SEED PRODUCTION IN CHINA ASTER
(*Callistephus chinensis* (L.) Nees.)

LUCKANA PHETPRADAP

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ABSTRACT

Seed production of two cultivars (Powderpuff and Kurenai) of China aster (*Callistephus chinensis* (L.) Nees.), grown under field conditions, was assessed to determine plant responses to the effects of plant density, crop manipulation by hand pinching and the application of three plant growth regulating chemicals, and some selected herbicides.

Plant density effects on vegetative plant growth, flowering pattern, seed development, seed yield and yield components were investigated in 1987/1988 using a radial spacing design which provided plant densities ranging from 4.2 to 44.7 plants m^{-2}. Increasing plant densities increased branch numbers m^{-2} which led to increased leaf numbers, leaf area, plant dry matter and flowers and resulted in an increased number of potential seed production sites. The number of flower heads m^{-2} was the most important component determining final seed yield in both cultivars and was identified as an important plant characteristic to be manipulated for improving seed yield. A period of 18 days was required to complete flowering within each individual flower head, since florets opened sequentially from the outside ring through to the centre. The flowering period lasted for 8 weeks. Each seedhead needed 30 or 39 days from first opening for seed to reach physiological maturity and seeds could remain on the seedhead for a further 9 or 12 days (cv. Kurenai and cv. Powderpuff respectively) before seed shedding started. Kurenai produced maximum seed yield at 27.8 plants m^{-2} (140 g m^{-2}) and cv. Powderpuff at 17.4 plants m^{-2} (42 g m^{-2}) but these yields did not differ significantly from those over a wide range of densities (between 12.7 to 44.7 plants m^{-2} in cv. Kurenai and 4.9 to 44.7 plants m^{-2} in cv. Powderpuff). Both cultivars exhibited a high ability for compensatory reproductive growth. Lodging and weeds were identified as constraints for seed production at this site and were studied in subsequent years.

A series of experiments were conducted in 1987/1988 and 1988/1989 to evaluate herbicides which would provide good weed control without seed yield reduction, and which would not be phytotoxic to aster plants grown either as transplanted seedlings or when direct sown. For transplanted aster, a single application of oryzalin (3.75 kg a.i. ha^{-1} at 4 days after transplanting) provided excellent weed control and a tenfold increase in seed yield (to 568 kg ha^{-1}). For direct sown aster, only trifluralin (2 kg a.i. ha^{-1}) applied pre-sowing did not significantly reduce aster emergence, while oryzalin (4.5 kg a.i. ha^{-1} applied 10 days after sowing) provided the best aster seedling survival. However weed control from both chemicals was only partial and further work is required.

In 1988/1989, hand pinching and the application of two different rates of three growth retardants, paclobutrazol (0.5 and 1.0 kg a.i. ha^{-1}), daminozide (2.5 and 5.0 kg a.i. ha^{-1}) and chlormequat chloride (1.5 and 3.0 kg a.i. ha^{-1}) were carried out at two different growth stages (visible terminal bud and stem elongation stages) on cv. Powderpuff to investigate their retardation ability, any alterations in the partitioning of assimilate, and subsequent effects on seed yield and yield components. Powderpuff plant structure was altered by hand pinching only at the visible terminal bud stage. Neither pinching treatment increased seed yield, because, particularly for the earlier pinching time, fewer branches were produced from limited node numbers. The growth retarding effect of the three chemicals was transient and the differences in efficacy and the effective duration of each growth retardant treatment was recorded. The longevity of chlormequat activity in treated plants was short compared to paclobutrazol. Although paclobutrazol and daminozide decreased plant height at seed harvest, lodging was not prevented. None of the three chemicals increased flower head numbers or shortened the duration of flowering, and subsequently failed to increase seed yield. However, paclobutrazol showed enough promise for plant height reduction and seed yield improvement to warrant further investigation.

Two experiments with paclobutrazol were conducted in 1989/1990. The first was on cv. Powderpuff, where two rates of paclobutrazol (0.5 and 1.0 kg a.i. ha^{-1}) were applied at three growth stages (vegetative, terminal flower bud initiation and first visible terminal flower bud stages) to assess their effects on seed yield. The second was an investigation of cultivar/density responses, where the same two paclobutrazol rates were applied to two aster cultivars grown at two different plant densitites (16 and 36 plants m^{-2} for cv. Powderpuff and 25 and 49 plants m^{-2} for cv. Kurenai) at the terminal flower bud initiation stage. Paclobutrazol effects on China aster plant height were cultivar dependent. Both paclobutrazol rates effectively controlled plant height of cv. Kurenai but the results in cv. Powderpuff were inconsistent and the plant height reduction was insufficient to prevent lodging.

Results from all the experiments showed that flowering was strongly influenced by environment (daylength and temperature), and since no growth retardant treatments shortened the duration of flowering, a high variation in seed maturity caused by sequential flowering and subsequent high losses of immature seeds during cleaning resulted in no significant seed yield increases. However, paclobutrazol significantly increased potential harvestable seed yield through increasing the number of seeds per plant when applied (i) at the vegetative stage at 1.0 kg a.i. ha^{-1} to cv. Powderpuff grown at 16 plants m^{-2} (56 % seed yield increase from 83.8 to 130 g m^{-2}). (ii) at the terminal flower bud initiation stage at 0.5 kg a.i. ha^{-1} to late sown plants of cv. Powderpuff grown at 36 plants m^{-2} (48 % increase from 136 to 202 g m^{-2}). and (iii) during flower bud initiation and early stem elongation at 0.5 and 1.0 kg a.i. ha^{-1} in cv. Kurenai grown at 49 plants m^{-2} (32 and 42 % increase from 178 to 236 and 253 g m^{-2} for the low and high rate respectively).

Seed production problems and possibilities for the production of China aster seed under New Zealand and Thailand conditions are also discussed.

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CHAPTER 1

GENERAL INTRODUCTION

Progress in the evolution of the floricultural industry has been very rapid in the past 20 years particularly in terms of the range of products grown, the nature of producing units, consumer preference, marketing, methods of transportation and distribution and the location of production. These changes have been largely due to the ability of cargo air transport to deliver perishable products (e.g. cut flowers) to distant markets at reasonable freight rates. The entry of private companies has also dramatically increased changes in the flower industry, by making the industry move to be more international in its marketing, and by the provision of all-year-round supplies of fresh flowers. International trade in cut flowers is a multi-million dollar industry. For example Pegrum (1990) reported cut flower exports from the Netherlands in 1989 exceeded $NZ 5300 million while turn-over through the Dutch auction system is about $NZ 5.1 million per day. Japan alone imported flowers and foliage to the value of 13.9 billion yen in 1988 ($NZ 180.4 million). This equates to around 13,000 tonnes of mostly fresh flowers.

Energy and labour costs are also another important cause of the changes in the floriculture industry. Jarvesou (1983) reported that northern US cut flower production had decreased due to South American competition where labour costs are much lower. This situation was also faced by the Netherlands. Both countries have had to compete on the basis of higher yields per unit area, better quality, and efficient marketing and distribution (Smith and Miller, 1983). Any technology which reduces energy consumption and labour costs, while maintaining higher productivity has become a priority. This situation has also lead to field-grown cut flower crops increasing in popularity in many European countries in recent years (Armitage, 1987), an industry which has been operating in California and Florida for many years (Kelly, 1991). However, due to climatic advantages, lack of need for expensive greenhouse structures or heating mechanisms, and cheaper labour, a number of enterprises have been established in South America, Africa and Asia.

Thailand is one of the world's fresh flower exporting countries. Although orchids make up more than 80 % of the total export flower trade (Department of Information, 1986), there is a great opportunity to expand the production of other flower crops. The advantages of low labour costs and climate are important. However Thailand also has a different flowering peak compared with the peak production time of other exporters such as the Netherlands and Israel. This situation has increased the demand for good quality seed in Thailand, a situation which has induced many European and Japanese seed companies to set up seed enterprises to ensure continuous supplies of high quality flower seeds to growers. Transportation and marketing costs from seed producer to consumer can also be minimized.

The consumer and fresh flower market demand for varieties of seed propagated flower crops which cover a very wide range of species of bedding plants, potted plants and cut flowers, is rapidly changing (Kestr, 1990), and has changed the development of the floriculture industry from quality improvement of existing species and cultivars to the development of new products and methods of marketing to meet changing consumer interests. Cultivars have been developed by breeders to satisfy the needs of growers as well as consumers. New technologies are being applied to create new genetic variation and to increase the efficiency of breeding procedures and seed multiplication. The already essential tools are tissue culture and seed technology. High quality seed is the most critical input upon which all other inputs depend for their full effectiveness (Thomson, 1979). Seed production and processing also make a major contribution to seed quality aspects (Kestr, 1990). Many papers have been published on the production of agricultural and horticultural seeds, but comparatively few on flower seeds, due to the highly competitive (and therefore confidential) nature of this business.

The basic difference between flower and field grain crops limits seed industry growth. The quality of the bloom is the most important factor for the cut flower business, because the buyer expects to receive a flower that looks freshly picked and has a long vase life. Thus, the grower is concerned with crop quality and not seed production (FAO,1961). In agronomic crops where the seed is the marketed end product, selection for seed quality has often naturally accompanied that for yield. In many flower crops, the flowers, foliage, bracts or the overall morphology, the ‘freshness’, the strength of the stem, the proportion of flowers with leaves or bracts and the absence of diseases and pests are the critically important characters. Perhaps as a result, very little selection has occured specifically for high seed quality.

There is limited information available for cultural techniques either for the production of flower seed or for field grown cut flowers, particularly in non traditional or minor crops like China aster. In the past, most of the cut flower production in Europe and northern US was under protected cultivation, and there was a great demand for greenhouse cut flower research, particularly on major crops, such as carnations, roses, and chrysanthemums. The primary reasons that cut flower production shifted to protected cultivation were that higher quality flowers could be produced under glass, weather-related losses from wind, hail and other storms were greatly reduced, and year-round production was possible (Kelly, 1991). Foreign competition has forced many greenhouse operations to switch to pot plant culture, and consequently, floriculture research also changed to potted crops. As the need for field cut flower research became more evident, recent research has begun to focus more on these field-grown crops (Tjia, 1985; Armitage, 1987; Default *et.al.*, 1990). Many new species are being introduced to the market place. The enormous diversity of crops with potential as field-grown cut flowers has advantages and disadvantages to producers as discussed by Kelly (1991). Often, too many choices can impair the initial adoption of any one species. Also, while researchers may be able to study a new edible crop in great detail, studying hundreds of new floral crops is not feasible. Too many crops may lead to diluted research or superficial data accumulation, insufficient to improve the knowledge base. However, the diversity of crops also creates great opportunity, because it gives producers a challenge to find an unfilled market niche. Thus, the need for production information of any particular species varies between countries or marketplaces, either by substitution of imports or creating a new product for export.

China asters [*Callistephus chinensis* (L.) Nees.], despite having lost some popularity over the years in the European and American floricultural business because of disease and insect problems, are still popular choices for late summer and autumn bloom. The taller types are excellent cutflowers while the dwarf types are important to the bedding plant grower. Most cultivars on the market today are tolerant to aster or fusarium wilt (Mastalerz and Holcomb, 1985).

In Thailand, China aster is one of the main cut flowers . They grow very well, need less labour and have fewer costs and expenses compared with other popular cut flowers such as chrysanthemum or carnation. The net profit is approximately seven times the total cost of production (Department of Agriculture Extension, 1981). The high net returns on a smaller area when compared with field crops, led initially to grower interest in aster flower crops, and then to seed production.

Most of the aster seed sown in Thailand is imported, although some small quantities of local seed are produced. Preliminary studies on seed production of a number of flower crops at Maejo, Chiang mai, Thailand showed that good quality seed could be produced (Phetpradap, unpublished data). The cooler night temperatures (10-18 °C) and a rainfree period during flowering in the North and North-East parts of Thailand offer a possibility for flower seed production including China aster, although these plants can be grown elsewhere in the country (Pitchayakul, 1980; Teravet, 1984; Dittachaivong, 1985). Some growers have tried to produce aster seeds but have generally been discouraged by low seed yields and quality. It is likely that this fluctuating return from seed production in aster has occurred through lack of information about the desirable agronomic management and research requirements for maximizing seed yield. If seed growers could overcome these difficulties, aster seed production might be accepted and become another great opportunity for growers.

The present study was divided into three parts, each emphasizing one particular aspect. The first part (Chapter 3) was designed to provide basic information on the effects of plant density on the growth and development of the plant, flower, seed development, seed yield and yield components of two China aster cultivars: Powderpuff which is tall for cutting and Kurenai, a medium-tall bedding plant. These two cultivars were chosen because of their adaptability to the Thailand climate and acceptability by the consumer. Parts two (Chapter 4) and three (Chapter 5 and 6) were based on the problems encountered in Chapter 3. Chapter 4 consists of a series of experiments to identify herbicides which would provide good weed control without seed yield reduction, and which would not be phytotoxic to aster plants grown either as transplanted seedlings or when direct sown. In Chapter 5 particular emphasis has been placed on investigating the effects of hand pinching and chemical manipulation on plant growth to improve seed yield in China aster. The most potent plant growth regulating chemical, paclobutrazol was further investigated in Chapter 6 to provide more detailed information related to chemical application time, plant density and cultivar responses. A glossary for all botanical terms used in this study is presented in Appendix 2.1. The possibilities and problems for seed production of China aster are also discussed for both New Zealand and Thailand conditions.

CHAPTER 2

LITERATURE REVIEW

2.1 General description of China aster

China aster [*Callistephus chinensis* (L.) Nees.] is a native of China and Japan (Laurie *et.al.*, 1942; Hay *et.al.*, 1976; Larson, 1980; Cockshull, 1985), a diploid (2n=18), and a member of the family Compositae (Cockshull, 1985). The word 'Callistephus' is derived from a Greek word for beautiful crown (Salunkhe *et.al.*, 1987). The plant was introduced to Europe by a Jesuist missionary, R.P. d'Incarville in 1731 (Emsweller, 1937). The original form was single, with two to four rows of ray florets of red, blue, violet, or white and numerous yellow disk florets. Early improvement work was concentrated in France and yielded double flower forms with large numbers of ray florets in each inflorescence (Emsweller, 1937; Cockshull, 1985). In the nineteenth century the centre of production shifted to Germany, where the quilled varieties were first produced and subsequently became known in America as German aster. In 1839 the branched types appeared, and since then many new strains have been developed by American seedsmen (Coats, 1968). The plant has undergone many changes both in growth habit and flower characteristics (e.g. stronger flower stems and larger blooms), and the present day florist types do not have much resemblance to their ancestors (Salunkhe *et.al.*, 1987).

China aster is cultivated as a cut flower both in the field and under protection (Post, 1950; Warren, 1980), and is excellent for garden landscaping (Ballinger, 1985), or for decorative use as a potted plant (Hay *et.al.*, 1976). Asters were well known in American commercial outdoor cut flower production in the late 1800's and early 1900's (Post, 1950). They were grown extensively outside in cloth houses in the 1950's and can be produced all year round in glasshouses (Ball, 1985). Unfortunately, heavy losses due to two diseases, Fusarium wilt and Aster yellows wiped out many aster flower production businesses even though wilt resistant strains became available later. However, because of their beauty and excellent keeping quality they were promoted again as a potted plant by the U.S.A. seed companies and new cultivars were recently released and made available for growers from Japan. In New Zealand, the plant is most popular with new section owners but in more established gardens is prone to aster wilt particularly when asters are grown as successive crops (Ballinger, 1985).

China aster is an erect, branching annual, with ovate or triangular ovate leaves with dentate margins forming a basal rosette in the young plant, but spirally arranged on the stems. The leaves gradually become smaller and spatulate in the upper parts of the stem where they become indistinguishable from bracts (Cockshull, 1985; Webb *et.al.*, 1988).

Each flower is actually a capitulum; composed of a mass of smaller flowers which together make up the 'composite' head. The individual flower within the head is perfectly formed with five anthers and five petals surrounding a central style. Two forms of floret exist in each compound flower. Those on the outside of the disc posses five long petals which are fused together on four edges thus forming a colourful flat or ligulate petal. Towards the centre of the disc the petals become diminutive and are fused on all edges to form a tube. Anthers are regularly fused in the form of a tube within both types of floret, but generally, they are not functional in ray florets. Thus, the terms female ray florets and hermaphrodite disk florets are used to describe these two types of florets (Watts, 1980; Cockshull, 1985). Because of the sequential opening of florets, a compound compositae flower is fit to be pollinated over a period of several days. Mature seeds may be forming in the outer (or ray) florets while the central ones are either still receptive to pollen or may not yet have opened (Watts, 1980). The outer involucral bracts surrounding the inflorescence are often large, green, and reflexed (Vis, 1980), and inner bracts spatulate, glabrous and may be equal, bigger or smaller than outer bracts (Webb *et.al.*, 1988). The fruit is an achene and usually has a pappus of short hairs (Vis, 1980; Webb *et.al.*, 1988).

The complete flowering shoot constitutes a lax cyme, consisting of a large terminal inflorescence (the first to be initiated) and many smaller axillary inflorescences carried on thin wiry stems bearing a few leaves and bracts (Cockshull, 1985).

There are numerous cultivars in a diversity of form; tall, dwarf, single, double and pompon (Hay *et.al.*, 1976). However most growers produce plants of two types, the talls for florist cut flowers and the dwarfs for pot plants or more popularly for bedding plants (Mellon and Goldsmith, 1985). The flowers vary in size, form, shape and colour (Salunkhe *et.al.*, 1987).

Cultivar classification is generally based on flower type and plant height. The popular dwarf cultivars are Burpee's Dwarf Border, Dwarf Queen, Pinocchio, Pixie, Princess, and Rainbow. The important tall and medium-tall cultivars are American Beauty, Bouquet Powderpuff, Heart of France, Kurenai, Perfection, Super Princess, Totem Pole, and Queen of the Market. The flower head may be single (e.g. Andrella, Fireglow, Kurenai, Rainbow); double (e.g. Burpeena Extra Early, Liliput, Powderpuff); incurved (e.g. Ballade, Perfection); quilled (e.g. Super Princess); pompon (e.g. Ariane, Chikuma, Pompon); recurving petals (e.g. Ostrich Feather) or needle-shaped petal (e.g. Giant Ray) (Ball, 1984; Burpee, 1984; Kieft Blokker Holland, 1988).

The two cultivars used for this study were Powderpuff and Kurenai (Figure 2.1).

Powderpuff asters are of a wilt resistant bouquet type. The flower head is fully double, medium size (6-8 cm in diameter) and comes in a wide range of colours (azure-blue, crimson, purple, rose, scarlet and white; Hay *et.al.*, 1976). They are popular as cut flowers as they have several fully double flowers on each stem. The stems are erect, 60 cm high (Ball, 1985).

Kurenai aster is a new cultivar from Japan. The plant is more bushy in habit with strong but shorter stems (40-50 cm). The flower head is a single or a semi-double flower type, 3-4 cm in diameter. The colour is red with golden yellow at the centre of the head (Kieft Blokker Holland, 1988).

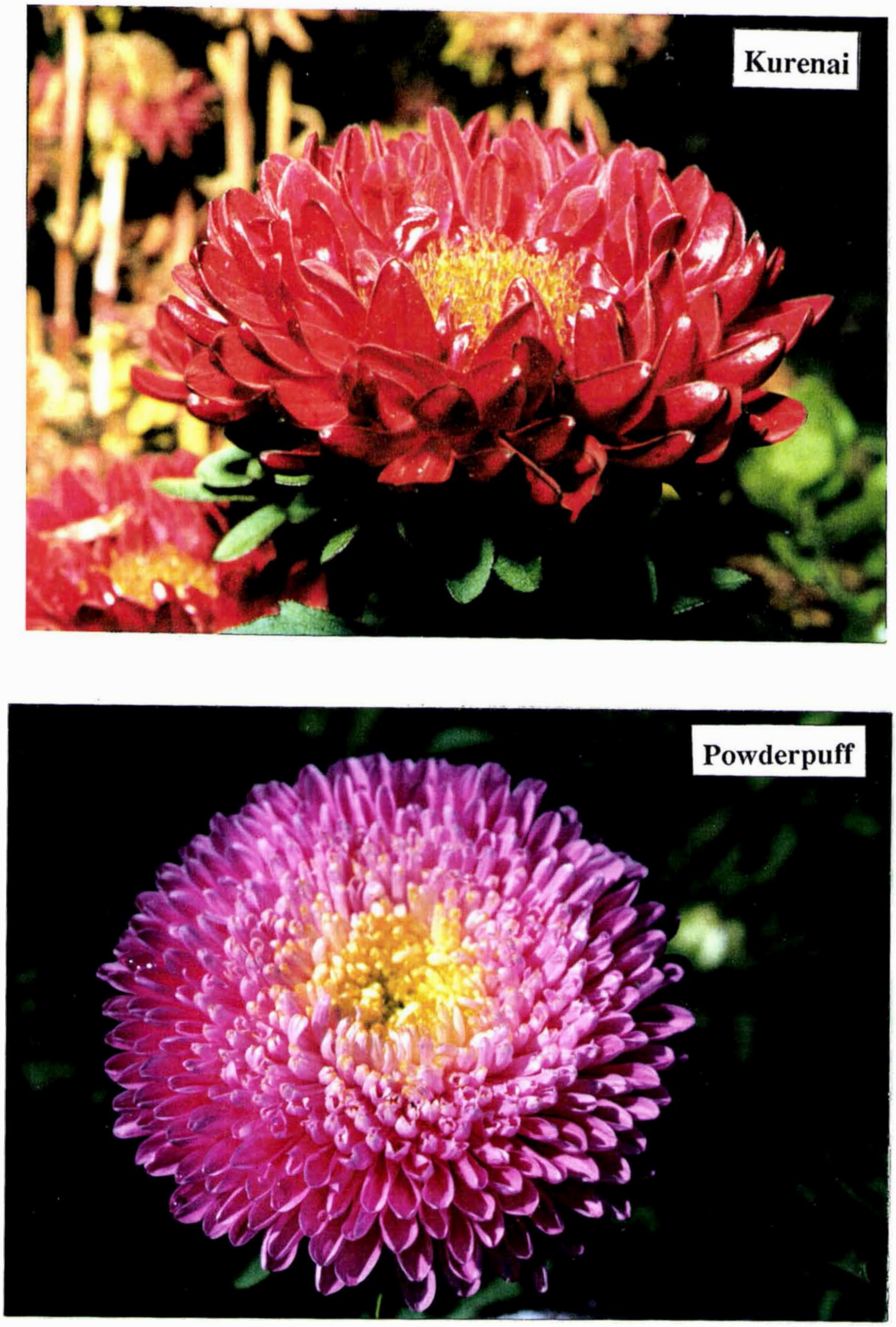


Figure 2.1 The two cultivars, Kurenai and Powderpuff used for this study.

2.2 Plant growth and flowering as affected by photoperiod and temperature

China aster is a quantitative long day plant for flower initiation (Doorenbos, 1959; Kinet and Sachs, 1984; Cockshull, 1985). Doorenbos (1959) found that in long days flower induction was completed by about 6 weeks after sowing, but actual inflorescence initiation did not take place until several leaves were formed some weeks later. This resulted in inflorescence buds which appeared earlier (Withrow and Withrow, 1940; Lin and Watson, 1950) and often reached anthesis earlier than in short days (Withrow and Withrow, 1940; Lin and Watson, 1950; Hughes and Cockshull, 1965). In contrast, it is a quantitative short day plant for flower development (Cockshull, 1985). The work of Doorenbos (1959) showed that aster cv. Giant Comet planted either in continuous short days or long days flowered almost simultaneously. In short days, initiation is delayed and the development of the inflorescence bud proceeds more rapidly than in long days. Therefore, when a long day induction is followed by short days, flowering occurs more rapidly, about a month earlier than in plants grown entirely in long days.

In addition, there is a pronounced interaction between photoperiod and temperature (Biebel *et.al.*, 1935; Biebel, 1936; Lin and Watson, 1950). Plants flower earlier and produced long stemmed flowers of moderate diameter when grown under high temperature (18-20 °C) and long days (five hours of artificial light produced from a 60 watt 120 volt incandescent lamp suspended 75 cm above the plants was added after sunset). The flowering was regular and the first flowers in the plot to open were still in good shape before the last ones opened. Under natural short days and high temperature in Michigan, plants flowered rather profusely but had small flowers and short stems. Flowering was very irregular and the first flowers to open were completely faded before the last flowers opened. Low temperature (10 °C) with long days produced vigorous flowering. The plants flowered two weeks later than plants in the higher temperature. They had just as many flowers as the plants in the higher temperature, but stem length was shorter. Flower diameter, on the other hand, was considerably greater than that of the plants in the higher temperature. The plants given the lower temperature and short photoperiod remained in the vegetative stage and failed to flower. Neither 30 or 60 days of higher temperature exposure early in the plant's life were sufficient to overcome the inhibiting effect of low inhibiting effect of low temperature and a short photoperiod on flowering (Biebel, 1936; Lin and Watson, 1950).

Long days promote leaf expansion, stem extension and dry matter accumulation, and the promotion of inflorescence development in short days is accompanied by an inhibition of stem extension (Biebel, 1936; Hughes and Cockshull, 1965; Cockshull and Hughes, 1969). The effect of daylength on aster leaf expansion has been studied in some detail and Cockshull (1966) found that long day treatment accelerated expansion of the leaf surface and increased the specific leaf area. The increase in leaf expansion was also found in response to a one hour night-break (8 hours day - 16 hours night, interrupted at its mid point by one hour of low intensity light provided by six 40 watt tungsten bulbs illuminating an area of 3.4 m^2 and suspended about 90 cm above the plants) but it could not be further stimulated by cyclic lighting (8 hours day - 16 hours night, interrupted after every 59 minutes of darkness by 1 minute of low intensity light and giving a total of 15 minutes of 'cyclic lighting' in each 16 hours dark period) throughout the night or by continuous light, although stem extension and flowering were both promoted further by these treatments (Cockshull and Hughes, 1969).

Photoperiod can also influence both the production and distribution of dry matter in aster. Hughes and Cockshull (1965) showed that the distribution of dry matter to leaves, stem and roots of cultivar Queen of the Market followed a similar pattern relative to the total vegetative dry weight in both flowering and vegetative plants. Although this pattern was similar for plants growing in short days or with a one hour night-break, the use of continuous low-intensity light (or cyclic lighting of 1 minute in every 60) during a 16 hour night gave greater diversion of dry matter to the stem at any given vegetative dry weight (Cockshull and Hughes, 1969).

