped bulbs engendered by ethrel C under greenhouse and field conditions. In spite of the fact that foliar sprays of $AgNO_3$ and STS were only applied under greenhouse and field conditions respectively, the former led to an exiguous reduction in bulb size, but without altering bulb shape. In contrast STS was apparently unaffective and this may be either attributed to problems of penetration, poor translocation or photo-oxidation. Since ethrel C severely suppressed total plant dry weight, a reduction in the photosynthetic rate may be presumed. Indeed the diminution in leaf area with a

resultant decline in light interception may have contributed to the reduction in photosynthetic capacity and led to the production of small bulbs at maturity under greenhouse and field conditions. This argument is further supported by the fact that onion bulb yields are positively related to leaf height, fresh and dry weight (Pande & Mundra, 1971) and to total radiation intercepted during bulb growth (Brewster, 1982).

Ethrel C also influenced the SWC of the combined basal region & leaf sheaths and roots. A decline in the former character probably reflected indirectly the higher predominance of dry matter accumulating in the bulb whereas an increase in the latter parameter could indicate symptoms of increased cell expansion.

The severe curtailment on leaf length engendered by ethrel C can be attributed mainly to a diminution in epidermal and palisade mesophyll cell length. Although leaf width was also reduced by ethrel C, the negligible change in epidermal and palisade mesophyll cell width suggests a suppression of cell division at right angles to the longitudinal axis of the leaves. As a consequence of the shortening imposed on the epidermal cell length and the proposed lateral reduction in cell number, an increase in stomatal and vascular bundle propinquity was established. Certainly the ability of ethylene, the active ingredient of ethrel C, to moderate cell expansion and cell division was also observed in the subhook region of etiolated Pisum sativum seedlings (Apelbaum & Burg, 1972; Stewart et al, 1974). Although the increased leaf gauge produced by ethrel C reducing the lumen area in preference to the tissue area could be due to either a diminution in cell number and/or a curtailment in epidermal and palisade mesophyll cell expansion parallel to the leaf surface, the possibility of cell expansion at right angles to the leaf surface should not be overlooked. Support for the latter option arises from the augmented lateral expansion in the subhook cortex cells of etiolated Pisum sativum seedlings treated with ethylene (Stewart et al, 1974).

The plant growth regulators IAA, phosphon D, ethrel C and $GA_{4/7}$ interacted with light quality over the control they exerted on certain gross morphological and cellular characters, whereas TIBA

appeared to act independently of the effects elicited by light quality. In general IAA, ethrel C and $GA_{4/7}$ decreased the expected augmentation of a particular character by C37 light to a value approaching that achieved with AW light in combination with the same regulator. In contrast phosphon D produced an increase of certain gross morphological and cellular characters under C37 light, while having a negligible or inhibitory effect under AW light.

However the various plant growth regulators appeared to show a degree of selectivity in regard to which characters they regulated through an interaction with light quality. Thus interactions with $GA_{4/7}$ and ethrel C were only evident on the leaf area and the fresh and dry weight of the total plant and leaf, IAA and ethrel C on the combined basal region & leaf sheath dry and fresh weight and phosphon D on the root fresh and dry weight. In regard to bulb development, the interactions were only produced by $GA_{4/7}$ on the bulb diameter and bulbing ratio and likewise ethrel C on the haulm and leaf sheath length. Nevertheless it was apparent that IAA and phosphon D could also interact with light quality over leaf development, if young leaves emerging during the period of treatment, were specifically examined.

When cellular components of the young emerging leaves were considered during the period of treatment, it was demonstrated that the interactive regulation by IAA or phosphon D with light quality over leaf length was also reflected in the determinants of epidermal and palisade mesophyll cell length for the former regulator, but only in palisade mesophyll cell length for the latter regulator. In contrast the interactive control exerted by $GA_{4/7}$ or ethrel C with light quality on leaf length was not paralleled by similar influences on epidermal and palisade mesophyll cell length and as a consequence cell division may be the factor under interactive control.

Assuming that the different R:FR ratios of C37 and AW light influence phytochrome activity (Smith, 1982), it is proposed that the various plant growth regulators may interact with phytochrome at the membrane level, since this represents one of the primary sites for phytochrome action (Marmé, 1977). Certainly the ability of R and

FR light to influence the number of NAA binding sites believed to be located on the endoplasmic reticulum (Walton & Ray, 1981), regulate the ethylene synthesizing system on the plasma membrane surface (Rohwer & Schierle, 1982) and interact with GA over the degree of membrane permeability in protoplasts (Blakeley et al, 1983) reinforces the above argument.

To conclude this overview, the major morphological changes produced by the various light qualities and plant growth regulators are depicted in Fig.5.1.

5.3. Future research

Assuming an unlimited period of time in which to pursue studies on the physiology of Kelsae onion development, future experiments could be centered on five main areas.

Firstly, information is required on whether the development rates for various onion plant characters assessed were in any way correlated with the F:FR ratios of light sources used to irradiate the plants and if the responses show a fluence rate dependency. This is important since work on the dicotyledenous species Chenopodium album showed correlations between leaf dry weight : stem dry weight ratio and the phytochrome photostationary state (Morgan & Smith, 1978), in addition to the SLA being specifically regulated by light intensity, while stem elongation was controlled by an interaction between light quality and intensity (Morgan & Smith, 1981).

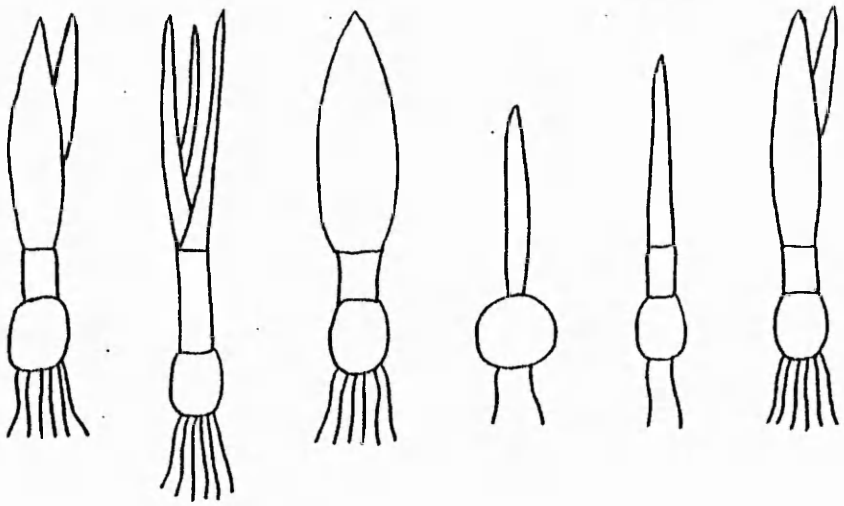
Secondly, accurate determinations of which auxins, gibberellins and cytokinins are indigenous to Allium cepa are required. Furthermore information is also needed on how these endogenous factors change in various plant parts during major ontogenetical shifts evoked through alterations in photoperiod, light quality and exogenous applications of plant growth regulators. Recent development of accurate immunoassay methods for the quantification of low quantities of endogenous plant growth regulators from small tissue samples (Weiler, et al, 1981 Atzorn & Weiler, 1983) should facilitate such an investigation. Further, since $AgNO_3$, STS and TIBA generally produced exiguous developmental changes, since certain plant growth retardants could only evoked their responses

Fig. 5.1.

Generalised diagram depicting the major morphological changes engendered by light quality and certain plant growth regulators.

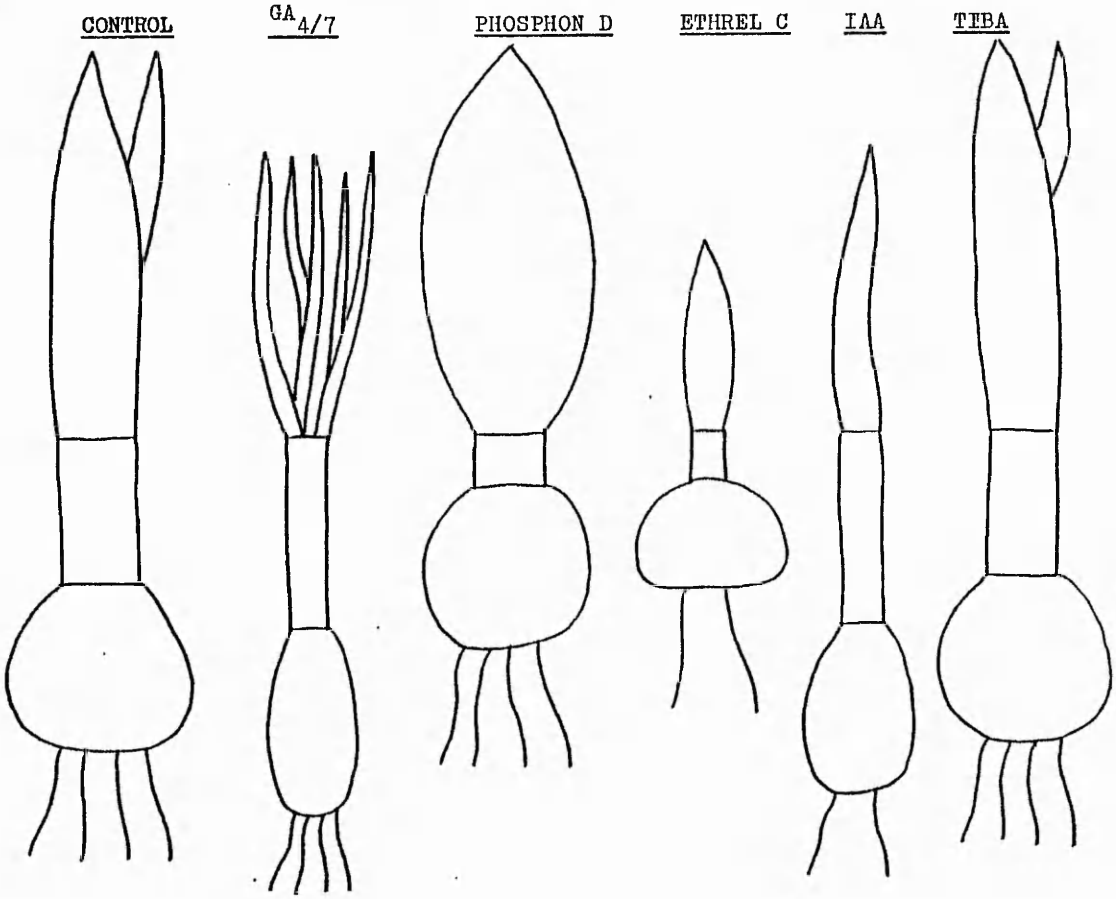
AW LIGHT

CONTROL $GA_{4/7}$ PHOSPHON D ETHREL C IAA TIBA



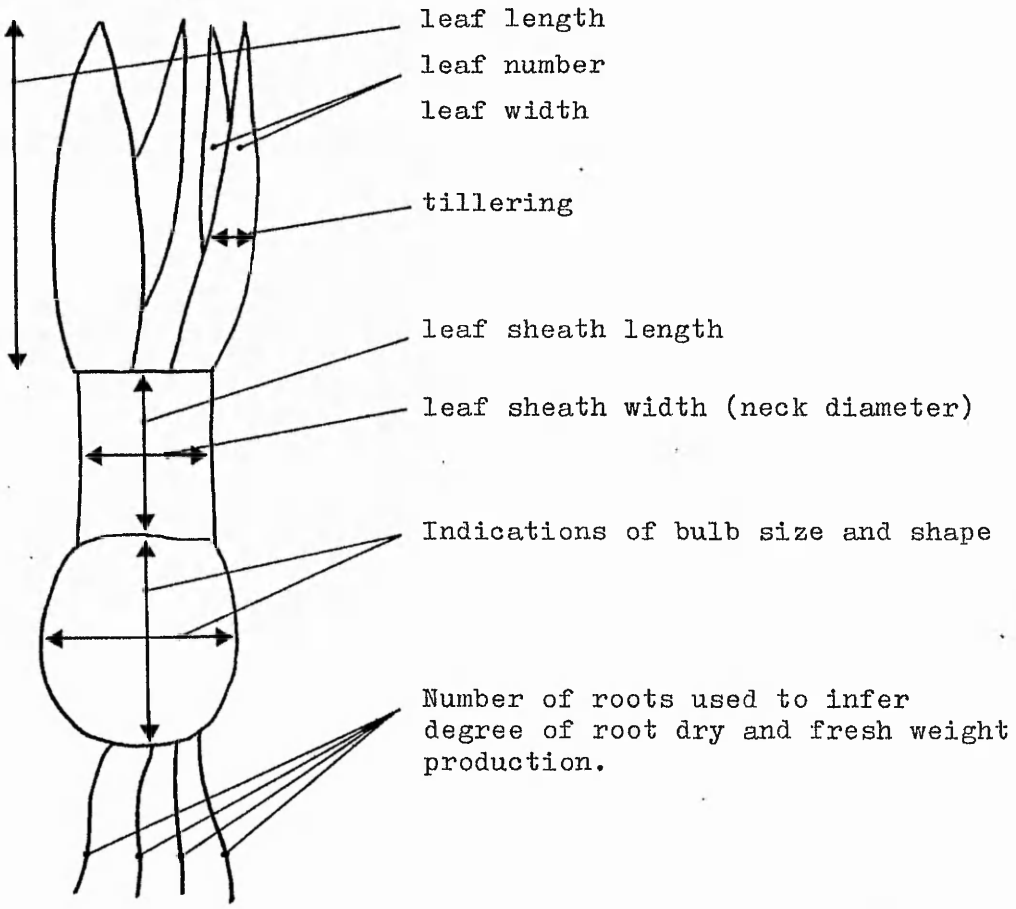
C37 LIGHT OR SUNLIGHT

CONTROL $GA_{4/7}$ PHOSPHON D ETHREL C IAA TIBA



(Fig. 5.1. cont.)

KEY:



N.B.

It must be stressed that information concerning the effect of IAA and TIBA on leaf sheath length and width has still to be determined quantitatively, though the latter parameter was noticeably thinner following IAA treatment. In regard to leaf sheath length, available evidence suggests that the synthetic auxin, 2,4-D, enhances the length of this parameter (Terabun, 1976). Since TIBA appeared to be far less active than IAA, it was assumed that the growth characteristics were comparable to those produced by the control plants. Furthermore $GA_{4/7}$ regulation of tiller production under AW light has still to be determined and in these circumstances the presence of tillers was omitted in the relevant diagram.

when applied as soil drenches and since the plant growth regulator effects were generally engendered in young leaves emerging from intercalary basal meristems, information regarding the effectiveness of penetration and translocation of these regulators appears necessary. This may entail the use of radioactive labelled plant growth regulators applied at selected locations on the plant and monitoring the subsequent distribution and integrity of the radioactive labelled regulator over a period of time.

Thirdly, the major dry matter distribution patterns promoted by the various plant growth regulators and light qualities need to be confirmed by studying the rate of translocation and distribution of radioactive labelled sugars applied to the leaves. Furthermore the effects of different light qualities and plant growth regulators on photosynthesis and respiration requires scrutiny, especially as the former factors apparently failed to change the ULR, RGR and LAR during the pre-bulbing phase of onion plant development, even though plant dry weight and in particular leaf area were increased by C37 light. Certainly a repeat of Experiment A in Chapter 3, but utilizing a greater number of replicate plants, may assist in determining whether alterations in the ULR, RGR and LAR can be expected during the pre-bulbing phase of plant development. In addition this work should be accompanied by estimations of CO_2 fixation using infra-red gas analysis techniques (Long, 1982) to determine if photosynthetic capacity and efficiency will be affected by the different light qualities and plant growth regulators. Certainly these photosynthetic determinants should provide evidence on whether the higher leaf Chl content evoked by light emitting a high rather than a low R:FR ratio on onion plants (data not presented) improved CO_2 fixation.

Fourthly, more information is required on how the different light qualities and plant growth regulators influenced leaf expansion at the cellular level. Most of the theories were based on the absence or occurence of epidermal and palisade mesophyll cell expansion and whether these results concurred with major changes in leaf dimensions. In regard to the palisade mesophyll cells, such data cannot fully account for possible alterations in cell number or area devoted to intercellular air spaces, which may contribute

towards the modification in leaf shape. Thus an assessment of the mean palisade cell size and number per unit area, as viewed from the leaf surface, may clarify this problem. Since the different light qualities and plant growth regulators also influenced the leaf guage, an assessment of epidermal, palisade mesophyll, spongy mesophyll and parenchymal cell thickness and number at right angles to the leaf surface, should give valuable information on how the various cell types contribute towards major changes in the leaf gauge.

Fifthly, techniques need to be developed to further improve plant uniformity, since increased plant variability observed in certain experiments may have been responsible for reducing the resolution of some treatment effects. Since some of this plant variability can be attributed to genetic variation, the *in vitro* vegetative propagation technique of Hussey's (1978) may resolve this problem. Using Hussey's technique, axillary and adventitious shoot proliferation can be obtained from scale explants dissected from a single bulb and grown on nutrient agar, thus giving uniform plants.

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7. APPENDIX

STATISTICAL TABLES FOR

CHAPTER 2

Table 2.1.

Analysis of variance for length of the third leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	263	5701680.69					
LIGHT QUALITY	1	163580.07	163580.07	86.280	7.71	21.20	74.14
ERROR A	4	7583.66	1895.91	29.963	2.42	3.44	4.90
DAYLENGTH	3	171939.13	57313.04	29.164	3.49	5.95	10.80
(i) LINEAR	1	155451.43	155451.43	79.103	4.75	9.33	18.64
(ii) QUADRATIC	1	15409.27	15409.27	7.841	4.75	9.33	18.64
(iii) CUBIC	1	1078.44	1078.44	0.549	4.75	9.33	18.64
LIGHT QUALITY X DAYLENGTH INTERACTION	3	53468.38	17822.79	9.069	3.49	5.95	10.80
(i) DEV. X LINEAR	1	47086.12	47086.12	23.960	4.75	9.33	18.64
(ii) DEV. X QUADRATIC	1	2712.33	2712.33	1.380	4.75	9.33	18.64
(iii) DEV. X CUBIC	1	3669.93	3669.93	1.867	4.75	9.33	18.64
ERROR B	12	23582.12	1965.18	31.057	1.80	2.30	2.98
TIME	10	5062402.31	506240.23	8000.537	1.90	2.46	3.24
(i) LINEAR	1	4993794.13	4993794.13	78921.097	3.90	6.80	11.31
(ii) QUADRATIC	1	51558.01	51558.01	814.814	3.90	6.80	11.31
(iii) CUBIC	1	15545.16	15545.16	245.673	3.90	6.80	11.31
DEVIATIONS	7	1505.03	215.00	3.398	2.06	2.77	3.75
LIGHT QUALITY X TIME INTERACTION	10	102739.17	10273.92	162.367	1.90	2.46	3.24
(i) DEV. X LINEAR	1	98896.14	98896.14	1562.938	3.90	6.80	11.31
(ii) DEV. X QUADRATIC	1	585.48	585.48	9.253	3.90	6.80	11.31
(iii) DEV. X CUBIC	1	2173.41	2173.41	34.348	3.90	6.80	11.31
DEVIATIONS	7	1084.13	154.88	2.448	2.06	2.77	3.75
DAYLENGTH X TIME INTERACTION	30	82683.77	2756.13	43.557	1.40	1.64	2.25
(i) LINEAR X LINEAR	1	74878.98	74878.98	1183.375	3.90	6.80	11.31
(ii) QUADRATIC X LINEAR	1	4761.61	4761.61	75.252	3.90	6.80	11.31
(iii) LINEAR X QUADRATIC	1	57.00	57.00	0.901	3.90	6.80	11.31
(iv) CUBIC X LINEAR	1	272.82	272.82	4.312	3.90	6.80	11.31
(v) QUADRATIC X QUADRATIC	1	11.52	11.52	0.182	3.90	6.80	11.31

(Table 2.1. cont.)

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
(vi) LINEAR X CUBIC	1	1819.82	1819.82	28.760	3.90	6.80	11.31
(vii) CUBIC X QUADRATIC	1	41.46	41.46	0.655	3.90	6.80	11.31
(viii) QUADRATIC X CUBIC	1	8.47	8.47	0.134	3.90	6.80	11.31
(ix) LINEAR X DEV.	7	502.67	71.81	1.135	2.06	2.77	3.75
(x) CUBIC X CUBIC	1	46.60	46.60	0.736	3.90	6.80	11.31
(xi) QUADRATIC X DEV.	7	104.25	14.89	0.235	2.06	2.77	3.75
(xii) CUBIC X DEV.	7	178.58	25.51	0.403	2.06	2.77	3.75
LIGHT QUALITY X DAYLENGTH X TIME INTERACTION	30	23577.93	785.93	12.421	1.40	1.64	2.25
(i) DEV. X LINEAR X LINEAR	1	21777.80	21777.80	344.173	3.90	6.80	11.31
(ii) DEV. X QUADRATIC X LINEAR	1	200.54	200.54	3.169	3.90	6.80	11.31
(iii) DEV. X LINEAR X QUADRATIC	1	0.55	0.55	0.009	3.90	6.80	11.31
(iv) DEV. X CUBIC X LINEAR	1	0.69	0.69	0.011	3.90	6.80	11.31
(v) DEV. X QUADRATIC X QUADRATIC	1	24.23	24.23	0.383	3.90	6.80	11.31
(vi) DEV. X LINEAR X CUBIC	1	836.37	836.37	13.218	3.90	6.80	11.31
(vii) DEV. X CUBIC X QUADRATIC	1	350.25	350.25	5.535	3.90	6.80	11.31
(viii) DEV. X QUADRATIC X CUBIC	1	19.02	19.02	0.301	3.90	6.80	11.31
(ix) DEV. X LINEAR X DEV.	7	114.81	16.40	0.259	2.06	2.77	3.75
(x) DEV. X CUBIC X CUBIC	1	14.05	14.05	0.222	3.90	6.80	11.31
(xi) DEV.X QUADRATIC X DEV.	7	51.18	7.31	0.116	2.06	2.77	3.75
(xii) DEV.X CUBIC X DEV.	7	188.46	26.92	0.425	2.06	2.77	3.75
ERROR C	160	10124.13	63.28				
COMBINED ERROR	-	-	-				

Table 2.2.