2.3 Seed production practice

It is of paramount importance that the greatest care is taken over seed production, as only seed harvested under good conditions can be expected to have high quality and can be stored for several years (Vis, 1980). Unlike many agricultural and other horticultural crops, there have been very few publications on aster seed production. Therefore, the information cited refers to previous publications on aster flower production and aster seed production where possible or otherwise to other kinds of flower or vegetable seed crops where the findings are also applicable to aster.

2.3.1 Area of production

The production of seeds of flowers and vegetables tends to concentrate in rather limited geographical areas compared with grasses or field crops (McCorkle and Reed, 1961). The environment has considerable influence on the development and quality of seed (Delouche, 1980). Good soils, rainfall or controlled moisture supply through irrigation, and bright sunny weather contribute to stability of production, high yields, and high quality of the seed produced (Delouche, 1980). Sufficient rainfall to ensure complete development and maturation of the seeds (George, 1985), and a rainless period with relatively little wind during flowering for satisfactory pollination, seed ripening and to allow harvesting operations to be completed with minimal deterioration and crop loss, are all very important factors in flower seed production (Vis, 1980; Salunkhe *et.al.*, 1987).

Extremes, either wet and cold or dry and hot during flowering and seed set may cause low yields and poor germination because they interfere with the fertilization process or encourage death of developing embryos (Scott and Longden, 1978). A lack of inclement weather during the final stages of development and ripening is also important from the point of view of disease control as a low relative humidity with minimal rainfall and moderate temperatures minimizes the spread of seed borne diseases (Delouche, 1980; Gaunt and Liew, 1981). Although low humidities are generally favourable for seed production, there are exceptions. For example, the location of some flower seed production in California in areas adjacent to the ocean where humidity tends to be high at harvest time. The high relative humidity in coastal areas prevents over drying of unthreshed material in the field and can assist in reducing loss from shattering during harvesting (Hawthorn and Pollard, 1954; George, 1985).

According to George (1985), excessive wind increases water loss from the crop and soil, prevents maximum activity of pollinating insects, carries wind-borne pollen over long distances, and increases loss of seed by enhancing shattering during seed ripening. Strong winds during the reproductive phase can cause severe crop losses through lodging, shattering and shedding of seed. The lodging effect of wind can be aggravated by heavy rain, which soaks the ripening heads, thus increasing the lodging tendency (Thompson, 1979). Sheltered areas with wind breaks of taller plants grown around the fields may be necessary for successful seed production to reduce wind damage (Salunkhe *et.al.*, 1987).

Other components of the environment, such as pollinating insects, suitable isolation from other crops, as well as an abundance of low cost labour for controlled pollination of F_1 hybrid seeds and hand harvesting of crops are also important, as well as the effectiveness and efficiency of communication and transport systems (Delouche, 1980; Vis, 1980).

2.3.2 Soil and fertilizer

Aster will grow on most soils as long as drainage is good and water is well supplied (Post,1950; Ballinger, 1985) but plant and flower development is better on more fertile soils (Ballinger, 1985). Rich loamy or sandy loam soil is the best for aster production (Hay *et.al.*, 1976; Salunkhe *et.al.*, 1987). Heavy loamy soil is not suitable unless it is amended by adding sand or river bed soil to improve drainage. Aster also needs an ample supply of organic matter in the soil. The most suitable soil pH is within the range 5.5 to 6.5 (Salunkhe *et.al.*, 1987). For commercial cultivation, adequate drainage is considered the most important factor in the selection of the production site (Boodley, 1981; Salunkhe *et.al.*, 1987) since aster will not tolerate waterlogged conditions which may aggravate serious soil-borne disease problems (McKay, 1984).

Aster flowers are produced under widely varying fertilizer programmes and it is difficult to draw any conclusions on fertilizer requirements, as little nutrition trial work has been published for either seed or crop production. According to Post (1950) only one application of a complete fertilizer such as 5-10-5 (N-P-K) at 100 g m^{-2} at planting time is enough for flower production. But Boodley, (1981) stated that asters require a medium strength fertilizer programme and suggested a preplant application with any balanced fertilizer such as 10-10-10 at the rate of 100 g m^{-2} mixed thoroughly into the soil, followed by 20-20-20 applied at a concentration of 2.5 g l^{-1} of water three weeks after planting. Salunkhe *et.al.* (1987) suggested applying nitrogen in two or three split doses, one at the time of transplanting, followed by another one month after transplanting and repeated again when flower buds appeared. McKay (1984) also recommended that side dressings of urea at 0.35 kg per 30 metres of planting bed applied four to six weeks after planting, and approximately four weeks later, following a preplant fertilizer of 5:6:5 at a rate of 250 g m^{-2}. Liquid feeding programmes are now widely used in the United States and Europe by growers relying on contracting seed company consulting services.

2.3.3 Sowing and planting

It is of the utmost importance to sow and plant at the optimum time to achieve optimal flower formation and seed setting and to avoid delay in harvesting (Vis, 1980). Asters are quite susceptible to frost injury which can damage both flowers and plants. Therefore, sowing time should be adjusted to avoid any chances of exposure to freezing or chilling temperatures. The best growing temperature is around 15.4 °C (night), but the plant will grow well up to 20 °C (night). Flowers can also be damaged by high night temperature and severe wind. High night temperature in summer (above 23 °C), reduces stem strength and flower size. Asters need ample quantities of sunlight, but they can also tolerate light shading (McKay, 1984; Salunkhe *et.al.*, 1987).

In the cooler parts of New Zealand, the seed should be sown under glass in September and the plants transplanted outside about the end of October. In warmer climates seed can be germinated without protection and is sometimes sown directly into the garden (Ballinger, 1985). Seed germination takes 8-10 days at 21 °C under glass (Larson, 1980; Ball, 1985) or 14-21 days for germination in direct field sowings (Walls, 1982; Walls, 1988). Seedlings are ready for transplanting three weeks later (Boodley, 1981; Salunkhe *et.al.*, 1987). Planting out is usually done about 35-40 days after sowing (Ball, 1985). Production time is 5-6 months from sowing to flowering (Larson, 1980).

Asters need regular watering, the frequency and rate of which is determined by soil type and climatic conditions. A thorough soaking once a week is essential in dry weather or throughout a dry summer for best flower production in U.S.A.. However, if soils are too wet, severe stem rot loss may occur (Ball, 1985). Sufficient soil moisture must be available during the flowering stage as the crop is moisture sensitive, and stem length and flower size are reduced by a water shortage (McKay, 1984). Irrigation must be stopped when the seed begins to mature (McCorkle and Reed, 1961; FAO, 1961). Seed viability can be seriously affected by high rainfall during the seed ripening period. This may even lead to premature seed germination and will increase the cost of seed drying (Salunkhe *et.al.*, 1987).

2.3.4 Plant density

It is advantageous to achieve the optimum sowing or planting distance, as plant density can markedly affect plant performance. Too dense a plant stand increases competition for certain essential growth factors (nutrients, sunlight and water) and the risk of disease, resulting in lower yield and quality because of thinner, weaker plants with lower tolerance to less favourable conditions. In contrast, with too low a population, weeds have the opportunity to enter the crop and can indeed overgrow it. Only a well developed plant with sufficient space at the fully grown stage, so that it can dry quickly after rain or dew, can produce high seed yield and quality (Janick, 1972; Vis, 1980).

Optimum spacing for aster plants is generally recommended to be about 30-40 x 30-40 cm for taller cultivars and 15-20 x 15-20 cm for the dwarf varieties (Ballinger, 1985; Salunkhe *et.al.*, 1987), depending on the method of weed control (Post, 1950). The usual planting distance of aster for seed production, in Czechoslovakia is a 40 cm row spacing and 20-30 cm between plants depending on plant height. Kobza (1987) found that aster seed yield per unit area increased with increasing plant density. The highest seed yield of cv.'Alena' (low, bedding type) was obtained from plants grown at 40x10 cm spacing and 40x15 cm for cv.'Tamara' (tall, needle for cutting).

2.3.5 Disease control

China aster used to be one of the most important annual flowers in U.S.A. (Laurie *et.al.*, 1942) but because of its great susceptibility to a number of diseases and pests, seeds sales dropped drastically. Plants wilt suddenly, and most frequently near maturity, when they are attacked by the aster wilt fungus (*Fusarium oxysporum f.sp callistephi*). The fungus attacks the plants at ground level, and an orange coloured growth appears on the stem during moist weather. The stem is rotted completely at the surface of the soil, usually with dark brown lesions extending up the stem (Post, 1950; Boodley, 1981; Ball, 1985). Wilt resistant strains are suggested (Walls, 1982; Ball, 1985; Salunkhe *et.al.*, 1987) and have been introduced from time to time, but results can still be variable as the disease is soil borne (Ballinger, 1985). Deep planting should be avoided in summer. Plants should be set as shallow as possible without exposing the roots (Ball, 1985). It is suggested that aster should not be planted in the same area for a second year unless the soil and all equipment used are sterilized, and asters must be moved to fresh ground after three years of continuous planting (Larson, 1980; Ball, 1985).

Plants also wilt when attacked by root rot (*Phytophthora cryptogea* Pcthybr. Laff). Affected plants are easily pulled and the affected parts are soft and rotten on the outside only. This pathogen does not affect the xylem as does *Fusarium* (Post, 1950; Boodley, 1981).

Aster yellows, a viral infection, is another serious disease problem. Part or all of the plant turns a sickly yellow and stops growing. Flowers on affected plants are also more or less yellowed and do not open properly. Infected plants should be destroyed at the first sign of infection. However, Aster Yellows can be eliminated if plants are grown in cloth enclosures kept tight enough to exclude the leafhopper vector (Ball, 1985).

Despite the serious problem of diseases like Fusarium wilt and virus yellows, aster flowers can still be grown profitably in some areas of the USA, chiefly by specialists (Ball, 1985).

Most of the insects found on ornamentals attack asters. The common ones are: aphids, thrips, spider mite, cyclamen mite, mealy bugs, leaf rollers and leaf hoppers (Post, 1950; Boodley, 1981; Salunkhe *et.al.*, 1987).

Just as in other types of seed crops, disease and pest control are both very important to ensure high seed yield and quality. The difficulty is that there are no chemicals specifically licensed for use on flower seed crops, and consequently control must be carried out using products developed for use on other crops. To minimize insect populations including the aster yellows vector, plants should be sprayed every week with an all purpose insecticide. A fungicide may be used also if the weather is wet and humid (Boodley, 1981; Ball, 1985).

2.3.6 Weed control

Optimisation of yield and quality by protecting crops against diseases, insect pests, and weeds, is one means of ensuring successful production. Weeds can smother crops reducing yields. So, weed control plays a key role in crop production. Traditionally this has always been a highly work intensive operation in crop production because much of the tillage (ploughing, harrowing, and hoeing), is done to control weeds. The use of herbicides has enabled farmers to eliminate the weed flora with greater ease and meant that crops are no longer deprived of nutrients, light, water and growing space. Herbicide application also facilitates the use of modern harvesting machines, because the problem of weed seeds being harvested along with the crop, and becoming a part of the seed lot after threshing, is reduced. The cleaning process entails much time and expense, so weed control in the field is of the utmost importance. Effective pre emergence or pretransplant herbicide spraying of the crops is advised (Vis, 1980).

There is no published information on weed control in aster seed production, although some herbicides have been evaluated in glasshouse flower production, and these are detailed in chapter 4. Normally weed seeds are killed before planting by soil sterilization, as recommended in glasshouse production to prevent Fusarium wilt.

2.3.7 Harvesting

The timing of harvest is a crucial decision and can govern whether or not a seed crop produces an economic return.If crops are harvested too early, there may be a high percentage of immature seeds which will have to be removed later by means of cleaning machinery. On the other hand if crops are harvested over-ripe some yield may be lost through shedding during wind or rain. Members of the family Compositae bear the type of head which provides a perfect environment for fungal disease if the plant suffers wet weather conditions for too long during maturation. This causes deterioration in seed quality. Aster seedheads are ripe and can be harvested when the feathery pappus shows. Two or more hand pickings of individual seedheads has been suggested (Hawthorn and Pollard, 1954), followed by drying in a warm dry place such as a covered shed. Dried seed should be stored in air-tight containers in a cool dry place (FAO,1961; Salunkhe *et.al.*, 1987)

2.3.8 Other management

Although ‘pinching’ (removal of the apical bud) is a widely used commercial management practice in crops such as carnations and chrysanthemums, this procedure is not considered necessary in asters. However, the disbudding of the sideshoots or "suckers" from the 8-10 lateral stems on each plant is essential to obtain the best quality flowers. If too many sideshoots develop, some of the lower branches may be removed to prevent overcropping (Post, 1950; Larson, 1980; Boodley, 1981; Ball, 1985). Although it is not essential to pinch asters, some growers prefer to do so to achieve more uniform flowers. The decision on whether or not to pinch an aster crop depends on the daylength under which the crop is being grown and also on when the crop is desired for market, as pinching delays flowering (McKay, 1984). The effects of pinching on seed production are not known.

Support of plant stems with nets or stakes may be needed to prevent lodging (Boodley, 1981; Walls, 1982).

CHAPTER 3

EFFECTS OF PLANT DENSITY ON VEGETATIVE GROWTH, REPRODUCTIVE DEVELOPMENT AND SEED YIELD.

3.1 INTRODUCTION

Plant density is a primary factor to be considered in studies on plant production. The number of plants per unit area can have a major effect in altering the environment (i.e. light, water, nutrients etc.) and result in changes in both vegetative and reproductive crop yields. A number of morphological characteristics have been reported to be affected by plant density. Plants at high density increased their height faster than that of low density plants e.g. in maize (Balico, 1984; Tolentino, 1985), and in soybean (Wilcox, 1974; Chanprasert, 1988) due to greater elongation of the internodes (Chanprasert, 1988). Along with this increase in plant height, the stems of plants at high densities became thinner, making them more susceptible to lodging (Wilcox, 1974; Lueschen and Hicks, 1977). Leaf number, leaf area and branch number per shoot were also reduced by increased plant density (Kirby, 1976). However, although individual plant leaf numbers were decreased, leaf yield of tea bushes as well as green fresh weight and dry weight have been shown to increase through increasing plant density (Magambo, 1981). Increased dry matter production with increasing plant densities has also been reported in *Medicago sativa* L. (lucerne) (Kowithayakorn, 1978), and in *Macroptilium atropurpureum* (siratro) (Juntakool, 1983).

Different plant densities are investigated usually with the intention of finding an optimal density giving maximum yield per unit area (Holliday, 1960; Willey and Heath, 1969). This parameter is the sum of yield per plant and the number of plants. When the population is below the level at which competition between plants occurs, increasing the population will only have an indirect effect on individual plant performance. In such cases the yield per unit area will increase in direct proportion to the population increase. As soon as competition between plants occurs, however, the yield per plant will decrease. Donald (1963) concluded that "competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organism". Competition can occur both within each individual plant (intra or internal plant competition) or between individual plants (interplant competition). Intraplant competition is defined as the competition for limited growth factors between the organs within a plant. For example, competition between leaves for light. In such cases it is common for leaves to be so heavily shaded by those above as to die because they are not supported by export of assimilates from other parts of the plant (Etherington, 1982). Each flower and fruit is also to some degree in competition with the other flowers and fruits on the plant (Addicott, 1982). Competition between vegetative and reproductive organs is recognized as an important phenomenon and, in many instances, can affect the agricultural yield of a crop (Williams and Joseph, 1976). Interplant competition commonly occurs because of limited supplies of light, water, nutrients and carbon dioxide (Donald, 1963; Etherington, 1982) and may occur either between plants in a single species or between plants of separate species (e.g. cultivated crop vs weeds). The outcome of such competition will differ. However, intraspecific competition is keener than interspecific. As Daubenmire (1968) pointed out the more similar the needs of two organisms, the more intense the contest.

The two main factors involved in plant population are the number of plants per unit area (plant density) and spatial arrangement (plant rectangularity). Plant population density is a more important determinant of yield than planting arrangement (Field and Nkumbula, 1986). At a given density, the highest yield is normally obtained from an equidistant plant spacing since this offers a more desirable environment for the spread and development of plants than those with a spacing of unequal dimensions (Mack and Varseveld, 1982). Mack and Hatch (1968) showed that densities of *Phaseolus vulgaris* L. (French beans) ranging from 43-65 plants m^{-2} planted in a square pattern produced 35 % higher yields than the same densities in 91.4 cm rows. That a square arrangement can give a higher seed yield in French beans has also been confirmed by Rogers (1976) and in soybeans by Miura *et.al.* (1988). The rearrangement of a plant population in rows increases competition in comparison to equidistant plant spacing, but this may be necessary for cultural considerations such as cultivation for weed control and access for spraying and harvesting equipment. However, this was always originally related to the limitations of machinery and the need to be able to inter-row cultivate for weed control. Thus, it would seem logical to try to define the relationship between crop yield and density first, and to incorporate the effects of rectangularity subsequently (Willey and Heath, 1969).

The relationship between seed yield and plant density is very complex because of the plasticity of yield components and the interaction between the environment and genotype. This relationship is extensively reviewed by Willey and Heath (1969) and more recently by Chapman (1981). In general, this relationship conforms to two curves - parabolic where yield of a crop reaches a maximum at a given population density and then declines, and asymtotic where yield approaches a maximum and is then relatively constant at high densities. Holliday (1960) suggested that those forms of yield which constituted a vegetative part of the crop conformed to an asymptotic relationship and that reproductive forms of yield (i.e. fruits, grains and seeds) conformed to a parabolic relationship.

Seed yield is built up from several yield components which relate to plant structure and in turn are determined by a combination of plant and environmental factors (Adams, 1975). The number of pods per unit area or per plant is usually the first component to be influenced by environmental and cultural practices as reported in *Phaseolus vulgaris* (Leakey, 1972; Bennett *et.al.*, 1977), in *Vicia faba* (Ingram, 1976), in *Macroptilium atropurpureum* (Juntakool, 1983) and in soybean (Chanprasert, 1988) i.e. pod numbers increased at higher density in spite of a reduction in the number of pods per plant as plant density increased. Conversely, both seed weight and number of seeds per pod tend to be less affected by changes in plant density and are capable of considerable compensation depending on the number of pods per plant (Adams, 1967; Ishag, 1973; Bennett *et.al.*, 1977).

The systematic designs originally suggested by Nelder (1962) and modified by Bleasdale (1967) for plant spacing studies are popular with some agronomists. Mead (1979) discussed the use of these designs for competition experiments and pointed out that they do have potential statistical advantages in the sense of the efficient use of available material, through the reduction of non-harvested areas. They also have the advantage of not being tied to a single particular objective which is important when prior information about parameters of a response model is slight. The disadvantage of systematic designs is that the lack of randomization means that any simple analysis of variance must rely on the homogeneity of the systematic plot together with the assumptions that the plants are randomly allocated and that the errors of yields are normally distributed and independent. However, usually a simple fitting and comparison of response curves is an adequate form of analysis (Mead, 1979; Pearce, 1983).

Many different types of model have been used to describe the effects of spacing on plant growth. Each type of model differs in its underlying assumptions and there is no general agreement as to which model is the most accurate. However, the most common model relates individual plant yield to population density through a reciprocal equation. The equation proposed by Holliday (1960) is $y^{-1} = a+bd$ where y is individual plant weight or yield, d is plant density, and a and b are parameters of the model. This linear form of the equation describes an asymptotic response of area yield to plant density, whereas expansion to a quadratic equation ($y^{-1} = a+bd+cd^2$) describes a parabolic response. This yield-density model is commonly used over other models because the estimates of the parameters have been shown to be less biased (Willey and Heath, 1969; Gillis and Ratkowsky, 1978). For the asymtotic relationship, the parameters a and b can be given simple biological interpretations (Willey and Heath, 1969; Frappell, 1979). As density tends toward zero, the value of the weight per plant tends to a^{-1}, and this value is considered to be a measure of the genetic potential of a crop in a particular environment, i.e. a^{-1} is a measure of the size of the plant when there is no competition. As density tends towards infinity, the yield per unit area approaches the asymtotic value of b^{-1}, and this value is considered to be a measure of the potential of the environment.

Objectives

China asters are classified according to plant height and flower type. The usual growing distance for seed production of this species in Central Europe is 40 x 20-30 cm depending on plant height (Kobza, 1987). Kobza (1987) also reported that aster seed yield was increased by increasing plant density, and the best density for the highest seed yield varied between cultivars. In the tall cultivar 'Tamara', the highest seed yield was produced at 40x15 cm spacings but a spacing of 40x10 cm was the best for the bedding type cultivar, 'Alena'.

Since there is very little information available on China aster cultivation under New Zealand conditions and few published reports on seed production elsewhere, a knowledge of how China aster crops respond to spacing would be useful in providing a basic understanding of the factors affecting seed yield, which would then serve as a guide to growing practice. A study of the effects of plant density on plant growth and reproductive development using a wide range of plant populations would therefore be beneficial to explain the relationships between plant density and seed yield. The radial plant spacing design type Ia of Nelder (1962) was selected for this study, because this design allows a large range of plant densities to be grown in a small area, and has been used to describe yield:density relationships for other plants of commercial interest, for example, parsnips (Bleasdale and Thompson, 1966), tomatoes (Nichols *et.al.*, 1973), onions (Frappell, 1973), sweetcorn (Nichols,1974), carrots and radishes (Bleasdale,1976), blackcurrants (Kerslake and Menary, 1986) and soybean (Chanprasert, 1988).

The objectives of this study were therefore to determine the effects of plant densities on
i) vegetative growth,
ii) flower production,
iii) seed development and
iv) seed yield and yield components
of two different types of China aster.

3.2 MATERIALS AND METHODS

3.2.1 Experimental site and soil preparation

The field experiment was conducted on a Tokomaru silt loam soil at The Seed Technology Centre, Massey University, Palmerston North (40° S 175° E). This land had been left fallow for 1 year after an old apple orchard had been removed. The land was cultivated in May 1986, with a deep ridge cultivator and then leveled. Agricultural lime at the rate of 1 t ha^{-1} was applied before a repeat cultivation. Oats and barley were sown as cover crops in September, 1986. The paddock was ploughed on 16 October 1987 and harrowed two weeks later. Soil samples were taken from the area where the aster plants were to be established and sent to the MAF Computerised Fertiliser Advisory Service, Ministry of Agriculture and Fisheries, Palmerston North for analysis. On 20 November 1987, Treflan (trifluralin, 400 g litre^{-1}) was incorporated at a rate of 2 litres a.i. ha^{-1}. A broad spectrum granular insecticide, Thimet 20 G (phorate, 200 g kg^{-1}) was applied at a rate of 1 kg a.i. ha^{-1} to control chewing insects. Sulphate of potash (500 kg ha^{-1}) and calcium ammonium nitrate (150 kg ha^{-1}) were also added as a basal fertilizer. The field was harrowed immediately prior to planting (21 November 1987). Weather data at this site are shown in Appendix 3.1. A description of the Tokomaru soil and soil sample test results are given in Appendices 3.2 and 3.3 respectively.

3.2.2 Experimental design

Plant density responses were studied using the systematic plant spacing design type Ia of Nelder (1962) with a rectangularity close to 1.0 (a square spacing). This design allows a large range of plant densities to be grown in a small area, through using grids which can be defined by the intersections of sets of parallel or concurrent straight lines and the arcs of concentric circles. Plants are grown in rows which radiate from a point, with the distance between plants along a radius approximately equal to the distance between radii at that point (Appendix 3.4).

Two cultivars of China aster: Kurenai, a medium height, single flower type and Powderpuff, a tall, double flower type were used for this study. Seedlings of each cultivar were planted in two full circles. Field layout is shown in Appendix 3.5. Each circle contained 80 radii and 22 concentric arcs. Each arc represented one plant density. The two outermost and four innermost acted as border rows, and thus 16 different plant densities, ranging from 4.2 to 44.7 plants m^{-2}, were studied in this experiment. The calculation of distances between each radius and between plants along the radii was based on the method of Bleasdale (1967) and the details are presented in Table 3.1.

3.2.3 Planting and crop management

Seeds of cv. Kurenai were thiram dusted [1 g product (80 % wettable powder)/100 g seed], sown on 21 October 1987 into root trainers (45 mm x 30 mm x 80 mm deep) filled with Smith's soil (a sterile mixture of peat, pumice and sand containing balanced proportions of fertilizer and slow release trace elements plus terrazole soil fungicide; Smith Soil Industries Limited, Auckland, New Zealand) and raised in a glasshouse (30/20 ± 5°C) at the Plant Growth Unit, Plant Science Department, Massey University. Thinning to one plant per root trainer cell was made at seven days after emergence. Foliar fertilizer, 'Happy garden' 12-8-16 (Nylex New Zealand Ltd, Auckland) was applied via a fertilizer dispenser attached to a soft spray wand at

Table 3.1 Numerical data for the layout of the radial spacing experiments.

Arc number (from innermost)	Distance along radii (m)	Area per plant (cm^2)	Plant density (plants m^{-2})
1#	1.35	119	83.9
2#	1.47	140	71.6
3#	1.59	163	61.2
4#	1.71	191	52.3
5	1.86	224	44.7
6*	2.01	262	38.2
7	2.18	307	32.6
8	2.35	359	27.8
9	2.55	421	23.8
10*	2.76	493	20.3
11	2.98	578	17.4
12	3.23	675	14.8
13	3.49	790	12.7
14*	3.78	925	10.8
15	4.09	1083	9.2
16	4.42	1268	7.9
17	4.79	1484	6.7
18*	5.18	1738	5.8
19	5.60	2034	4.9
20	6.06	2382	4.2
21#	6.56	2788	3.6
22#	7.10	3264	3.1

Border rows

* Selected plant densities used for reproductive studies

the rate of 35 kg ha^{-1} and fungicide, benlate (Benomyl, 500 g kg^{-1}) was sprayed at 0.25 kg a.i. ha^{-1} ten days later. Insecticide, lannate (Methomyl, 200 g $litre^{-1}$) was sprayed at 0.24 kg a.i. ha^{-1} when the seedlings were moved to the field for hardening, five days before planting.