Analysis of variance for length of the fourth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	191	1094149.3					
LIGHT QUALITY	1	25594.1	25594.1	15.542	7.71	21.20	74.14
ERROR A	4	6587.2	1646.8	14.485	2.46	3.47	4.97
DAYLENGTH	3	84872.6	28290.9	20.606	3.49	5.95	10.80
(i) LINEAR	1	81036.9	81036.9	59.025	4.75	9.33	18.64
(ii) QUADRATIC	1	3835.5	3835.5	2.794	4.75	9.33	18.64
(iii) CUBIC	1	0.2	0.2	0.000	4.75	9.33	18.64
LIGHT QUALITY X DAYLENGTH INTERACTION	3	24549.7	8183.2	5.960	3.49	5.95	10.80
(i) DEV. X LINEAR	1	21895.8	21895.8	15.948	4.75	9.33	18.64
(ii) DEV. X QUADRATIC	1	1861.1	1861.1	1.356	4.75	9.33	18.64
(iii) DEV. X CUBIC	1	792.9	792.9	0.578	4.75	9.33	18.64
ERROR B	12	16475.0	1372.9	12.076	1.84	2.35	3.03
TIME	7	827326.4	118189.5	1039.541	2.10	2.82	3.83
(i) LINEAR	1	762679.8	762679.8	6708.187	3.93	6.87	11.40
(ii) QUADRATIC	1	64156.6	64156.6	564.292	3.93	6.87	11.40
(iii) CUBIC	1	87.8	87.8	0.773	3.93	6.87	11.40
DEVIATIONS	4	402.1	100.5	0.884	2.46	3.47	4.97
LIGHT QUALITY X TIME INTERACTION	7	20920.2	2988.6	26.286	2.10	2.82	3.83
(i) DEV. X LINEAR	1	19763.8	19763.8	173.833	3.93	6.87	11.40
(ii) DEV. X QUADRATIC	1	953.5	953.5	8.387	3.93	6.87	11.40
(iii) DEV. X CUBIC	1	92.0	92.0	0.809	3.93	6.87	11.40
DEVIATIONS	4	110.8	27.7	0.244	2.46	3.47	4.97
DAYLENGTH X TIME INTERACTION	21	62082.1	2956.3	26.002	1.69	2.06	2.58
(i) LINEAR X LINEAR	1	56231.3	56231.3	494.585	3.93	6.87	11.40
(ii) QUADRATIC X LINEAR	1	2191.7	2191.7	19.278	3.93	6.87	11.40
(iii) LINEAR X QUADRATIC	1	2330.0	2330.0	20.494	3.93	6.87	11.40
(iv) CUBIC X LINEAR	1	164.2	164.2	1.444	3.93	6.87	11.40

Table 2.2. (cont.)

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
(v) QUADRATIC X QUADRATIC	1	164.8	164.8	1.449	3.93	6.87	11.40
(vi) LINEAR X CUBIC	1	264.9	264.9	2.330	3.93	6.87	11.40
(vii) CUBIC X QUADRATIC	1	127.9	127.9	1.125	3.93	6.87	11.40
(viii) QUADRATIC X CUBIC	1	4.3	4.3	0.038	3.93	6.87	11.40
(ix) LINEAR X DEV.	4	137.3	34.3	0.302	2.46	3.47	4.97
(x) CUBIC X CUBIC	1	96.3	96.3	0.847	3.93	6.87	11.40
(xi) QUADRATIC X DEV.	4	37.6	9.4	0.083	2.46	3.47	4.97
(xii) CUBIC X DEV.	4	331.8	83.0	0.730	2.46	3.47	4.97
LIGHT QUALITY X DAYLENGTH X TIME INTERACTION	21	13008.2	619.4	5.448	1.69	2.06	2.58
(i) DEV. X LINEAR X LINEAR	1	11957.9	11957.9	105.176	3.93	6.87	11.40
(ii) DEV. X QUADRATIC X LINEAR	1	604.4	604.4	5.316	3.93	6.87	11.40
(iii) DEV. X LINEAR X QUADRATIC	1	81.7	81.7	0.719	3.93	6.87	11.40
(iv) DEV. X CUBIC X LINEAR	1	17.9	17.9	0.158	3.93	6.87	11.40
(v) DEV. X QUADRATIC X QUADRATIC	1	8.8	8.8	0.078	3.93	6.87	11.40
(vi) DEV. X LINEAR X CUBIC	1	19.1	19.1	0.168	3.93	6.87	11.40
(vii) DEV. X CUBIC X QUADRATIC	1	18.8	18.8	0.165	3.93	6.87	11.40
(viii) DEV. X QUADRATIC X CUBIC	1	17.5	17.5	0.154	3.93	6.87	11.40
(ix) DEV. X LINEAR X DEV.	4	74.4	18.6	0.164	2.46	3.47	4.97
(x) DEV. X CUBIC X CUBIC	1	27.4	27.4	0.241	3.93	6.87	11.40
(xi) DEV. X QUADRATIC X DEV.	4	32.8	8.2	0.072	2.46	3.47	4.97
(xii) DEV. X CUBIC X DEV.	4	147.4	36.9	0.324	2.46	3.47	4.97
ERROR C	112	12733.7	113.7				
COMBINED ERROR	-	-	-				

Table 2.3.

Analysis of variance for length of the fifth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	95	18584.33					
LIGHT QUALITY	1	493.23	493.23	5.512	7.71	21.20	74.14
ERROR A	4	357.95	89.49	3.121	2.57	3.75	5.51
DAYLENGTH	3	2675.06	891.69	9.875	3.49	5.95	10.80
(i) LINEAR	1	2579.19	2579.19	28.564	4.75	9.33	18.64
(ii) QUADRATIC	1	95.80	95.80	1.061	4.75	9.33	18.64
(iii) CUBIC	1	0.07	0.07	0.001	4.75	9.33	18.64
LIGHT QUALITY X DAYLENGTH INTERACTION	3	768.58	256.19	2.837	3.49	5.95	10.80
(i) DEV. X LINEAR	1	634.66	634.66	7.029	4.75	9.33	18.64
(ii) DEV. X QUADRATIC	1	28.15	28.15	0.312	4.75	9.33	18.64
(iii) DEV. X CUBIC	1	105.77	105.77	1.171	4.75	9.33	18.64
ERROR B	12	1083.55	90.30	3.149	1.96	2.59	3.48
TIME	3	8730.09	2910.03	101.500	2.79	4.22	6.37
(i) LINEAR	1	8055.85	8055.85	280.982	4.35	7.20	12.30
(ii) QUADRATIC	1	669.82	669.82	23.363	4.35	7.20	12.30
(iii) CUBIC	1	4.42	4.42	0.154	4.35	7.20	12.30
LIGHT QUALITY X TIME INTERACTION	3	430.04	143.35	5.000	2.79	4.22	6.37
(i) DEV. X LINEAR	1	390.93	390.93	13.635	4.35	7.20	12.30
(ii) DEV. X QUADRATIC	1	37.68	37.68	1.314	4.35	7.20	12.30
(iii) DEV. X CUBIC	1	1.43	1.43	0.050	4.35	7.20	12.30
DAYLENGTH X TIME INTERACTION	9	1984.62	220.51	7.691	2.05	2.99	4.22
(i) LINEAR X LINEAR	1	1691.42	1691.42	58.996	4.35	7.20	12.30
(ii) QUADRATIC X LINEAR	1	82.24	82.24	2.868	4.35	7.20	12.30
(iii) LINEAR X QUADRATIC	1	70.90	70.90	2.473	4.35	7.20	12.30
(iv) CUBIC X LINEAR	1	0.13	0.13	0.005	4.35	7.20	12.30
(v) QUADRATIC X QUADRATIC	1	41.55	41.55	1.449	4.35	7.20	12.30
(vi) LINEAR X CUBIC		1.47	1.47	0.051	4.35	7.20	12.30

Table 2.3. (cont.)

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
(vii) CUBIC X QUADRATIC	1	10.48	10.48	0.366	4.35	7.20	12.30
(viii) QUADRATIC X CUBIC	1	44.81	44.81	1.563	4.35	7.20	12.30
(ix) CUBIC X CUBIC	1	41.61	41.61	1.451	4.35	7.20	12.30
LIGHT QUALITY X DAYLENGTH X TIME INTERACTION	9	685.05	76.12	2.655	2.05	2.99	4.22
(i) DEV. X LINEAR X LINEAR	1	553.23	553.23	19.296	4.35	7.20	12.30
(ii) DEV. X QUADRATIC X LINEAR	1	7.38	7.38	0.257	4.35	7.20	12.30
(iii) DEV. X LINEAR X QUADRATIC	1	69.43	69.43	2.422	4.35	7.20	12.30
(iv) DEV. X CUBIC X LINEAR	1	21.23	21.23	0.741	4.35	7.20	12.30
(v) DEV. X QUADRATIC X QUADRATIC	1	0.60	0.60	0.021	4.35	7.20	12.30
(vi) DEV. X LINEAR X CUBIC	1	3.57	3.57	0.124	4.35	7.20	12.30
(vii) DEV. X CUBIC X QUADRATIC	1	0.04	0.04	0.001	4.35	7.20	12.30
(viii) DEV. X QUADRATIC X CUBIC	1	10.37	10.37	0.362	4.35	7.20	12.30
(ix) DEV. X CUBIC X CUBIC	1	19.20	19.20	0.670	4.35	7.20	12.30
ERROR C	48	1376.18	28.67				
COMBINED ERROR	-	-	-				

Table 2.4.

Analysis of variance for leaf sheath length of the third leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	23	4547.86					
LIGHT QUALITY	1	3019.08	3019.08	427.63	4.49	8.53	16.12
ERROR A	4	26.51	6.63	0.92	3.26	5.41	9.63
DAYLENGTH	3	1158.93	386.31	54.72	3.24	5.29	9.00
LIGHT QUALITY X DAYLENGTH INTERACTION	3	256.91	85.64	12.13	3.24	5.29	9.00
ERROR B	12	86.43	7.20				
COMBINED ERROR (A+B)	16	112.94	7.06				

Table 2.5.

Analysis of variance for length of the sixth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	263	12512890.1					
LIGHT QUALITY	1	325055.5	325055.5	60.269	7.71	21.20	74.14
ERROR A	4	21573.7	5393.4	10.357	2.42	3.44	4.90
DAYLENGTH	3	630722.6	210240.9	56.586	3.49	5.95	10.80
(i) LINEAR	1	219077.0	219077.0	58.964	4.75	9.33	18.64
(ii) QUADRATIC	1	411577.4	411577.4	110.775	4.75	9.33	18.64
(iii) CUBIC	1	68.3	68.3	0.018	4.75	9.33	18.64
LIGHT QUALITY X DAYLENGTH INTERACTION	3	195556.4	65185.5	17.545	3.49	5.95	10.80
(i) DEV. X LINEAR	1	30993.9	30993.9	8.342	4.75	9.33	18.64
(ii) DEV. X QUADRATIC	1	160198.5	160198.5	43.117	4.75	9.33	18.64
(iii) DEV. X CUBIC	1	4364.1	4364.1	1.175	4.75	9.33	18.64
ERROR B	12	44585.2	3715.4	7.135	1.80	2.30	2.98
TIME	10	10630512.8	1063051.3	2041.398	1.90	2.46	3.24
(i) LINEAR	1	10087750.6	10087750.6	19371.699	3.90	6.80	11.31
(ii) QUADRATIC	1	453405.7	453405.7	870.684	3.90	6.80	11.31
(iii) CUBIC	1	78691.9	78691.9	151.114	3.90	6.80	11.31
DEVIATIONS	7	10664.6	1523.5	2.926	2.06	2.77	3.75
LIGHT QUALITY X TIME INTERACTION	10	88639.8	8864.0	17.022	1.90	2.46	3.24
(i) DEV. X LINEAR	1	251.4	251.4	0.483	3.90	6.80	11.31
(ii) DEV. X QUADRATIC	1	76200.9	76200.9	146.330	3.90	6.80	11.31
(iii) DEV. X CUBIC	1	5771.4	5771.4	11.083	3.90	6.80	11.31
DEVIATIONS	7	6416.0	916.6	1.760	2.06	2.77	3.75
DAYLENGTH X TIME INTERACTION	30	304861.7	10162.1	19.514	1.40	1.64	2.25
(i) LINEAR X LINEAR	1	53565.1	53565.1	102.862	3.90	6.80	11.31
(ii) QUADRATIC X LINEAR	1	105741.6	105741.6	203.058	3.90	6.80	11.31
(iii) LINEAR X QUADRATIC	1	63681.5	63681.5	122.289	3.90	6.80	11.31
(iv) CUBIC X LINEAR	1	773.6	773.6	1.486	3.90	6.80	11.31
(v) QUADRATIC X QUADRATIC	1	20390.4	20390.4	39.156	3.90	6.80	11.31

Table 2.5. (cont.)

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
(vi) LINEAR X CUBIC	1	46467.1	46467.1	89.232	3.90	6.80	11.31
(vii) CUBIC X QUADRATIC	1	290.7	290.7	0.558	3.90	6.80	11.31
(viii) QUADRATIC X CUBIC	1	5017.9	5017.9	9.636	3.90	6.80	11.31
(ix) LINEAR X DEV.	7	3483.4	497.6	0.956	2.06	2.77	3.75
(x) CUBIC X CUBIC	1	98.4	98.4	0.189	3.90	6.80	11.31
(xi) QUADRATIC X DEV.	7	4954.3	707.8	1.359	2.06	2.77	3.75
(xii) CUBIC X DEV.	7	397.6	56.8	0.109	2.06	2.77	3.75
LIGHT QUALITY X DAYLENGTH X TIME INTERACTION	30	188063.1	6268.8	12.038	1.40	1.64	2.25
(i) DEV. X LINEAR X LINEAR	1	75963.2	75963.2	145.874	3.90	6.80	11.31
(ii) DEV. X QUADRATIC X LINEAR	1	33626.4	33626.4	64.573	3.90	6.80	11.31
(iii) DEV. X LINEAR X QUADRATIC	1	36675.8	36675.8	70.429	3.90	6.80	11.31
(iv) DEV. X CUBIC X LINEAR	1	584.1	584.1	1.122	3.90	6.80	11.31
(v) DEV. X QUADRATIC X QUADRATIC	1	10299.8	10299.8	19.779	3.90	6.80	11.31
(vi) DEV. X LINEAR X CUBIC	1	21054.0	21054.0	40.430	3.90	6.80	11.31
(vii) DEV. X CUBIC X QUADRATIC	1	492.3	492.3	0.945	3.90	6.80	11.31
(viii) DEV. X QUADRATIC X CUBIC	1	1473.4	1473.4	2.829	3.90	6.80	11.31
(ix) DEV. X LINEAR X DEV.	7	1327.6	189.7	0.364	2.06	2.77	3.75
(x) DEV. X CUBIC X CUBIC	1	33.0	33.0	0.063	3.90	6.80	11.31
(xi) DEV. X QUADRATIC X DEV.	7	5178.4	739.8	1.421	2.06	2.77	3.75
(xii) DEV. X CUBIC X DEV.	7	1355.0	193.6	0.372	2.06	2.77	3.75
ERROR C	160	83319.5	520.7				
COMBINED ERROR	-	-	-				

Table 2.6.

Analysis of variance for length of the seventh leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	239	7339783.1					
LIGHT QUALITY	1	18584.2	18584.2	5.546	7.71	21.20	74.14
ERROR A	4	13404.3	3351.1	10.406	2.43	3.46	4.94
DAYLENGTH	3	534327.1	178109.0	47.383	3.49	5.95	10.80
(i) LINEAR	1	44809.5	44809.5	11.921	4.75	9.33	18.64
(ii) QUADRATIC	1	477591.1	477591.1	127.056	4.75	9.33	18.64
(iii) CUBIC	1	11926.5	11926.5	3.173	4.75	9.33	18.64
LIGHT QUALITY X DAYLENGTH INTERACTION	3	483734.0	161244.7	42.897	3.49	5.95	10.80
(i) DEV. X LINEAR	1	70253.6	70253.6	18.690	4.75	9.33	18.64
(ii) DEV. X QUADRATIC	1	398189.5	398189.5	105.932	4.75	9.33	18.64
(iii) DEV. X CUBIC	1	15290.9	15290.9	4.068	4.75	9.33	18.64
ERROR B	12	45106.9	3758.9	11.673	1.81	2.32	3.01
TIME	9	5407683.0	600853.7	1865.883	1.91	2.48	3.27
(i) LINEAR	1	5243501.3	5243501.3	16283.096	3.91	6.82	11.34
(ii) QUADRATIC	1	92910.4	92910.4	288.523	3.91	6.82	11.34
(iii) CUBIC	1	66071.9	66071.9	205.179	3.91	6.82	11.34
DEVIATIONS	6	5199.5	866.6	2.691	2.16	2.94	4.00
LIGHT QUALITY X TIME INTERACTION	9	41090.7	4565.6	14.178	1.91	2.48	3.27
(i) DEV. X LINEAR	1	2737.1	2737.1	8.500	3.91	6.82	11.34
(ii) DEV. X QUADRATIC	1	34767.7	34767.7	107.967	3.91	6.82	11.34
(iii) DEV. X CUBIC	1	1842.6	1842.6	5.722	3.91	6.82	11.34
DEVIATIONS	6	1743.3	290.6	0.902	2.16	2.94	4.00
DAYLENGTH X TIME INTERACTION	27	431985.8	15999.5	49.685	1.41	1.66	2.30
(i) LINEAR X LINEAR	1	137052.4	137052.4	425.601	3.91	6.82	11.34
(ii) QUADRATIC X LINEAR	1	210198.5	210198.5	652.748	3.91	6.82	11.34
(iii) LINEAR X QUADRATIC	1	48576.5	48576.5	150.849	3.91	6.82	11.34
(iv) CUBIC X LINEAR	1	113.1	113.1	0.351	3.91	6.82	11.34
(v) QUADRATIC X QUADRATIC	1	4790.0	4790.0	14.875	3.91	6.82	11.34
(vi) LINEAR X CUBIC	1	2782.1	2782.1	8.639	3.91	6.82	11.34

Table 2.6. (cont.)

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
(vii) CUBIC X QUADRATIC	1	6057.9	6057.9	18.812	3.91	6.82	11.34
(viii) QUADRATIC X CUBIC	1	11422.3	11422.3	35.471	3.91	6.82	11.34
(ix) LINEAR X DEV.	6	6885.9	1147.7	3.564	2.16	2.94	4.00
(x) CUBIC X CUBIC	1	158.3	158.3	0.492	3.91	6.82	11.34
(xi) QUADRATIC X DEV.	6	1349.0	224.8	0.698	2.16	2.94	4.00
(xii) CUBIC X DEV.	6	2599.9	433.3	1.346	2.16	2.94	4.00
LIGHT QUALITY X DAYLENGTH X TIME INTERACTION	27	317495.9	11759.1	36.517	1.41	1.66	2.30
(i) DEV. X LINEAR X LINEAR	1	119216.4	119216.4	370.213	3.91	6.82	11.34
(ii) DEV. X QUADRATIC X LINEAR	1	143323.6	143323.6	445.075	3.91	6.82	11.34
(iii) DEV. X LINEAR X QUADRATIC	1	30422.9	30422.9	94.475	3.91	6.82	11.34
(iv) DEV. X CUBIC X LINEAR	1	535.6	535.6	1.663	3.91	6.82	11.34
(v) DEV. X QUADRATIC X QUADRATIC	1	8368.6	8368.6	25.988	3.91	6.82	11.34
(vi) DEV. X LINEAR X CUBIC	1	328.0	328.0	1.019	3.91	6.82	11.34
(vii) DEV. X CUBIC X QUADRATIC	1	3039.9	3039.9	9.440	3.91	6.82	11.34
(viii) DEV. X QUADRATIC X CUBIC	1	5251.1	5251.1	16.307	3.91	6.82	11.34
(ix) DEV. X LINEAR X DEV.	6	1790.1	298.4	0.926	2.16	2.94	4.00
(x) DEV. X CUBIC X CUBIC	1	1.1	1.1	0.003	3.91	6.82	11.34
(xi) DEV. X QUADRATIC X DEV.	6	4334.8	722.5	2.244	2.16	2.94	4.00
(xii) DEV. X CUBIC X DEV.	6	883.7	147.3	0.457	2.16	2.94	4.00
ERROR C	144	46371.0	322.0				
COMBINED ERROR	-	-	-				

Table 2.7.