Seedlings were hand transplanted into the field on 21 November 1987. A metal rod was marked at the specified distances (Table 3.1) before being laid on the soil surface, with the inner end fixed at the centre of the circle to establish the first radius. Aster seedlings were then planted at the marked positions. After the first radius was planted, the outer end was moved 56 cm around the circumference of the outer arc or rotated by 4.5 degrees, while the inner end was kept fixed at the centre. Planting proceeded, with the rod being moved progressively until the whole circle was completed (Figure 3.1). Surplus seedlings were planted near to the experimental plot for later replacement of plants which failed to establish. Any such transplants were identified with coloured wool to avoid their later use for gathering of data. These plants could have been differentially affected by environmental factors as well as variability in density (Nelder, 1962).

Water was applied immediately after planting using a garden sprinkler which delivered 6000 litres h^{-1} ha^{-1}. During the first week after planting, a 20 minute irrigation was applied every evening to ensure good plant establishment. One hour of irrigation with the same sprinkler was subsequently applied every 7-10 days except during wet periods until two weeks after peak flowering and then discontinued. Foliar fertilizer 12-8-16 (35 kg ha^{-1}) was applied 10 days after planting and ammophos (12:10:10:8) fertilizer was added at 100 kg ha^{-1} one month later. Hand weeding was employed throughout the experiment. Snail and slug bait, Mesurol (Methiocarb, 20 g kg^{-1} bait) was broadcast at about 100 baits m^{-2} one day after planting. Disease and pest control was achieved by spraying broad spectrum fungicides, Orthocide 80 W (captan, 800 g kg^{-1}) at 1.2 kg a.i. ha^{-1} or Benlate 0.25 kg a.i. ha^{-1}, and the insecticides Attack (pirimiphos-methyl, 475 g $litre^{-1}$ plus permathrin 25 g $litre^{-1}$) at 0.5 kg a.i. ha^{-1} or Mavrik aquaflow (fluvalinate, 240 g $litre^{-1}$) at 0.1 kg a.i. ha^{-1} or Lannate (methomyl, 200 g $litre^{-1}$) at 0.24 kg a.i. ha^{-1} every two weeks. These fungicides or insecticides were used in rotation to prevent possible disease or pest resistance.

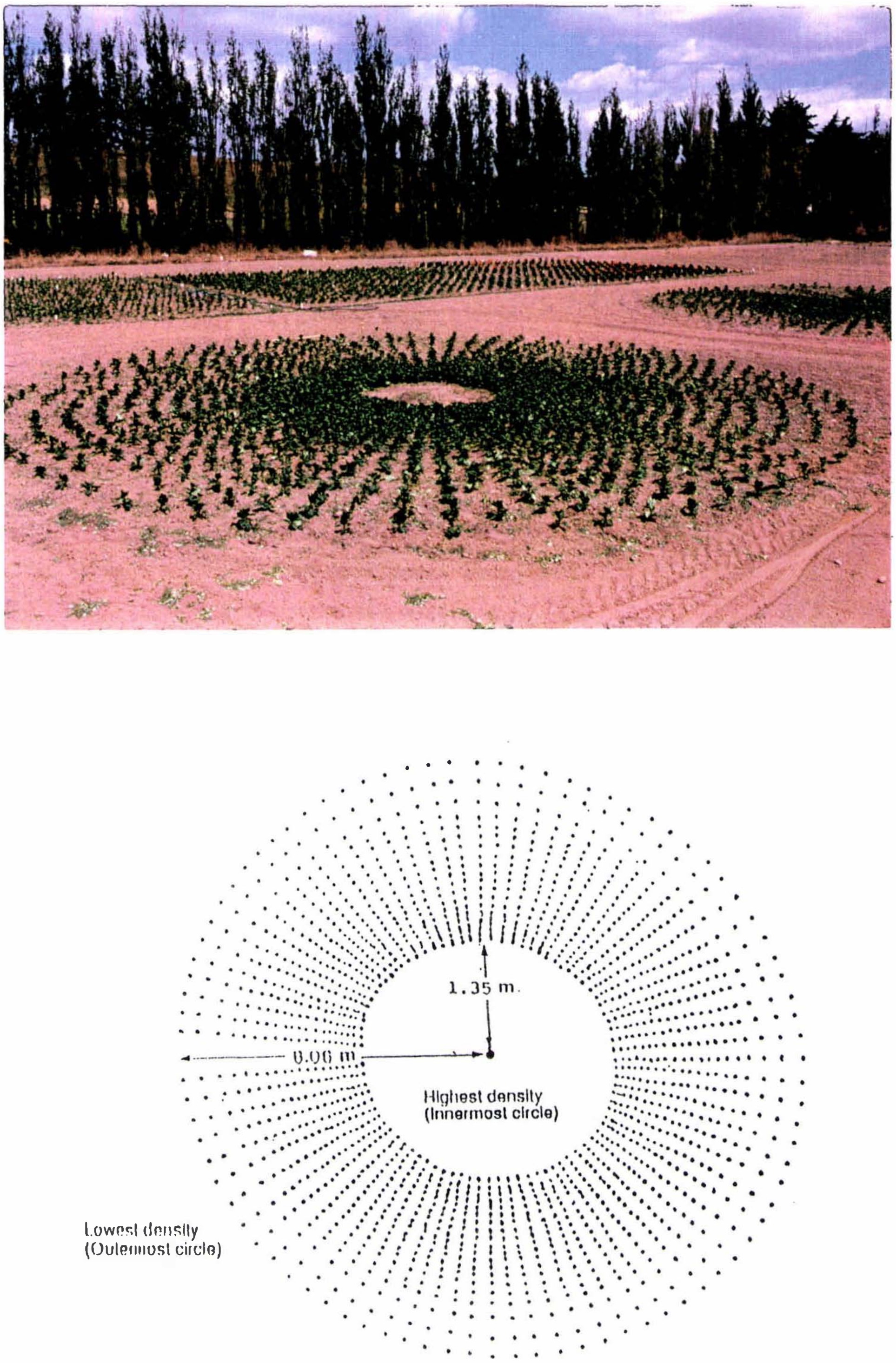


Figure 3.1 A layout of Nelder's radial spacing design (Type Ia).

Seeds of cv. Powderpuff were sown, raised and transplanted using the same methods as for cv. Kurenai. However due to a delay in the arrival of seed, sowing was not made until 9 November, and the radial trial established on 16 December 1987.

3.2.4 Data collection and analysis

3.2.4.1 Vegetative study

Four plants from each density were cut at ground level at 10 day intervals from planting to peak flowering for cv. Kurenai (10 times) and 10-15 day intervals for cv. Powderpuff (8 times). Each plant was separated into leaf, stem and branch components to determine the following characteristics:

stem length	-measured from cut end (ground level) to terminal tip,
branch number	-all branches were counted,
leaf number	-all leaves longer than 1 cm were counted
leaf area	-all counted leaves were measured by using a LI 3100 Li-Cor meter (Li-Cor Inc., Nebraska, USA)
plant dry weight	-all leaf, stem and branch components were oven dried at 80 °C to constant dry weight (3 days).

Pearce (1983) suggested that curve fitting is an appropriate statistical tool to explain the relationship between the output and plant density in a systematic radial design. Each individual part of the vegetative growth data was fitted to the reciprocal linear equation of Holliday (1960; $y^{-1} = a+bd$ where y = individual part yield, d = plant density, and a and b = constants) to describe the response of part yield to plant density, using the Minitab software package.

3.2.4.2 Reproductive development

Four plant densities: 5.8, 10.8, 20.3 and 38.2 plants m^{-2} were selected to represent low, medium, high and very high plant densities for reproductive development studies.

Flowering pattern

The number of buds, flowers and seedheads were counted from 3 randomly harvested plants from each density at 1, 10, 20, 27, 34, 41, 48 and 57 days after first flower opening (or 70, 80, 90, 97, 104, 111, 118 and 126 days after planting, DAP) for cv. Kurenai, and at 1, 15, 25, 35, 42, 47, 52 and 59 days after first flower opening (or 60, 75, 85, 95, 102, 107, 112 and 119 DAP) for cv. Powderpuff.

Any visible small buds and large buds enclosed by bracts were counted as buds. Flowers were defined as pollinated flower heads from when the outer ray florets had started to open through to when the innermost disk florets were receptive. When no more pollen was noticeable on the disk florets and the colour of the flower was dull and turning brown, the head was recorded as a seedhead.

3.2.4.3 Seed development study

Three plant samples per density were randomly collected every five to seven days starting from peak flowering. Seeds were hand removed from 10 seedheads taken at random from each plant. Two sets of 100 seeds per replicate were weighed immediately to obtain 100 seed fresh weight and then used to determine seed dry weight and seed moisture content by oven drying at 103 °C for 17 hours. The remaining seedheads were air-dried at room temperature for 3-4 weeks before seeds were hand threshed. Seeds at approximately seven percent moisture content were used for the germination test. The tests were conducted at 20 °C using four lots of 50 seeds per replicate by the 'top of paper' method (ISTA,1985). Potassium nitrate (0.2%) was used to break any dormancy. Seedlings were evaluated following the prescriptions in the ISTA Rules for Seed Testing (ISTA, 1985).

Seed development was also monitored for individual flower heads. At flowering, 150 newly opened (i.e. when the outer ray florets started to open) individual flower heads of outer border plants were tagged with coloured wool. From these tagged seedheads, six seedheads were randomly hand harvested at three day intervals between 6-51 days after anthesis. Each seedhead was investigated separately using 25 seeds (or 50 seeds when possible) for determining seed fresh weight, seed dry weight and seed moisture content, and 50 seeds for germination capacity and seed viability.

3.2.4.4 Seed yield and yield components

One whole radial trial circle was divided into four sections, each containing 20 radii. Seed yield of cv. Kurenai was obtained by hand harvest from three sections (16 plants per section) following cutting of the plant at ground level on 22 March 1988 when the average seed moisture content of the crop was 40 %. Plants were left to air dry at ambient temperature for 2 weeks. Seedheads were separated before being threshed by a brush machine thresher (Thrige-Titan Asea Cat. No. MkIII 813B) on 2 April 1988. Seeds were then cleaned on a Clipper seed cleaner using a 1.40 mm round perforation sieve. Seed weights per plot were determined and corrected to 7 % seed moisture content to determine the actual cleaned seed yield.

The number of seedheads was counted from four sample plants per replicate taken at the final harvest. Seed numbers per head were counted from 20 seedheads taken at random from the final harvest. Thousand seed weight was ten times the mean weight of four replicates of 100 seeds. Germination was done as previously described in 3.2.4.3, but beginning on 4 May 1988.

This procedure was also used for cv. Powderpuff except that only 8 plants per replicate were hand harvested on 18 April 1988. This cultivar lodged badly after strong winds followed by heavy rain during first flowering, and although plants were staked afterwards, losses from rotting were still high and caused a shortage of samples. Seeds were threshed and cleaned on 2 May 1988 and germination began on 27 May 1988.

Final harvested seed yields were fitted to the yield-density function of Holliday (1960): $y^{-1} = a+bd+cd^2$ where y = seed yield (g), d = plant density (plants m^{-2}) and a,b, and c are parameters of the model. This yield-density model was chosen in preference to other models because the estimates of the parameters had been shown to be less biased (Gillis and Ratkowsky, 1978). The function was fitted in the untransformed, natural logarithmic and reciprocal form. The equation which gave the best fit was selected to explain the yield-density relationships. Residuals from this equation were also plotted to ensure that the variations were random (Pearce, 1983). Correlation coefficients were calculated to evaluate the association between seed yield and its components.

3.3 RESULTS

3.3.1 Vegetative growth

3.3.1.1 Stem length

The main stem of both cultivars started to elongate at 20 DAP and this elongation was evident at 30 DAP (Appendix 3.1.1). Although plants in all densities started to elongate at the same time, higher density plants elongated faster than lower density plants. In cv. Kurenai, this effect appeared between 40 DAP up to first flowering (70 DAP) but was no longer evident at peak flowering (Figure 3.1.1; Appendix 3.1.2). Although high density plants reached maximum length at first flowering, lower density plants continued to grow, resulting in little difference at peak flowering. A different response was observed in cv. Powderpuff. In this cultivar density effects did not appear until first flowering (60DAP) but continued through to peak flowering (Figure 3.1.1; Appendix 3.1.2).

3.3.1.2 Branch number

Branches began to grow at 30 DAP in both cultivars and rapidly increased with time up to 10 days before first flowering (60 and 50 DAP in cv. Kurenai and cv. Powderpuff respectively). There was a slight delay before branch numbers continued to increase after first flowering (Figure 3.1.2). This delay was more evident in cv. Powderpuff than in cv. Kurenai. The number of branches developed before flowering was about 80-90 % of the total branch number per plant. Branch numbers per plant increased with decreasing plant density (Figure 3.1.2; Appendix 3.1.3) while branches per unit area increased as plant density increased. Kurenai plants had around 60 % more branches than Powderpuff plants.

3.3.1.3 Leaf number

Plants of cv. Kurenai had approximately 20-40 % more leaves than cv. Powderpuff but their leaves were smaller and darker green in colour. In both cultivars, the fourth or fifth leaf borne on the main stem was the biggest and leaves gradually became smaller in the upper parts of the stem. These stem leaves were however bigger than the leaves borne on branches. The effect of plant density on leaf number first appeared at 30 DAP in cv. Kurenai and 40 DAP in cv. Powderpuff, which was around the time that branch growth occurred. Increasing plant density decreased leaf number per plant but increased leaf number per unit area in both cultivars (Figure 3.1.3, Appendix 3.1.4) mainly due to the numbers of branch leaves. Main stem leaf number was not affected by plant density, as no relationship was shown during the early vegetative growth (Figure 3.1.3, Appendix 3.1.4). The lower leaves of the main stem gradually senesced and dropped over the flowering period.

3.3.1.4 Leaf area

Total plant leaf area increased at the same rate up to 50 DAP in all plant densities of cv. Kurenai (Figure 3.1.4) and subsequently slowed down at the very high plant density (38.2 plants m^{-2}). However leaf area at all plant densities reached a maximum at 80 DAP before decreasing rapidly (Figure 3.1.4). Again leaf area at the higher plant density dropped faster than at the lower density (Figure 3.1.4, Appendix 3.1.5). Leaf area index (LAI) increased with time and attained maximum values at 80 DAP for cv. Kurenai. Peak LAI ranged from 1-5.5 when plant density was increased from 5.8 to 38.2 plants m^{-2}. There were two LAI peaks for the high density plants because leaves on the main stem senesced and dropped before leaves of lateral branches had fully expanded (Figure 3.1.4). High density plants of both cultivars had a higher LAI and increased faster than the lower density plants. The subsequent decline in LAI as shown in cv. Kurenai was faster in the high densities than in the lower density plants by 90 DAP (Figure 3.1.4).

In cv. Powderpuff, both leaf area and LAI showed the same trends as for cv. Kurenai (Appendix 3.1.5), but data presented for >60 DAP are model extrapolations only (Figure 3.1.4) because bad lodging following strong winds lead to difficulties and delay in sample measurement.

3.3.1.5 Plant dry weight

Plant dry weight increased slowly during early vegetative growth and plant density effects first appeared at 50 DAP in cv. Kurenai and 40 DAP in cv. Powderpuff (Figure 3.1.5; Appendix 3.1.6). This was followed by a rapid increase before flowering, particularly in the low density plants. This increase in plant dry weight continued through to peak flowering but the subsequent increase after first flowering was not as rapid as before flowering, except for the two lower densities of cv. Kurenai (5.8 and 10.8 plants m^{-2}). At maximum plant dry weight, the dry weight of the lower density plants was approximately 3 times greater than that of the higher density plants in both cultivars. Plants of cv. Powderpuff were heavier than cv. Kurenai at the same density (Figure 3.1.5).

Partitioning plant dry weight into stem, branches, main stem leaves, branch leaves and flowers showed that each fraction of plant dry weight followed the same pattern as total plant dry weight (i.e. decreased with increasing plant density; Figures 3.1.6-3.1.7). However, the ratio of reproductive dry weight (flowers plus developing seedheads) to total plant dry weight at peak flowering in cv. Powderpuff decreased with increasing plant density to a greater extent than in cv. Kurenai (Figure 3.1.8).

3.3.2 Reproductive development

On 23 February 1988 the trial area was hit by strong winds (894 km windrun day^{-1}) and again (798 km day^{-1}) five days later (Appendix 3.1) and this caused severe lodging. Soil which had become soft following rain before the first winds and rains during these winds made plants more prone to lodge. Lodging occurred more severely in cv. Powderpuff due to the weaker stems and heavier flower heads. The two cultivars were also at different growth stages when lodging occurred. In cv. Powderpuff, lodging occurred during the onset of flowering of the main stem terminal flower head and the start of opening of the terminal flower heads of lateral branches, but lodging in cv. Kurenai occurred when the crop was already past peak flowering. All plants were individually staked with bamboo canes to avoid the rotting of flower heads and allow further reproductive data gathering.

Plant responses to density are shown in Figures 3.2.1 and 3.2.2. The terminal growing point became visibly reproductive at the same time as the main stem elongated and the onset of flower development occurred during stem elongation (Figure 3.2.3). The main stem bore a terminal inflorescence (flower head) and many lateral flowering branches. Each branch consisted of one terminal flower head and none (mostly in the basal branches of the high density plants of cv. Powderpuff) to several axillary flower heads (particularly in the low density plants of cv. Kurenai). However, not all the flower heads contained seeds at harvest. Increasing plant density reduced both the total (lateral flowering) branches and fertile (seedhead

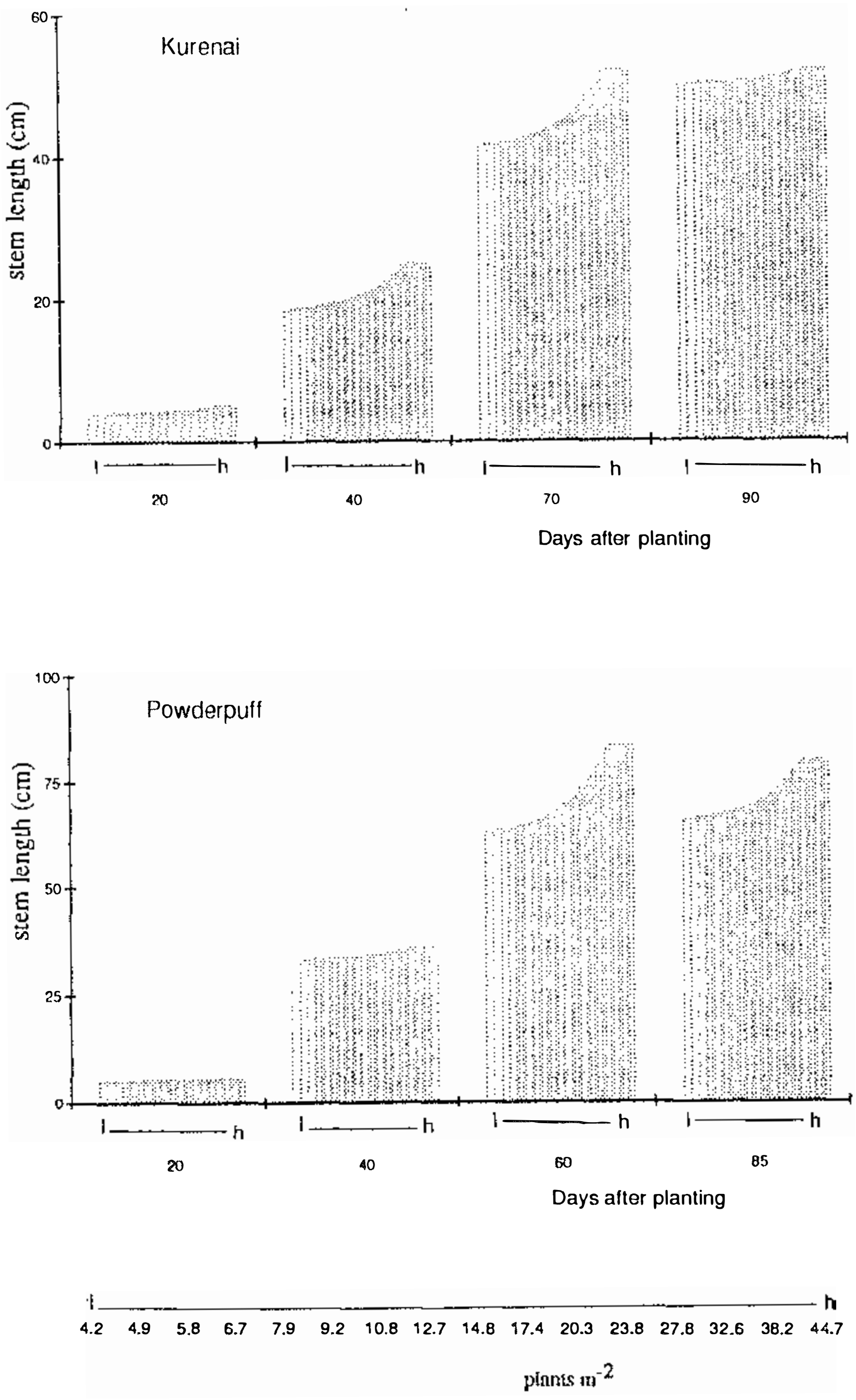


Figure 3.1.1 Effect of plant density on main stem length of China aster cv. Kurenai and cv. Powderpuff at four different growth stages: vegetative (20 DAP), stem elongation (40 DAP), first flowering (70 and 60 DAP) and peak flowering (90 and 85 DAP). (Predicted values from the equations presented in Appendix 3.1.2 are shown.)

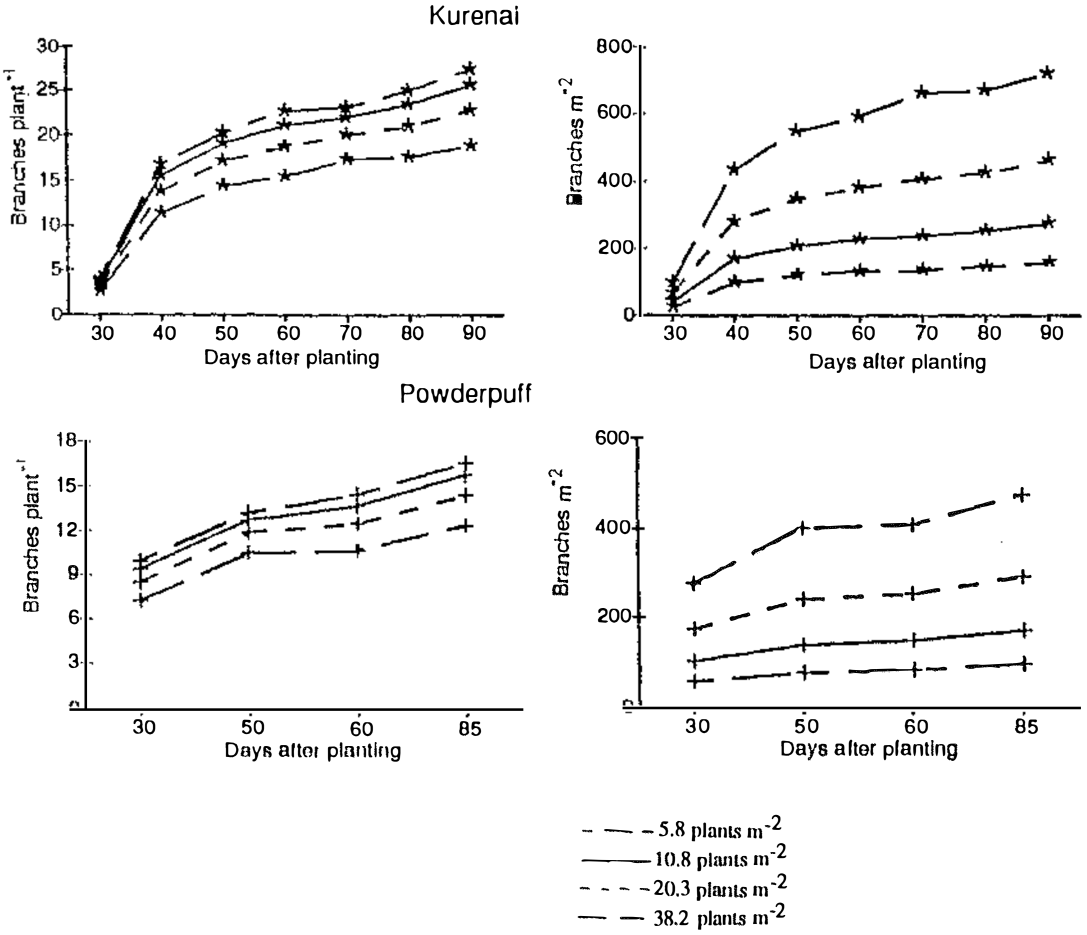


Figure 3.1.2 Effect of plant density on branch numbers per plant and per m ^{2} with time of China aster cv. Kurenai and cv. Powderpuff. (Predicted values from the equations presented in Appendix 3.1.3 are shown.)