Analysis of variance for length of the eighth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	167	1517008.2					
LIGHT QUALITY	1	6162.7	6162.7	8.031	7.71	21.20	74.14
ERROR A	4	3069.6	767.4	4.437	2.48	3.55	5.08
DAYLENGTH	3	127746.6	42582.2	25.133	3.49	5.95	10.80
(i) LINEAR	1	33822.5	33822.5	19.963	4.75	9.33	18.64
(ii) QUADRATIC	1	93924.1	93924.1	55.436	4.75	9.33	18.64
(iii) CUBIC	1	0.0	0.0	0.000	4.75	9.33	18.64
LIGHT QUALITY X DAYLENGTH INTERACTION	3	129281.4	43093.8	25.435	3.49	5.95	10.80
(i) DEV. X LINEAR	1	14217.4	14217.4	8.391	4.75	9.33	18.64
(ii) DEV. X QUADRATIC	1	114830.4	114830.4	67.775	4.75	9.33	18.64
(iii) DEV. X CUBIC	1	233.6	233.6	0.138	4.75	9.33	18.64
ERROR B	12	20331.5	1694.3	9.797	1.87	2.36	3.13
TIME	6	1007257.0	167876.2	970.711	2.20	3.01	4.15
(i) LINEAR	1	945920.5	945920.5	5469.600	3.95	6.91	11.50
(ii) QUADRATIC	1	59788.6	59788.6	345.716	3.95	6.91	11.50
(iii) CUBIC	1	1097.1	1097.1	6.344	3.95	6.91	11.50
DEVIATIONS	3	450.8	150.3	0.869	2.70	4.02	5.92
LIGHT QUALITY X TIME INTERACTION	6	6787.4	1131.2	6.541	2.20	3.01	4.15
(i) DEV. X LINEAR	1	484.7	484.7	2.802	3.95	6.91	11.50
(ii) DEV. X QUADRATIC	1	5890.1	5890.1	34.058	3.95	6.91	11.50
(iii) DEV. X CUBIC	1	318.6	318.6	1.842	3.95	6.91	11.50
DEVIATIONS	3	94.1	31.4	0.181	2.70	4.02	5.92
DAYLENGTH X TIME INTERACTION	18	109726.0	6095.9	35.248	1.76	2.22	2.83
(i) LINEAR X LINEAR	1	51084.8	51084.8	295.388	3.95	6.91	11.50
(ii) QUADRATIC X LINEAR	1	43614.4	43614.4	252.192	3.95	6.91	11.50
(iii) LINEAR X QUADRATIC	1	8726.8	8726.8	50.461	3.95	6.91	11.50
(iv) CUBIC X LINEAR	1	2830.8	2830.8	16.369	3.95	6.91	11.50
(v) QUADRATIC X QUADRATIC	1	66.0	66.0	0.382	3.95	6.91	11.50
(vi) LINEAR X CUBIC	1	174.0	174.0	1.006	3.95	6.91	11.50

Table 2.7. (cont.)

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
(vii) CUBIC X QUADRATIC	1	1635.2	1635.2	9.455	3.95	6.91	11.50
(viii) QUADRATIC X CUBIC	1	1162.2	1162.2	6.720	3.95	6.91	11.50
(ix) LINEAR X DEV.	3	184.9	61.6	0.356	2.70	4.00	5.92
(x) CUBIC X CUBIC	1	41.3	41.3	0.239	3.95	6.91	11.50
(xi) QUADRATIC X DEV.	3	16.5	5.5	0.032	2.70	4.02	5.92
(xii) CUBIC X DEV.	3	189.2	63.1	0.365	2.70	4.02	5.92
LIGHT QUALITY X DAYLENGTH X TIME INTERACTION	18	90043.7	5002.4	28.926	1.76	2.22	2.83
(i) DEV. X LINEAR X LINEAR	1	27672.4	27672.4	160.010	3.95	6.91	11.50
(ii) DEV. X QUADRATIC X LINEAR	1	48382.3	48382.3	279.761	3.95	6.91	11.50
(iii) DEV. X LINEAR X QUADRATIC	1	8301.4	8301.4	48.001	3.95	6.91	11.50
(iv) DEV. X CUBIC X LINEAR	1	2862.7	2862.7	16.553	3.95	6.91	11.50
(v) DEV. X QUADRATIC X QUADRATIC	1	102.6	102.6	0.593	3.95	6.91	11.50
(vi) DEV. X LINEAR X CUBIC	1	34.9	34.9	0.202	3.95	6.91	11.50
(vii) DEV. X CUBIC X QUADRATIC	1	962.4	962.4	5.565	3.95	6.91	11.50
(viii) DEV. X QUADRATIC X CUBIC	1	583.7	583.7	3.375	3.95	6.91	11.50
(ix) DEV. X LINEAR X DEV.	3	495.0	165.0	0.954	2.70	4.00	5.90
(x) DEV. X CUBIC X CUBIC	1	80.8	80.8	0.467	3.95	6.91	11.50
(xi) DEV. X QUADRATIC X DEV.	3	357.4	119.1	0.689	2.70	4.02	5.92
(xii) DEV. X CUBIC X DEV.	3	208.1	69.4	0.401	2.70	4.02	5.92
ERROR C	96	16602.4	172.9				
COMBINED ERROR	-	-	-				

Table 2.8.

Analysis of variance for length of the ninth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	95	104588.10					
LIGHT QUALITY	1	1206.01	1206.01	4.726	7.71	21.20	74.14
ERROR A	4	1020.80	255.20	3.449	2.57	3.75	5.51
DAYLENGTH	3	15123.86	5041.29	7.446	3.49	5.95	10.80
(i) LINEAR	1	6115.41	6115.41	9.032	4.75	9.33	18.64
(ii) QUADRATIC	1	7838.77	7838.77	11.578	4.75	9.33	18.64
(iii) CUBIC	1	1169.69	1169.69	1.728	4.75	9.33	18.64
LIGHT QUALITY X DAYLENGTH INTERACTION	3	16863.76	5621.25	8.302	3.49	5.95	10.80
(i) DEV. X LINEAR	1	287.37	287.37	0.424	4.75	9.33	18.64
(ii) DEV. X QUADRATIC	1	14289.13	14289.13	21.105	4.75	9.33	18.64
(iii) DEV. X CUBIC	1	2287.26	2287.26	3.378	4.75	9.33	18.64
ERROR B	12	8124.77	677.06	9.150	1.96	2.59	3.48
TIME	3	41871.93	13957.31	188.622	2.79	4.22	6.37
(i) LINEAR	1	40448.92	40448.92	546.635	4.35	7.20	12.30
(ii) QUADRATIC	1	1405.31	1405.31	18.992	4.35	7.20	12.30
(iii) CUBIC	1	17.71	17.71	0.239	4.35	7.20	12.30
LIGHT QUALITY X TIME INTERACTION	3	366.65	122.22	1.652	2.79	4.22	6.37
(i) DEV. X LINEAR	1	85.85	85.85	1.160	4.35	7.20	12.30
(ii) DEV. X QUADRATIC	1	213.37	213.37	2.883	4.35	7.20	12.30
(iii) DEV. X CUBIC	1	67.43	67.43	0.911	4.35	7.20	12.30
DAYLENGTH X TIME INTERACTION	9	9362.64	1040.29	14.059	2.05	2.99	4.22
(i) LINEAR X LINEAR	1	4797.98	4797.98	64.841	4.35	7.20	12.30
(ii) QUADRATIC X LINEAR	1	2776.04	2776.04	37.516	4.35	7.20	12.30
(iii) LINEAR X QUADRATIC	1	554.87	554.87	7.499	4.35	7.20	12.30
(iv) CUBIC X LINEAR	1	1088.65	1088.65	14.712	4.35	7.20	12.30
(v) QUADRATIC X QUADRATIC	1	0.34	0.34	0.005	4.35	7.20	12.30
(vi) LINEAR X CUBIC	1	26.65	26.65	0.360	4.35	7.20	12.30
(vii) CUBIC X QUADRATIC	1	108.72	108.72	1.469	4.35	7.20	12.30

Table 2.8. (cont.)

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
(viii) QUADRATIC X CUBIC	1	9.27	9.27	0.125	4.35	7.20	12.30
(ix) CUBIC X CUBIC	1	0.11	0.11	0.001	4.35	7.20	12.30
LIGHT QUALITY X DAYLENGTH X TIME INTERACTION	9	7095.86	788.43	10.655	2.05	2.99	4.22
(i) DEV. X LINEAR X LINEAR	1	415.08	415.08	5.610	4.35	7.20	12.30
(ii) DEV. X QUADRATIC X LINEAR	1	4874.07	4874.07	65.869	4.35	7.20	12.30
(iii) DEV. X LINEAR X QUADRATIC	1	11.55	11.55	0.156	4.35	7.20	12.30
(iv) DEV. X CUBIC X LINEAR	1	1553.81	1553.81	20.999	4.35	7.20	12.30
(v) DEV. X QUADRATIC X QUADRATIC	1	19.80	19.80	0.268	4.35	7.20	12.30
(vi) DEV. X LINEAR X CUBIC	1	24.08	24.08	0.325	4.35	7.20	12.30
(vii) DEV. X CUBIC X QUADRATIC	1	113.08	113.08	1.528	4.35	7.20	12.30
(viii) DEV. X QUADRATIC X CUBIC	1	80.34	80.34	1.086	4.35	7.20	12.30
(ix) DEV. X CUBIC X CUBIC	1	4.03	4.03	0.055	4.35	7.20	12.30
ERROR C	48	3551.82	74.00				
COMBINED ERROR	-	-	-				

Table 2.9.

Analysis of variance for the bulbing ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	143	103.3567					
LIGHT QUALITY	1	12.9642	12.9642	743.775	7.71	21.20	74.14
ERROR A	4	0.0697	0.0174	3.256	2.50	3.59	5.19
DAYLENGTH	3	22.3081	7.4360	453.061	3.49	5.95	10.80
(i) LINEAR	1	17.3070	17.3070	1054.474	4.75	9.33	18.64
(ii) QUADRATIC	1	4.9059	4.9059	298.902	4.75	9.33	18.64
(iii) CUBIC	1	0.0953	8.0953	5.806	4.75	9.33	18.64
LIGHT QUALITY X DAYLENGTH INTERACTION	3	21.5050	7.1683	436.750	3.49	5.95	10.80
(i) DEV. X LINEAR	1	17.0894	17.0894	1041.216	4.75	9.33	18.64
(ii) DEV. X QUADRATIC	1	4.3330	4.3330	263.999	4.75	9.33	18.64
(iii) DEV. X CUBIC	1	0.0827	0.0827	5.037	4.75	9.33	18.64
ERROR B	12	0.1970	0.0164	3.066	1.89	2.44	3.21
TIME	5	11.8250	2.3650	441.812	2.34	3.28	4.64
(i) LINEAR	1	11.4948	11.4948	2147.368	3.97	6.77	11.77
(ii) QUADRATIC	1	0.1243	0.1243	23.227	3.97	6.77	11.77
(iii) CUBIC	1	0.1756	0.1756	32.798	3.97	6.77	11.77
DEVIATIONS	2	0.0303	0.0152	2.833	3.12	4.91	7.61
LIGHT QUALITY X TIME INTERACTION	5	8.9277	1.7855	333.562	2.34	3.28	4.64
(i) DEV. X LINEAR	1	8.6328	8.6328	1612.716	3.97	6.77	11.77
(ii) DEV. X QUADRATIC	1	0.1599	0.1599	29.870	3.97	6.77	11.77
(iii) DEV. X CUBIC	1	0.1307	0.1307	24.425	3.97	6.77	11.77
DEVIATIONS	2	0.0043	0.0021	0.399	3.12	4.91	7.61
DAYLENGTH X TIME INTERACTION	15	12.6890	0.8459	158.031	1.83	2.35	3.12
(i) LINEAR X LINEAR	1	10.4228	10.4228	1947.104	3.97	6.77	11.77
(ii) QUADRATIC X LINEAR	1	1.7132	1.7132	320.051	3.97	6.77	11.77
(iii) LINEAR X QUADRATIC	1	0.0430	0.0430	8.032	3.97	6.77	11.77
(iv) CUBIC X LINEAR	1	0.0026	0.0026	0.479	3.97	6.77	11.77
(v) QUADRATIC X QUADRATIC	1	0.0828	0.0828	15.468	3.97	6.77	11.77
(vi) LINEAR X CUBIC	1	0.1736	0.1736	32.429	3.97	6.77	11.77

Table 2.9. (cont.)

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
(vii) CUBIC X QUADRATIC	1	0.1080	0.1080	20.175	3.97	6.77	11.77
(viii) QUADRATIC X X CUBIC	1	0.0585	0.0585	10.927	3.97	6.77	11.77
(ix) LINEAR X DEV.	2	0.0134	0.0067	1.252	3.12	4.91	7.61
(x) CUBIC X CUBIC	1	0.0167	0.0167	3.128	3.97	6.77	11.77
(xi) QUADRATIC X DEV.	2	0.0289	0.0145	2.701	3.12	4.91	7.61
(xii) CUBIC X DEV.	2	0.0255	0.0128	2.383	3.12	4.91	7.61
LIGHT QUALITY X DAYLENGTH X TIME INTERACTION	15	12.4426	0.8295	154.961	1.83	2.35	3.12
(i) DEV. X LINEAR X LINEAR	1	10.1485	10.1485	1895.855	3.97	6.77	11.77
(ii) DEV. X QUADRATIC X LINEAR	1	1.6868	1.6868	315.107	3.97	6.77	11.77
(iii) DEV. X LINEAR X QUADRATIC	1	0.0415	0.0415	7.749	3.97	6.77	11.77
(iv) DEV. X CUBIC X LINEAR	1	0.0231	0.0231	4.311	3.97	6.77	11.77
(v) DEV. X QUADRATIC X QUADRATIC	1	0.0696	0.0696	12.995	3.97	6.77	11.77
(vi) DEV. X LINEAR X CUBIC	1	0.1572	0.1572	29.360	3.97	6.77	11.77
(vii) DEV. X CUBIC X QUADRATIC	1	0.1607	0.1607	30.016	3.97	6.77	11.77
(viii) DEV. X QUADRATIC X CUBIC	1	0.0810	0.0810	15.125	3.97	6.77	11.77
(ix) DEV. X LINEAR X DEV.	2	0.0174	0.0087	1.629	3.12	4.91	7.61
(x) DEV. X CUBIC X CUBIC	1	0.0003	0.0003	0.057	3.97	6.77	11.77
(xi) DEV. X QUADRATIC X DEV.	2	0.0452	0.0226	4.220	3.12	4.91	7.61
(xii) DEV. X CUBIC X DEV.	2	0.0115	0.0058	1.075	3.12	4.91	7.61
ERROR C	80	0.4282	0.0054				
COMBINED ERROR	-	-	-				

STATISTICAL TABLES FOR

CHAPTER 3

Table 3.2.

Analysis of variance for total plant fresh weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	2953.827					
LIGHT QUALITY	1	26.702	26.702	11.380	3.92	6.85	11.38
ERROR A	8	19.197	2.400	1.002	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	654.215	327.108	139.412	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	6.473	3.237	1.380	3.07	4.79	7.32
ERROR B	16	32.518	2.032	0.849	1.80	2.27	2.93
DAY	4	1418.269	354.567	151.115	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	14.034	3.509	1.496	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	531.805	66.476	28.332	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	20.766	2.596	1.106	2.02	2.66	3.55
ERROR C	96	229.846	2.394				
COMBINED ERROR (A+B+C)	120	281.561	2.346				

Table 3.3.

Analysis of variance for total plant dry weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	13.231					
LIGHT QUALITY	1	0.036	0.036	4.118	3.92	6.85	11.38
ERROR A	8	0.078	0.010	1.070	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	3.037	1.519	171.609	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.017	0.009	0.983	3.07	4.79	7.32
ERROR B	16	0.114	0.007	0.783	1.80	2.27	2.93
DAY	4	6.635	1.659	187.456	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	0.027	0.007	0.758	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	2.347	0.293	33.152	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.070	0.009	0.984	2.02	2.66	3.55
ERROR C	96	0.871	0.009				
COMBINED ERROR (A+B+C)	120	1.062	0.009				

Table 3.4.

Analysis of variance for number of leaves attained

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	29	10.117					
LIGHT QUALITY	1	0.014	0.014	0.137	5.32	11.26	25.42
ERROR A	8	0.813	0.102	3.290	2.59	3.89	6.19
PLANT GROWTH REGULATOR	2	8.672	4.336	139.87	3.63	6.23	10.97
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.117	0.058	1.871	3.63	6.23	10.97
ERROR B	16	0.501	0.031				
COMBINED ERROR (A+B)	-	-	-				

Table 3.5.

Analysis of variance for total leaf area.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	6.674×10^{9}					
LIGHT QUALITY	1	3.960×10^{7}	3.960×10^{7}	6.102	3.92	6.85	11.38
ERROR A	8	7.704×10^{7}	9.631×10^{6}	1.477	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	1.440×10^{9}	7.200×10^{8}	110.941	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	2.575×10^{7}	1.287×10^{7}	1.983	3.07	4.79	7.32
ERROR B	16	7.603×10^{7}	4.752×10^{6}	0.729	1.80	2.27	2.93
DAY	4	3.457×10^{9}	8.643×10^{8}	133.176	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	2.211×10^{7}	5.529×10^{6}	0.852	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	8.454×10^{8}	1.057×10^{8}	16.287	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	6.581×10^{7}	8.226×10^{6}	1.268	2.02	2.66	3.55
ERROR C	96	6.258×10^{8}	6.518×10^{6}				
COMBINED ERROR (A+B+C)	120	7.788×10^{8}	6.490×10^{6}				

Table 3.6.

Analysis of variance for total leaf fresh weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	1258.833					
LIGHT QUALITY	1	14.251	14.251	14.280	3.92	6.85	11.38
ERROR A	8	7.431	0.929	0.911	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	306.469	153.234	153.541	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	4.476	2.238	2.242	3.07	4.79	7.32
ERROR B	16	14.411	0.901	0.884	1.80	2.27	2.93
DAY	4	561.189	140.297	140.580	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	7.923	1.981	1.977	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	236.679	29.585	29.078	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	8.134	1.017	1.019	2.02	2.66	3.55
ERROR C	96	97.870	1.019				
COMBINED ERROR (A+B+C)	120	119.712	0.998				

Table 3.7.

Analysis of variance for total leaf dry weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	5.642					
LIGHT QUALITY	1	0.018	0.018	4.517	3.92	6.85	11.38
ERROR A	8	0.031	0.004	0.930	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	1.384	0.692	173.941	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.014	0.007	1.723	3.07	4.79	7.32
ERROR B	16	0.052	0.003	0.798	1.80	2.27	2.93
DAY	4	2.676	0.669	168.122	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	0.012	0.003	0.737	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	1.026	0.128	32.220	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.035	0.004	1.107	2.02	2.66	3.55
ERROR C	96	0.394	0.004				
COMBINED ERROR(A+B+C)	120	0.478	0.004				

Table 3.8.

Analysis of variance for dry weight of senesced leaf material.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	0.10196					
LIGHT QUALITY	1	0.00046	0.00046	4.241	3.92	6.85	11.38
ERROR A	8	0.00098	0.00012	1.119	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	0.03860	0.01930	176.180	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.00043	0.00021	1.949	3.07	4.79	7.32
ERROR B	16	0.00167	0.00010	0.957	1.80	2.27	2.93
DAY	4	0.03229	0.00807	73.678	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	0.00046	0.00011	1.046	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.01618	0.00202	18.463	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.00039	0.00005	0.446	2.02	2.66	3.55
ERROR C	96	0.01049	0.00011				
COMBINED ERROR (A+B+C)	120	0.01315	0.00011				

Table 3.9.

Analysis of variance for combined basal region & leaf sheaths fresh weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	175.229					
LIGHT QUALITY	1	3.581	3.581	33.456	3.92	6.85	11.38
ERROR A	8	0.739	0.092	0.822	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	26.890	13.445	125.605	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.930	0.465	4.345	3.07	4.79	7.32
ERROR B	16	1.317	0.082	0.733	1.80	2.27	2.93
DAY	4	101.980	25.495	238.181	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	3.305	0.826	7.719	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	24.716	3.090	28.863	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.982	0.123	1.146	2.02	2.66	3.55
ERROR C	96	10.789	0.112				
COMBINED ERROR (A+B+C)	120	12.845	0.107				

Table 3.10.

Analysis of variance for combined basal region & leaf sheaths dry weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	0.8417					
LIGHT QUALITY	1	0.0104	0.0104	23.918	3.92	6.85	11.38
ERROR A	8	0.0042	0.0005	1.189	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	0.1359	0.0680	157.080	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.0028	0.0014	3.213	3.07	4.79	7.32
ERROR B	16	0.0053	0.0003	0.752	1.80	2.27	2.93
DAY	4	0.5005	0.1251	289.165	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	0.0143	0.0036	8.265	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.1217	0.0152	35.164	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.0041	0.0005	1.186	2.02	2.66	3.55
ERROR C	96	0.0424	0.0004				
COMBINED ERROR (A+B+C)	120	0.0519	0.0004				

Table 3.11.

Analysis of variance for root fresh weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	55.941					
LIGHT QUALITY	1	0.248	0.248	1.892	3.92	6.85	11.38
ERROR A	8	0.875	0.109	0.835	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	9.706	4.853	37.004	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.282	0.141	1.074	3.07	4.79	7.32
ERROR B	16	2.292	0.143	1.094	1.80	2.27	2.93
DAY	4	18.117	4.529	34.536	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	0.787	0.197	1.501	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	8.581	1.073	8.179	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	2.481	0.310	2.364	2.02	2.66	3.55
ERROR C	96	12.571	0.131				
COMBINED ERROR (A+B+C)	120	15.738	0.131				

Table 3.12.

Analysis of variance for root dry weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	0.1960					
LIGHT QUALITY	1	0.0020	0.0020	5.125	3.92	6.85	11.38
ERROR A	8	0.0024	0.0003	0.726	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	0.0406	0.0203	51.566	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.0011	0.0006	1.415	3.07	4.79	7.32
ERROR B	16	0.0058	0.0004	0.893	1.80	2.27	2.93
DAY	4	0.0605	0.0151	38.413	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	0.0044	0.0011	2.776	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.0326	0.0041	10.370	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.0076	0.0009	2.404	2.02	2.66	3.55
ERROR C	96	0.0390	0.0004				
COMBINED ERROR (A+B+C)	120	0.0472	0.0004				

Table 3.13.

Analysis of variance for leaf dry weight ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	0.1954					
LIGHT QUALITY	1	0.0006	0.0006	0.893	3.92	6.85	11.38
ERROR A	8	0.0047	0.0006	0.834	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	0.0336	0.0168	25.066	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.0009	0.0005	0.708	3.07	4.79	7.32
ERROR B	16	0.0088	0.0005	0.787	1.80	2.27	2.93
DAY	4	0.0404	0.0101	15.086	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	0.0023	0.0006	0.861	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.0230	0.0029	4.296	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.0140	0.0018	2.619	2.02	2.66	3.55
ERROR C	96	0.0670	0.0007				
COMBINED ERROR (A+B+C)	120	0.0804	0.0007				

Table 3.14.

Analysis of variance for combined basal region & leaf sheath dry weight ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	0.1679					
LIGHT QUALITY	1	0.0037	0.0037	9.069	3.92	6.85	11.38
ERROR A	8	0.0012	0.0002	0.373	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	0.0155	0.0078	19.010	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.0001	0.0001	0.160	3.07	4.79	7.32
ERROR B	16	0.0081	0.0005	1.232	1.80	2.27	2.93
DAY	4	0.0685	0.0171	41.885	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	0.0084	0.0021	5.126	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.0139	0.0017	4.266	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.0087	0.0011	2.659	2.02	2.66	3.55
ERROR C	96	0.0397	0.0004				
COMBINED ERROR (A+B+C)	120	0.0490	0.0004				

Table 3.15.

Analysis of variance for root dry weight ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	0.1437					
LIGHT QUALITY	1	0.0070	0.0070	18.363	3.92	6.85	11.38
ERROR A	8	0.0021	0.0003	0.643	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	0.0035	0.0018	4.620	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.0016	0.0008	2.091	3.07	4.79	7.32
ERROR B	16	0.0045	0.0003	0.696	1.80	2.27	2.93
DAY	4	0.0694	0.0173	45.497	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	0.0033	0.0008	2.135	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.0071	0.0009	2.344	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.0061	0.0008	1.990	2.02	2.66	3.55
ERROR C	96	0.0391	0.0004				
COMBINED ERROR (A+B+C)	120	0.0457	0.0004				

Table 3.16.

Analysis of variance for unit leaf rate during spray period.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	29	0.465					
LIGHT QUALITY	1	0.008	0.008	1.006	4.26	7.82	14.03
ERROR A	8	0.051	0.006	0.722	2.59	3.89	6.19
PLANT GROWTH REGULATOR	2	0.256	0.128	16.061	3.40	5.61	9.34
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.010	0.005	0.638	3.40	5.61	9.34
ERROR B	16	0.140	0.009				
COMBINED ERROR (A+B)	24	0.191	0.008				

Table 3.17.

Analysis of variance for unit leaf rate during post-spray period.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	29	0.303					
LIGHT QUALITY	1	0.003	0.003	0.588	4.26	7.82	14.03
ERROR A	8	0.026	0.003	0.514	2.59	3.89	6.19
PLANT GROWTH REGULATOR	2	0.148	0.074	14.120	3.40	5.61	9.34
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.027	0.013	2.530	3.40	5.61	9.34
ERROR B	16	0.100	0.006				
COMBINED ERROR (A+B)	24	0.126	0.005				

Table 3.18.

Analysis of variance for relative growth rate during spray period.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	29	0.0229					
LIGHT QUALITY	1	0.0004	0.0004	1.054	4.26	7.82	14.03
ERROR A	8	0.0027	0.0003	0.892	2.59	3.89	6.19
PLANT GROWTH REGULATOR	2	0.0134	0.0067	18.741	3.40	5.61	9.34
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.0005	0.0002	0.649	3.40	5.61	9.34
ERROR B	16	0.0060	0.0004				
COMBINED ERROR (A+B)	24	0.0086	0.0004				

Table 3.19.

Analysis of variance for relative growth rate during post-spray period.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	29	0.0141					
LIGHT QUALITY	1	0.0004	0.0004	1.361	4.26	7.82	14.03
ERROR A	8	0.0014	0.0002	0.544	2.59	3.89	6.19
PLANT GROWTH REGULATOR	2	0.0061	0.0031	11.459	3.40	5.61	9.34
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.0012	0.0006	2.227	3.40	5.61	9.34
ERROR B	16	0.0051	0.0003				
COMBINED ERROR (A+B)	24	0.0064	0.0003				

Table 3.20.

Analysis of variance for leaf area ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	1.607×10^{9}					
LIGHT QUALITY	1	1.640×10^{6}	1.640×10^{6}	0.191	3.92	6.85	11.38
ERROR A	8	5.085×10^{7}	6.356×10^{6}	0.701	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	1.033×10^{8}	5.163×10^{7}	6.004	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	4.770×10^{7}	2.385×10^{7}	2.773	3.07	4.79	7.32
ERROR B	16	1.100×10^{8}	6.874×10^{6}	0.758	1.80	2.27	2.93
DAY	4	8.019×10^{7}	2.005×10^{7}	2.332	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	4.650×10^{7}	1.163×10^{7}	1.352	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	2.650×10^{8}	3.312×10^{7}	3.851	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	3.086×10^{7}	3.858×10^{6}	0.449	2.02	2.66	3.55
ERROR C	96	8.711×10^{8}	9.073×10^{6}				
COMBINED ERROR (A+B+C)	120	1.032×10^{9}	8.600×10^{6}				

Table 3.21.

Analysis of variance for specific leaf area.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	4.611×10^{9}					
LIGHT QUALITY	1	1.825×10^{3}	1.825×10^{3}	0.000	3.92	6.85	11.38
ERROR A	8	2.197×10^{8}	2.746×10^{7}	1.012	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	1.714×10^{8}	8.570×10^{7}	3.368	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	9.886×10^{7}	4.943×10^{7}	1.942	3.07	4.79	7.32
ERROR B	16	2.294×10^{8}	1.434×10^{7}	0.529	1.80	2.27	2.93
DAY	4	2.468×10^{8}	6.171×10^{7}	2.425	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	9.262×10^{7}	2.315×10^{7}	0.910	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	7.641×10^{8}	9.551×10^{7}	3.754	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	1.846×10^{8}	2.308×10^{7}	0.907	2.02	2.66	3.55
ERROR C	96	2.604×10^{9}	2.712×10^{7}				
COMBINED ERROR (A+B+C)	120	3.053×10^{9}	2.544×10^{7}				

Table 3.22.

Analysis of variance for leaf specific water content.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	388.344					
LIGHT QUALITY	1	21.228	21.228	21.334	3.92	6.85	11.38
ERROR A	8	7.080	0.885	0.904	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	25.948	12.974	13.038	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.782	0.391	0.393	3.07	4.79	7.32
ERROR B	16	18.340	1.146	1.171	1.80	2.27	2.93
DAY	4	131.661	32.915	33.079	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	16.329	4.082	4.102	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	66.457	8.307	8.348	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	6.531	0.816	0.820	2.02	2.66	3.55
ERROR C	96	93.988	0.979				
COMBINED ERROR (A+B+C)	120	119.408	0.995				

Table 3.23.

Analysis of variance for combined basal region & leaf sheaths specific water content.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	433.713					
LIGHT QUALITY	1	6.727	6.727	2.957	3.92	6.85	11.38
ERROR A	8	26.373	3.297	1.574	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	27.332	13.666	6.007	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	5.793	2.896	1.273	3.07	4.79	7.32
ERROR B	16	45.574	2.848	1.360	1.80	2.27	2.93
DAY	4	63.438	15.859	6.971	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	35.880	8.970	3.943	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	9.080	1.135	0.499	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	12.494	1.562	0.687	2.02	2.66	3.55
ERROR C	96	201.023	2.094				
COMBINED ERROR (A+B+C)	120	272.970	2.275				

Table 3.24.

Analysis of variance for root specific water content.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	872.585					
LIGHT QUALITY	1	0.172	0.172	0.035	3.92	6.85	11.38
ERROR A	8	55.524	6.940	1.406	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	3.479	1.739	0.355	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	21.745	10.872	2.222	3.07	4.79	7.32
ERROR B	16	57.863	3.616	0.733	1.80	2.27	2.93
DAY	4	71.115	17.779	3.633	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	72.188	18.047	3.688	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	69.074	8.634	1.765	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	47.659	5.957	1.217	2.02	2.66	3.55
ERROR C	96	473.766	4.935				
COMBINED ERROR (A+B+C)	120	587.153	4.893				

Table 3.26.

Analysis of variance for leaf length of the fourth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	4750192.5					
LIGHT QUALITY	1	34504.5	34504.5	38.309	3.92	6.85	11.38
ERROR A	8	6280.7	785.1	0.913	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	118799.8	59399.9	65.949	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	13804.5	6902.2	7.663	3.07	4.79	7.32
ERROR B	16	19222.9	1201.4	1.397	1.80	2.27	2.93
DAY	4	4398299.1	1099574.8	1220.803	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	19321.2	4830.3	5.363	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	48395.6	6049.5	6.716	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	8983.9	1123.0	0.137	2.02	2.66	3.55
ERROR C	96	82580.2	860.2				
COMBINED ERROR (A+B+C)	120	108083.8	900.698				

Table 3.27.

Analysis of variance for maximum leaf width of the fourth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	584.385					
LIGHT QUALITY	1	1.062	1.062	4.070	3.92	6.85	11.38
ERROR A	8	3.334	0.417	1.703	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	127.046	63.523	243.476	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.861	0.431	1.650	3.07	4.79	7.32
ERROR B	16	4.484	0.280	1.145	1.80	2.27	2.93
DAY	4	351.701	87.925	337.008	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	1.080	0.270	1.035	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	67.978	8.497	32.569	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	3.346	0.418	1.603	2.02	2.66	3.55
ERROR C	96	23.493	0.245				
COMBINED ERROR (A+B+C)	120	31.311	0.261				

Table 3.28.

Analysis of variance for leaf area of the fourth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	1.042×10^{9}					
LIGHT QUALITY	1	6.949×10^{6}	6.949×10^{6}	16.280	3.92	6.85	11.38
ERROR A	8	2.850×10^{6}	3.563×10^{5}	0.862	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	1.394×10^{8}	6.972×10^{7}	163.342	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	3.717×10^{6}	1.858×10^{6}	4.353	3.07	4.79	7.32
ERROR B	16	8.671×10^{6}	5.419×10^{5}	1.310	1.80	2.27	2.93
DAY	4	7.472×10^{8}	1.868×10^{8}	437.639	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	5.497×10^{6}	1.374×10^{6}	3.219	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	8.198×10^{7}	1.025×10^{7}	24.014	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	5.574×10^{6}	6.968×10^{5}	1.632	2.02	2.66	3.55
ERROR C	96	3.970×10^{7}	4.135×10^{5}				
COMBINED ERROR (A+B+C)	120	5.122×10^{5}	4.268×10^{5}				

Table 3.29.

Analysis of variance for fresh weight of the fourth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	223.855					
LIGHT QUALITY	1	2.280	2.280	16.170	3.92	6.85	11.38
ERROR A	8	0.910	0.114	0.811	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	26.793	13.397	94.992	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	1.150	0.575	4.076	3.07	4.79	7.32
ERROR B	16	2.538	0.159	1.130	1.80	2.27	2.93
DAY	4	151.034	37.759	267.735	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	1.862	0.465	3.300	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	22.549	2.819	19.987	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	1.263	0.158	0.821	2.02	2.66	3.55
ERROR C	96	13.476	0.140				
COMBINED ERROR (A+B+C)	120	16.924	0.141				

Table 3.30.

Analysis of variance for dry weight of the fourth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	149	1.1043					
LIGHT QUALITY	1	0.0035	0.0035	5.960	3.92	6.85	11.38
ERROR A	8	0.0042	0.0005	0.875	2.05	2.72	3.66
PLANT GROWTH REGULATOR	2	0.1477	0.0738	125.064	3.07	4.79	7.32
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.0032	0.0016	2.743	3.07	4.79	7.32
ERROR B	16	0.0095	0.0006	1.002	1.80	2.27	2.93
DAY	4	0.7424	0.1856	314.329	2.45	3.48	4.95
LIGHT QUALITY X DAY INTERACTION	4	0.0091	0.0023	3.844	2.45	3.48	4.95
PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.1179	0.0147	24.962	2.02	2.66	3.55
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	8	0.0096	0.0012	2.036	2.02	2.66	3.55
ERROR C	96	0.0571	0.0006				
COMBINED ERROR (A+B+C)	120	0.0709	0.0006				

Table 3.31.

Analysis of variance for length of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	119966.9					
LIGHT QUALITY	1	12247.3	12247.3	48.558	3.95	6.94	11.62
ERROR A	8	1700.9	212.6	0.811	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	50577.6	25288.8	100.265	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	5333.7	2666.9	10.574	3.10	4.87	7.50
ERROR B	16	3643.7	227.7	0.869	1.83	2.34	3.04
DAY	3	24823.0	8274.3	32.806	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	866.1	288.7	1.145	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	891.4	148.6	0.589	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	1014.9	169.1	0.670	2.20	3.02	4.17
ERROR C	72	18868.4	262.1				
COMBINED ERROR (A+B+C)	96	24213.0	252.219				

Table 3.32.

Analysis of variance for width of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	85.846					
LIGHT QUALITY	1	1.266	1.265	6.361	3.95	6.94	11.62
ERROR A	8	1.062	0.133	0.637	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	42.656	21.328	107.194	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.721	0.361	1.812	3.10	4.87	7.50
ERROR B	16	3.022	0.189	0.906	1.83	2.34	3.04
DAY	3	17.049	5.683	28.562	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	1.982	0.661	3.321	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	2.560	0.427	2.144	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	0.511	0.085	0.428	2.20	3.02	4.17
ERROR C	72	15.017	0.209				
COMBINED ERROR (A+B+C)	96	19.101	0.199				

Table 3.33.

Analysis of variance for fresh weight of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	5.671					
LIGHT QUALITY	1	0.580	0.580	32.041	3.95	6.94	11.62
ERROR A	8	0.054	0.007	0.345	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	2.379	1.189	65.748	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.171	0.085	4.723	3.10	4.87	7.50
ERROR B	16	0.287	0.018	0.924	1.83	2.34	3.04
DAY	3	0.245	0.082	4.521	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	0.145	0.048	2.679	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	0.328	0.055	3.021	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	0.087	0.014	0.798	2.20	3.02	4.17
ERROR C	72	1.396	0.019				
COMBINED ERROR (A+B+C)	96	1.736	0.018				

Table 3.34.

Analysis of variance for dry weight of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	0.02569					
LIGHT QUALITY	1	0.00189	0.00189	28.880	3.95	6.94	11.62
ERROR A	8	0.00029	0.00004	0.500	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	0.01241	0.00621	94.933	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.00063	0.00031	4.790	3.10	4.87	7.50
ERROR B	16	0.00084	0.00005	0.738	1.83	2.34	3.04
DAY	3	0.00251	0.00084	12.782	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	0.00022	0.00007	1.144	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	0.00128	0.00021	3.259	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	0.00047	0.00008	1.208	2.20	3.02	4.17
ERROR C	72	0.00515	0.00007				
COMBINED ERROR (A+B+C)	96	0.00628	0.00007				

Table 3.35.

Analysis of variance for length of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	116696.4					
LIGHT QUALITY	1	24840.6	24840.6	88.240	3.94	7.12	11.51
ERROR A	8	987.3	123.4	0.401	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	17708.5	8854.2	14.105	3.63	6.23	10.97
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	8792.1	4396.0	7.003	3.63	6.23	10.97
ERROR B	16	10043.8	627.7	2.039	1.90	2.47	3.30
DAY	2	35715.7	17857.9	63.435	3.09	5.02	7.86
LIGHT QUALITY X DAY INTERACTION	2	2581.2	1290.6	4.585	3.09	5.02	7.86
PLANT GROWTH REGULATOR X DAY INTERACTION	4	1143.3	285.8	1.015	2.47	3.69	5.39
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	106.5	26.6	0.095	2.47	3.69	5.39
ERROR C	48	14777.4	307.9				
COMBINED ERROR (A+C)	56	15764.7	281.513				

Table 3.36.

Analysis of variance for width of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	269.691					
LIGHT QUALITY	1	0.198	0.198	0.523	3.98	7.03	11.85
ERROR A	8	2.612	0.327	0.856	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	183.427	91.714	241.66	3.13	4.94	7.67
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.183	0.092	0.241	3.13	4.94	7.67
ERROR B	16	6.408	0.401	1.051	1.90	2.47	3.30
DAY	2	45.721	22.860	60.236	3.13	4.94	7.67
LIGHT QUALITY X DAY INTERACTION	2	1.479	0.740	1.949	3.13	4.94	7.67
PLANT GROWTH REGULATOR X DAY INTERACTION	4	9.374	2.344	6.175	2.50	3.62	5.19
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	1.984	0.496	1.307	2.50	3.62	5.19
ERROR C	48	18.303	0.381				
COMBINED ERROR (A+B+C)	72	27.325	0.380				

Table 3.37.

Analysis of variance for fresh weight of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	24.245					
LIGHT QUALITY	1	2.228	2.228	33.567	3.98	7.03	11.85
ERROR A	8	0.579	0.072	1.163	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	11.429	5.715	86.113	3.13	4.94	7.67
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	1.203	0.602	9.067	3.13	4.94	7.67
ERROR B	16	1.213	0.076	1.219	1.90	2.47	3.30
DAY	2	2.544	1.272	19.166	3.13	4.94	7.67
LIGHT QUALITY X DAY INTERACTION	2	0.402	0.201	3.031	3.13	4.94	7.67
PLANT GROWTH REGULATOR X DAY INTERACTION	4	1.487	0.372	5.603	2.50	3.62	5.19
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	0.174	0.043	0.657	2.50	3.62	5.19
ERROR C	48	2.986	0.062				
COMBINED ERROR (A+B+C)	72	4.778	0.066				

Table 3.38.

Analysis of variance for dry weight of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	0.1159					
LIGHT QUALITY	1	0.0060	0.0060	22.181	3.98	7.03	11.85
ERROR A	8	0.0036	0.0004	1.815	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	0.0588	0.0294	109.298	3.13	4.94	7.67
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.0049	0.0024	9.099	3.13	4.94	7.67
ERROR B	16	0.0039	0.0002	0.979	1.90	2.47	3.30
DAY	2	0.0183	0.0092	34.024	3.13	4.94	7.67
LIGHT QUALITY X DAY INTERACTION	2	0.0016	0.0008	2.917	3.13	4.94	7.67
PLANT GROWTH REGULATOR X DAY INTERACTION	4	0.0060	0.0015	5.604	2.50	3.62	5.19
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	0.0009	0.0002	0.812	2.50	3.62	5.19
ERROR C	48	0.0119	0.0002				
COMBINED ERROR (A+B+C)	72	0.0194	0.0003				

Table 3.39.

Analysis of variance for length of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	59	26188.9					
LIGHT QUALITY	1	846.2	846.2	1.824	5.32	11.26	25.42
ERROR A	8	3710.9	463.9	2.542	2.36	3.36	4.99
PLANT GROWTH REGULATOR	2	6209.1	3104.5	11.864	3.23	5.18	8.25
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	6.7	3.4	0.013	3.23	5.18	8.25
ERROR B	16	6087.5	380.5	2.085	2.11	2.91	4.17
DAY	1	4189.4	4189.4	16.009	4.08	7.31	12.61
LIGHT QUALITY X DAY INTERACTION	1	0.2	0.2	0.001	4.08	7.31	12.61
PLANT GROWTH REGULATOR X DAY INTERACTION	2	310.7	155.4	0.594	3.23	5.18	8.25
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	448.5	224.2	0.857	3.23	5.18	8.25
ERROR C	24	4379.8	182.5				
COMBINED ERROR (B+C)	40	10467.3	261.683				

Table 3.40.

Analysis of variance for width of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	59	162.211					
LIGHT QUALITY	1	10.660	10.660	9.430	4.05	7.22	12.35
ERROR A	8	7.044	0.880	0.642	2.36	3.36	4.99
PLANT GROWTH REGULATOR	2	64.954	32.477	28.731	3.20	4.91	8.05
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	2.810	1.405	1.243	3.20	4.91	8.05
ERROR B	16	14.283	0.893	0.651	2.11	2.91	4.17
DAY	1	25.129	25.129	22.231	4.05	7.22	12.35
LIGHT QUALITY X DAY INTERACTION	1	0.930	0.930	0.823	4.05	7.22	12.35
PLANT GROWTH REGULATOR X DAY INTERACTION	2	0.012	0.006	0.005	3.20	4.91	8.05
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	3.458	1.729	1.530	3.20	4.91	8.05
ERROR C	24	32.931	1.372				
COMBINED ERROR (A+B+C)	48	54.258	1.130				

Table 3.41.

Analysis of variance for fresh weight of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	59	5.780					
LIGHT QUALITY	1	0.066	0.066	1.649	4.05	7.22	12.35
ERROR A	8	0.354	0.044	1.610	2.36	3.36	4.99
PLANT GROWTH REGULATOR	2	3.275	1.638	41.174	3.20	4.91	8.05
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.089	0.044	1.113	3.20	4.91	8.05
ERROR B	16	0.894	0.056	2.031	2.11	2.91	4.17
DAY	1	0.272	0.272	6.839	4.05	7.22	12.35
LIGHT QUALITY X DAY INTERACTION	1	0.016	0.016	0.407	4.05	7.22	12.35
PLANT GROWTH REGULATOR X DAY INTERACTION	2	0.097	0.048	1.218	3.20	4.91	8.05
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	0.056	0.028	0.706	3.20	4.91	8.05
ERROR C	24	0.660	0.028				
COMBINED ERROR (A+B+C)	48	1.909	0.040				

Table 3.42.

Analysis of variance for dry weight of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	58	0.0251					
LIGHT QUALITY	1	0.0006	0.0006	3.226	4.05	7.23	12.39
ERROR A	8	0.0012	0.0001	0.930	2.38	3.41	5.09
PLANT GROWTH REGULATOR	2	0.0127	0.0063	36.832	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.0002	0.0001	0.533	3.20	5.11	8.57
ERROR B	16	0.0032	0.0002	1.237	2.13	2.95	4.05
DAY	1	0.0025	0.0025	14.325	4.05	7.23	12.39
LIGHT QUALITY X DAY INTERACTION	1	0.0002	0.0002	1.004	4.05	7.23	12.39
PLANT GROWTH REGULATOR X DAY INTERACTION	2	0.0007	0.0004	2.049	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	0.0003	0.0001	0.779	3.20	5.11	8.57
ERROR C	23(a)	0.0037	0.0002				
COMBINED ERROR (A+B+C)	47	0.0081	0.0002				

a - One missing value

Table 3.44.