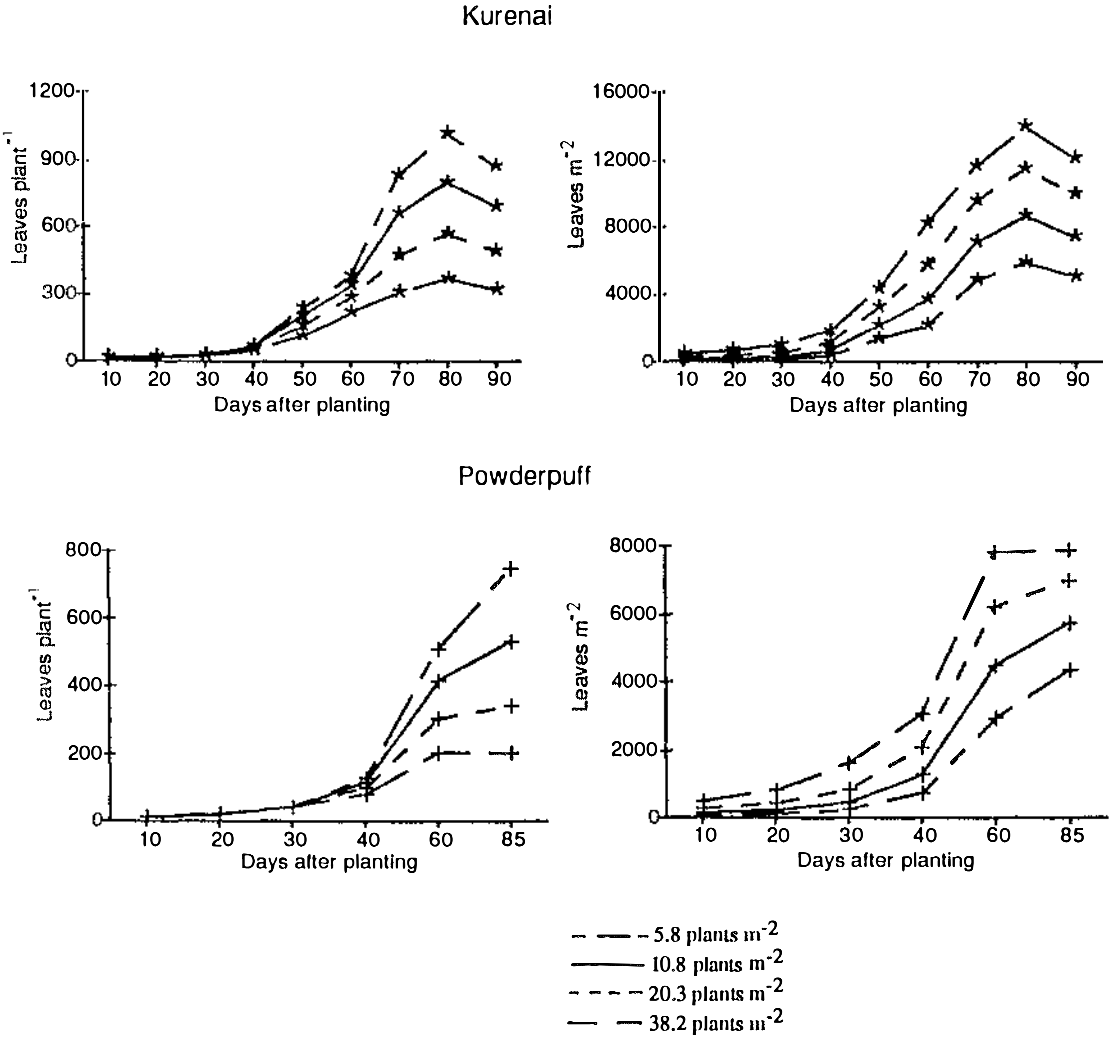


Figure 3.1.3 Effect of plant density on leaf numbers per plant and per m ^{2} with time of China aster cv. Kurenai and cv. Powderpuff. (Predicted values from the equations presented in Appendix 3.1.4 are shown.)

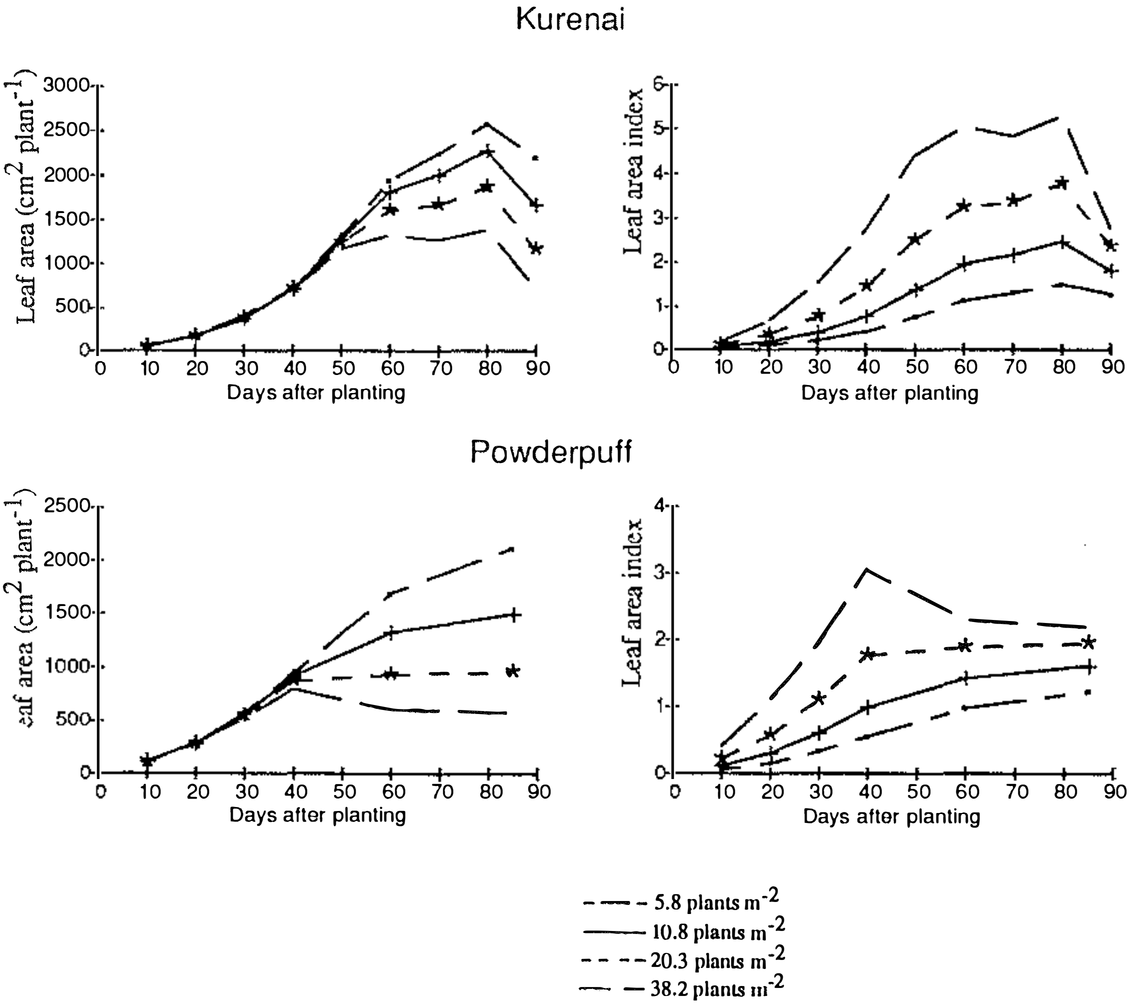


Figure 3.1.4 Effect of plant density on leaf area per plant and leaf area index of China aster cv. Kurenai and cv. Powderpuff at different times after planting.

(Predicted values from the equations presented in Appendix 3.1.5 are shown.)

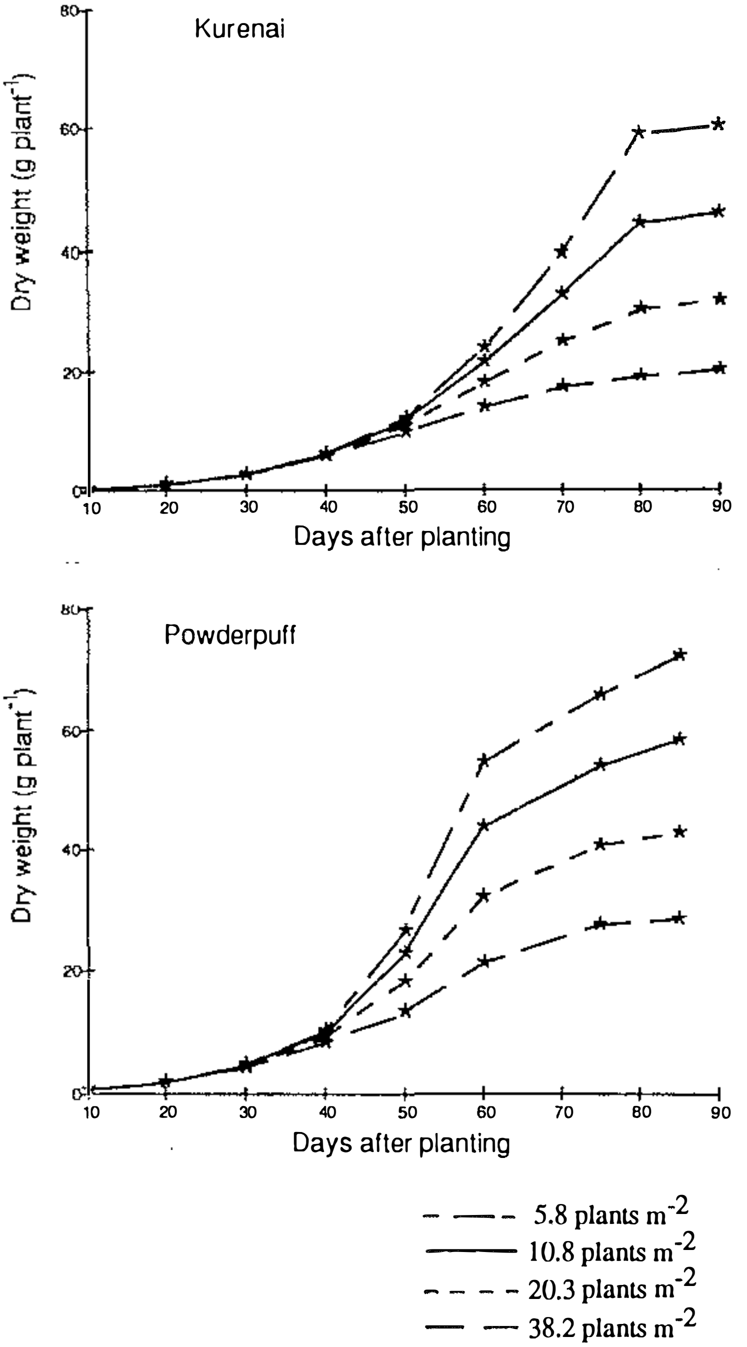


Figure 3.1.5 Effect of plant density on plant dry weight with time of China aster cv. Kurenai and cv. Powderpuff. (Predicted values from the equations presented in Appendix 3.1.6 are shown.)

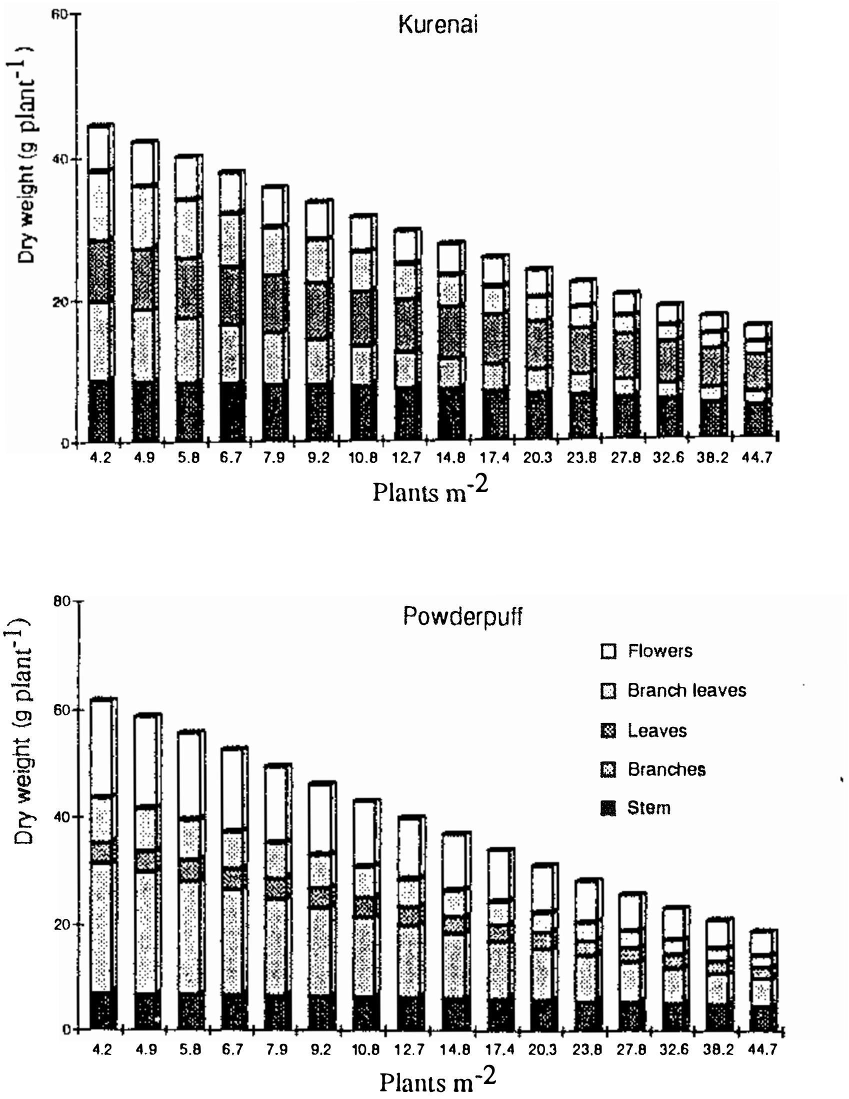


Figure 3.1.6 Distribution of plant dry weight at first flowering of China aster cv. Kurenai and cv. Powderpuff.

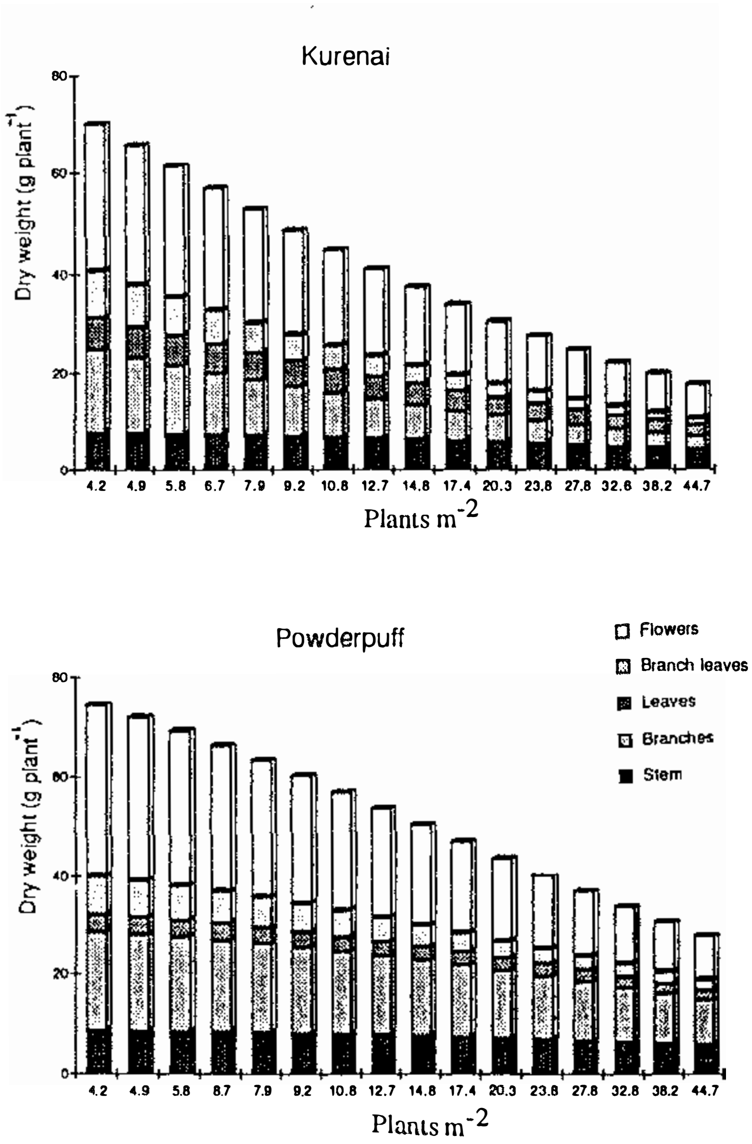


Figure 3.1.7 Distribution of plant dry weight at peak flowering of China aster cv. Kurenai and cv. Powderpuff.

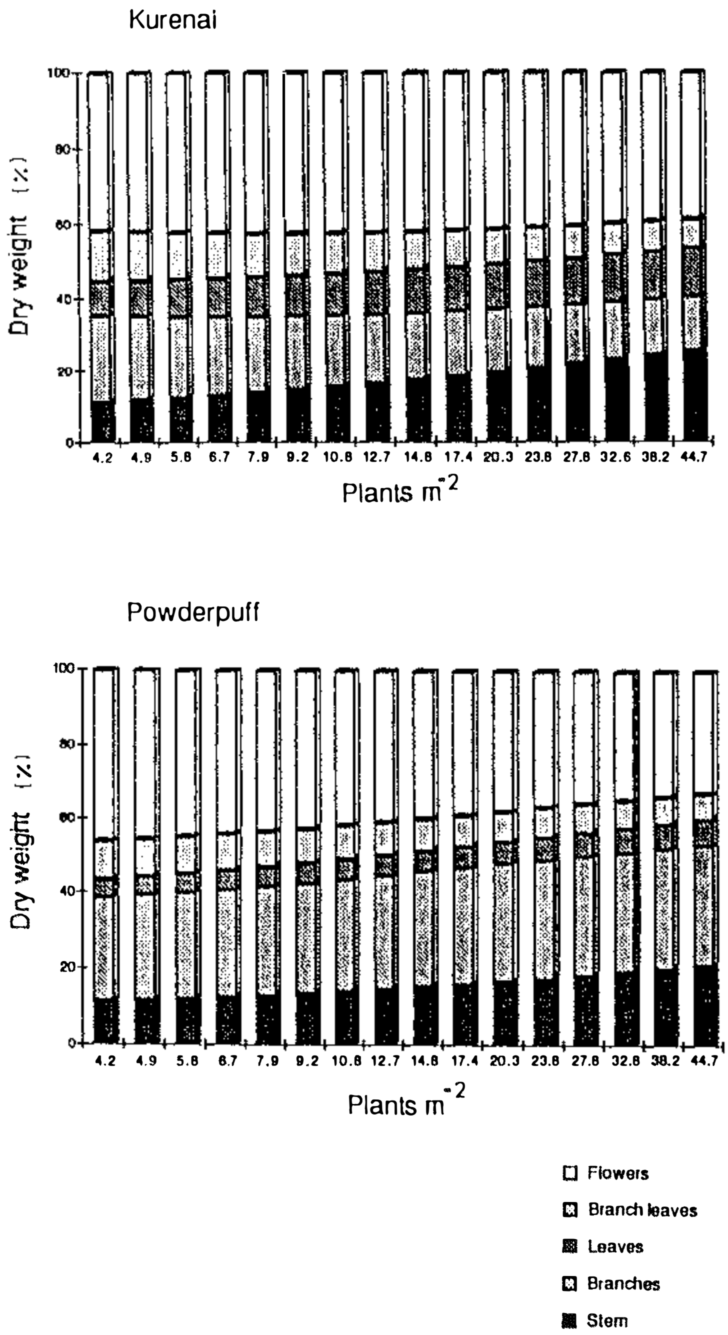
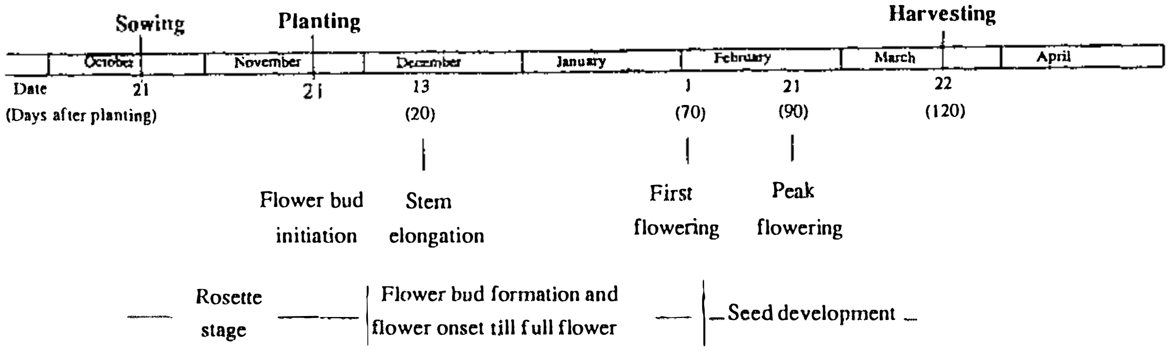


Figure 3.1.8 Distribution of main stem, branch, leaf and flower dry weight (as percentage of total plant dry weight) at peak flowering of China aster cv. Kurenai and cv. Powderpuff.

Figure 3.2.1 Effect of plant density on reproductive development in China aster cv. Kurenai.

Figure 3.2.2 Effect of plant density on reproductive development in China aster cv. Powderpuff.

Kurenai



Powderpuff

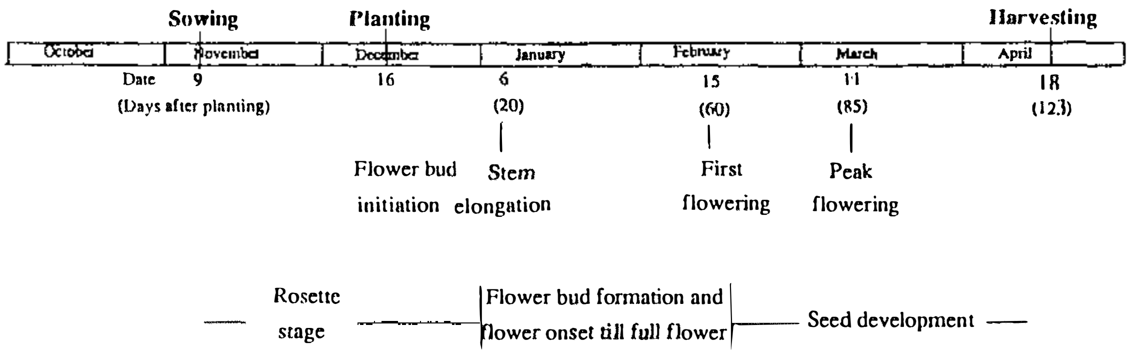


Figure 3.2.3 Diagram showed the duration of reproductive development of China aster cv. Kurenai and cv. Powderpuff.

bearing branches) in both cultivars. However, while in cv. Kurenai the total/fertile ratio reduction was reasonably constant, in cv. Powderpuff the reduction in fertile branches became greater as plant density increased (Figure 3.2.4, Appendix 3.2.1). Total flower numbers at peak flowering gradually decreased with increasing plant density in both cultivars (Figure 3.2.5, Appendix 3.2.2).

Total accumulated flower numbers (buds+flowers+seedheads) per plant exhibited a similar decrease to the number of flowers counted at peak flowering (Table 3.2). As density increased, flower number decreased in both cultivars. At the same density cv. Powderpuff produced less flowers than cv. Kurenai.

3.3.2.1 Bud production

Most bud production in cv. Kurenai occurred prior to 70 DAP. This was then followed by a break of about two weeks before a small number of new buds appeared (Figure 3.2.6). These late buds were produced on the lower lateral branches or on the secondary or tertiary branches of the upper lateral branches. Almost all buds found developed into flowers, and thus this 'late flush' explains the second small peak in the flowering pattern shown in Figure 3.2.7.

Bud development in cv. Powderpuff occurred continuously through to the end of the experiment, particularly at the lower density (Figure 3.2.6). However most of the late buds failed to develop into flowers, especially at the high density, and so a second 'flush' of flowering was either absent or insignificant.

3.3.2.2 Flowering pattern

First flowering in cv. Kurenai occurred at 70 days after planting (DAP) and peak flowering was reached 20 days later (90 DAP). There was also a further small peak at 118 DAP (Figure 3.2.7). All plant densities showed a similar pattern except for the highest density (38.2 plants m^{-2}) which reached peak flowering seven days later (97 DAP).

The first flowers of cv. Powderpuff started to open at 60 DAP, 10 days earlier than cv. Kurenai, but this cultivar needed a longer time to reach peak flowering, i.e 25 days from first flowering (85 DAP) (Figure 3.2.7). All plant densities showed a

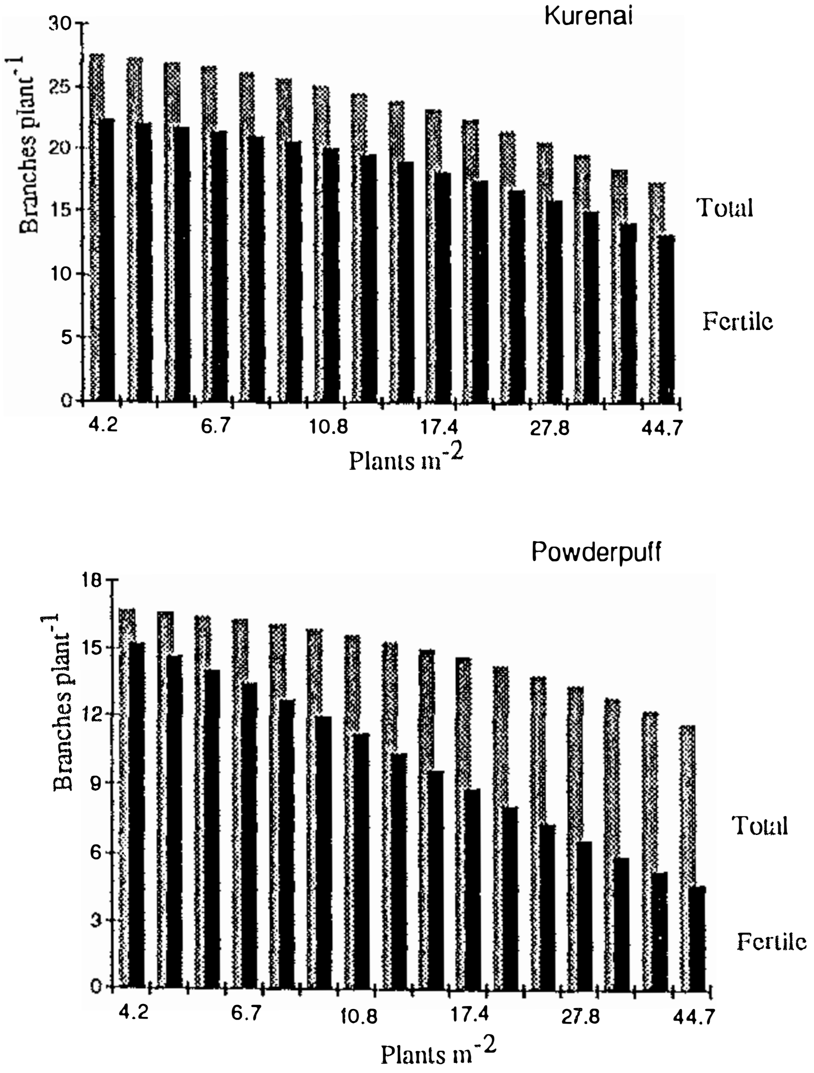


Figure 3.2.4 Effect of plant density on the number of lateral flowering (total) and seedhead bearing (fertile) branches per plant of China aster cv. Kurenai and cv. Powderpuff.

(Predicted values from the equations presented in Appendix 3.2.1 are shown.)

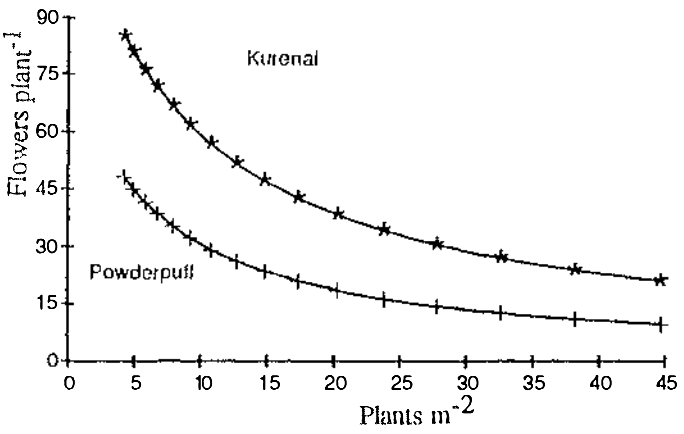


Figure 3.2.5 Effect of plant density on flower numbers per plant at peak flowering of China aster cv. Kurenai and cv. Powderpuff. (Predicted values from the equations presented in Appendix 3.2.2 are shown.)

Table 3.2 Effect of plant density on total accumulated flower numbers per plant (buds+flowers+seedheads) for four different plant densities of cv. Kurenai and cv. Powderpuff.

Plant density (plants m^{-2})	Total flowers plant^{-1} Kurenai		Powderpuff	
5.8	85	(6.7)	59	(5.9)
10.8	71	(10.0)	43	(3.7)
20.3	50	(6.8)	26	(0.9)
38.2	30	(3.1)	17	(1.3)

( ) = standard error

similar pattern except at the lowest density (5.8 plants m^{-2}), where flower head numbers did not drop as quickly as at the other densities. The later peak was not as pronounced as in cv. Kurenai, especially at 20.3 plants m^{-2}, and was absent at the highest density (38.2 plants m^{-2}).

3.3.2.3 Seedheads

The number of seedheads of cv. Kurenai increased slowly up to seven days after peak flowering (DAPF) and then increased rapidly, reaching a maximum at 14 DAPF (104 DAP) for the lowest (5.8 plants m^{-2}) and the highest (38.2 plants m^{-2}) densities and at 21 DAPF (111 DAP) for the two middle densities (10.8 and 20.3 plants m^{-2}, Figure 3.2.8). While the three higher densities (10.8, 20.3 and 38.2 plants m^{-2}) maintained a relatively constant seedhead number after reaching a maximum, the lowest density (5.8 plants m^{-2}) had seedhead losses which occurred between 111 and 118 DAP or 14 days after maximum seedhead numbers were achieved.

Powderpuff seedhead numbers increased linearly from peak flowering, reaching a maximum at 17 DAPF (102 DAP) in the three higher densities, and then becoming relatively constant. In the lowest plant density (5.8 plants m^{-2}) seedheads continued to increase past 102 DAP and reached a maximum 10 days later (112 DAP) (Figure 3.2.8).

3.3.3 Seed development

3.3.3.1 Seed fresh weight

Seed fresh weight of cv. Kurenai reached a maximum between 7-14 DAPF (97-104 DAP) before gradually decreasing (Figure 3.3.1). The lowest density (5.8 plants m^{-2}) attained maximum seed fresh weight seven days later than the other higher densities and the highest density (38.2 plants m^{-2}) decreased faster than other densities. However, by 36 DAPF (126 DAP) all densities had a seed fresh weight of 0.15 g.

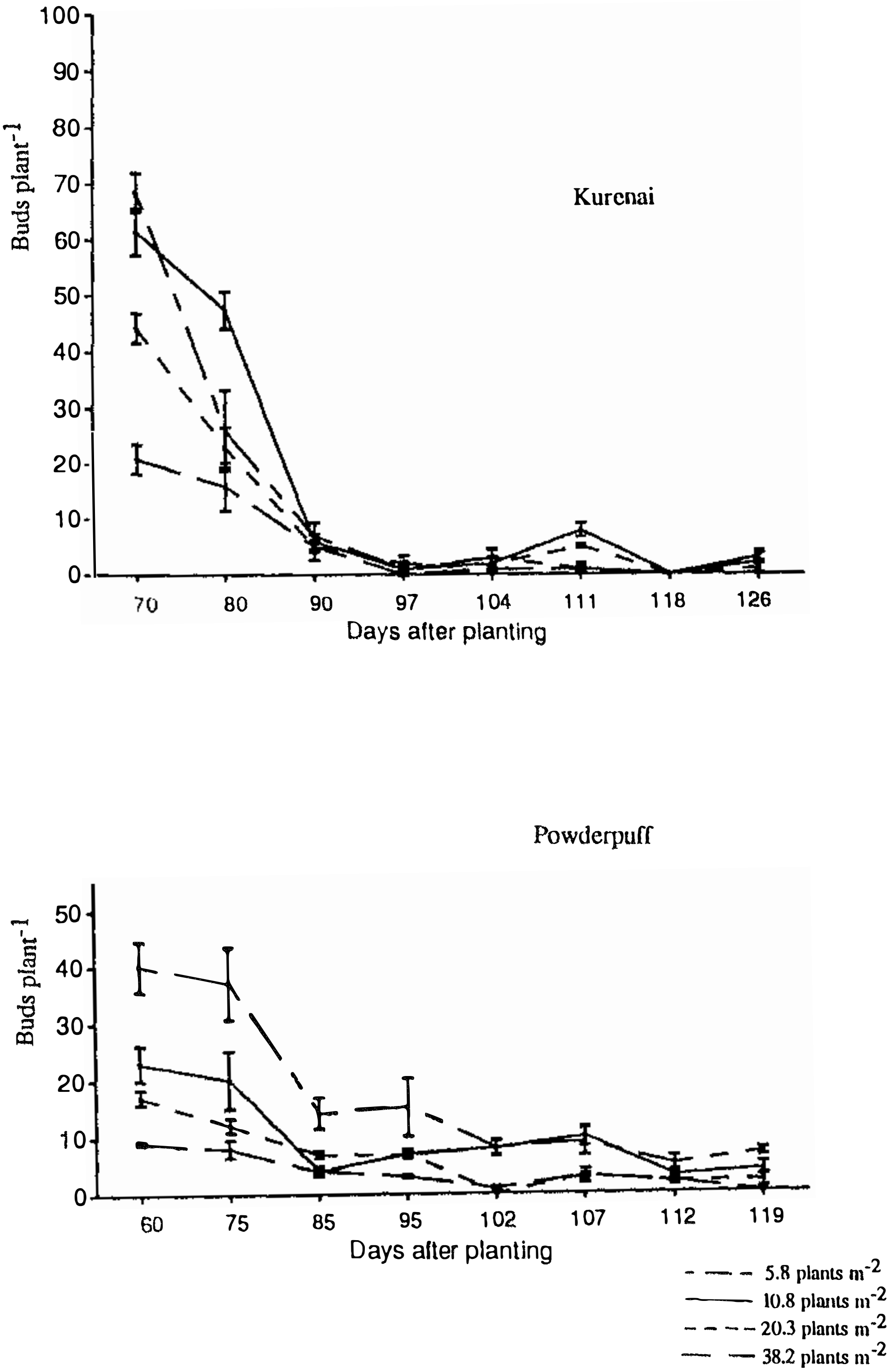


Figure 3.2.6 Effect of plant density on number of buds per plant in China aster cv. Kurenai and cv. Powderpuff.
(Vertical bars represent SE of the means).

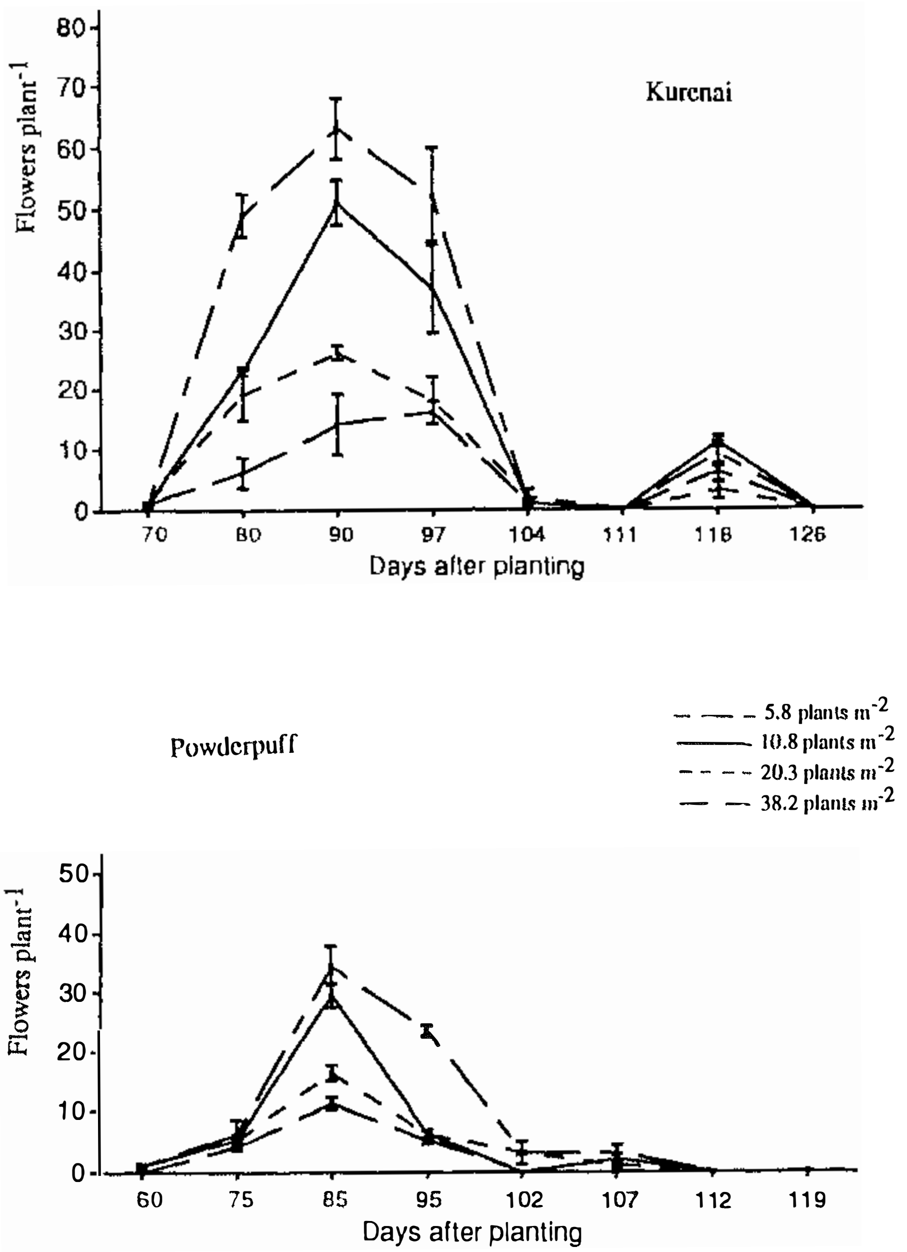


Figure 3.2.7 Flowering pattern of China aster cv. Kurenai and cv. Powderpuff. (Vertical bars represent SE of the means).

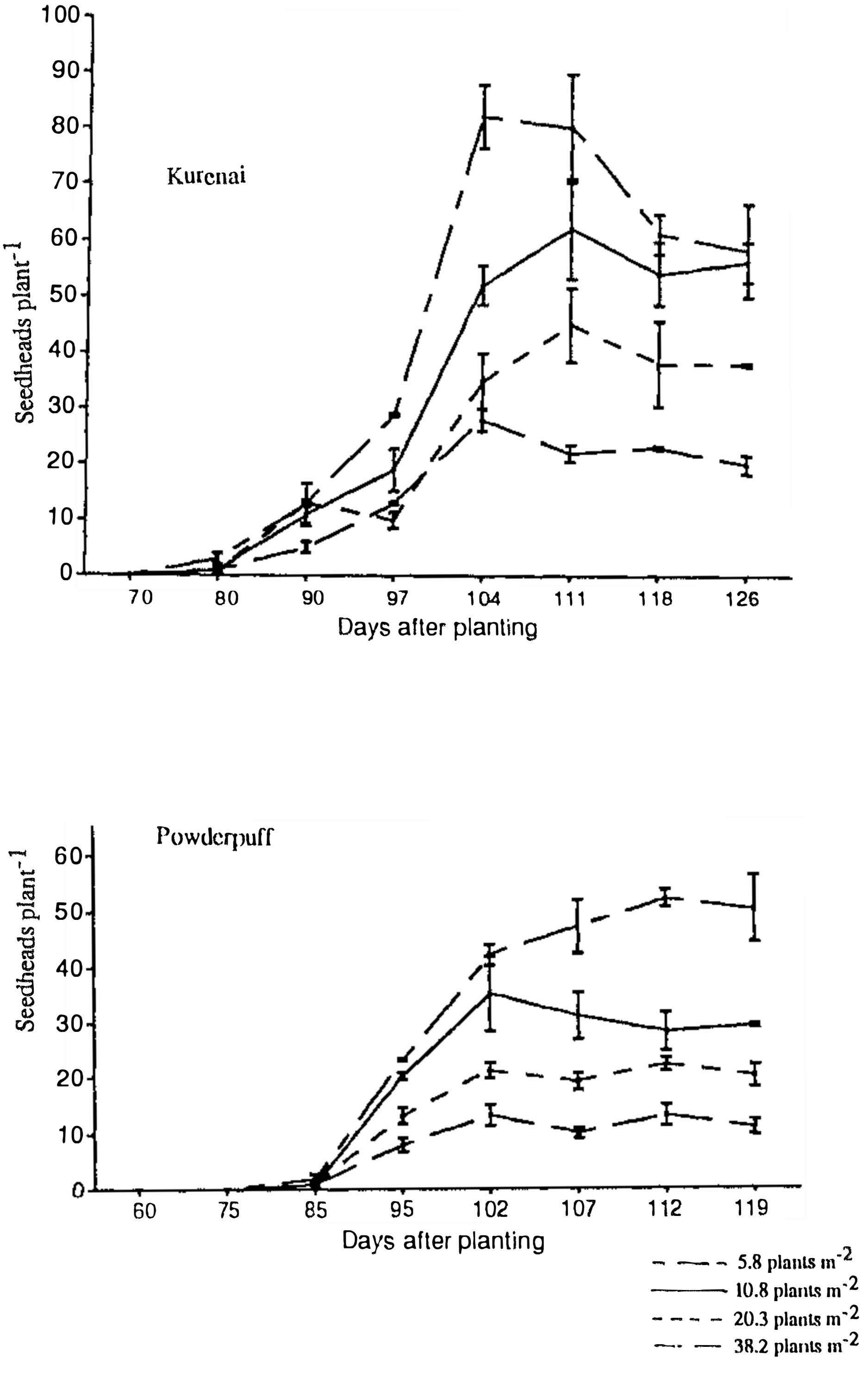


Figure 3.2.8 Effect of plant density on seedhead numbers per plant in China aster cv. Kurenai and cv. Powderpuff.

(Vertical bars represent SE of the means).

In cv. Powderpuff, seed fresh weight continued to increase until 22-34 DAPF (107-119 DAP). The lowest plant density (5.8 plants m^{-2}), in contrast to cv. Kurenai, gained maximum seed fresh weight 5-12 days earlier than the higher densities. The density of 10.8 plants m^{-2} took longer to reach maximum seed fresh weight, and at 119 DAP the highest density (38 plants m^{-2}) had a significantly lower seed fresh weight than seed of the 5.8 and 10.8 plants m^{-2} densities (Figure 3.3.1), but by 126 DAP fresh seed weight of all densities was similar (around 0.22 g).

3.3.3.2 Seed dry weight

In cv. Kurenai there were no significant differences in seed dry weight between plant densities at any of the sampling times (Figure 3.3.2). Seed dry weight had increased from 0.0677 g (mean of four plant densities) at 90 DAP to 0.1385 g by 126 DAP, with a slow further increase after 118 DAP (28 DAPF).

No significant difference in seed dry weight of cv. Powderpuff between plant densities was recorded except at the final harvest, where the plants grown at 10.8 plants m^{-2} gave a higher seed dry weight than plants at other densities (Figure 3.3.2). Seeds of cv. Powderpuff were bigger and heavier than cv. Kurenai (mean seed dry weight of four densities at final harvest of cv. Kurenai = 0.1385 g and of cv. Powderpuff = 0.1994 g).

3.3.3.3 Seed moisture content

Seed moisture content of cv. Kurenai fell from over 70 % at 90 DAP to 14 % at 126 DAP, the rate of loss averaging 1.7 % per day (Figure 3.3.3). The rate of dehydration was very rapid after the flower heads had dried. Although there were no statistically significant differences at most observation times, seed dehydration at the highest plant density tended to occur faster than at the lowest plant density.

The rate of dehydration was relatively slower in the long petaled, double flower type cv. Powderpuff than in the single type cv. Kurenai. The 20 plants m^{-2} density showed a tendency to gain and retain moisture to a greater extent and for longer than the other densities when subjected to rain during 112-119 DAP. Seed moisture content dropped sharply between 119 and 126 DAP, after the flower heads (particularly the petals) had dried (Figure 3.3.3).

3.3.3.4 Germination

The germination capacity of air-dried seed of cv. Kurenai increased rapidly and reached a maximum at 21 DAPF (111 DAP) except at the lowest density (5.8 plants m^{-2}) which was seven days later (118 DAP). All plant densities had a maximum seed germination level of 98-99 % (Figure 3.3.4).

In cv. Powderpuff, increased germination capacity was not as rapid as in cv. Kurenai and the maximum was reached at 34 DAPF (119 DAP), except for the highest density which continued to increase until the last observation time (126 DAP). Powderpuff seeds generally had a lower germination capacity than Kurenai seeds and seeds produced from high density plants had a higher germination capacity than seeds produced from lower density plants (Figure 3.3.4). Plants grown at 20 plants m^{-2} produced seeds with the highest germination capacity (97 %) while the maximum germination capacity of the lowest density (5.8 plants m^{-2}) was only 88 %.

3.3.3.5 Viability

Viability of seeds of both cv. Kurenai and Powderpuff followed the same pattern as germination (Figure 3.3.5) because only a few abnormal seedlings were added to the normal germination. Most of the abnormals found in aster were categorized as having no roots or short roots, and were produced from immature seeds.

3.3.3.6 Seed development study in individual flower heads

Flower heads for both cultivars (Figures 3.3.6 and 3.3.7) took six days for all ray florets and another 12 days for disk florets to complete blooming, after which the petals gradually wilted. The bright red and pink colour at blooming in cv. Kurenai and cv. Powderpuff respectively became dull and then changed to brown as heads dried. Seeds could be distinguished from 12 days after tagging (when the first outer ray florets opened -DAF) particularly in cv. Powderpuff. The pappus started to appear and could be clearly seen by 39 DAF in cv. Kurenai, which was the time that petals began to drop. At this stage, seeds were easily shed from the seedhead. In cv. Powderpuff, pappus were not visible until after all petals had completely dried and dropped.

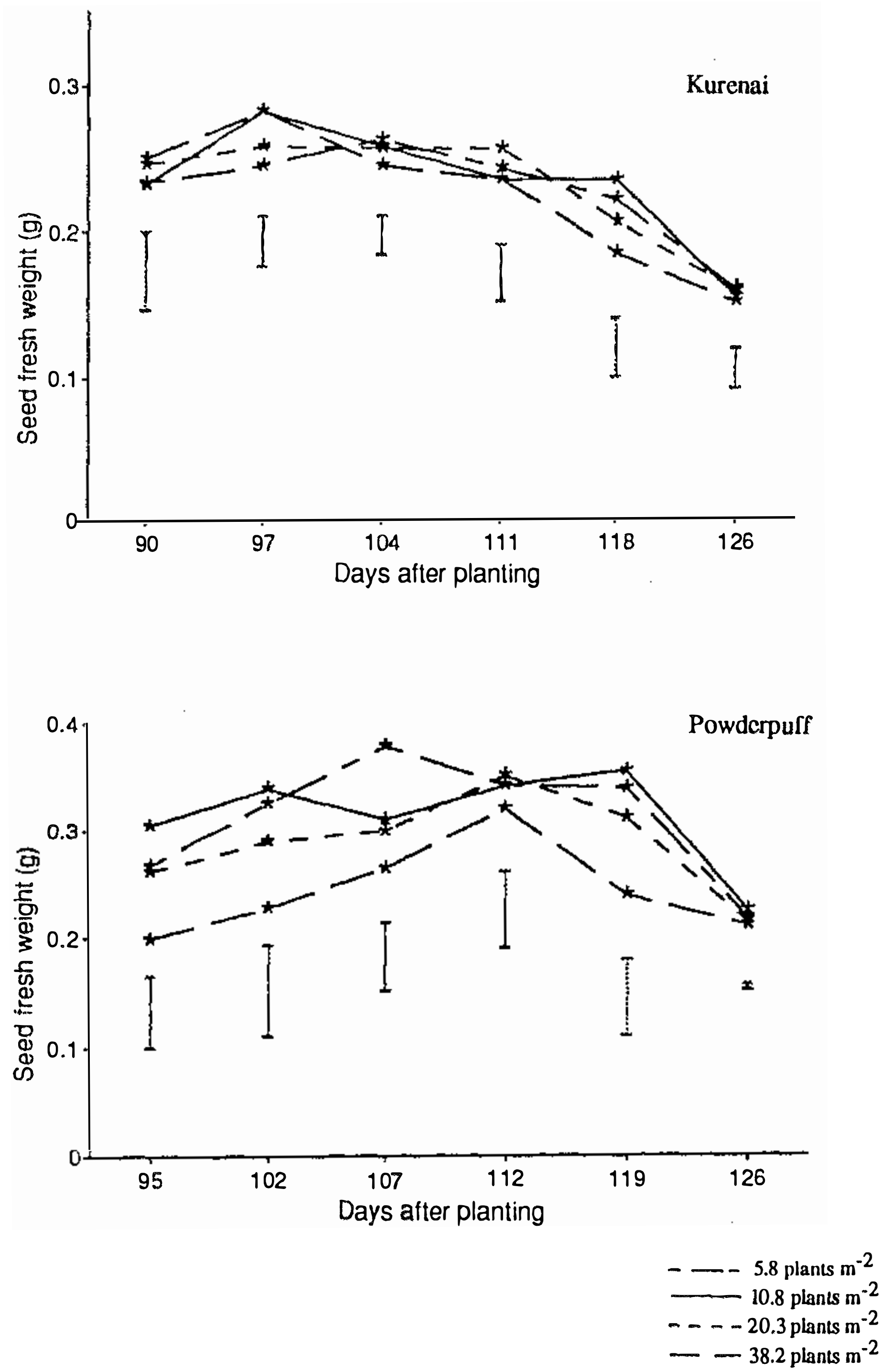


Figure 3.3.1 Changes in seed fresh weight with time at four different plant densities (5.8, 10.8, 20.3 and 38.2 plants m^{-2}) in China aster cv. Kurenai and cv. Powderpuff.

(Vertical bars represent LSD at $P \leq 0.05$).

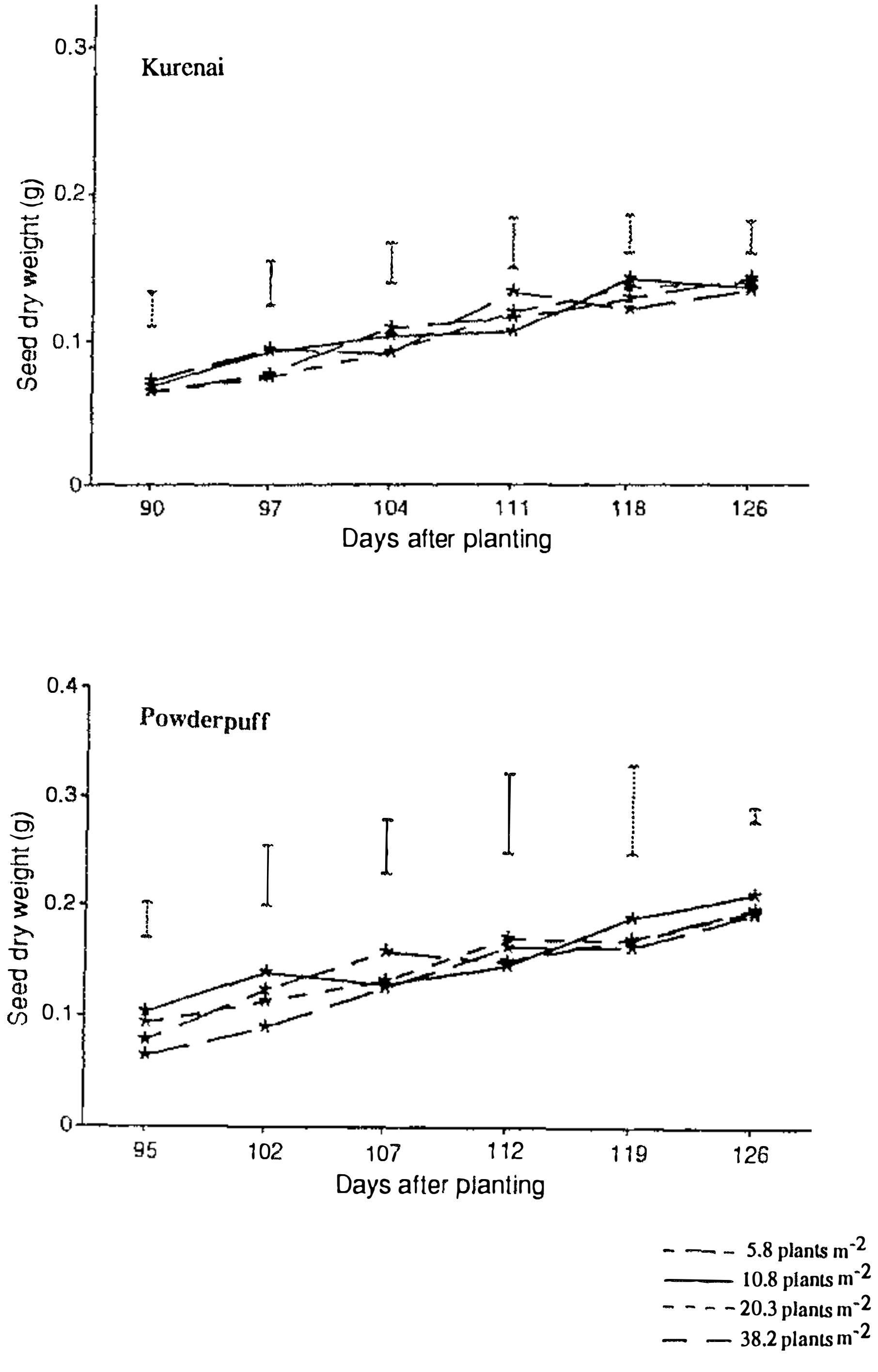


Figure 3.3.2 Changes in seed dry weight with time at four different plant densities (5.8, 10.8, 20.3 and 38.2 plants m^{-2}) in China aster cv. Kurenai and cv. Powderpuff.