Analysis of variance for length of the second leaf from experimental unit 1.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	125	1341904.1					
PLANT GROWTH REGULATOR	6	8193.2	1365.5	6.116	2.22	3.06	4.24
DAY	5	1310251.4	262050.3	1173.668	2.34	3.58	4.62
(i) LINEAR	1	1211421.3	1211421.3	5425.702	3.97	6.99	11.73
(ii) QUADRATIC	1	87477.9	87477.9	391.795	3.97	6.99	11.73
(iii) CUBIC	1	8452.9	8452.9	37.859	3.97	6.99	11.73
(iv) DEVIATIONS	2	2899.3	1449.7	6.493	3.12	4.90	7.58
PLANT GROWTH REGULATOR X DAY INTERACTION	30	4704.4	156.8	0.702	1.63	2.00	2.46
(i) DEV. X LINEAR	6	3997.6	666.3	2.984	2.22	3.06	4.24
(ii) DEV. X QUADRATIC	6	275.3	45.9	0.206	2.22	3.06	4.24
(iii) DEV. X CUBIC	6	222.1	37.0	0.166	2.22	3.06	4.24
(iv) DEVIATIONS	12	209.5	17.5	0.078	1.63	2.44	3.19
ERROR	84	18755.1	223.3				

Table 3.45.

Analysis of variance for length of the second leaf from experimental unit 2.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	143	1659569.4					
PLANT GROWTH REGULATOR	7	14999.7	2142.8	7.097	2.12	2.87	4.43
DAY	5	1609503.4	321900.7	1066.123	2.32	3.24	4.56
(i) LINEAR	1	1468431.5	1468431.5	4863.388	3.95	6.94	11.62
(ii) QUADRATIC	1	132804.1	132804.1	439.842	3.95	6.94	11.62
(iii) CUBIC	1	5792.7	5792.7	19.185	3.95	6.94	11.62
(iv) DEVIATIONS	2	2475.1	1237.6	4.099	3.10	4.87	7.50
PLANT GROWTH REGULATOR X DAY INTERACTION	35	6080.4	173.7	0.575	1.62	1.93	2.33
(i) DEV. X LINEAR	7	3771.0	538.7	1.784	2.12	2.87	4.43
(ii) DEV. X QUADRATIC	7	1880.5	268.6	0.890	2.12	2.87	4.43
(iii) DEV. X CUBIC	7	216.4	30.9	0.102	2.12	2.87	4.43
(iv) DEVIATIONS	14	212.5	15.2	0.050	1.82	2.34	3.04
ERROR	96	28985.8	301.9				

Table 3.46.

Tests of significance between plant growth regulator treatments.

(i) Unit 1 - Length of the second leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7
AMO-1618	FOLIAR SPRAY	1	226.9		NS	NS	NS	*	**	**
CONTROL	FOLIAR SPRAY	2	218.9			NS	NS	NS	NS	**
MEPIQUAT CHLORIDE	FOLIAR SPRAY	3	214.2				NS	NS	NS	*
ANCYMIDOL	SOIL DRENCH	4	211.9					NS	NS	NS
ANCYMIDOL	FOLIAR SPRAY	5	210.4						NS	NS
AMO-1618	SOIL DRENCH	6	207.3							NS
PHOSPHON D	SOIL DRENCH	7	199.4							

Q (P0.05) = 14.58

Q (P0.01) = 17.43

(ii) Unit 2 - Length of the second leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7	8
CONTROL	FOLIAR SPRAY	1	241.7		NS	NS	NS	NS	NS	**	**
CCC	SOIL DRENCH	2	240.9			NS	NS	NS	NS	**	**
GA_3	FOLIAR SPRAY	3	235.2				NS	NS	NS	**	**
PACLOBUTRAZOL	FOLIAR SPRAY	4	231.1					NS	NS	NS	NS
$GA_{4/7}$	FOLIAR SPRAY	5	228.8						NS	NS	NS
SADH	FOLIAR SPRAY	6	224.5							NS	NS
PACLOBUTRAZOL	SOIL DRENCH	7	213.7								NS
CCC	FOLIAR SPRAY	8	213.7								

Q (P0.01) = 20.72

Table 3.47.

Analysis of variance for maximum width of the second leaf from experimental unit 1.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	125	215.375					
PLANT GROWTH REGULATOR	6	1.715	0.286	9.084	2.22	3.06	4.24
DAY	5	210.404	42.081	1337.041	2.34	3.58	4.62
(i) LINEAR	1	206.741	206.741	6568.841	3.97	6.99	11.73
(ii) QUADRATIC	1	2.978	2.978	94.624	3.97	6.99	11.73
(iii) CUBIC	1	0.189	0.189	6.001	3.97	6.99	11.73
(iv) DEVIATIONS	2	0.495	0.248	7.868	3.12	4.90	7.58
PLANT GROWTH REGULATOR X DAY INTERACTION	30	0.612	0.020	0.648	1.63	2.00	2.46
(i) DEV. X LINEAR	6	0.350	0.058	1.851	2.22	3.06	4.24
(ii) DEV. X QUADRATIC	6	0.229	0.038	1.211	2.22	3.06	4.24
(iii) DEV. X CUBIC	6	0.015	0.002	0.078	2.22	3.06	4.24
(iv) DEVIATIONS	12	0.019	0.002	0.051	1.63	2.44	3.19
ERROR	84	2.644	0.031				

Table 3.48.

Analysis of variance for maximum width of the second leaf from experimental unit 2.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	143	241.088					
PLANT GROWTH REGULATOR	7	1.159	0.166	3.817	2.12	2.87	4.43
DAY	5	234.632	46.926	1082.293	2.32	3.24	4.56
(i) LINEAR	1	228.603	228.603	5272.410	3.95	6.94	11.62
(ii) QUADRATIC	1	5.359	5.359	123.595	3.95	6.94	11.62
(iii) CUBIC	1	0.028	0.028	0.655	3.95	6.94	11.62
(iv) DEVIATIONS	2	0.642	0.321	7.402	3.10	4.87	7.50
PLANT GROWTH REGULATOR X DAY INTERACTION	35	1.135	0.032	0.748	1.62	1.93	2.33
(i) DEV. X LINEAR	7	0.690	0.099	2.273	2.12	2.87	4.43
(ii) DEV. X QUADRATIC	7	0.169	0.024	0.558	2.12	2.87	4.43
(iii) DEV. X CUBIC	7	0.109	0.016	0.359	2.12	2.87	4.43
(iv) DEVIATIONS	14	0.166	0.012	0.274	1.82	2.34	3.04
ERROR	96	4.162	0.043				

Table 3.49.

Tests of significance between plant growth regulator treatments.

(i) Unit 1 - Maximum width of the second leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7
AMO-1618	FOLIAR SPRAY	1	3.188		NS	NS	NS	**	**	**
ANCYMIDOL	SOIL DRENCH	2	3.132			NS	NS	NS	NS	**
PHOSPHON D	SOIL DRENCH	3	3.084				NS	NS	NS	**
ANCYMIDOL	FOLIAR SPRAY	4	3.026					NS	NS	**
MEPIQUAT CHLORIDE	FOLIAR SPRAY	5	2.972						NS	NS
CONTROL	FOLIAR SPRAY	6	2.963							NS
AMO-1618	SOIL DRENCH	7	2.808							

Q (P0.01) = 0.207

(ii) Unit 2 - Maximum width of the second leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7	8
SADH	FOLIAR SPRAY	1	3.298		NS	NS	NS	NS	NS	NS	**
PACLOBUTRAZOL	SOIL DRENCH	2	3.288			NS	NS	NS	NS	NS	**
CONTROL	FOLIAR SPRAY	3	3.249				NS	NS	NS	NS	**
PACLOBUTRAZOL	FOLIAR SPRAY	4	3.238					NS	NS	NS	*
GA_3	FOLIAR SPRAY	5	3.217						NS	NS	NS
CCC	SOIL DRENCH	6	3.151							NS	NS
$GA_{4/7}$	FOLIAR SPRAY	7	3.113								NS
CCC	FOLIAR SPRAY	8	3.018								

Q (P0.05) = 0.210

Q (P0.01) = 0.248

Table 3.50.

Analysis of variance for leaf sheath length of the second leaf from experimental unit 1.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	20	929.638					
PLANT GROWTH REGULATOR	6	890.278	148.380	52.777	2.85	4.46	7.43
ERROR	14	39.360	2.811				

Table 3.51.

Analysis of variance for leaf sheath length of the second leaf from experimental unit 2.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	23	432.260					
PLANT GROWTH REGULATOR	7	396.640	56.663	25.452	2.66	4.04	6.50
ERROR	16	35.620	2.226				

Table 3.52.

Tests of significance between plant growth regulator treatments.

(i) Unit 1 - Leaf sheath length of the second leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7
AMO-1618	FOLIAR SPRAY	1	19.13		NS	NS	NS	NS	**	**
ANCYMIDOL	SOIL DRENCH	2	17.53			NS	NS	NS	**	**
CONTROL	FOLIAR SPRAY	3	17.33				NS	NS	**	**
ANCYMIDOL	FOLIAR SPRAY	4	16.47					NS	**	**
MEPIQUAT CHLORIDE	FOLIAR SPRAY	5	15.20						**	**
PHOSPHON D	SOIL DRENCH	6	3.33							NS
AMO-1618	SOIL DRENCH	7	2.53							

Q (P0.01) = 5.69

(ii) Unit 2 - Leaf sheath length of the second leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7	8
$GA_{4/7}$	FOLIAR SPRAY	1	24.53		NS	NS	NS	*	**	**	**
GA_3	FOLIAR SPRAY	2	21.20			NS	NS	NS	NS	*	**
CCC	SOIL DRENCH	3	20.73				NS	NS	NS	NS	**
CCC	FOLIAR SPRAY	4	20.67					NS	NS	NS	**
PACLOBUTRAZOL	FOLIAR SPRAY	5	20.27						NS	NS	**
CONTROL	FOLIAR SPRAY	6	17.33							NS	**
SADH	FOLIAR SPRAY	7	16.90								**
PACLOBUTRAZOL	SOIL DRENCH	8	9.93								

Q (P0.05) = 4.08

Q (P0.01) = 5.09

Table 3.53.

Analysis of variance for length of the third leaf from experimental unit 1.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	146	2894905.2					
PLANT GROWTH REGULATOR	6	11706.2	1951.0	6.574	2.20	3.02	4.16
DAY	6	2850881.4	475146.9	1601.081	2.20	3.02	4.16
(i) LINEAR	1	2605632.4	2605632.4	8780.083	3.95	6.93	11.60
(ii) QUADRATIC	1	222330.2	222330.2	749.176	3.95	6.93	11.60
(iii) CUBIC	1	15515.6	15515.6	52.282	3.95	6.93	11.60
(iv) DEVIATIONS	3	7403.3	2467.8	8.315	2.71	4.02	5.93
PLANT GROWTH REGULATOR X DAY INTERACTION	36	3234.5	89.8	0.303	1.61	1.91	2.98
(i) DEV. X LINEAR	6	1769.7	295.0	0.994	2.20	3.02	4.16
(ii) DEV. X QUADRATIC	6	724.1	120.7	0.407	2.20	3.02	4.16
(iii) DEV. X CUBIC	6	265.2	44.2	0.149	2.20	3.02	4.16
(iv) DEVIATIONS	18	475.5	26.4	0.089	1.75	2.21	2.82
ERROR	98	29083.1	296.8				

Table 3.54.

Analysis of variance for length of the third leaf from experimental unit 2.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	167	2945590.8					
PLANT GROWTH REGULATOR	7	49571.4	7081.6	14.694	2.11	2.83	3.84
DAY	6	2822169.5	470361.6	975.966	2.18	2.98	4.08
(i) LINEAR	1	2508784.3	2508784.3	5205.547	3.93	6.88	11.46
(ii) QUADRATIC	1	299645.6	299645.6	621.743	3.93	6.88	11.46
(iii) CUBIC	1	6808.3	6808.3	14.127	3.93	6.88	11.46
(iv) DEVIATIONS	3	6931.3	2310.4	4.794	2.69	3.97	5.84
PLANT GROWTH REGULATOR X DAY INTERACTION	42	19872.1	473.1	0.982	1.56	1.82	2.14
(i) DEV. X LINEAR	7	14984.2	2140.6	4.442	2.11	2.83	3.84
(ii) DEV. X QUADRATIC	7	2007.8	286.8	0.595	2.11	2.83	3.84
(iii) DEV. X CUBIC	7	1803.6	257.7	0.535	2.11	2.83	3.84
(iv) DEVIATIONS	21	1076.5	51.3	0.106	1.56	2.07	2.60
ERROR	112	53977.8	481.9				

Table 3.55.

Tests of significance between plant growth regulator treatments.

(i) Unit 1 - Length of the third leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7
ANCYMIDOL	SOIL DRENCH	1	278.9		NS	NS	NS	NS	**	**
AMO-1618	FOLIAR SPRAY	2	277.9			NS	NS	NS	**	**
PHOSPHON D	SOIL DRENCH	3	267.0				NS	NS	NS	NS
AMO-1618	SOIL DRENCH	4	266.8					NS	NS	NS
ANCYMIDOL	FOLIAR SPRAY	5	265.6						NS	NS
CONTROL	FOLIAR SPRAY	6	256.0							NS
MEPIQUAT CHLORIDE	FOLIAR SPRAY	7	253.8							

Q (P0.01) = 18.53

(ii) Unit 2 - Length of the third leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7	8
CONTROL	FOLIAR SPRAY	1	294.4		NS	NS	NS	NS	**	**	**
CCC	SOIL DRENCH	2	292.1			NS	NS	NS	**	**	**
PACLOBUTRAZOL	FOLIAR SPRAY	3	277.6				NS	NS	NS	NS	**
GA_3	FOLIAR SPRAY	4	276.0					NS	NS	NS	**
SADH	FOLIAR SPRAY	5	275.7						NS	NS	**
CCC	FOLIAR SPRAY	6	266.2							NS	**
PACLOBUTRAZOL	SOIL DRENCH	7	261.3								**
$GA_{4/7}$	FOLIAR SPRAY	8	236.7								

Q (P0.01) = 24.05

Table 3.56.

Analysis of variance for maximum width of the third leaf from experimental unit 1.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	146	573.433					
PLANT GROWTH REGULATOR	6	15.806	2.634	31.158	2.20	3.02	4.16
DAY	6	545.119	90.853	1074.624	2.20	3.02	4.16
(i) LINEAR	1	486.704	486.704	5756.803	3.95	6.93	11.60
(ii) QUADRATIC	1	56.909	56.909	673.128	3.95	6.93	11.60
(iii) CUBIC	1	0.002	0.002	0.020	3.95	6.93	11.60
(iv) DEVIATIONS	3	1.504	0.501	5.930	2.71	4.02	5.93
PLANT GROWTH REGULATOR X DAY INTERACTION	36	4.222	0.117	1.387	1.61	1.91	2.98
(i) DEV. X LINEAR	6	3.499	0.583	6.898	2.20	3.02	4.16
(ii) DEV. X QUADRATIC	6	0.403	0.067	0.794	2.20	3.02	4.16
(iii) DEV. X CUBIC	6	0.032	0.005	0.064	2.20	3.02	4.16
(iv) DEVIATIONS	18	0.288	0.016	0.189	1.75	2.21	2.82
ERROR	98	8.285	0.085				

Table 3.57.

Analysis of variance for maximum width of the third leaf from experimental unti 2.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	167	571.278					
PLANT GROWTH REGULATOR	7	39.936	5.705	35.919	2.11	2.83	3.84
DAY	6	496.549	82.758	521.034	2.18	2.98	4.08
(i) LINEAR	1	433.077	433.077	2726.594	3.93	6.88	11.46
(ii) QUADRATIC	1	61.793	61.793	389.037	3.93	6.88	11.46
(iii) CUBIC	1	0.030	0.030	0.186	3.93	6.88	11.46
(iv) DEVIATIONS	3	1.650	0.550	3.463	2.69	3.97	5.84
PLANT GROWTH REGULATOR X DAY INTERACTION	42	17.003	0.405	2.549	1.56	1.82	2.14
(i) DEV. X LINEAR	7	15.404	2.201	13.855	2.11	2.83	3.84
(ii) DEV. X QUADRATIC	7	0.867	0.124	0.780	2.11	2.83	3.84
(iii) DEV. X CUBIC	7	0.262	0.037	0.235	2.11	2.83	3.84
(iv) DEVIATIONS	21	0.469	0.022	0.141	1.56	2.07	2.60
ERROR	112	17.790	0.159				

Table 3.58.

Tests of significance between plant growth regulator treatments.

(i) Unit 1 - Maximum width of the third leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7
AMO-1618	SOIL DRENCH	1	5.002		NS	**	**	**	**	**
PHOSPHON D	SOIL DRENCH	2	4.971			**	**	**	**	**
AMO-1618	FOLIAR SPRAY	3	4.606				NS	*	**	**
ANCYMIDOL	SOIL DRENCH	4	4.500					NS	*	**
ANCYMIDOL	FOLIAR SPRAY	5	4.330						NS	NS
CONTROL	FOLIAR SPRAY	6	4.226							NS
MEPIQUAT CHLORIDE	FOLIAR SPRAY	7	4.088							

Q (P0.05) = 0.262

Q (P0.01) = 0.313

(ii) Unit 2 - Maximum width of the third leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7	8
PACLOBUTRAZOL	SOIL DRENCH	1	5.549		**	**	**	**	**	**	**
SADH	FOLIAR SPRAY	2	4.748			NS	NS	NS	**	**	**
PACLOBUTRAZOL	FOLIAR SPRAY	3	4.603				NS	NS	NS	*	**
CCC	SOIL DRENCH	4	4.567					NS	NS	NS	**
CONTROL	FOLIAR SPRAY	5	4.534						NS	NS	**
GA_3	FOLIAR SPRAY	6	4.307							NS	**
CCC	FOLIAR SPRAY	7	4.205								**
$GA_{4/7}$	FOLIAR SPRAY	8	3.721								

Q (P0.05) = 0.370

Q (P0.01) = 0.437

Table 3.59.

Analysis of variance for leaf sheath length of the third leaf from experimental unit 1.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	20	243.478					
PLANT GROWTH REGULATOR	6	208.145	34.691	13.745	2.85	4.46	7.43
ERROR	14	35.333	2.524				

Table 3.60.

Analysis of variance for leaf sheath length of the third leaf from experimental unit 2.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	23	180.625					
PLANT GROWTH REGULATOR	7	131.185	18.741	6.065	2.66	4.04	6.50
ERROR	16	49.440	3.090				

Table 3.61.

Tests of significance between plant growth regulator treatments.

(i) Unit 1 - Leaf sheath length of the third leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7
ANCYMIDOL	SOIL DRENCH	1	17.67		NS	NS	NS	*	**	**
CONTROL	FOLIAR SPRAY	2	16.27			NS	NS	NS	**	**
ANCYMIDOL	FOLIAR SPRAY	3	16.07				NS	NS	**	**
AMO-1618	FOLIAR SPRAY	4	14.80					NS	*	**
MEPIQUAT CHLORIDE	FOLIAR SPRAY	5	13.33						NS	*
PHOSPHON D	SOIL DRENCH	6	9.93							NS
AMO-1618	SOIL DRENCH	7	8.60							

Q (P0.05) = 4.26

Q (P0.01) = 5.39

(ii) Unit 2 - Leaf sheath length of the third leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7	8
$GA_{4/7}$	FOLIAR SPRAY	1	19.60		NS	NS	NS	NS	NS	NS	**
GA_3	FOLIAR SPRAY	2	18.47			NS	NS	NS	NS	NS	**
CCC	FOLIAR SPRAY	3	18.07				NS	NS	NS	NS	**
CONTROL	FOLIAR SPRAY	4	16.87					NS	NS	NS	*
CCC	SOIL DRENCH	5	16.07						NS	NS	NS
SADH	FOLIAR SPRAY	6	15.87							NS	NS
PACLOBUTRAZOL	FOLIAR SPRAY	7	15.47								NS
PACLOBUTRAZOL	SOIL DRENCH	8	11.40								

Q (P0.05) = 4.81

Q (P0.01) = 6.00

Table 3.62.

Analysis of variance for length of the fourth leaf from experimental unit 1.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	146	4779403.3					
PLANT GROWTH REGULATOR	6	23987.0	3997.8	8.753	2.20	3.02	4.16
DAY	6	4704250.1	784041.7	1716.671	2.20	3.02	4.16
(i) LINEAR	1	4625563.1	4625563.1	10127.739	3.95	6.93	11.60
(ii) QUADRATIC	1	9583.5	9583.5	20.983	3.95	6.93	11.60
(iii) CUBIC	1	67734.7	67734.7	148.306	3.95	6.93	11.60
(iv) DEVIATIONS	3	1368.7	456.2	0.999	2.71	4.02	5.93
PLANT GROWTH REGULATOR X DAY INTERACTION	36	6407.6	178.0	0.390	1.61	1.91	2.98
(i) DEV. X LINEAR	6	4839.9	806.6	1.766	2.20	3.02	4.16
(ii) DEV. X QUADRATIC	6	537.8	89.6	0.196	2.20	3.02	4.16
(iii) DEV. X CUBIC	6	475.0	79.2	0.173	2.20	3.02	4.16
(iv) DEVIATIONS	18	554.9	30.8	0.068	1.75	2.21	2.82
ERROR	98	44758.8	456.7				

Table 3.63.