(Vertical bars represent LSD at $P \leq 0.05$).

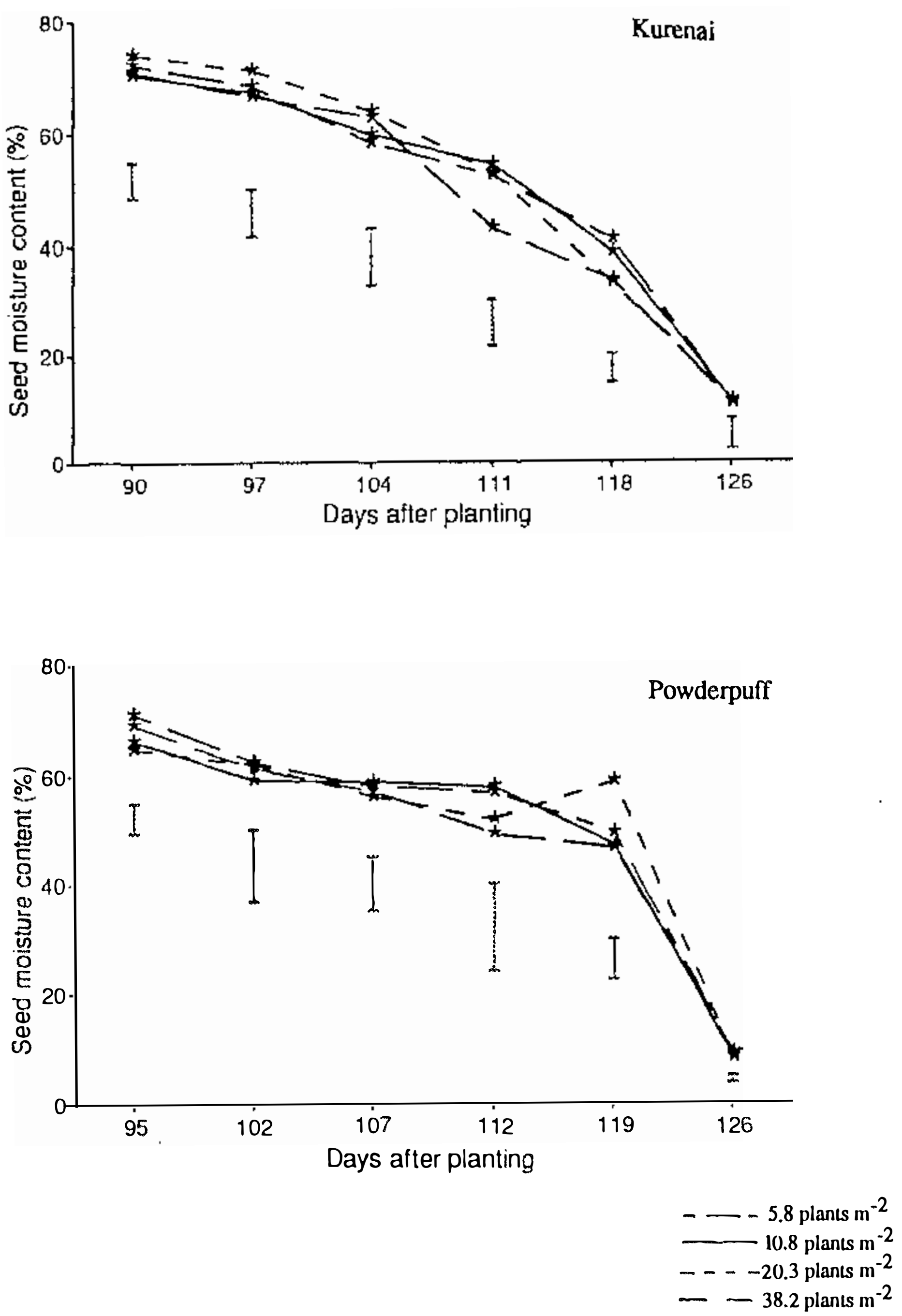


Figure 3.3.3 Changes in seed moisture content with time at four different plant densities (5.8, 10.8, 20.3 and 38.2 plants m^{-2}) in China aster cv. Kurenai and cv. Powderpuff.

(Vertical bars represent LSD at $P \leq 0.05$).

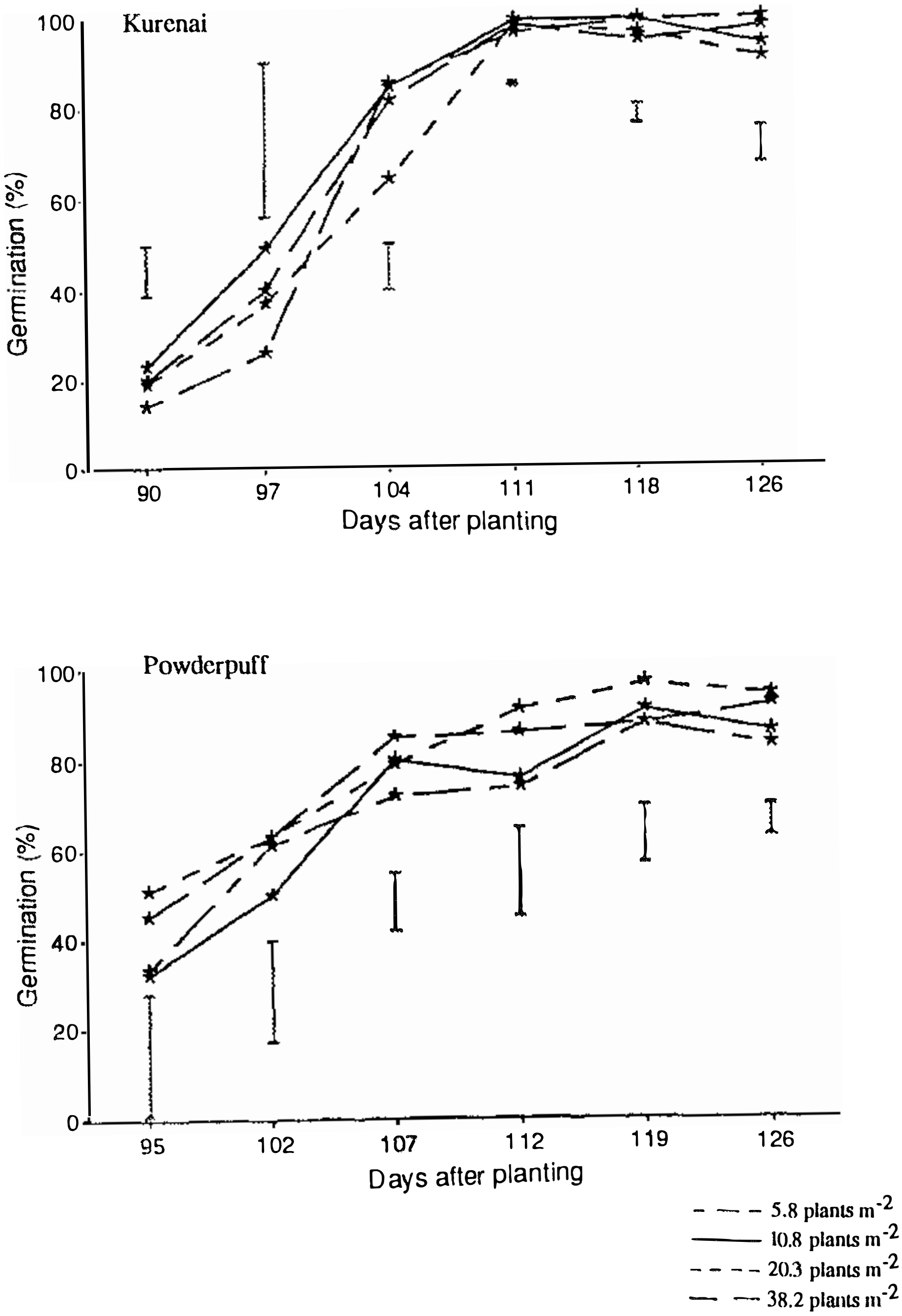


Figure 3.3.4 Changes in air-dried seed germination with time at four different plant densities (5.8, 10.8, 20.3 and 38.2 plants m^{-2}) in China aster cv. Kurenai and cv. Powderpuff.

(Vertical bars represent LSD at $P \leq 0.05$).

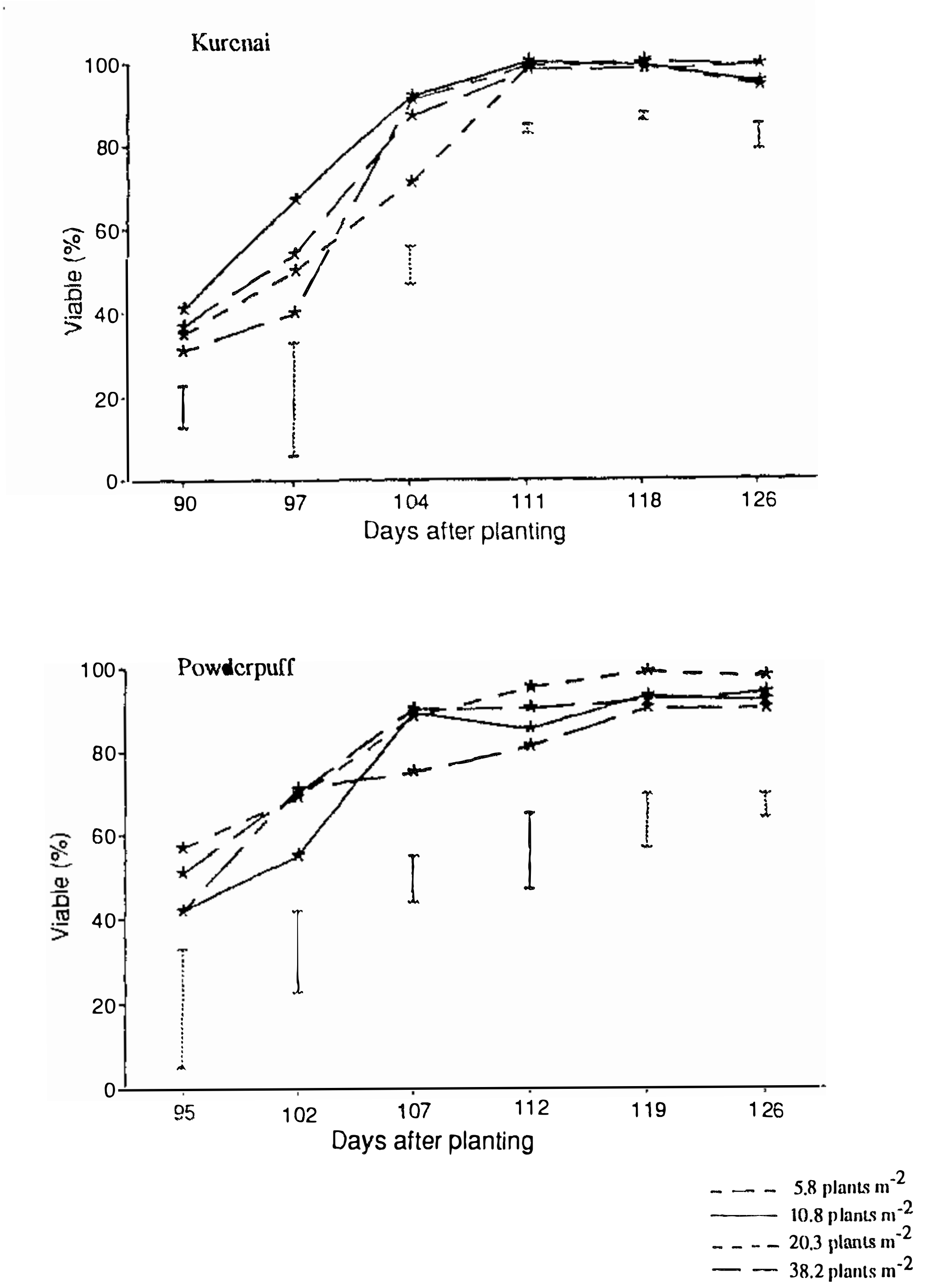


Figure 3.3.5 Changes in seed viability with time at four different plant densities (5.8, 10.8, 20.3 and 38.2 plants m^{-2}) in China aster cv. Kurenai and cv. Powderpuff.
(Vertical bars represent LSD at $P \leq 0.05$).

Changes in seed fresh weight, dry weight, moisture content, germination and viability at different seed ages for cv. Kurenai are shown in Figure 3.3.8. Average seed fresh weight (100 seeds) increased markedly from 6 to 9 days after anthesis (DAF) and continued to gradually increase up to 30 DAF. After reaching a maximum (0.28 g) at 30 DAF seed weight decreased rapidly to 0.23 g at 39 DAF. The apparent regain in seed weight observed at 42 DAF was due to rewetting of seedheads following a soaking by rain. Seed dry weight increased up to 30 DAF, remained constant to 45 DAF, and then started to decrease. Seed moisture content fell from around 75 % during 6-12 DAF to 9.6 % at 39 DAF. A rapid and marked increase in germination capacity occurred during 12-21 DAF, and remained consistently high (99-100 %) between 21-45 DAF, before declining slightly after 45 DAF. Viability of seeds followed the same pattern as germination.

In cv. Powderpuff, marked increases in seed fresh weight occurred during 6-15 DAF, with further gradual increases until a maximum (0.38 g) was reached at 39 DAF, before a decrease started (Figure 3.3.9). Although maximum seed dry weight (0.24 g) was obtained at 42 DAF, the mean dry weight of seed during 39-48 DAF did not differ significantly ($P \leq 0.05$). The rate of dehydration was relatively slower than in cv. Kurenai. Around 5 % germination was recorded in seed which had been harvested at 18 DAF, followed by a marked increase during 18-27 DAF (to 75 %), with a maximum being reached at 36 DAF. This high germination capacity (80+ %) was maintained only for a short period (33-39 DAF) before rapidly decreasing, particularly between 45-48 DAF. The pattern of seed viability was also similar to germination (Figure 3.3.9).

3.3.4 Seed yield and yield components

Increasing plant density decreased seed yield per plant (Figure 3.4.1) due to decreases in seedhead numbers per plant, seed numbers per head and seed weight (Tables 3.3-3.4). Plant density had a large effect on total seedheads per plant. The total seedheads per plant fell from 66 (cv. Kurenai) and 46 (cv. Powderpuff) at the lowest plant density to 20 and 9 at the highest plant density, which represented 70 and 80 % reductions. Seedheads decreased most as plant density rose to 17.3 and 12.7 plants m^{-2} (cv. Kurenai and cv. Powderpuff respectively). Seed numbers per head of cv. Powderpuff decreased 36 % from the lowest to the highest plant density. The decrease in seed number in cv. Kurenai was not significantly different between plant densities by mean comparison ($LSD_{0.05}$). The decrease in seed weight as affected by plant density was 6 and 9 % from the lowest to the highest plant density in cv. Kurenai and cv. Powderpuff respectively. There were no significant differences ($LSD_{0.05}$) in germination capacity at final seed yield harvest except for the three lowest plant densities (Tables 3.3 and 3.4).

Seed yield per m^{-2} response to plant density is shown in Figure 3.4.2 using the predicted values from the quadratic reciprocal equation which gave the best least squares fit to the observed data (Appendix 3.4.1). Both cultivars showed a parabolic yield-density relationship with a maximum yield of 140 g m^{-2} from 27.8 plants m^{-2} and 42 g m^{-2} from 17.3 plants m^{-2} in cv. Kurenai and cv. Powderpuff respectively (Figure 3.4.2). There were no significant yield difference among the densities from 12.7 to 44.7 plants m^{-2} for cv. Kurenai (Figure 3.4.2). Increasing plant density from 4.2 to 12.7 plants m^{-2} increased seed yield by 75 % but a further density increase to 27.8 plants m^{-2} only gave a 25 % further increase in yield. In cv. Powderpuff, seed yield did not differ significantly with plant density, with the exception of 4.2 plants m^{-2} (Figure 3.4.2). The cultivar Kurenai produced a 1.8-3.5 times greater seed yield than cv. Powderpuff at the same plant density.

Initial seed yield increased with increasing plant density in cv. Kurenai primarily due to an increase in branch numbers which led to increased leaf number, leaf area and flower heads (Table 3.5). Total seedhead production showed a parabolic relationship with plant density (Figure 3.4.3) as the reduction in seedhead number per plant was compensated for by the increase in plant numbers. The number of seeds m^{-2} followed the pattern of seedheads m^{-2} as seed numbers per seedhead were not different (Figure 3.4.3, Table 3.3). Mean seed weight (1000 seeds) showed a negative correlation with seed yield. The difference in seed weight was great enough to compensate for the lower seed number m^{-2} of the lower density plants and the net result was no significant difference in seed yield between plant densities of 12.7 to 44.7 plants m^{-2}.

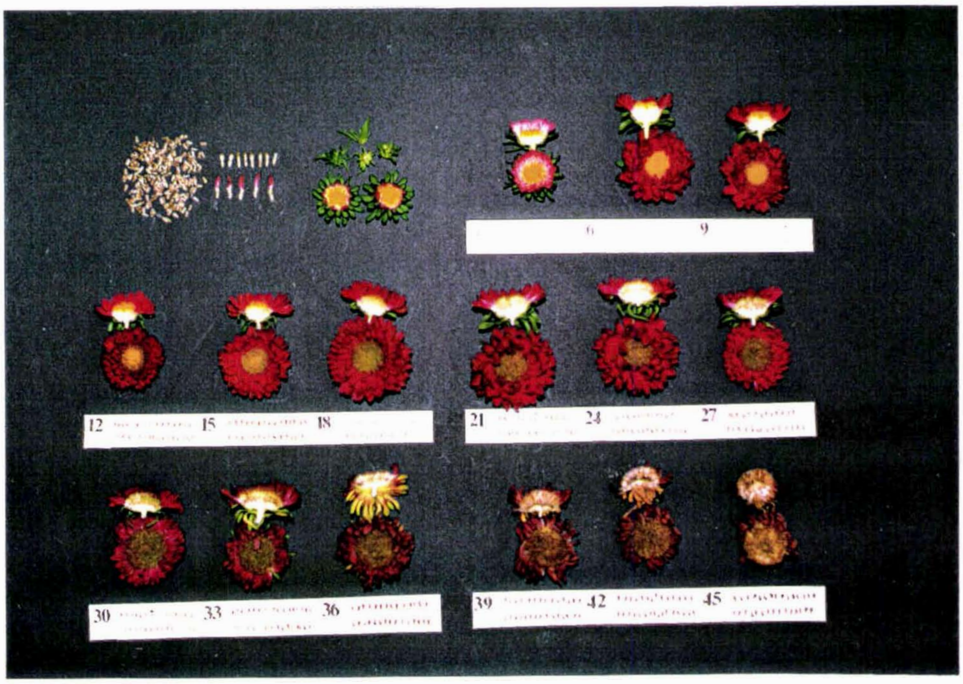


Figure 3.3.6 Flowering sequence within the flower head and seedhead development of cv. Kurenai.

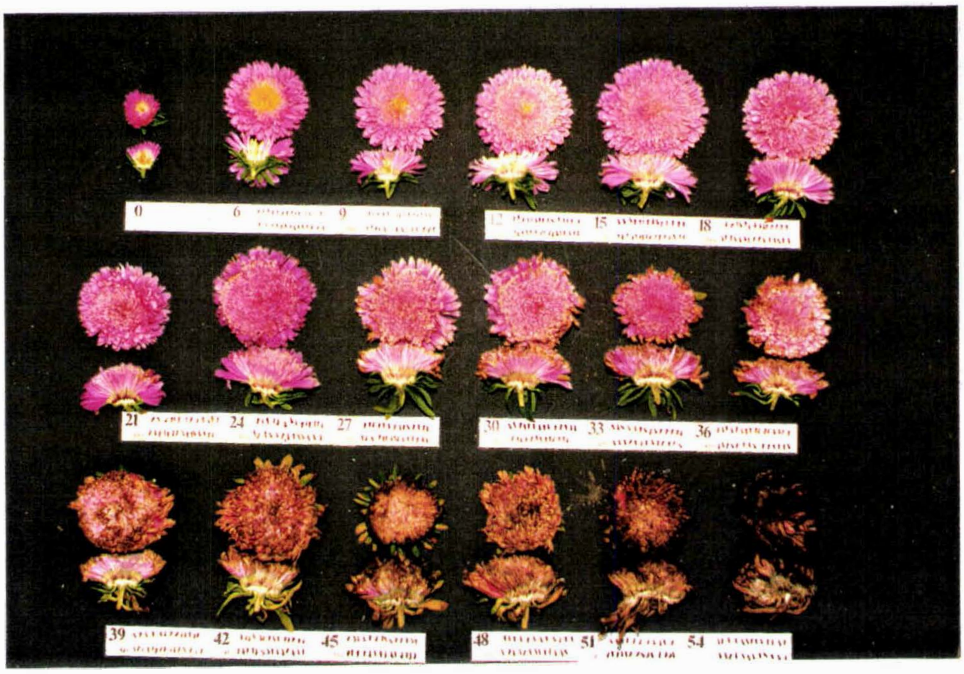


Figure 3.3.7 Flowering sequence within the flower head and seedhead development of cv. Powderpuff.

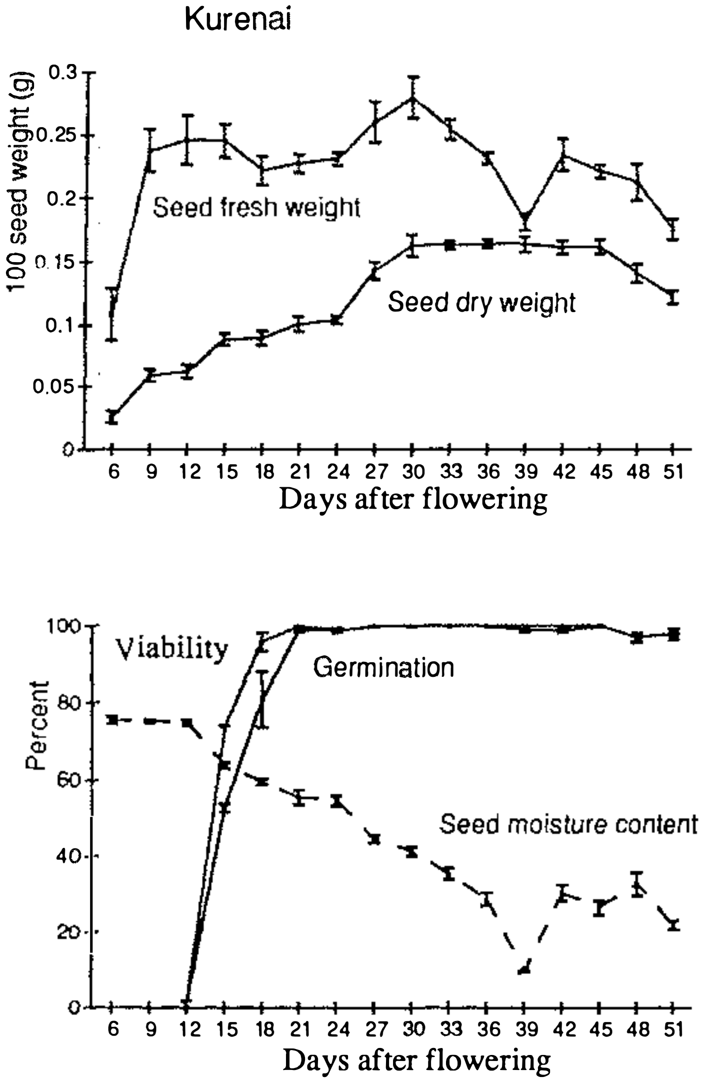


Figure 3.3.8 Seed fresh weight, dry weight, moisture content, germination and viability between 6 and 51 days after flowering for cv. Kurenai.

(Vertical bars represent SE of means).

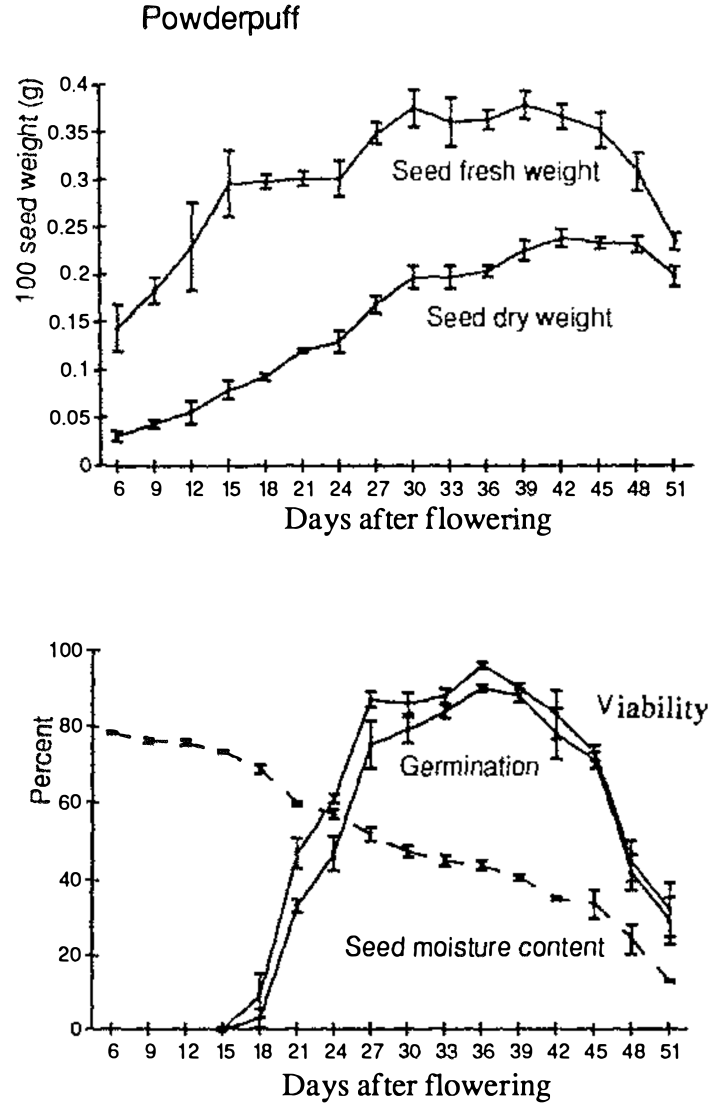


Figure 3.3.9 Seed fresh weight, dry weight, moisture content, germination and viability between 6 and 51 days after flowering for cv. Powderpuff
(Vertical bars represent SE of means).