Analysis of variance for length of the fourth leaf from experimental unit 2.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	167	4808339.2					
PLANT GROWTH REGULATOR	7	78994.1	11284.9	15.254	2.11	2.83	3.84
DAY	6	4589296.6	764882.8	1033.888	2.18	2.98	4.08
(i) LINEAR	1	4483696.2	4483696.2	6060.586	3.93	6.88	11.46
(ii) QUADRATIC	1	44689.6	44689.6	60.407	3.93	6.88	11.46
(iii) CUBIC	1	57376.2	57376.2	77.555	3.93	6.88	11.46
(iv) DEVIATIONS	3	3534.6	1178.2	1.593	2.69	3.97	5.84
PLANT GROWTH REGULATOR X DAY INTERACTION	42	57189.5	1361.7	1.841	1.56	1.82	2.14
(i) DEV. X LINEAR	7	38769.4	5538.5	7.486	2.11	2.83	3.84
(ii) DEV. X QUADRATIC	7	13966.7	1995.2	2.697	2.11	2.83	3.84
(iii) DEV. X CUBIC	7	2546.2	363.7	0.492	2.11	2.83	3.84
(iv) DEVIATIONS	21	1907.2	90.8	0.123	1.56	2.07	2.60
ERROR	112	82859.0	739.8				

Table 3.64.

Tests of significance between plant growth regulator treatments.

(i) Unit 1 - Length of the fourth leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7
AMO-1618	FOLIAR SPRAY	1	284.6		NS	**	**	**	**	**
ANCYMIDOL	SOIL DRENCH	2	268.0			NS	NS	NS	NS	*
ANCYMIDOL	FOLIAR SPRAY	3	260.6				NS	NS	NS	NS
AMO-1618	SOIL DRENCH	4	255.7					NS	NS	NS
CONTROL	FOLIAR SPRAY	5	249.8						NS	NS
PHOSPHON D	SOIL DRENCH	6	248.3							NS
MEPIQUAT CHLORIDE	FOLIAR SPRAY	7	245.2							

Q (P0.05) = 19.26

Q (P0.01) = 22.99

(ii) Unit 2 - Length of the fourth leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7	8
GA_3	FOLIAR SPRAY	1	275.9		NS	NS	NS	NS	NS	NS	**
CCC	SOIL DRENCH	2	274.5			NS	NS	NS	NS	NS	**
CONTROL	FOLIAR SPRAY	3	274.0				NS	NS	NS	NS	**
PACLOBUTRAZOL	FOLIAR SPRAY	4	263.4					NS	NS	NS	**
CCC	FOLIAR SPRAY	5	260.9						NS	NS	**
SADH	FOLIAR SPRAY	6	260.6							NS	**
$GA_{4/7}$	FOLIAR SPRAY	7	251.9								**
PACLOBUTRAZOL	SOIL DRENCH	8	204.8								

Q (P0.01) = 35.08

Table 3.65.

Analysis of variance for maximum width of the fourth leaf from experimental unit 1.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	146	1000.097					
PLANT GROWTH REGULATOR	6	31.365	5.228	46.677	2.20	3.02	4.16
DAY	6	942.968	157.161	1403.329	2.20	3.02	4.16
(i) LINEAR	1	913.109	913.109	8153.350	3.95	6.93	11.60
(ii) QUADRATIC	1	26.141	26.141	233.422	3.95	6.93	11.60
(iii) CUBIC	1	1.177	1.177	10.513	3.95	6.93	11.60
(iv) DEVIATIONS	3	2.541	0.847	7.562	2.71	4.02	5.93
PLANT GROWTH REGULATOR X DAY INTERACTION	36	14.788	0.411	3.668	1.61	1.91	2.98
(i) DEV. X LINEAR	6	13.948	2.325	20.757	2.20	3.02	4.16
(ii) DEV. X QUADRATIC	6	0.211	0.035	0.314	2.20	3.02	4.16
(iii) DEV. X CUBIC	6	0.189	0.032	0.281	2.20	3.02	4.16
(iv) DEVIATIONS	18	0.440	0.025	0.218	1.75	2.21	2.82
ERROR	98	10.975	0.112				

Table 3.66.

Analysis of variance for maximum width of the fourth leaf from experimental unit 2.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	167	932.161					
PLANT GROWTH REGULATOR	7	43.157	6.165	27.825	2.11	2.83	3.84
DAY	6	828.027	138.004	622.847	2.18	2.98	4.08
(i) LINEAR	1	786.696	786.696	3550.550	3.93	6.88	11.46
(ii) QUADRATIC	1	37.592	37.592	169.660	3.93	6.88	11.46
(iii) CUBIC	1	1.484	1.484	6.699	3.93	6.88	11.46
(iv) DEVIATIONS	3	2.255	0.752	3.392	2.69	3.97	5.84
PLANT GROWTH REGULATOR X DAY INTERACTION	42	36.162	0.861	3.886	1.56	1.82	2.14
(i) DEV. X LINEAR	7	33.858	4.837	21.830	2.11	2.83	3.84
(ii) DEV. X QUADRATIC	7	1.345	0.192	0.867	2.11	2.83	3.84
(iii) DEV. X CUBIC	7	0.173	0.025	0.112	2.11	2.83	3.84
(iv) DEVIATIONS	21	0.786	0.037	0.169	1.56	2.07	2.60
ERROR	112	24.816	0.222				

Table 3.67.

Tests of significance between plant growth regulator treatments.

(i) Unit 1 - Maximum width of the fourth leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7
AMO-1618	SOIL DRENCH	1	5.316		NS	**	**	**	**	**
PHOSPHON D	SOIL DRENCH	2	5.071			**	**	**	**	**
AMO-1618	FOLIAR SPRAY	3	4.624				*	**	**	**
ANCYMIDOL	SOIL DRENCH	4	4.315					NS	NS	NS
ANCYMIDOL	FOLIAR SPRAY	5	4.206						NS	NS
CONTROL	FOLIAR SPRAY	6	4.125							NS
MEPIQUAT CHLORIDE	FOLIAR SPRAY	7	4.022							

Q (P0.05) = 0.302

Q (P0.01) = 0.360

(ii) Unit 2 - Maximum width of the fourth leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7	8
PACLOBUTRAZOL	SOIL DRENCH	1	5.119		**	**	**	**	**	**	**
SADH	FOLIAR SPRAY	2	4.578			NS	NS	NS	**	**	**
CONTROL	FOLIAR SPRAY	3	4.495				NS	NS	*	**	**
PACLOBUTRAZOL	FOLIAR SPRAY	4	4.450					NS	NS	*	**
CCC	SOIL DRENCH	5	4.357						NS	NS	**
GA_3	FOLIAR SPRAY	6	4.032							NS	**
CCC	FOLIAR SPRAY	7	3.975								**
$GA_{4/7}$	FOLIAR SPRAY	8	3.267								

Q (P0.05) = 0.437

Q (P0.01) = 0.516

Table 3.68.

Analysis of variance for leaf sheath length of the fourth leaf from experimental unit 1.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	20	800.198					
PLANT GROWTH REGULATOR	6	667.211	111.202	11.707	2.85	4.46	7.43
ERROR	14	132.987	9.499				

Table 3.69.

Analysis of variance for leaf sheath length of the fourth leaf from experimental unit 2.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	23	1395.89					
PLANT GROWTH REGULATOR	7	1107.57	158.22	8.781	2.66	4.04	6.50
ERROR	16	288.31	18.02				

Table 3.70.

Tests of significance between plant growth regulator treatments.

(i) Unit 1 - Leaf sheath length of the fourth leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7
CONTROL	FOLIAR SPRAY	1	18.80		NS	NS	NS	NS	**	**
MEPIQUAT CHLORIDE	FOLIAR SPRAY	2	17.73			NS	NS	NS	**	**
ANCYMIDOL	SOIL DRENCH	3	16.60				NS	NS	**	**
ANCYMIDOL	FOLIAR SPRAY	4	16.53					NS	**	**
AMO-1618	FOLIAR SPRAY	5	15.47						*	**
AMO-1618	SOIL DRENCH	6	5.53							NS
PHOSPHON D	SOIL DRENCH	7	4.0							

Q (P0.05) = 8.26

Q (P0.01) = 10.46

(ii) Unit 2 - Leaf sheath length of the fourth leaf:

TREATMENT	METHOD OF APPLICATION		MEAN	1	2	3	4	5	6	7	8
$GA_{4/7}$	FOLIAR SPRAY	1	24.93		NS	NS	NS	NS	NS	NS	**
CCC	SOIL DRENCH	2	23.13			NS	NS	NS	NS	NS	**
GA_3	FOLIAR SPRAY	3	21.93				NS	NS	NS	NS	**
CCC	FOLIAR SPRAY	4	20.40					NS	NS	NS	**
PACLOBUTRAZOL	FOLIAR SPRAY	5	18.00						NS	NS	**
SADH	FOLIAR SPRAY	6	16.23							NS	**
CONTROL	FOLIAR SPRAY	7	16.00								**
PACLOBUTRAZOL	SOIL DRENCH	8	1.67								

Q (P0.05) = 11.62

Q (P0.01) = 14.48

Table 3.72.

Analysis of variance for total plant fresh weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	10683.39					
LIGHT QUALITY	1	2160.85	2160.85	146.280	4.08	7.31	12.61
ERROR A	8	133.95	16.74	1.173	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	7291.75	1822.94	123.405	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	639.91	159.98	10.830	2.61	3.83	5.70
ERROR B	32	456.93	14.28				
COMBINED ERROR (A+B)	40	590.88	14.77				

Table 3.73.

Analysis of variance for total plant dry weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	294.848					
LIGHT QUALITY	1	88.754	88.754	117.490	4.08	7.31	12.61
ERROR A	8	9.237	1.155	1.761	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	149.826	37.456	49.584	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	26.051	6.513	8.625	2.61	3.83	5.70
ERROR B	32	20.979	0.656				
COMBINED ERROR (A+B)	40	30.217	0.755				

Table 3.74.

Analysis of variance for leaf number attained.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	19.281					
LIGHT QUALITY	1	0.031	0.031	0.685	4.08	7.31	12.61
ERROR A	8	0.056	0.007	0.127	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	16.638	4.159	91.155	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.788	0.197	4.315	2.61	3.83	5.70
ERROR B	32	1.769	0.055				
COMBINED ERROR (A+B)	40	1.825	0.046				

Table 3.75.

Analysis of variance for total leaf area.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	5.001×10^{9}					
LIGHT QUALITY	1	8.391×10^{8}	8.391×10^{8}	74.093	4.08	7.31	12.61
ERROR A	8	1.440×10^{8}	1.801×10^{7}	1.864	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	3.503×10^{9}	8.757×10^{8}	77.325	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	2.058×10^{8}	5.144×10^{7}	4.542	2.61	3.83	5.70
ERROR B	32	3.090×10^{8}	9.658×10^{6}				
COMBINED ERROR (A+B)	40	4.530×10^{8}	1.130×10^{7}				

Table 3.76.

Analysis of variance for total leaf fresh weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	4350.755					
LIGHT QUALITY	1	840.238	840.238	110.956	4.08	7.31	12.61
ERROR A	8	70.133	8.767	1.205	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	2947.628	736.907	97.311	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	259.980	64.995	8.583	2.61	3.83	5.70
ERROR B	32	232.776	7.274				
COMBINED ERROR (A+B)	40	302.909	7.573				

Table 3.77.

Analysis of variance for total leaf dry weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	20.902					
LIGHT QUALITY	1	2.954	2.954	71.854	4.08	7.31	12.61
ERROR A	8	0.328	0.041	0.998	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	15.324	3.831	93.187	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.980	0.245	5.962	2.61	3.83	5.70
ERROR B	32	1.316	0.041				
COMBINED ERROR (A+B)	40	1.644	0.041				

Table 3.78.

Analysis of variance for senesced leaf material.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	1.380					
LIGHT QUALITY	1	0.033	0.033	4.162	4.08	7.31	12.61
ERROR A	8	0.047	0.006	0.690	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	0.998	0.249	31.242	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.029	0.007	0.922	2.61	3.83	5.70
ERROR B	32	0.272	0.009				
COMBINED ERROR (A+B)	40	0.319	0.008				

Table 3.79.

Analysis of variance for combined basal region & leaf sheaths fresh weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	1083.847					
LIGHT QUALITY	1	568.384	568.384	178.965	5.32	11.26	25.42
ERROR A	8	25.408	3.176	2.416	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	358.808	89.702	68.241	2.67	3.98	6.04
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	89.184	22.296	16.962	2.67	3.98	6.04
ERROR B	32	42.064	1.314				
COMBINED ERROR	-	-	-	-	-	-	-

Table 3.80.

Analysis of variance for combined basal region & leaf sheaths dry weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	107.099					
LIGHT QUALITY	1	60.463	60.463	216.214	4.08	7.31	12.61
ERROR A	8	2.975	0.372	1.450	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	26.607	6.652	23.787	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	8.844	2.211	7.907	2.61	3.83	5.70
ERROR B	32	8.210	0.257				
COMBINED ERROR (A+B)	40	11.186	0.280				

Table 3.81.

Analysis of variance for root fresh weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	347.730					
LIGHT QUALITY	1	40.230	40.230	19.681	4.08	7.31	12.61
ERROR A	8	13.842	1.730	0.815	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	195.216	48.804	23.875	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	30.518	7.630	3.733	2.61	3.83	5.70
ERROR B	32	67.923	2.123				
COMBINED ERROR (A+B)	40	81.765	2.044				

Table 3.82.

Analysis of variance for root dry weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	23.867					
LIGHT QUALITY	1	0.005	0.005	0.024	4.08	7.31	12.61
ERROR A	8	2.844	0.356	1.825	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	11.343	2.836	12.494	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	3.441	0.860	3.791	2.61	3.83	5.70
ERROR B	32	6.234	0.195				
COMBINED ERROR (A+B)	40	9.078	0.227				

Table 3.83.

Analysis of variance for bulb diameter.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	907.540					
LIGHT QUALITY	1	692.292	692.292	385.249	4.08	7.31	12.61
ERROR A	8	12.459	1.557	0.839	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	84.851	21.213	11.803	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	58.509	14.627	8.139	2.61	3.83	5.70
ERROR B	32	59.430	1.857				
COMBINED ERROR (A+B)	40	71.889	1.797				

Table 3.84.

Analysis of variance for neck diameter.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	35.867					
LIGHT QUALITY	1	6.273	6.273	19.104	4.08	7.31	12.61
ERROR A	8	2.357	0.295	0.875	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	13.493	3.373	10.273	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	2.967	0.742	2.259	2.61	3.83	5.70
ERROR B	32	10.777	0.337				
COMBINED ERROR (A+B)	40	13.134	0.328				

Table 3.85.

Analysis of variance for bulbing ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	9.365					
LIGHT QUALITY	1	6.401	6.401	287.532	4.08	7.31	12.61
ERROR A	8	0.141	0.018	0.752	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	1.472	0.368	16.536	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.601	0.150	6.754	2.61	3.83	5.70
ERROR B	32	0.750	0.023				
COMBINED ERROR (A+B)	40	0.890	0.022				

Table 3.86.

Analysis of variance for haulm length.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	207063.85					
LIGHT QUALITY	1	52510.68	52510.68	617.366	4.08	7.31	12.61
ERROR A	8	367.39	45.92	0.484	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	138135.32	34533.83	406.013	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	13015.61	3253.90	38.256	2.61	3.83	5.70
ERROR B	32	3034.85	94.84				
COMBINED ERROR (A+B)	40	3402.24	85.06				

Table 3.87.

Analysis of variance for leaf sheath length of the fourth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	19764.98					
LIGHT QUALITY	1	4868.87	4868.87	358.321	4.08	7.31	12.61
ERROR A	8	170.68	21.34	1.831	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	12750.46	3187.62	234.591	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	1602.13	400.53	29.477	2.61	3.83	5.70
ERROR B	32	372.84	11.65				
COMBINED ERROR (A+B)	40	543.52	13.59				

Table 3.88.

Analysis of variance for leaf sheath length of the fifth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	17608.65					
LIGHT QUALITY	1	3681.68	3681.68	161.150	4.08	7.31	12.61
ERROR A	8	152.73	19.09	0.803	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	11987.40	2996.85	131.176	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	1025.73	256.43	11.224	2.61	3.83	5.70
ERROR B	32	761.12	23.79				
COMBINED ERROR (A+B)	40	913.85	22.85				

Table 3.89.

Analysis of variance for leaf dry weight ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	0.188					
LIGHT QUALITY	1	0.058	0.058	24.419	4.08	7.31	12.61
ERROR A	8	0.030	0.004	1.833	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	0.015	0.004	1.564	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.019	0.005	2.025	2.61	3.83	5.70
ERROR B	32	0.065	0.002				
COMBINED ERROR (A+B)	40	0.095	0.002				

Table 3.90.

Analysis of variance for combined basal region & leaf sheaths dry weight ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	0.4687					
LIGHT QUALITY	1	0.3441	0.3441	232.439	4.08	7.31	12.61
ERROR A	8	0.0061	0.0008	0.456	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	0.0637	0.0159	10.756	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.0017	0.0004	0.288	2.61	3.83	5.70
ERROR B	32	0.0531	0.0017				
COMBINED ERROR (A+B)	40	0.0592	0.0015				

Table 3.91.

Analysis of variance for root dry weight ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	0.330					
LIGHT QUALITY	1	0.119	0.119	32.280	4.08	7.31	12.61
ERROR A	8	0.040	0.005	1.505	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	0.038	0.010	2.595	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.024	0.006	1.611	2.61	3.83	5.70
ERROR B	32	0.107	0.003				
COMBINED ERROR (A+B)	40	0.148	0.004				

Table 3.92.

Analysis of variance for leaf area ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	56607356					
LIGHT QUALITY	1	12792770	12792770	7.991	5.32	11.26	25.42
ERROR A	8	12806570	1600821	2.392	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	4249773	1062443	1.587	2.67	3.98	6.04
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	5338498	1334624	1.994	2.67	3.98	6.04
ERROR B	32	21419745	669367				
COMBINED ERROR	-	-	-				

Table 3.93.

Analysis of variance for specific leaf area.

ITEM	D.F.	M.S.	S.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	74269807					
LIGHT QUALITY	1	1284098	1284098	1.131	4.08	7.31	12.61
ERROR A	8	15563729	1945466	2.086	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	16894895	4223724	3.721	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	10688611	2672153	2.354	2.61	3.83	5.70
ERROR B	32	29838474	932452				
COMBINED ERROR (A+B)	40	45402203	1135055				

Table 3.94.

Analysis of variance for leaf specific water content.

ITEM	D.F.	M.S.	S.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	28.438					
LIGHT QUALITY	1	5.462	5.462	14.261	4.08	7.31	12.61
ERROR A	8	1.640	0.205	0.480	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	5.619	1.405	3.667	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	2.048	0.512	1.337	2.61	3.83	5.70
ERROR B	32	13.670	0.427				
COMBINED ERROR (A+B)	40	15.309	0.383				

Table 3.95.

Analysis of variance for combined basal region & leaf sheaths specific water content

ITEM	D.F.	M.S.	S.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	8.821					
LIGHT QUALITY	1	0.054	0.054	0.438	4.08	7.31	12.61
ERROR A	8	1.259	0.157	1.360	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	3.089	0.772	6.226	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.718	0.180	1.447	2.61	3.83	5.70
ERROR B	32	3.702	0.116				
COMBINED ERROR (A+B)	40	4.960	0.124				

Table 3.96.

Analysis of variance for root specific water content.

ITEM	D.F.	M.S.	S.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	60.269					
LIGHT QUALITY	1	16.133	16.133	10.802	5.32	11.26	25.42
ERROR A	8	11.948	1.494	2.535	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	6.348	1.587	2.694	2.67	3.98	6.04
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	6.989	1.747	2.966	2.67	3.98	6.04
ERROR B	32	18.851	0.589				
COMBINED ERROR	-	-	-				

Table 3.98.

Analysis of variance for leaf area of the fifth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	781955608					
LIGHT QUALITY	1	51579217	51579217	42.287	4.08	7.31	12.61
ERROR A	8	12275039	1534380	1.345	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	653119448	163279862	133.864	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	28467270	7116818	5.835	2.61	3.83	5.70
ERROR B	32	36514635	1141082				
COMBINED ERROR (A+B)	40	48789674	1219742				

Table 3.99.

Analysis of variance for leaf fresh weight of the fifth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	2221.159					
LIGHT QUALITY	1	264.463	264.463	88.457	4.08	7.31	12.61
ERROR A	8	21.659	2.707	0.885	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	1742.171	435.543	145.679	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	94.936	23.734	7.938	2.61	3.83	5.70
ERROR B	32	97.931	3.060				
COMBINED ERROR (A+B)	40	119.590	2.990				

Table 3.100.

Analysis of variance for leaf dry weight of the fifth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	10.560					
LIGHT QUALITY	1	0.864	0.864	43.325	4.08	7.31	12.61
ERROR A	8	0.125	0.016	0.745	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	8.526	2.132	106.874	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.372	0.093	4.660	2.61	3.83	5.70
ERROR B	32	0.672	0.021				
COMBINED ERROR (A+B)	40	0.798	0.020				

Table 3.101.

Analysis of variance for length of the fifth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	349	24366698.0					
LIGHT QUALITY	1	904316.5	904316.5	173.884	5.32	11.26	25.42
ERROR A	8	41605.4	5200.7	17.197	1.99	2.61	3.48
PLANT GROWTH REGULATOR	4	4236178.2	1059044.5	413.700	2.67	3.98	6.04
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	83105.6	20776.4	8.116	2.67	3.98	6.04
ERROR B	32	81917.9	2559.9	8.465	1.55	1.87	2.30
DAY	6	16869929.0	2811654.8	9297.079	2.14	2.90	3.96
(i) LINEAR	1	16510936.0	16510936.0	54595.422	3.88	6.75	11.20
(ii) QUADRATIC	1	78204.2	78204.2	258.592	3.88	6.75	11.20
(iii) CUBIC	1	270168.0	270168.0	893.344	3.88	6.75	11.20
(iv) DEVIATIONS	3	10620.9	3540.3	11.706	2.64	3.87	5.67
LIGHT QUALITY X DAY INTERACTION	6	361255.8	60209.3	199.089	2.14	2.90	3.96
(i) DEV. X LINEAR	1	290105.3	290105.3	959.269	3.88	6.75	11.20
(ii) DEV. X QUADRATIC	1	44742.3	44742.3	147.946	3.88	6.75	11.20
(iii) DEV. X CUBIC	1	23943.1	23943.1	79.171	3.88	6.75	11.20
(iv) DEVIATIONS	3	2465.2	821.7	2.717	2.64	3.87	5.67
PLANT GROWTH REGULATOR X DAY INTERACTION	24	1674690.5	69778.8	230.732	1.58	1.91	2.34
(i) DEV. X LINEAR	4	1608932.4	402233.1	1330.033	2.41	3.42	4.84
(ii) DEV. X QUADRATIC	4	39011.3	9752.8	32.249	2.41	3.42	4.84
(iii) DEV. X CUBIC	4	25973.5	6493.4	21.471	2.41	3.42	4.84
(iv) DEVIATIONS	12	773.3	64.4	0.213	1.80	2.30	2.95
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	24	41117.3	1713.2	5.665	1.58	1.91	2.34
(i) DEV. X DEV. X LINEAR	4	32595.6	8148.9	26.945	2.41	3.42	4.84
(ii) DEV. X DEV. X QUADRATIC	4	5843.3	1460.8	4.830	2.41	3.42	4.84
(iii) DEV. X DEV. X CUBIC	4	1707.6	426.9	1.412	2.41	3.42	4.84
(iv) DEVIATIONS	12	970.8	80.9	0.268	1.80	2.30	2.95
ERROR C	240	72581.6	302.4				

Table 3.102.