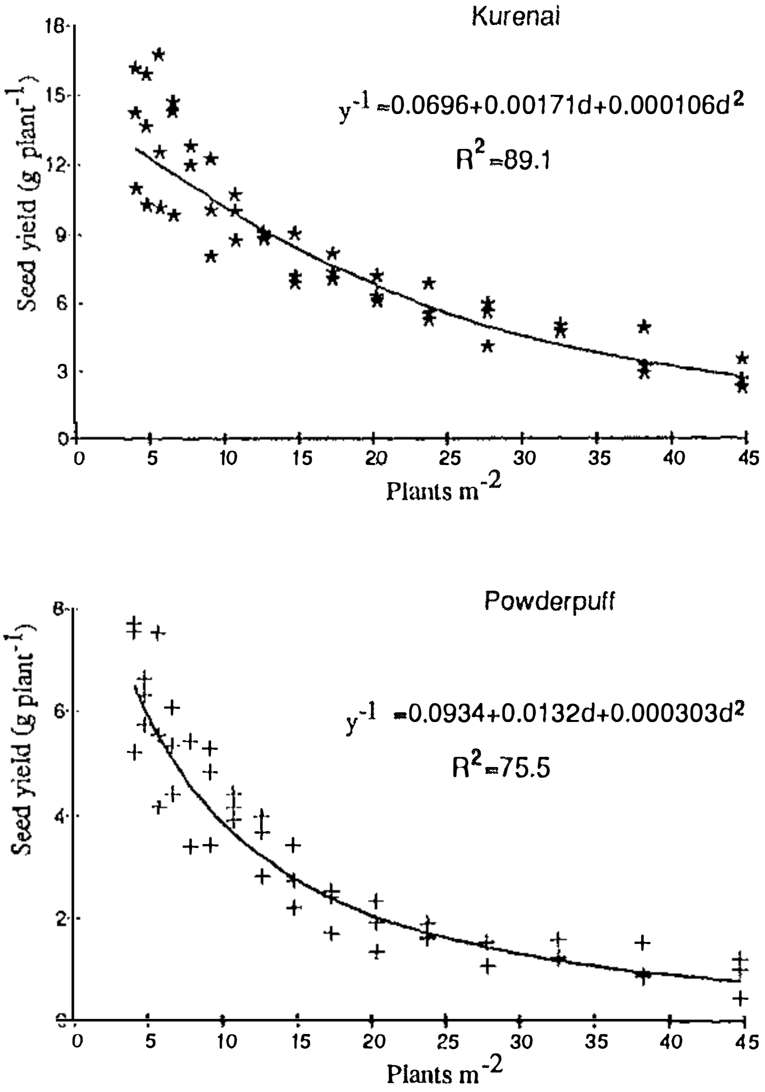


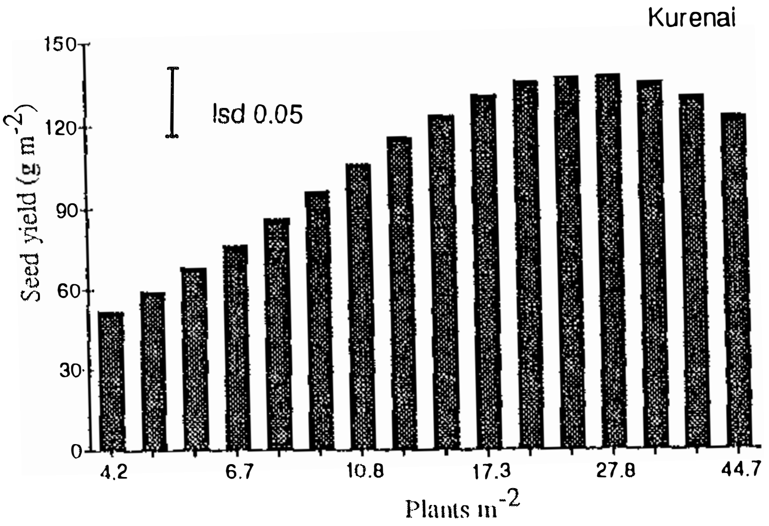
Figure 3.4.1 Effect of plant density on seed yield per plant of China aster cv. Kurenai and cv. Powderpuff.

Table 3.3 Seed yield components of cv. Kurenai.

Plant density (plants m^{-2})	Seedheads $plant^{-1}$	Seeds $head^{-1}$	TSW (g)	Germination (%)
4.2	66	135	1.6419	93
4.9	65	132	1.6372	93
5.8	66	133	1.5984	92
6.7	68	135	1.5895	95
7.9	61	137	1.6332	95
9.2	57	127	1.5902	99
10.8	62	128	1.5971	96
12.7	57	125	1.6042	98
14.8	51	127	1.6098	97
17.3	38	129	1.6201	97
20.3	39	123	1.5880	99
23.8	35	125	1.5852	98
27.8	30	121	1.5673	96
32.6	28	121	1.5724	99
38.2	24	120	1.5678	99
44.7	20	118	1.5499	99
LSD (0.05)	7	24	0.0580	4
CV %	8.97	11.45	2.18	2.67

Table 3.4 Seed yield components of cv. Powderpuff.

Plant density (plants m^{-2})	Seedheads $plant^{-1}$	Seeds $head^{-1}$	TSW (g)	Germination (%)
4.2	46	66	2.2220	80
4.9	42	63	2.2877	80
5.8	43	64	2.2060	83
6.7	43	58	2.1713	89
7.9	39	53	2.0667	88
9.2	36	60	2.2970	91
10.8	31	56	2.0140	86
12.7	24	59	1.9460	91
14.8	22	55	2.2553	89
17.3	21	48	2.1903	91
20.3	21	55	2.0037	94
23.8	17	52	1.9667	96
27.8	15	50	2.0470	90
32.6	12	48	2.0547	93
38.2	12	46	2.0433	92
44.7	9	42	2.0290	93
LSD (0.05)	8	18	0.1351	10
CV %	16.96	19.53	3.84	6.64



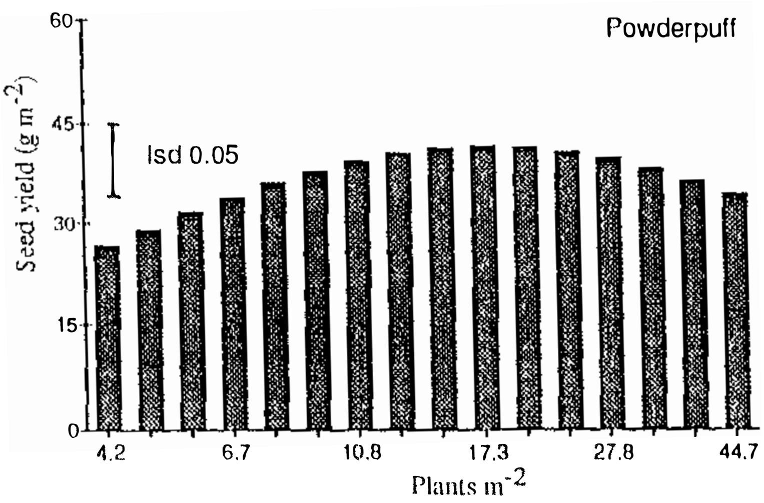


Figure 3.4.2 Effect of plant density on seed yield per m^2 of China aster cv. Kurenai and cv. Powderpuff.

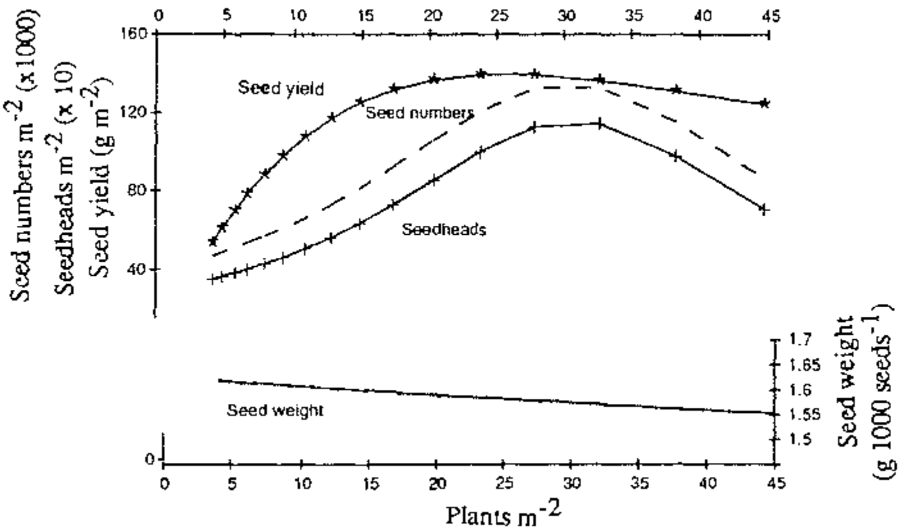
In cv. Powderpuff the seed yield increase was best explained by significant increases in flower heads m^{-2}, the number of seeds and total seed weight harvested m^{-2}, and was only poorly related to fertile branch numbers m^{-2}, LAI, plant dry weight, leaf number and seedhead numbers (Table 3.5). The decrease in seed number per plant was compensated for by the increase in plant numbers which resulted in little difference in seed numbers m^{-2} (Figure 3.4.3). Mean seed weight (1000 seeds) also showed a negative correlation with seed yield but decreased non-linearly. Compensation by seed weight and seed number m^{-2} was great enough to result in no significant differences in seed yield between all plant densities, except for the lowest plant density (4.2 plants m^{-2}).

Table 3.5 Relationships between seed yield and yield components

Component	Variance accounted for (%)	
	Kurenai	Powderpuff
Seedheads m^{-2}	75.9***	38.5**
Seed numbers m^{-2}	78.9***	62.9***
Seed weight m^{-2}	60.2***	66.2***
Seedhead bearing branches m^{-2}	69.6***	34.8*
Flowering branches m^{-2}	68.2***	16.4^{ns}
Flower heads m^{-2}	88.0***	90.5***
Leaves m^{-2}	86.6***	44.7**
Leaf area index	75.2***	36.9*
Plant dry weight m^{-2}	86.6***	33.3*

***, **, * and ^{ns} indicated significance at $P \leq 0.001$, 0.01, 0.05 and no significant difference.

Kurenai



Powderpuff

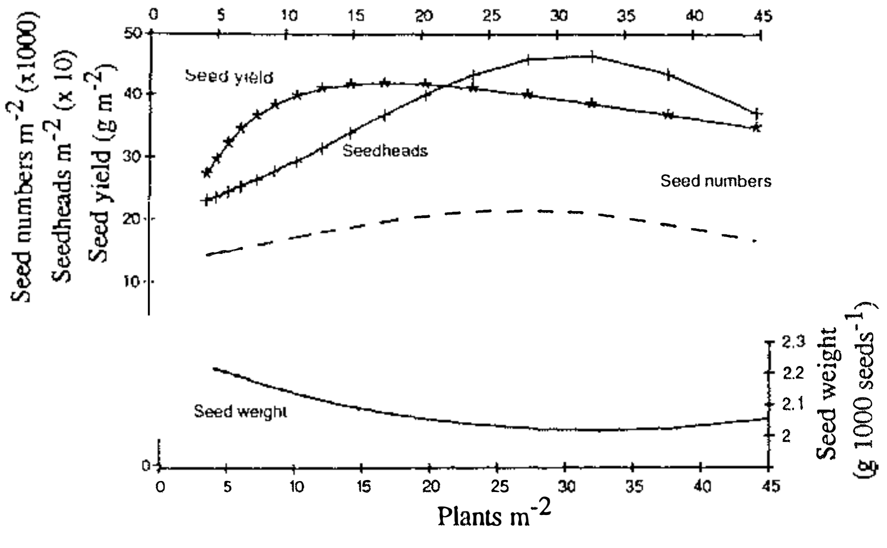


Figure 3.4.3 Relationships of seed yield m^{-2} and seedheads m^{-2}, seed numbers m^{-2} and mean seed weight (1000 seeds) of China aster cv. Kurenai and cv. Powderpuff.

3.4 DISCUSSION

3.4.1 Vegetative plant growth as affected by plant density

The changes in plant morphological characteristics as a result of different plant densities in this study were similar to those reported previously in soybean (Chanprasert, 1988), maize (Balico, 1984; Tolentino, 1985), lupin (Herbert and Hill, 1978) and siratro (Juntakool, 1983). The present study showed that plant density had only a small effect on phenology up until stem elongation, but differences among densities then became apparent as plants grew bigger (Figure 3.1.1). These differences occurred because more lateral branches were produced by plants grown at low densities (Figure 3.1.2) and this led rapidly to increased leaf production (both leaf number and leaf area) and plant dry weight accumulation (Figures 3.1.3-3.1.5). By 50 DAP, the growth of high density plants was obviously depressed due to competition, presumably for light, as every effort had been made to maximise soil fertility, irrigation, weed control and insect and disease protection so that maximum plant growth could be maintained throughout the experiment. Under such conditions Donald (1963) has suggested that of all the factors influencing competition in crops, light ultimately becomes the major limiting factor to production. Herbert and Litchfield (1984) have also suggested that competition for light is the major factor inducing morphological changes in plants when plant density is increased.

In this experiment, plants grown at low densities showed the greatest branch development and subsequently leaf and flower production, which thus increased potential seed production sites. Plant density may influence light distribution in plant canopies (Kasperbauer and Karlen, 1986). Kirby (1976) showed in cereals that about 60 % of the light was intercepted by the upper layer of leaves in the crop canopy at high plant density (800 plants m^{-2}), and less than 10 % reaches the lower leaves. In a low density crop (50 plants m^{-2}), 30 % reached the lower leaves and the soil surface. A study on bud yield of blackcurrants as influenced by plant density and light interception by Kerslake and Menary (1986) also showed that increased competition for available light resulted in smaller plants at high as compared to low plant densities. Under the high light conditions experienced by low density blackcurrant plants, assimilate production was enhanced, resulting in thicker basal canes with more assimilate reserves. The quality of light is also changed as it passes through the crop canopy, because the visible part of the spectrum is attenuated more than the infra-red part, so that the ratio of red to far-red wavelengths decreases (Kirby, 1976). In China aster cv. Heart of France (which is classed in the same group as cv. Powderpuff: tall, for cut flowers), Withrow and Benedict (1936) showed that plant growth was increased with light intensity (incandescent) and reponded most to orange and red wavelengths. In this study, the canopy of low density plants was more open, plants had a more even leaf distribution from the upper to the lower levels, and thus light presumably was able to penetrate to basal branches. In contrast, a dense upper canopy was formed in the high density plants which probably caused some degree of both mutual and self-shading. This structural and spacial arrangement probably contributed to the higher yield of low density plants.

Plant height is also another prime indicator of light competition. Tamaki *et.al.* (1973) explained that competition for light at different degrees of mutual shading stimulates cell elongation. This increases plant height by an increase in internode length. Kirby (1976) mentioned that stem growth of plants at low densities was delayed and was initiated at a higher internode. In plants at higher densities, the stem growth started at a lower internode, resulting in taller, thinner and weaker stems in the higher density plants. In the present study, only the height of the main stem was measured. The two cultivars had different stem elongation ability. Although stems of both cultivars started to elongate at 20 DAP, stems of cv. Powderpuff grew very fast during the stem elongation stage (20-50 days) resulting in the same stem height irrespective of plant density, but stems became thinner and with lower dry weight as plant density increased. In contrast, density effects were clearly shown in cv. Kurenai where the main stem length was increased at higher plant densities during vegetative growth, although stems did not differ in dry weight. However this contrast was reversed from first flowering onwards, where for reproductive growth, plant density effects on stem length were clearly shown in cv. Powderpuff but not in cv. Kurenai. A different growth response between cultivars was also observed for branch growth, although this was not measured. Branches grew rapidly, surpassing the main stem length, and canopy height exhibited the same responses as recorded for main stem length. The difference between the tip of the highest branch and the tip of the main stem was greater in cv. Powderpuff than in cv. Kurenai. There are no reports available on light responsiveness for these two cultivars, but it is likely from this experiment that cv. Powderpuff is more sensitive to light competition than cv. Kurenai. Plant height may be important at high plant density for seed yield because it may also be associated with lodging, particularly for cv. Powderpuff. At high density, stem strength of this cultivar may be reduced to a greater extent than that of cv. Kurenai, as stems were thinner and weaker. This may result in a greater proness to lodging. Certainly, lodging at high plant density occurs in poppies (*Papaver somniferum*) when this species is grown at >100 plants m^{-2} (100-150 plants m^{-2} is the common commercial plant density for this species in Australia; Chung, 1987). It is therefore perhaps not surprising that Chung (1990) showed that lodging was reduced by reducing plant density to 70 plants m^{-2} without any decrease in seed yield.

Both cultivars exhibited two flushes of branching, the first appearing during stem elongation, and the second after first flowering. As many as 27 and 16 branches were produced by low density plants of cv. Kurenai and cv. Powderpuff respectively. These more than compensated for the lower plant number, resulting in a greater number of branches m^{-2} (Figure 3.1.2). As leaf number per branch was relatively constant, the production of leaves and the increase in leaf area always followed the branching capacity (Figures 3.1.3-3.1.4). Changes in leaf area with plant density subsequently affected plant dry weight. Differences in plant dry weight first appeared at 50 DAP in cv. Kurenai and 40 DAP in cv. Powderpuff (Figure 3.1.5; Appendix 3.1.6) with rapid increases before flowering, particularly in the low density plants, as a result of rapid branch and leaf growth. The lower plant dry weight accumulation of high compared to low density plants suggests greater competition for light as already discussed in terms of morphological structure. At maximum plant dry weight, the dry weight of lower density plants was approximately three times greater than that of the higher density plants in both cultivars. The distribution of dry matter amongst the vegetative plant parts (stem, branches, main stem leaves and branch leaves) followed a similar pattern relative to total vegetative dry weight. This pattern of dry matter distribution under various light treatments has also been reported in cv. Queen of the Market by Hughes and Cockshull (1965).

The number of branches appears to be the primary characteristic to be manipulated for increasing seed yield, particularly the branches arising from the first flush during main stem elongation, as they comprised 80-90 % of the total branch numbers per plant. Different plant growth patterns and morphologies between cultivars also suggest that different optimum densities may be necessary to express their full seed yield potential (Nangju, 1979).

3.4.2 Reproductive development

This study indicates that assimilate competition is likely to occur between vegetative and reproductive plant parts as lateral branches and leaves grew rapidly at the same time as the onset of main stem terminal flower development during stem elongation. This competition has been demonstrated in other species by the removal of young branches or young leaves when they appeared. Miura *et.al.* (1988) reported that branch removal increased seed yield on the main stem of soybean cv. Toyosuzu by 53, 91 and 84 % when grown at 330, 648 and 1798 plants ha^{-1} respectively, due to increases in pod numbers per plant, seeds per pod and seed weight. Increased flower and pod numbers in soybean cv. Amsoy have also been reported following young leaf removal, without however significantly increasing seed yield (Chanprasert, 1988). Assimilate competition is also likely to have occurred between reproductive plant parts. The overlaps in flowering between the primary flower head of the main stem and the terminal flower heads of lateral branches, and in flowering between lateral branches may also have caused competition for assimilates required for seed setting (Farrington, 1976; Herbert and Hill 1978). Under stress conditions (light, temperature or water stress), young flower buds constitute a weak sink in comparison with vegetative apices, developing leaves, fruits or storage organs and compete poorly with them for available assimilate (Subhadrabandhu *et.al.*, 1978; Mor and Halevy, 1979; Monselise and Goldschmidt, 1982). Flower abortion during inflorescence development has been found to be aggravated with low light intensity, low or extremely high temperature or water stress (Withrow and Benedict, 1936; Halevy, 1975; 1984). In plants possessing young flower buds and open flowers, these environmental stresses promote abortion and abscission of the flower buds while other organs may only be slightly affected (Kinet, 1977). A similar result in *Phaseolus vulgaris* L., was reported by Tayo (1986) and Pachan and Webter (1986), most of the pods which were retained to maturity being formed from early flowers that opened within 3-4 days of anthesis and were positioned basally on the raceme. Prolonged flowering also results in seeds of varying maturity and physiological age from a single harvest, as reported in carrot (Halevy, 1985; Gray, 1987).

Flowering branch production of the two cultivars differed in that cv. Powderpuff had a poorer branching performance than cv. Kurenai. The high percent decrease in fertile branches at high plant density and a greater percentage of dry matter in vegetative branches is likely to reflect a stronger competition from vegetative growth in Powderpuff plants than in cv. Kurenai. This different capacity may influence the total seed yield of the plant (Arnon, 1972).

Flower production per plant of both aster cultivars was greater under wide than under close spacing, possibly due to light competition, as Withrow and Benedict (1936) have shown that not only vegetative plant growth but also flowering was increased by high light intensity. Similar results have also been reported in *Dianthus caryophyllus* (Khanna *et. al.*, 1988), and in soybean (Chanprasert, 1988). The number of flower heads changed dramatically with time, showing a sharp flowering peak at 20 and 25 days after first flowering in cv. Kurenai and cv. Powderpuff respectively and a small subsequent peak about 3-4 weeks later. This double peak was not as clear in cv. Powderpuff, particularly for the high (20.3 plants m^{-2}) and very high (30.8 plants m^{-2}) plant densities (Figure 3.2.7). This was probably a result of the higher competitive ability of either the vegetative growth (rather than reproductive growth) and the earlier flowers (which inhibited the later flower growth, particularly those borne on the basal lateral branches) of this cultivar as already discussed. Two flowering peaks have also been reported in leaf lettuce which also belongs to the compositae family (Sukprakarn, 1985) but they differed in magnitude. The second peak flowering found in lettuce produced far greater flower numbers than the first peak, which makes it difficult to judge the optimum time for machine harvest. In China aster, the second flowering peak which occurred in this study was small compared with lettuce, but it may still have adversely affected seed yield, as these flowers grew at the same time as the seed filling period of the early flower heads. This latter peak possibly occurred as a result of the continuous irrigation used to maximise plant growth, as shown by the work of Herbert and Hill (1978) in *Lupinus angustifolius.*

From these results plant density did not alter flowering pattern or duration but greatly influenced flower numbers. This confirmed the previous suggestion that manipulation to increase branching may lead to increased flower numbers and subsequently seed sites.

3.4.3 Seed development

Seed development studies have been valuable in ensuring the harvesting of both the maximum quality and quantity of many different seed crops such as *Medicago sativa* (Kowithayakorn and Hill, 1982), *Lactuca sativa* (Sukprakarn, 1985), soybean (Chanprasert, 1988) and many flower crops (STC, 1986). Results from the seed development sequence in China aster were useful for judging the optimum seed harvesting time. Correct harvest timing is very important, since delayed harvesting can result in much of the seed being lost because of shattering (Hawthorn and Pollard, 1954), while harvesting too early, particularly before seed reaches physiological maturity, can reduce seed yields and quality, particularly seed storage life (Harrington, 1972).

Individual seedhead tagging so that seeds of known age could be collected at different stages of development was easier to use for judging the time of harvest than the whole plant destructive method, although results from both methods were mostly similar. High variation in seed maturity among seedheads borne at different positions on individual plants make it more difficult to distinguish important development stages, particularly maximum seed dry weight. It was clearly shown from individual flower heads that seed dry weight reached a maximum at 30 DAF (cv. Kurenai) and 39 DAF (cv. Powderpuff) but average seed dry weight of a whole plant showed continual increase through to final harvest. As most of the results did not differ significantly between plant densities at any observation time for either cultivar, data of the four densities were combined and recalculated. Means for each cultivar are presented in Appendices 3.3.1 and 3.3.2 and are further used for discussion along with the results from the individual flower heads.

The length of time from anthesis to physiological maturity [the point at which seed first reaches maximum dry weight (Shaw and Loomis, 1950; Harrington, 1972)] differed between cultivars (30 and 39 DAF from individual flower heads and 28 and 41 DAPF from whole plant method for cv. Kurenai and cv. Powderpuff respectively). At this time average seed moisture content obtained from individual flower heads was around 41 % in both cultivars. The time taken from seed maturity until seed ripeness (10 % and 13 %) was 9 and 12 days for cv. Kurenai and cv. Powderpuff respectively. At this stage the pappus started to appear, and was suggested as a time for seed harvest by Hawthorn and Pollard (1954) and by Post (1954). At seed maturity maximum germination capacity and viability of seed had already been obtained. The length of time required to reach maximum germination was similar for both tagged and whole plant methods (21 and 33 DAF and 21 and 34 DAPF for cv. Kurenai and cv. Powderpuff respectively). At this time average whole plant seed germination was 98 % (cv. Kurenai) and 91 % (cv. Powderpuff) and average seed moisture content was around 50 % for both cultivars.

At maturity seed of Powderpuff was larger and heavier than Kurenai seed but germination and viability was lower. This lower seed germination capacity and viability may have been affected by environmental conditions during seed development. In general, Kurenai needed 120 days from planting to seed harvest but Powderpuff took 3 days longer. However Powderpuff was sown 19 days later than cv. Kurenai due to a delay in the arrival of seed. Kurenai seed filled and ripening during dry conditions but Powderpuff seedheads were soaked by rain water between 27-34 DAPF (Appendix 3.1). At this time seeds were mostly in the final stages of seed filling and/or seed ripening. This may have reduced seed quality, a situation which may also have been aggravated by frost following this wet period (air frost occurred once at 42 DAF but eight continual days of ground frost were recorded between 35 to 43 DAF). Sprouting also occurred in seedheads that were left in the field (Appendix 3.5.1). The principal natural protective block to germination in China aster seed is in the inner membranous coat surrounding the embryo (Atwater and Vivrette, 1987). This membrane blocks oxygen entry and is impermeable to water, which is necessary to leach inhibitors located in the cotyledons. Atwater and Vivrette (1987) reported that aging, washing and sharp temperature alternation can overcome this block and thus cause sprouting to occur on seedheads. This result also suggests that planting of China aster for seed production should not be delayed, to reduce the risk from early frost damage prior to seed harvest.