Analysis of variance for maximum width of the fifth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	349	3265.638					
LIGHT QUALITY	1	71.263	71.263	73.377	5.32	11.26	25.42
ERROR A	8	7.769	0.971	11.022	1.99	2.61	3.48
PLANT GROWTH REGULATOR	4	335.245	83.811	103.780	2.67	3.98	6.04
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	5.505	1.376	1.704	2.67	3.98	6.04
ERROR B	32	25.843	0.808	9.166	1.55	1.87	2.30
DAY	6	2651.782	441.964	5015.987	2.14	2.90	3.96
(i) LINEAR	1	2609.088	2609.088	29611.380	3.88	6.75	11.20
(ii) QUADRATIC	1	33.430	33.430	379.412	3.88	6.75	11.20
(iii) CUBIC	1	1.490	1.490	16.907	3.88	6.75	11.20
(iv) DEVIATIONS	3	7.773	2.591	29.408	2.64	3.87	5.67
LIGHT QUALITY X DAY INTERACTION	6	22.975	3.829	43.459	2.14	2.90	3.96
(i) DEV. X LINEAR	1	16.185	16.185	183.691	3.88	6.75	11.20
(ii) DEV. X QUADRATIC	1	3.553	3.553	40.319	3.88	6.75	11.20
(iii) DEV. X CUBIC	1	2.944	2.944	33.415	3.88	6.75	11.20
(iv) DEVIATIONS	3	0.293	0.098	1.109	2.64	3.87	5.67
PLANT GROWTH REGULATOR X DAY INTERACTION	24	117.000	4.875	55.328	1.58	1.91	2.34
(i) DEV. X LINEAR	4	101.313	25.328	287.459	2.41	3.42	4.84
(ii) DEV. X QUADRATIC	4	2.804	0.701	7.955	2.41	3.42	4.84
(iii) DEV. X CUBIC	4	1.964	0.491	5.573	2.41	3.42	4.84
(iv) DEVIATIONS	12	10.919	0.910	10.327	1.80	2.30	2.95
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	24	7.110	0.296	3.362	1.58	1.91	2.34
(i) DEV. X DEV. X LINEAR	4	3.347	0.837	9.496	2.41	3.42	4.84
(ii) DEV. X DEV. X QUADRATIC	4	0.127	0.032	0.359	2.41	3.42	4.84
(iii) DEV. X. DEV. X CUBIC	4	2.735	0.684	7.761	2.41	3.42	4.84
(iv) DEVIATIONS	12	0.901	0.075	0.852	1.80	2.30	2.95
ERROR C	240	21.147	0.088				

Table 3.104.

Analysis of variance for lumen area of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	1777.374					
LIGHT QUALITY	1	20.812	20.812	7.664	3.95	6.94	11.62
ERROR A	8	27.320	3.415	1.269	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	1153.491	576.746	212.381	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	4.843	2.422	0.892	3.10	4.87	7.50
ERROR B	16	39.631	2.477	0.920	1.83	2.34	3.04
DAY	3	229.402	76.467	28.158	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	15.394	5.131	1.889	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	73.256	12.209	4.496	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	19.478	3.246	1.195	2.20	3.02	4.17
ERROR C	72	193.748	2.691				
COMBINED ERROR (A+B+C)	96	260.699	2.716				

Table 3.105.

Analysis of variance for tissue of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	88.340					
LIGHT QUALITY	1	1.534	1.534	2.243	3.95	6.94	11.62
ERROR A	8	4.890	0.611	0.849	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	2.984	1.492	2.182	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	1.227	0.614	0.895	3.10	4.87	7.50
ERROR B	16	8.910	0.557	0.773	1.83	2.34	3.04
DAY	3	3.351	1.117	1.634	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	4.395	1.465	2.143	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	6.409	1.068	1.562	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	2.791	0.465	0.680	2.20	3.02	4.17
ERROR C	72	51.847	0.720				
COMBINED ERROR (A+B+C)	96	65.648	0.684				

Table 3.106.

Analysis of variance for lumen area of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	7411.094					
LIGHT QUALITY	1	29.869	29.869	3.431	3.98	7.03	11.85
ERROR A	8	101.870	12.734	1.526	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	5259.431	2629.715	302.079	3.13	4.94	7.67
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	13.675	6.837	0.785	3.13	4.94	7.67
ERROR B	16	124.385	7.774	0.932	1.90	2.47	3.30
DAY	2	1031.704	515.852	59.257	3.13	4.94	7.67
LIGHT QUALITY X DAY INTERACTION	2	12.837	6.418	0.737	3.13	4.94	7.67
PLANT GROWTH REGULATOR X DAY INTERACTION	4	415.790	103.948	11.941	2.50	3.62	5.19
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	21.000	5.250	0.603	2.50	3.62	5.19
ERROR C	48	400.533	8.344				
COMBINED ERROR (A+B+C)	72	626.788	8.705				

Table 3.107.

Analysis of variance for tissue area of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	407.044					
LIGHT QUALITY	1	0.078	0.078	0.042	3.98	7.03	11.85
ERROR A	8	23.019	2.877	1.657	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	204.512	102.256	54.553	3.13	4.94	7.67
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	4.681	2.340	1.248	3.13	4.94	7.67
ERROR B	16	28.592	1.787	1.029	1.90	2.47	3.30
DAY	2	28.456	14.228	7.591	3.13	4.94	7.67
LIGHT QUALITY X DAY INTERACTION	2	7.583	3.791	2.022	3.13	4.94	7.67
PLANT GROWTH REGULATOR X DAY INTERACTION	4	21.930	5.482	2.925	2.50	3.62	5.19
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	4.845	1.211	0.646	2.50	3.62	5.19
ERROR C	48	83.349	1.736				
COMBINED ERROR (A+B+C)	72	134.96	1.874				

Table 3.108.

Analysis of variance for lumen area of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	59	3468.50					
LIGHT QUALITY	1	43.92	43.92	3.390	4.05	7.22	12.35
ERROR A	8	114.14	14.27	1.039	2.36	3.36	4.99
PLANT GROWTH REGULATOR	2	1806.49	903.25	69.717	3.20	4.91	8.05
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	25.97	12.98	1.002	3.20	4.91	8.05
ERROR B	16	178.18	11.14	0.811	2.11	2.91	4.17
DAY	1	722.80	722.80	55.789	4.05	7.22	12.35
LIGHT QUALITY X DAY INTERACTION	1	49.66	49.66	3.833	4.05	7.22	12.35
PLANT GROWTH REGULATOR X DAY INTERACTION	2	146.89	73.44	5.668	3.20	4.91	8.05
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	50.88	25.44	1.964	3.20	4.91	8.05
ERROR C	24	329.57	13.73				
COMBINED ERROR (A+B+C)	48	621.89	12.96				

Table 3.109.

Analysis of variance for tissue area of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	59	728.528					
LIGHT QUALITY	1	24.246	24.246	3.563	4.05	7.22	12.35
ERROR A	8	35.212	4.402	0.516	2.36	3.36	4.99
PLANT GROWTH REGULATOR	2	326.603	163.302	23.997	3.20	4.91	8.05
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	23.509	11.755	1.727	3.20	4.91	8.05
ERROR B	16	86.618	5.414	0.634	2.11	2.91	4.17
DAY	1	1.148	1.148	0.169	4.05	7.22	12.35
LIGHT QUALITY X DAY INTERACTION	1	6.457	6.457	0.949	4.05	7.22	12.35
PLANT GROWTH REGULATOR X DAY INTERACTION	2	12.593	6.296	0.925	3.20	4.91	8.05
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	7.322	3.661	0.538	3.20	4.91	8.05
ERROR C	24	204.820	8.534				
COMBINED ERROR (A+B+C)	48	326.650	6.805				

Table 3.110.

Analysis of variance for stomatal frequency of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	151839.2					
LIGHT QUALITY	1	1941.3	1941.3	8.766	3.95	6.94	11.62
ERROR A	8	3373.5	421.7	1.892	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	90127.5	45063.7	203.483	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	1091.1	545.5	2.463	3.10	4.87	7.50
ERROR B	16	1839.8	115.0	0.516	1.83	2.34	3.04
DAY	3	33895.1	11298.4	51.017	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	1164.0	388.0	1.752	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	1052.5	175.4	0.792	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	1307.4	217.9	0.984	2.20	3.02	4.17
ERROR C	72	16047.0	222.9				
COMBINED ERROR (A+B+C)	96	21260.3	221.46				

Table 3.111.

Analysis of variance for stomatal frequency of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	120171.3					
LIGHT QUALITY	1	8143.2	8143.2	20.140	3.98	7.03	11.85
ERROR A	8	6026.0	753.2	1.987	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	40554.4	20277.2	50.150	3.13	4.94	7.67
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	1642.0	821.0	2.031	3.13	4.94	7.67
ERROR B	16	4888.1	305.5	0.806	1.90	2.47	3.30
DAY	2	37306.1	18653.1	46.134	3.13	4.94	7.67
LIGHT QUALITY X DAY INTERACTION	2	567.3	283.7	0.702	3.13	4.94	7.67
PLANT GROWTH REGULATOR X DAY INTERACTION	4	1828.0	457.0	1.130	2.50	3.62	5.19
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	1018.6	254.6	0.630	2.50	3.62	5.19
ERROR C	48	18197.5	379.1				
COMBINED ERROR (A+B+C)	72	29111.6	404.33				

Table 3.112.

Analysis of variance for stomatal frequency of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	58	99178					
LIGHT QUALITY	1	16997	16997	13.343	4.05	7.23	12.39
ERROR A	8	9130	1141	0.880	2.38	3.41	5.09
PLANT GROWTH REGULATOR	2	3102	1551	1.218	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	6810	3405	2.673	3.20	5.11	8.57
ERROR B	16	20913	1307	1.008	2.13	2.95	4.05
DAY	1	10837	10837	8.508	4.05	7.23	12.39
LIGHT QUALITY X DAY INTERACTION	1	252	252	0.198	4.05	7.23	12.39
PLANT GROWTH REGULATOR X DAY INTERACTION	2	849	425	0.334	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	461	231	0.181	3.20	5.11	8.57
ERROR C	23(1)[a]	29826	1297				
COMBINED ERROR (A+B+C)	47	59869	1274				

a - One missing value

Table 3.113.

Analysis of variance for epidermal cell length of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	0.431					
LIGHT QUALITY	1	0.025	0.025	15.342	3.95	6.94	11.62
ERROR A	8	0.014	0.002	1.069	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	0.080	0.040	24.243	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.014	0.007	4.348	3.10	4.87	7.50
ERROR B	16	0.024	0.001	0.880	1.83	2.34	3.04
DAY	3	0.113	0.038	22.725	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	0.011	0.004	2.297	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	0.012	0.002	1.241	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	0.017	0.003	1.689	2.20	3.02	4.17
ERROR C	72	0.121	0.002				
COMBINED ERROR (A+B+C)	96	0.158	0.002				

Table 3.114.

Analysis of variance for epidermal cell length of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	0.689					
LIGHT QUALITY	1	0.131	0.131	30.251	3.98	7.03	11.85
ERROR A	8	0.055	0.007	1.566	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	0.015	0.008	1.748	3.13	4.94	7.67
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.063	0.032	7.313	3.13	4.94	7.67
ERROR B	16	0.048	0.003	0.690	1.90	2.47	3.30
DAY	2	0.120	0.060	13.826	3.13	4.94	7.67
LIGHT QUALITY X DAY INTERACTION	2	0.006	0.003	0.690	3.13	4.94	7.67
PLANT GROWTH REGULATOR X DAY INTERACTION	4	0.016	0.004	0.938	2.50	3.62	5.19
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	0.026	0.007	1.505	2.50	3.62	5.19
ERROR C	48	0.209	0.004				
COMBINED ERROR (A+B+C)	72	0.312	0.004				

Table 3.115.

Analysis of variance for epidermal cell length of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	58	0.745					
LIGHT QUALITY	1	0.199	0.199	36.537	4.05	7.23	12.39
ERROR A	8	0.060	0.007	1.442	2.38	3.41	5.09
PLANT GROWTH REGULATOR	2	0.153	0.076	14.021	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.104	0.052	9.549	3.20	5.11	8.57
ERROR B	16	0.077	0.005	0.924	2.13	2.95	4.05
DAY	1	0.015	0.015	2.739	4.05	7.23	12.39
LIGHT QUALITY X DAY INTERACTION	1	0.002	0.002	0.403	4.05	7.23	12.39
PLANT GROWTH REGULATOR X DAY INTERACTION	2	0.005	0.003	0.476	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	0.011	0.006	1.031	3.20	5.11	8.57
ERROR C	23(1)[a]	0.119	0.005				
COMBINED ERROR (A+B+C)	47	0.256	0.005				

a - One missing value

Table 3.116.

Analysis of variance for epidermal cell width of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	17894.23					
LIGHT QUALITY	1	197.79	197.79	7.493	3.95	6.94	11.62
ERROR A	8	145.06	18.13	0.727	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	14047.24	7023.62	266.065	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	24.18	12.09	0.458	3.10	4.87	7.50
ERROR B	16	592.94	37.06	1.485	1.83	2.34	3.04
DAY	3	664.16	221.39	8.387	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	33.03	11.01	0.417	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	311.73	51.96	1.968	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	81.89	13.65	0.517	2.20	3.02	4.17
ERROR C	72	1796.22	24.95				
COMBINED ERROR (A+B+C)	96	2534.22	26.398				

Table 3.117.

Analysis of variance for epidermal cell width of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	27335.78					
LIGHT QUALITY	1	279.64	279.64	9.265	3.98	7.03	11.85
ERROR A	8	160.45	20.06	0.620	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	22279.03	11139.52	369.06	3.13	4.94	7.67
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	54.78	27.39	0.907	3.13	4.94	7.67
ERROR B	16	458.92	28.68	0.886	1.90	2.47	3.30
DAY	2	2034.06	1017.03	33.695	3.13	4.94	7.67
LIGHT QUALITY X DAY INTERACTION	2	42.56	21.28	0.705	3.13	4.94	7.67
PLANT GROWTH REGULATOR X DAY INTERACTION	4	330.62	82.66	2.739	2.50	3.62	5.19
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	141.91	35.48	1.175	2.50	3.62	5.19
ERROR C	48	1553.82	32.37				
COMBINED ERROR (A+B+C)	72	2173.19	30.183				

Table 3.118.

Analysis of variance for epidermal cell width of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	58	18706.01					
LIGHT QUALITY	1	413.55	413.55	10.560	4.05	7.23	12.39
ERROR A	8	123.26	15.41	0.387	2.38	3.41	5.09
PLANT GROWTH REGULATOR	2	13405.25	6702.63	171.146	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	130.72	65.36	1.669	3.20	5.11	8.57
ERROR B	16	801.01	50.06	1.256	2.13	2.95	4.05
DAY	1	2525.94	2525.94	64.498	4.05	7.23	12.39
LIGHT QUALITY X DAY INTERACTION	1	3.89	3.89	0.099	4.05	7.23	12.39
PLANT GROWTH REGULATOR X DAY INTERACTION	2	306.48	153.24	3.913	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	79.49	39.75	1.015	3.20	5.11	8.57
ERROR C	23(1)[a]	916.40	39.84				
COMBINED ERROR (A+B+C)	47	1840.67	39.163				

a - One missing value

Table 3.119.

Analysis of variance for palisade mesophyll length of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	1774.712					
LIGHT QUALITY	1	75.160	75.160	16.270	3.95	6.94	11.62
ERROR A	8	57.409	7.176	1.624	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	245.808	122.904	26.610	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	84.764	42.382	9.176	3.10	4.87	7.50
ERROR B	16	67.798	4.237	0.959	1.83	2.34	3.04
DAY	3	770.488	256.829	55.605	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	28.878	9.626	2.084	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	47.260	7.877	1.705	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	78.951	13.159	2.849	2.20	3.02	4.17
ERROR C	72	318.197	4.419				
COMBINED ERROR (A+B+C)	96	443.404	4.619				

Table 3.120.

Analysis of variance for palisade mesophyll length of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	1674.635					
LIGHT QUALITY	1	158.719	158.719	21.418	3.98	7.03	11.85
ERROR A	8	96.853	12.107	1.705	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	141.573	70.787	9.552	3.13	4.94	7.67
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	62.298	31.149	4.203	3.13	4.94	7.67
ERROR B	16	95.802	5.988	0.843	1.90	2.47	3.30
DAY	2	678.523	339.261	45.780	3.13	4.94	7.67
LIGHT QUALITY X DAY INTERACTION	2	6.351	3.175	0.428	3.13	4.94	7.67
PLANT GROWTH REGULATOR X DAY INTERACTION	4	44.034	11.009	1.486	2.50	3.62	5.19
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	49.569	12.392	1.672	2.50	3.62	5.19
ERROR C	48	340.913	7.102				
COMBINED ERROR (A+B+C)	72	533.568	7.411				

Table 3.121.

Analysis of variance for palisade mesophyll length of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	58	2479.20					
LIGHT QUALITY	1	328.67	328.67	14.834	4.05	7.23	12.39
ERROR A	8	223.77	27.97	1.539	2.38	3.41	5.09
PLANT GROWTH REGULATOR	2	719.44	359.72	16.236	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	182.53	91.26	4.119	3.20	5.11	8.57
ERROR B	16	399.46	24.97	1.373	2.13	2.95	4.05
DAY	1	143.16	143.16	6.461	4.05	7.23	12.39
LIGHT QUALITY X DAY INTERACTION	1	9.28	9.28	0.419	4.05	7.23	12.39
PLANT GROWTH REGULATOR X DAY INTERACTION	2	0.32	0.16	0.007	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	54.46	27.23	1.229	3.20	5.11	8.57
ERROR C	23(1)[a]	418.12	18.18				
COMBINED ERROR (A+B+C)	47	1041.35	22.156				

a - One missing value

Table 3.122.

Analysis of variance for palisade mesophyll width of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	9263.90					
LIGHT QUALITY	1	96.50	96.50	7.924	3.95	6.94	11.62
ERROR A	8	52.54	6.57	0.544	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	7028.99	3514.49	288.583	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	16.65	8.33	0.684	3.10	4.87	7.50
ERROR B	16	247.64	15.48	1.282	1.83	2.34	3.04
DAY	3	656.35	218.78	17.965	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	52.21	17.40	1.429	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	169.63	28.27	2.321	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	74.44	12.41	1.019	2.20	3.02	4.17
ERROR C	72	868.95	12.07				
COMBINED ERROR (A+B+C)	96	1169.13	12.178				

Table 3.123.

Analysis of variance for palisade mesophyll width of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	16002.46					
LIGHT QUALITY	1	155.55	155.55	11.964	3.94	7.12	11.51
ERROR A	8	157.45	19.68	1.656	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	12739.30	6369.65	275.922	3.63	6.23	10.97
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	5.31	2.66	0.115	3.63	6.23	10.97
ERROR B	16	369.36	23.08	1.942	1.90	2.47	3.30
DAY	2	1700.55	850.28	65.398	3.09	5.02	7.86
LIGHT QUALITY X DAY INTERACTION	2	17.36	8.68	0.668	3.09	5.02	7.86
PLANT GROWTH REGULATOR X DAY INTERACTION	4	250.26	62.57	4.812	2.47	3.69	5.39
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	36.68	9.17	0.705	2.47	3.69	5.39
ERROR C	48	570.64	11.89				
COMBINED ERROR (A+C)	56	728.09	13.00				

Table 3.124.

Analysis of variance for palisade mesophyll width of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	58	11301.28					
LIGHT QUALITY	1	685.52	685.52	18.519	4.05	7.23	12.39
ERROR A	8	169.90	21.24	0.480	2.38	3.41	5.09
PLANT GROWTH REGULATOR	2	6894.28	3447.14	93.122	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	75.06	37.53	1.014	3.20	5.11	8.57
ERROR B	16	551.59	34.47	0.779	2.13	2.95	4.05
DAY	1	1527.12	1527.12	41.254	4.05	7.23	12.39
LIGHT QUALITY X DAY INTERACTION	1	33.42	33.42	0.903	4.05	7.23	12.39
PLANT GROWTH REGULATOR X DAY INTERACTION	2	299.93	149.96	4.051	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	46.13	23.06	0.623	3.20	5.11	8.57
ERROR C	23(1)[a]	1018.33	44.28				
COMBINED ERROR (A+B+C)	47	1739.82	37.017				

a - One missing value

Table 3.125.

Analysis of variance for vascular bundle frequency of section B.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	119	71.262					
LIGHT QUALITY	1	0.711	0.711	3.818	3.95	6.94	11.62
ERROR A	8	0.559	0.070	0.381	2.08	2.79	3.81
PLANT GROWTH REGULATOR	2	44.449	22.224	119.37	3.10	4.87	7.50
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.153	0.077	0.411	3.10	4.87	7.50
ERROR B	16	4.098	0.256	1.395	1.83	2.34	3.04
DAY	3	6.324	2.108	11.322	2.71	4.02	5.94
LIGHT QUALITY X DAY INTERACTION	3	0.455	0.152	0.815	2.71	4.02	5.94
PLANT GROWTH REGULATOR X DAY INTERACTION	6	0.776	0.129	0.694	2.20	3.02	4.17
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	6	0.521	0.087	0.466	2.20	3.02	4.17
ERROR C	72	13.216	0.184				
COMBINED ERROR (A+B+C)	96	17.873	0.186				

Table 3.126.

Analysis of variance for vascular bundle frequency of section C.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	89	81.494					
LIGHT QUALITY	1	0.584	0.584	3.486	3.98	7.03	11.85
ERROR A	8	1.395	0.174	1.148	2.15	2.92	4.07
PLANT GROWTH REGULATOR	2	59.576	29.788	177.71	3.13	4.94	7.67
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.337	0.169	1.006	3.13	4.94	7.67
ERROR B	16	3.382	0.211	1.392	1.90	2.47	3.30
DAY	2	4.775	2.387	14.242	3.13	4.94	7.67
LIGHT QUALITY X DAY INTERACTION	2	0.164	0.082	0.489	3.13	4.94	7.67
PLANT GROWTH REGULATOR X DAY INTERACTION	4	3.224	0.806	4.808	2.50	3.62	5.19
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	4	0.766	0.192	1.142	2.50	3.62	5.19
ERROR C	48	7.291	0.152				
COMBINED ERROR (A+B+C)	72	12.069	0.168				

Table 3.127.

Analysis of variance for vascular bundle frequency of section D.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	58	53.614					
LIGHT QUALITY	1	0.854	0.854	6.808	4.05	7.23	12.39
ERROR A	8	0.457	0.057	0.384	2.38	3.41	5.09
PLANT GROWTH REGULATOR	2	39.621	19.811	157.987	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	2	0.579	0.289	2.307	3.20	5.11	8.57
ERROR B	16	2.013	0.126	0.845	2.13	2.95	4.05
DAY	1	5.782	5.782	46.111	4.05	7.23	12.39
LIGHT QUALITY X DAY INTERACTION	1	0.045	0.045	0.361	4.05	7.23	12.39
PLANT GROWTH REGULATOR X DAY INTERACTION	2	0.568	0.284	2.264	3.20	5.11	8.57
LIGHT QUALITY X PLANT GROWTH REGULATOR X DAY INTERACTION	2	0.272	0.136	1.085	3.20	5.11	8.57
ERROR C	23(1)[a]	3.424	0.149				
COMBINED ERROR (A+B+C)	47	5.894	0.125				

a - One missing value

Table 3.129.

Analysis of variance for lumen area of the fifth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	11781.17					
LIGHT QUALITY	1	288.64	288.64	13.507	4.08	7.31	12.61
ERROR A	8	152.80	19.10	0.871	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	10573.59	2643.40	123.700	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	64.16	16.04	0.751	2.61	3.83	5.70
ERROR B	32	701.98	21.94				
COMBINED ERROR (A+B)	40	854.78	21.37				

Table 3.130.

Analysis of variance for tissue area of the fifth leaf.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	622.501					
LIGHT QUALITY	1	92.381	92.381	29.723	4.08	7.31	12.61
ERROR A	8	13.387	1.673	0.483	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	399.217	99.804	32.111	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	6.579	1.645	0.529	2.61	3.83	5.70
ERROR B	32	110.936	3.467				
COMBINED ERROR (A+B)	40	124.323	3.108				

Table 3.131.

Analysis of variance for stomatal frequency.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	27382.4					
LIGHT QUALITY	1	16109.4	16109.4	97.344	4.08	7.31	12.61
ERROR A	8	927.3	115.9	0.652	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	4405.5	1101.4	6.655	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	248.0	62.0	0.375	2.61	3.83	5.70
ERROR B	32	5692.3	177.9				
COMBINED ERROR (A+B)	40	6619.6	165.49				

Table 3.132.

Analysis of variance for epidermal cell length.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	0.531					
LIGHT QUALITY	1	0.221	0.221	55.161	4.08	7.31	12.61
ERROR A	8	0.040	0.005	1.326	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	0.122	0.030	7.582	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.028	0.007	1.732	2.61	3.83	5.70
ERROR B	32	0.120	0.004				
COMBINED ERROR (A+B)	40	0.160	0.004				

Table 3.133.

Analysis of variance for epidermal cell width.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	560.536					
LIGHT QUALITY	1	70.517	70.517	4.983	5.32	11.26	25.42
ERROR A	8	113.214	14.152	2.335	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	106.535	26.634	4.394	2.67	3.98	6.04
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	76.291	19.073	3.146	2.67	3.98	6.04
ERROR B	32	193.980	6.062				
COMBINED ERROR	-	-	-	-	-	-	-

Table 3.134.

Analysis of variance for palisade mesophyll length.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	1111.91					
LIGHT QUALITY	1	160.43	160.43	14.154	4.08	7.31	12.61
ERROR A	8	58.55	7.32	0.593	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	469.59	117.40	10.358	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	28.50	7.12	0.628	2.61	3.83	5.70
ERROR B	32	394.84	12.34				
COMBINED ERROR (A+B)	40	453.39	11.34				

Table 3.135.

Analysis of variance for palisade mesophyll width.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	309.816					
LIGHT QUALITY	1	64.487	64.487	14.758	4.08	7.31	12.61
ERROR A	8	49.772	6.222	1.593	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	39.059	9.765	2.235	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	31.489	7.872	1.802	2.61	3.83	5.70
ERROR B	32	125.009	3.907				
COMBINED ERROR (A+B)	40	174.781	4.370				

Table 3.136.

Analysis of variance for vascular bundle frequency.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	49	2.783					
LIGHT QUALITY	1	0.003	0.003	0.090	4.08	7.31	12.61
ERROR A	8	0.148	0.019	0.614	2.25	3.13	4.51
PLANT GROWTH REGULATOR	4	1.547	0.387	13.871	2.61	3.83	5.70
LIGHT QUALITY X PLANT GROWTH REGULATOR INTERACTION	4	0.117	0.029	1.050	2.61	3.83	5.70
ERROR B	32	0.967	0.030				
COMBINED ERROR (A+B)	40	1.116	0.028				

STATISTICAL TABLES FOR

CHAPTER 4

Table 4.1.

Analysis of variance for bulb diameter.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	139	1942.919					
BLOCKS	1	0.114	0.114	.0.019	3.91	6.83	11.35
PLANT GROWTH REGULATORS	6	1140.164	190.027	31.251	2.16	2.94	4.01
ERROR	132	802.641	6.081				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
ETHREL C	1	22.12		**	**	**	**	**	**
CONTROL	2	16.56			NS	NS	NS	*	**
CCC	3	16.24				NS	NS	NS	**
TIBA	4	16.11					NS	NS	**
$AgNO_3$	5	15.68						NS	**
GA_3	6	14.04							NS
IAA	7	12.09							

Q (P0.05) = 2.34

Q (P0.01) = 2.76

Table 4.2.

Analysis of variance for neck diameter.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	139	474.384					
BLOCKS	1	2.289	2.289	0.985	3.91	6.83	11.35
PLANT GROWTH REGULATORS	6	165.258	27.543	11.849	2.16	2.94	4.01
ERROR	132	306.837	2.325				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
CCC	1	12.46		NS	NS	NS	NS	**	**
CONTROL	2	12.40			NS	NS	NS	**	**
ETHREL C	3	12.17				NS	NS	**	**
TIBA	4	12.13					NS	**	**
$AgNO_3$	5	11.88						*	**
GA_3	6	10.35							NS
IAA	7	9.44							

Q (P0.05) = 1.45

Q (P0.01) = 1.71

Table 4.3.

Analysis of variance for bulbing ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	139	6.430					
BLOCK	1	0.024	0.024	1.662	3.91	6.83	11.35
PLANT GROWTH REGULATORS	6	4.524	0.754	52.882	2.16	2.94	4.01
ERROR	132	1.882	0.014				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
ETHREL C	1	1.829		**	**	**	**	**	**
GA_3	2	1.355			NS	NS	NS	NS	NS
TIBA	3	1.329				NS	NS	NS	NS
CONTROL	4	1.335					NS	NS	NS
$AgNO_3$	5	1.315						NS	NS
CCC	6	1.304							NS
IAA	7	1.277							

Q (P0.01) = 0.134

Table 4.4.

Analysis of variance for bulb diameter.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	139	16142.57					
BLOCK	1	32.40	32.40	0.507	3.91	6.83	11.35
PLANT GROWTH REGULATORS	6	7676.18	1279.36	20.023	2.16	2.94	4.01
ERROR	132	8433.98	63.89				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
CONTROL	1	60.44		NS	NS	*	**	**	**
CCC	2	60.43			NS	*	**	**	**
TIBA	3	56.84				NS	NS	**	**
$AgNO_3$	4	52.79					NS	**	**
ETHREL C	5	50.31						NS	**
IAA	6	42.87							NS
GA_3	7	40.55							

Q (P0.05) = 7.58

Q (P0.01) = 8.94

Table 4.5.

Analysis of variance for neck diameter.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	139	1206.962					
BLOCK	1	104.648	104.648	16.805	3.91	6.83	11.35
PLANT GROWTH REGULATORS	6	280.316	46.719	7.502	2.16	2.94	4.01
ERROR	132	821.997	6.227				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
CONTROL	1	15.79		NS	NS	NS	*	**	**
TIBA	2	15.23			NS	NS	NS	*	**
CCC	3	14.71				NS	NS	NS	**
$AgNO_3$	4	14.45					NS	NS	**
IAA	5	13.30						NS	NS
GA_3	6	12.68							NS
ETHREL C	7	11.47							

Q (P0.05) = 2.37

Q (P0.01) = 2.79

Table 4.6.

Analysis of variance for bulbing ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	139	87.816					
BLOCK	1	10.037	10.037	24.103	3.91	6.83	11.35
PLANT GROWTH REGULATORS	6	22.816	3.803	9.132	2.16	2.94	4.01
ERROR	132	54.964	0.416				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
ETHREL C	1	4.473		NS	NS	*	**	**	**
CCC	2	4.174			NS	NS	NS	**	**
CONTROL	3	3.938				NS	NS	NS	*
TIBA	4	3.811					NS	NS	NS
$AgNO_3$	5	3.685						NS	NS
GA_3	6	3.328							NS
IAA	7	3.259							

Q (P0.05) = 0.612

Q (P0.01) = 0.721

Table 4.7.

Analysis of variance for bulb fresh weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	139	1159835					
BLOCK	1	13459	13459	3.253	3.91	6.83	11.35
PLANT GROWTH REGULATORS	6	600183	100031	24.175	2.16	2.94	4.01
ERROR	132	546193	4138				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
CCC	1	265.6		NS	NS	**	**	**	**
CONTROL	2	258.4			NS	*	**	**	**
TIBA	3	226.0				NS	**	**	**
$AgNO_3$	4	187.8					NS	*	**
IAA	5	139.4						NS	NS
GA_3	6	116.9							NS
ETHREL C	7	86.2							

Q (P0.05) = 61.0

Q (P0.01) = 71.9

Table 4.8.

Analysis of variance for bulb diameter.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	137	26717.7					
BLOCK	1	131.0	131.0	1.236	3.91	6.83	11.35
PLANT GROWTH REGULATORS	6	12813.0	2135.5	20.155	2.16	2.94	4.01
ERROR	130(2)[a]	13773.7	106.0				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
CONTROL	1	76.47		NS	NS	NS	**	**	**
CCC	2	75.76			NS	NS	**	**	**
TIBA	3	70.66				NS	**	**	**
$AgNO_3$	4	66.96					NS	**	**
IAA	5	59.07						NS	NS
ETHREL C	6	53.92							NS
GA_3	7	50.86							

Q (P0.01) = 11.51

a = Two missing values

Table 4.9.

Analysis of variance for bulb height.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	137	45163.1					
BLOCKS	1	78.2	78.2	0.678	3.91	6.83	11.35
PLANT GROWTH REGULATORS	6	30100.3	5016.7	43.523	2.16	2.94	4.01
ERROR	130(2)[a]	14984.6	115.3				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
CCC	1	97.23		NS	NS	NS	NS	*	**
GA_3	2	96.19			NS	NS	NS	NS	**
TIBA	3	95.16				NS	NS	NS	**
CONTROL	4	89.69					NS	NS	**
$AgNO_3$	5	88.35						NS	**
IAA	6	86.53							**
ETHREL C	7	51.75							

Q (P0.05) = 10.18

Q (P0.01) = 12.01

a = Two missing values

Table 4.10.

Analysis of variance for bulb height: diameter ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	137	18.924					
BLOCKS	1	0.012	0.012	0.192	3.91	6.83	11.35
PLANT GROWTH REGULATORS	6	10.862	1.810	29.238	2.16	2.94	4.01
ERROR	130(2)[a]	8.050	0.062				

Tests of significance between plant growth regulator treatments.

TREATMENTS		MEAN	1	2	3	4	5	6	7
GA_3	1	1.940		**	**	**	**	**	**
IAA	2	1.485			NS	NS	NS	**	**
TIBA	3	1.395				NS	NS	NS	**
$AgNO_3$	4	1.354					NS	NS	**
CCC	5	1.300						NS	**
CONTROL	6	1.186							NS
ETHREL C	7	0.964							

Q (P0.05) = 0.236

Q (P0.01) = 0.278

a = Two missing values

Table 4.11.

Analysis of variance for outer fleshy scales.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	13	34.804					
BLOCKS	1	0.085	0.085	0.216	5.99	13.74	35.51
PLANT GROWTH REGULATORS	6	32.360	5.393	13.716	4.28	8.47	20.03
ERROR	6	2.359	0.393				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
$AgNO_3$	1	6.91		NS	NS	NS	NS	NS	**
CONTROL	2	6.87			NS	NS	NS	NS	**
ETHREL C	3	6.76				NS	NS	NS	**
CCC	4	6.50					NS	NS	**
IAA	5	6.35						NS	**
TIBA	6	6.16							**
GA_3	7	2.31							

Q (P0.01)= 3.69

Table 4.12.

Analysis of variance for primordial leaf units.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	13	25.657					
BLOCKS	1	0.769	0.769	2.552	5.99	13.74	35.51
PLANT GROWTH REGULATORS	6	23.083	3.847	12.778	4.28	8.47	20.03
ERROR	6	1.806	0.301				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7
GA_3	1	6.04		*	*	**	**	**	**
TIBA	2	3.08			NS	NS	NS	NS	NS
CCC	3	2.86				NS	NS	NS	NS
CONTROL	4	2.68					NS	NS	NS
$AgNO_3$	5	2.36						NS	NS
IAA	6	2.10							NS
ETHREL C	7	2.02							

Q (P0.05) = 2.285

Q (P0.01) = 3.224

Table 4.13.

Analysis of variance for bulb diameter.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	39	8018.62					
BLOCKS	3	303.62	101.21	2.767	2.96	4.60	7.27
PLANT GROWTH REGULATORS	9	6727.59	747.51	20.440	2.26	3.18	4.61
ERROR	27	987.41	36.57				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7	8	9	10
PHOSPHON D	1	77.57		NS	NS	NS	NS	NS	NS	*	**	**
CONTROL	2	73.40			NS	NS	NS	NS	NS	NS	**	**
PACLOBUTRAZOL	3	71.65				NS	NS	NS	NS	NS	**	**
DMMC	4	69.05					NS	NS	NS	NS	*	**
STS	5	67.73						NS	NS	NS	*	**
IAA	6	65.88							NS	NS	NS	**
TIBA	7	63.83								NS	NS	**
GA_3	8	60.33									NS	**
$GA_{4/7}$	9	52.15										**
ETHREL C	10	29.93										

Q (P0.05) = 14.74

Q (P0.01) = 17.66

Table 4.14.

Analysis of variance for neck diameter.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	39	586.583					
BLOCKS	3	30.873	10.291	1.591	2.96	4.60	7.27
PLANT GROWTH REGULATORS	9	381.104	42.345	6.548	2.26	3.18	4.61
ERROR	27	174.606	6.467				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7	8	9	10
CONTROL	1	20.40		NS	NS	NS	NS	NS	NS	NS	NS	**
IAA	2	20.35			NS	NS	NS	NS	NS	NS	NS	**
$GA_{4/7}$	3	19.70				NS	NS	NS	NS	NS	NS	**
GA_3	4	19.20					NS	NS	NS	NS	NS	**
PACLOBUTRAZOL	5	18.78						NS	NS	NS	NS	**
DMMC	6	18.50							NS	NS	NS	**
PHOSPHON D	7	18.25								NS	NS	**
TIBA	8	17.78									NS	**
STS	9	17.38										NS
ETHREL C	10	9.15										

Q (P0.01) = 7.43

Table 4.15.

Analysis of variance for bulbing ratios.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	39	12.303					
BLOCKS	3	1.218	0.406	3.954	2.96	4.60	7.27
PLANT GROWTH REGULATORS	9	8.312	0.924	8.994	2.26	3.18	4.61
ERROR	27	2.773	0.103				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7	8	9	10
PHOSPHON D	1	4.383		NS	NS	NS	NS	NS	**	**	**	**
STS	2	3.952			NS	NS	NS	NS	NS	NS	NS	**
PACLOBUTRAZOL	3	3.918				NS	NS	NS	NS	NS	NS	**
DMMC	4	3.805					NS	NS	NS	NS	NS	**
CONTROL	5	3.686						NS	NS	NS	NS	**
TIBA	6	3.677							NS	NS	NS	**
IAA	7	3.313								NS	NS	NS
ETHREL C	8	3.258									NS	NS
GA_3	9	3.175										NS
$GA_{4/7}$	10	2.703										

Q (P0.01) = 0.936

Table 4.16.

Analysis of variance for bulb height.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	39	14345.42					
BLOCKS	3	358.03	119.34	2.213	2.96	4.60	7.27
PLANT GROWTH REGULATORS	9	12531.17	1392.35	25.816	2.26	3.18	4.61
ERROR	27	1456.22	53.93				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7	8	9	10
CONTROL	1	100.4		NS	NS	NS	NS	NS	NS	NS	NS	**
GA_3	2	97.1			NS	NS	NS	NS	NS	NS	NS	**
TIBA	3	96.7				NS	NS	NS	NS	NS	NS	**
PACLOBUTRAZOL	4	95.4					NS	NS	NS	NS	NS	**
$GA_{4/7}$	5	94.9						NS	NS	NS	NS	**
IAA	6	94.8							NS	NS	NS	**
DMMC	7	94.3								NS	NS	**
STS	8	93.6									NS	**
PHOSPHON D	9	88.3										**
ETHREL C	10	36.8										

Q (P0.01) = 21.4

Table 4.17.

Analysis of variance for bulb height: diameter ratio.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	39	1.611					
BLOCKS	3	0.074	0.025	3.938	2.96	4.60	7.27
PLANT GROWTH REGULATORS	9	1.369	0.152	24.423	2.26	3.18	4.61
ERROR	27	0.168	0.006				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7	8	9	10
$GA_{4/7}$	1	1.826		*	**	**	**	**	**	**	**	**
GA_3	2	1.620			NS	NS	**	**	**	**	**	**
TIBA	3	1.516				NS	NS	NS	NS	NS	**	**
IAA	4	1.451					NS	NS	NS	NS	*	**
STS	5	1.386						NS	NS	NS	NS	**
CONTROL	6	1.372							NS	NS	NS	**
DMMC	7	1.366								NS	NS	*
PACLOBUTRAZOL	8	1.330									NS	NS
ETHREL C	9	1.236										NS
PHOSPHON D	10	1.139										

Q (P0.05) = 0.192

Q (P0.01) = 0.230

Table 4.18.

Analysis of variance for haulm length.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	39	69475.8					
BLOCKS	3	2000.8	666.9	2.929	2.96	4.60	7.27
PLANT GROWTH REGULATORS	9	61326.6	6814.1	29.923	2.26	3.18	4.61
ERROR	27	6148.4	227.7				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7	8	9	10
$GA_{4/7}$	1	221.7		NS	*	*	*	**	**	**	**	**
GA_3	2	220.1			*	*	*	**	**	**	**	**
CONTROL	3	181.8				NS	NS	NS	NS	NS	NS	**
IAA	4	180.1					NS	NS	NS	NS	NS	**
TIBA	5	178.9						NS	NS	NS	NS	**
DMMC	6	171.8							NS	NS	NS	**
STS	7	169.4								NS	NS	**
PACLOBUTRAZOL	8	167.1									NS	**
PHOSPHON D	9	146.5										**
ETHREL C	10	73.7										

Q (P0.05) = 36.8

Q (P0.01) = 44.1

Table 4.19.

Analysis of variance for bulb fresh weight.

ITEM	D.F.	S.S.	M.S.	V.R.	P0.05	P0.01	P0.001
TOTAL	39	243358					
BLOCKS	3	14017	4672	2.299	2.96	4.60	7.27
PLANT GROWTH REGULATORS	9	174471	19386	9.539	2.26	3.18	4.61
ERROR	27	54870	2032				

Tests of significance between plant growth regulator treatments.

TREATMENT		MEAN	1	2	3	4	5	6	7	8	9	10
PHOSPHON D	1	255.1		NS	NS	NS	NS	NS	NS	NS	**	**
CONTROL	2	249.4			NS	NS	NS	NS	NS	NS	*	**
PACLOBUTRAZOL	3	226.8				NS	NS	NS	NS	NS	NS	**
DMMC	4	207.6					NS	NS	NS	NS	NS	**
STS	5	201.0						NS	NS	NS	NS	**
IAA	6	192.3							NS	NS	NS	**
TIBA	7	181.6								NS	NS	**
GA_3	8	171.8									NS	**
$GA_{4/7}$	9	123.0										NS
ETHREL C	10	17.6										

Q (P0.05) = 109.9

Q (P0.01) = 131.6