The results of this investigation suggest that the optimum harvest time for aster seeds should be around 30 and 39 days after peak flowering for cv. Kurenai and cv. Powderpuff respectively. At this time seeds had reached physiological maturity, had already gained maximum germiability, and seed moisture content was around 41 %. Earlier harvest may cause lower yield and lower quality (immature but viable) seeds. Immature seeds have been noted as an important factor contributing to poor storage longevity by Thompson (1936). Delay in harvesting may cause seed yield losses due to seed shedding and lower quality due to weathering. A period of 18 days was required to complete flowering within each individual flower head, since florets opened sequentially from the outside ring through to the centre. The blooming period lasted for approximately 8 weeks for both cultivars or 5-6 weeks if only the first peak was considered. Each seedhead needed 30 (cv. Kurenai) or 39 (cv. Powderpuff) days from first opening to reach physiological maturity and could remain on the seedhead for a further 9 days (cv. Kurenai) or 12 days (cv. Powderpuff) before seed shedding started. Therefore a range of seed maturities occurred at harvest, and high seed yield loss could occur if harvesting is not done at the correct time. Because of this problem, hand picking of individual seedheads has been suggested for harvesting aster seeds by Hawthorn and Pollard (1954). A similar problem has also been reported in lettuce by Sukprakarn (1985). However, Sukprakarn (1985) has also reported that high temperature hastened seed maturity, germination and shattering in lettuce seed. This problem may also make it more difficult to judge the correct harvesting time for China aster.

3.4.4 Yield and yield components

Plant density effects on seed yield in this study agree well with a similar study by Kobza (1987) on other cultivars of this species which also showed that seed yield per plant is depressed but yield per unit area increased with increasing plant density. The cultivars used by Kobza (1987) also included both a tall cultivar for cutting and a low, bedding type, but differed from the present study in the spatial arrangement of plants i.e. row distance of 40 cm and a variation within row distance of 10-30 cm, depending on plant height (Kobza, 1987). Maximum seed yields per m ^{2} in the present study were obtained from plants grown at 27.8 (for the low, bedding type Kurenai) and 17.4 plants m ^{2} (for the tall, cutting cultivar Powderpuff). To enable a comparison with the present study, the plant density used by Kobza (1987) was recalculated based on the area per plant. This showed that maximum seed yields per m ^{2} were also obtained from a density very close to that used in the present study [i.e. 25 plants m^{-2} (40x10cm) in the low bedding cultivar, Alena and 16 plants m^{-2} (40x15cm) in the tall cutting cultivar, Tamara].

The results from this experiment show that lowest density plants produce the highest seed yield per plant as has also been reported in lucerne (Kowithayakorn, 1978), siratro (Juntakool, 1983), soybean (Chanprasert, 1988), *Salvia officinalis* L.

(Macchia *et.al.*, 1990), and *Hyssopus officinalis* L. (Macchia *et.al.*, 1990). This higher seed yield per plant at low plant density was in all cases due to a greater number of branches, flower heads and seedheads. Seed numbers per seedhead and seed weight were relatively less affected by plant density. The higher seedhead numbers from the lower plant densities were sufficient to achieve similar seed yield m^{-2} in a wide range of plant densities from 4.9 to 44.7 plants m^{-2} in cv. Powderpuff and 12.7 to 44.7 plants m^{-2} in cv. Kurenai.

Both cultivars showed a parabolic seed yield relationship with plant density. The number of flower heads m^{-2} was the most important seed yield component determining final seed yield in both cultivars (Table 3.5) and thus seems likely to be an important plant characteristic to be manipulated for improving seed yield in China aster. Branching may also be manipulated to increase seed yield in cv. Kurenai since increased branching led to increased leaf number, leaf area, plant dry weight and flower numbers. Branch number manipulation may also be important in cv. Powderpuff to increase seed sites, but could create problem with seed set due to lodging. Lodging may restrict pollen dispersal (Griffiths, 1969; George, 1985) resulting in fewer florets being fertilized. It may also restrict light interception and reduce the efficiency and longevity of photosynthesis, resulting in assimilate shortage (Hampton, 1983). Lodging often also encourages vegetative growth at the expense of reproductive growth (Hampton, 1983), and can result in increased flower abortion (Kinet, 1977), decreased fertile branch numbers (at high density) and to reduced seedhead and seed numbers.

Seed number m^{-2} of cv. Kurenai was well related to seed yield m^{-2}. However, the variance was only 3 % greater when related to seedhead numbers, because differences in the number of seeds per seedhead were not significant. In contrast, seed number was more strongly related to seed yield m^{-2} than seedhead numbers in cv. Powderpuff and seed weight m^{-2} gave the greater variance because seed weight reduction with plant density did not occur linearly as found in cv. Kurenai. This meant that the yield at very high plant density did not drop as expected, but showed a parabolic plateau. This may be attributed to effects of the vacant or unplanted centre of the radial trial, where the highest populations were planted. Interference from this unplanted centre has previously been reported by Escasinas (1984) and by Chanprasert (1988). Although attempts were made in the present experiment to overcome this problem by using four rows of plants as a border, these high density plants may have been able to utilize more light from the available space in the centre than the other plants at the intermediate densities, particularly for cv. Powderpuff. This difference between cultivars in light sensitivity was confirmed by the results of plant growth and stem length. A full centre planting is strongly recommended to avoid this possible confounding error.

Different flower types may be another cause of seed yield difference between cultivars. The short tubes of disk florets (which formed from five diminutive petals and fused together on all edges) in cv. Kurenai may allow pollination to occur by both selfing and crossing between the florets within or between flower heads, resulting in no significant difference in seed number among plant densities. On the other hand, as a result of plant breeding and selection to elongate the disk florets for double flower types, Powderpuff plants have disk florets with longer tubes. This may limit cross pollination (Gloyer, 1931) because the stigma and filaments are closed inside the tube, although there is a hole at the end of the tube. This may also have restricted bee activity. Honey bees (*Apis melliflera* L.) were introduced to the area for another study and also for pollinating pears growing in the next block of land. Powderpuff flowers were not visited by these bees but only by bumble bees (*Bombus spp.*) probably for nectar more than for pollen. In contrast, Kurenai flowers were continuously visited by honey bees. There are no reports available about pollination and the use of bees in this species. Research is required, and could be particularly useful for seed production of the single flower type of this species.

3.4.5 Seed production problems

Lodging was identified as a critical problem in cv. Powderpuff. Plant manipulation to prevent lodging was required and this was selected for further experiments (Chapter 5 and 6). A review by Herbert (1982) demonstrated that lodging imposes a large restriction on the yield, quality and profitability of wheat and barley. Although lodging occurred in both China aster cultivars, the severity and time of occurrence differed. Almost all Powderpuff plants were lodged at first flowering, which is a very sensitive time, as reproductive structures may fail to develop or embryos may abort (Boyer, 1988). Seed yield may be decreased up to 40 % in barley (Pinthus, 1973) and up to 60 % in perennial ryrgrass (Hebblethwaite *et.al.*, 1978). In cv. Kurenai, plants lodged after peak flowering and lodging was not as severe as in cv. Powderpuff, due to the difference in plant structure. Plants of cv. Powderpuff were taller, weaker and had heavier tops than cv. Kurenai. Root system and soil type can also increase lodging problems (Fifher and Dunham, 1984). Aster has a shallow fibrous root system, and was grown in soil which had become soft with rain before winds (Appendix 3.1) making plants more prone to lodge. High density plants tolerated wind better than low density plants because flower heads interlocked and supported each other (Appendix 3.5.2). This meant that the yield per plant at high density was not affected as much as at lower densities. In cv. Powderpuff, interlocking allowed plants to tolerate wind only for a short time. When flower heads were soaked by rain and consequently became heavier, they could no longer support each other. Flower heads may also be pulled apart by strong wind, resulting in seedhead loss.

Another serious problem associated with this experiment was the simultaneous germination of weeds with the crop. High population may be successfully utilized as a method of weed control and is used extensively in turf management (Janick, 1972). The increased shade produced by a dense cover of vigorous plants may permit the crop plant to outcompete weeds. However, effective herbicides are still required for China aster, as seedling growth is slow. Moreover the delicate seedlings can be easily damaged in the process of hand weeding and are poor competitors with weeds for moisture, nutrients and light depending on weed type (Kuhn and Haramaki, 1985). Selective herbicides can be helpful and extremely useful for field production. Some herbicides were evaluated and data are presented in Chapter 4.

A high population level for increasing seed yield may have an adverse effect on disease control. The dense cover produced by plants grown at close spacing may discourage rapid drying and may produce conditions favorable for the growth of many fungi (Thomson, 1979). As well it may be impenetrable to spray application which limits the success of chemical disease control. The past history of China aster has shown that several commercial growers have had to discontinue aster culture because of disease problems, particularly fusarium wilt (Post, 1950, Ball, 1985). Wilt resistant strains and avoidance of the same planting area for successive crops are suggested (Walls, 1982; Ball, 1985).

CHAPTER 4

AN EVALUATION OF SOME SELECTED HERBICIDES FOR USE IN CHINA ASTER SEED PRODUCTION.

4.1 INTRODUCTION

4.1.1 Problems

Weed control is an essential aspect of the production of all horticultural crops. Weeds compete with ornamentals for nutrients, water, space, and light, resulting in slower growth and poor quality plants. Such competition has been reported to cause between 47% to 75% loss, depending on weed species and density (Fretz, 1973). Weeds in cut flower crops are also troublesome, particularly in those crops grown under field conditions, since they tend to be more susceptible to weed infestation which is not as easily controlled as it is for cut flower crops produced in glasshouses (Watkins, 1986). Weed competition has resulted in yield and flower panicle quality reduction in statice (Hatterman *et.al.*, 1987); unattractive and displeasing bedding plant displays or landscapes (Costello and Elmore, 1987) and seed yield reduction in sunflower (Johnson, 1971).

Mechanical cultivation in flower crops is generally injurious to the shallow rooting system (Gilreath, 1989) and rosette growth form (Hatterman *et.al.*, 1987; Johnson, 1972). Moreover, mechanical weed control or inter-row cultivation is often impractical at the narrow row spacings used (Gilreath,1986), and hand weeding is laborious and in most cases expensive (Fretz, 1972; Davidson and Robert,1976; Gilreath, 1989), resulting in lower profit potential for the grower (Singh *et.al.*, 1984; Yadav and Bose, 1987). Lamont *et.al.* (1985) estimated that labour costs for manual weeding in Australia can exceed $A 10,000 per hectare, depending on the severity of the weed infestation. Soil fumigation controls most weeds and many soil-borne diseases but the cost can exceed $ 4000 per hectare (Lamont and O'Connell, 1986).

4.1.2 Use of herbicides

Raulston and Waters (1971) suggested the use of herbicides as an alternative way of controlling weeds, by preventing them from germinating. Herbicides can generally give more complete weed control in transplanted annual flowers (Fretz, 1976) and are particularly effective in the establishment of young direct seeded crops (Kinsella, 1978). Since young aster plants grow slowly and compete poorly with weeds, successful seed production will require the development of effective herbicide treatments. But the majority of herbicides available have been developed for use on large scale crops such as cotton, rice, or wheat. Few, if any herbicides, have been developed specifically for small scale crops such as cut flowers, particulary in a minor group like China aster. Weed control in cut flowers is often evaluated by conducting field trials to test the effectiveness and safety of herbicides in their own sites of production (Lamont, 1986). The results can be viewed only as a progress report and unfortunately, many of these herbicides may not have registration for use in flower crops (Agamalian, 1987).

Over the last few years herbicides have been registered specifically for the control of weeds in container grown ornamentals. Some herbicides have been evaluated for phytotoxicity and weed control on aster. Unfortunately, aster appears to be injured by many of the herbicides commonly used and chemically effective on other ornamentals. Brosh *et.al.* (1973) reported scorching of aster by oxadiazon (25 % e.c.) at 1.25 kg a.i. ha^{-1}, and chloroxuron (50% w.p.) at 2.0 kg a.i. ha^{-1} inhibited aster growth. Oxyfluorfen also caused severe scorching and stunting in aster (Lamont and O'Connell, 1986). Amos (1980) suggested that chlorpropham (1 kg a.i. ha^{-1}) or simazine (0.5 kg a.i. ha^{-1}) could be used for weed control in established aster plants. Haramaki and Kuhns (1984) concluded that China aster could tolerate the manufacturer's recommended rates of oryzalin and chlorpropham. Oryzalin provided excellent broad spectrum weed control (Bowman, 1983) without adversely affecting crop vigour in approximately 500 woody and 80 herbaceous ornamental genera/cultivars treated (Wilson and Hughes, 1985). Trifluralin at 1.8 kg a.i. ha^{-1} applied 3 days after planting has been shown to have no adverse effects on transplanted aster, but only provided moderate weed control (Brosh *et.al.* 1973). Similar results were found when trifluralin was used at 1 kg a.i. ha^{-1} applied pre-planting and soil incorporated mechanically, or at 2 kg a.i. ha^{-1} post-planting followed by sprinkler irrigation, applied either before, immediately after, or 1-2 months after planting (Brosh *et.al.*, 1976). Alachlor at 1.125 kg a.i. ha^{-1} does not significantly reduce shoot weight and, even at twice this rate, has been found to be safe on transplanted aster (Lamont and O'Connell, 1986).

4.1.3 Objectives

Weed pressure at the site used in this study was very high because the land had been left fallow after orchard trees had been removed. A freshly tilled soil, with the high moisture and nutrient levels required for growth of aster transplants creates an ideal environment for invading weeds. The choice of herbicide for a particular situation will depend upon several variables including climate, soil type, prevalent weed species, crop cultivar and method of propagation and management (Stephens, 1982). Limited information is available on herbicides for effective weed control in aster crop production, and none was available for this experimental site. It is also clear from the experiment of Lamont (1986) that flower species belonging to the same plant family may be affected in different ways by a particular herbicide. It would therefore not appear possible to predict the safety of a herbicide to use at this site from available published data if they existed. Three experiments were conducted during 1987 and 1988 to identify herbicides which would provide good weed control without seed yield reduction, and which would not be phytotoxic to aster plants grown either as transplanted seedlings or direct-seeded. The first experiment was designed to evaluate injury damage only, whereas the second and third experiments were designed to evaluate weed control and phytotoxicity.

4.1.4 Weed species

All weeds at this field site were common weeds of New Zealand. There were some grasses but the broadleaved weeds dominated. Major weeds present in the field included redroot (*Amaranthus powellii*), prostrate amaranth (*Amaranthus deflexus*), black nightshade (*Solanum nigrum*), willow weed or red shank (*Polygonum persicaria*), nettle (*Urtica urens*), sow thistle (*Sonchus oleraceus*), docks (*Rumex spp.*), field speedwell (*Veronica arvensis*), white clover (*Trifolium repens*), shepherd's purse (*Capsella bursa-pastoris*), groundsel (*Senecio vulgaris*), dandelion (*Taraxacum officinale*), spurrey (*Spergula arvensis*), knot grass or wireweed (*Polygonum aviculare*) and pelty spurze (*Euphorbia peplus*).

4.1.5 Herbicide information

The herbicides used for this study were selected from relevant publications (Brosh *et.al.*, 1973; Brosh *et.al.*, 1976; Amos, 1980; Bowman, 1983; Haramaki and Kuhns, 1984; Wilson and Hughes, 1985; Lamont and O'Connell, 1986) and manuals for bedding plant culture (Kuhns and Haramaki, 1985) and plant protection (O'Connor, 1990). Although broadleaved weeds dominated in the areas used, some grasses were also present and as the previous crops at the site were wheat and oats, effective grass control herbicides were also considered.

The five selected herbicides were:

Alachlor -a pre-emergence herbicide for control of annual grass and some broadleaf species (e.g. redroot, black nightshade). It is taken up by shoots of emerging seedlings. Rain or irrigation is required within 10 days of application to activate the herbicide (O'Connor, 1990).

Chlorpropham -a pre-emergence herbicide labelled for many crops and a variety of bedding plants included aster (Kuhns and Haramaki, 1985). It controls many grasses and broadleaved weeds (e.g. dock seedlings, willow weed, paspalum, wire weed, speedwell, spurrey and black nightshade). It is taken up by the emerging shoots of seedlings and through the roots of older plants. Adequate soil moisture (rainfall or irrigation) is necessary for effective weed control (O'Connor, 1990).

Oryzalin -a selective pre-emergence surface applied herbicide for the control of most annual grass and some broadleaved weeds. Susceptible weeds include red root, field speedwell, nettle, shepherds purse, willow weed and wire weed. The control of black nightshade and groundsel is variable. It does not control established plants but affects germination after being taken up by roots of germinating seedlings. It is non-volatile so that it can be applied during any season but rainfall or overhead irrigation is required within 7-10 days of application to activate oryzalin (Kuhns and Haramaki, 1985; O'Connor, 1990).

Simazine -a selective pre-emergence herbicide for weed control in many horticultural crops. It is very effective in preventing the germination of a wide range of annual and perenniel grass and broadleaved weeds but has little effect on established weeds. Label advice is that only small areas should be initially treated to establish safety on each species. Rain or irrigation is needed to move the chemical into the soil as simazine is root absorbed by the germinating weeds. The soil residual life ranges from 3-12 months depending on rate, soil type and rainfall (O'Connor, 1990).

Trifluralin -a pre-plant herbicide for selective weed control in many crops, included aster and many other bedding plants (Kuhns and Haramaki, 1985). It controls a wide range of annual grass and broadleaved weeds included Amaranth species, wireweed, nettle, spurrey and wild portulaca. It is volatile and must be soil incoporated to a depth of two to three inches, or followed by irrigation immediately after application (O'Connor, 1990). The residual effectiveness is about six weeks (Kuhns and Haramaki, 1985).

4.2 EXPERIMENT 1 : PRELIMINARY STUDY OF INJURY EFFECTS

In 1987, a preliminary experiment was conducted in a glasshouse to select non injurious herbicides and appropriate application rates, which were then further evaluated in the field.

4.2.1 MATERIALS AND METHODS

4.2.1.1 Treatments

Treatments included :

Control	: untreated.
Alachlor	: containing 500 g litre^{-1} emulsifiable concentrate of 2-chloro-N-(methoxymethyl) acetamide applied at 1.125 kg a.i. ha^{-1}.
Chlorpropham	: containing 400 g litre^{-1} emulsifiable concentrate of isopropyl 3-chlorophenyl carbamate applied at 1 kg a.i. ha^{-1}.
Oryzalin	: containing 750 g kg^{-1} wettable powder of 4-(dipropylamino)-3, 5-dinitrobenzenesulfonamide applied at 3 kg a.i. ha^{-1}.
Simazine	: containing 500 g litre^{-1} suspension of 6-chloro-N,N-diethyl-1,3,5-triazine-2,4-diamine applied at 0.25 kg a.i. ha^{-1}.

4.2.1.2 Establishment

Glasshouse trial

Aster seeds (*Callistephus chinensis* L.Nees.) cv. Kurenai were glasshouse sown in a 30x40x6 cm tray filled with Smith's potting mix containing peat, pumice and sand (Smith Soil Industries Limited, Auckland, New Zealand) on 20 October 1987. The glasshouse temperature was 25±5 °C. After 14 days, seedlings were transplanted into 8 cm pots containing the same medium at one seedling per pot. This procedure was repeated again using cv. Powderpuff on 9 November 1987 so that two seedling age groups (44 and 24 days) were available for spraying on 3 December 1987.

Pots were spaced 25x25 cm apart. Herbicides were sprayed over the top of the pot on an area basis via a portable 5 litre pressure sprayer. Treatments were allocated at random and replicated 6 times. There was one pot as one replicate of each treatment. Daily sprinkler irrigation began 24 h after herbicide application.

Field trial

The experimental site, soil preparation, germination procedure, handling of aster seedlings, transplanting and general management practices were identical to those described for the plant density experiment (Chapter 3). Seedlings of cv. Kurenai were transplanted into the field on 27 November 1987 and of cv. Powderpuff on 17 December 1987. All plants were of the same seedling age (38 days old), but the number of days after transplanting differed when sprayed on 22 December 1987 (i.e. 25 and 5 days after transplanting for cv. Kurenai and cv. Powderpuff respectively). The same herbicides at the same rates as used in the glasshouse trial were applied in 0.5 l water per plot with the same sprayer, but the herbicides were sprayed between the plant rows to minimize direct plant contact.

A completely randomized design with three replicates of each treatment (including an untreated control) was used for each cultivar. Plot size was 1x2.5 m^2, and plant spacing was 25x25 cm, so that there were 40 plants per plot. Field layout is shown in Appendix 3.5

4.2.1.3 Data collection

Visual injury effects were observed and described at 1, 2, 4 and 6 weeks after spraying in the glasshouse trial, and after 2 and 4 weeks in the field trial.

The number of weeds in the field trial at 30 days after spraying was determined by counting those present within a 0.1 m^2 quadrat placed at random in two positions within each plot. The mean of these two counts became the estimate of weed number. Weeds counted were converted to number m^{-2} before being square root transformed to overcome marked variance heterogeneity (Snedecor and Cochran, 1980).

4.2.2 RESULTS

Glasshouse trial

By 1 week after spraying, 24 day old Powderpuff seedlings sprayed with simazine were dying (Figure 4.1) and both 24 (Powderpuff) and 44 (Kurenai) day old seedlings were dead after 2 weeks (Figures 4.2 and 4.3).

Alachlor caused leaf necrosis in seedlings of both cultivars especially at the leaf tip and the margin of young leaves. It had produced distorted growth by one week after application, which had become very obvious at 4 weeks after spraying (Figure 4.4). However, there were no effects on new shoot growth, or the flower head (Figure 4.5).

No phytotoxicity was recorded at any time following chlorpropham or oryzalin applications.

Field evaluation trial

No herbicide provided complete control of the weed species present, but oryzalin and simazine significantly reduced weed numbers (Figures 4.6 and 4.7) when applied 5 days after transplanting aster seedlings. However alachlor and simazine produced leaf necrosis, and although the symptoms were not as severe as those recorded in the glasshouse and aster plants recovered from this injury, their subsequent growth was checked.

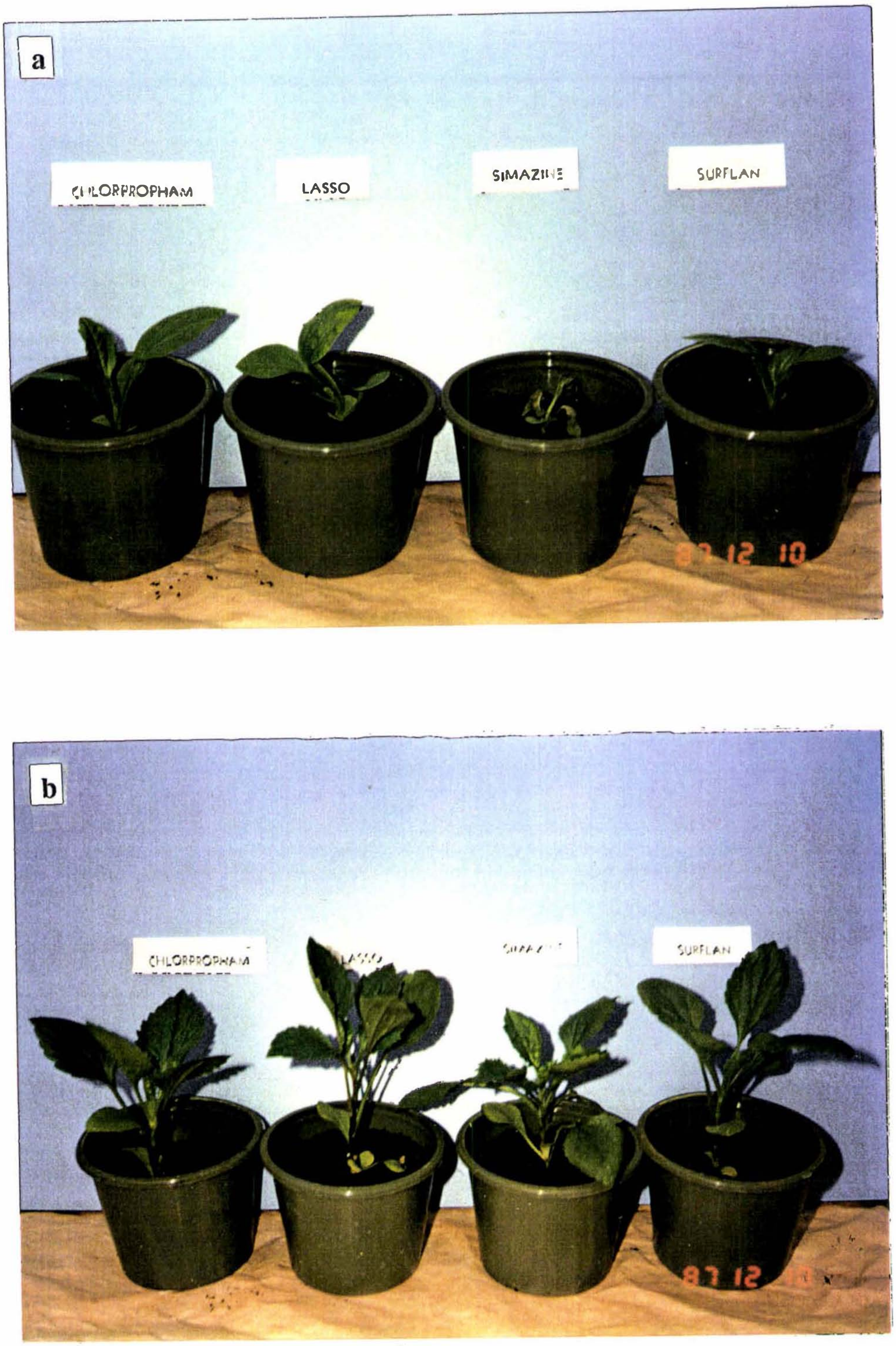


Figure 4.1 Effects of herbicides on aster seedlings a) 24 day old cv. Powderpuff and b) 44 day old cv Kurenai at one week after spraying.

Figure 4.2 Effects of herbicides on 44 day old seedlings of aster cv. Kurenai at two weeks after spraying.

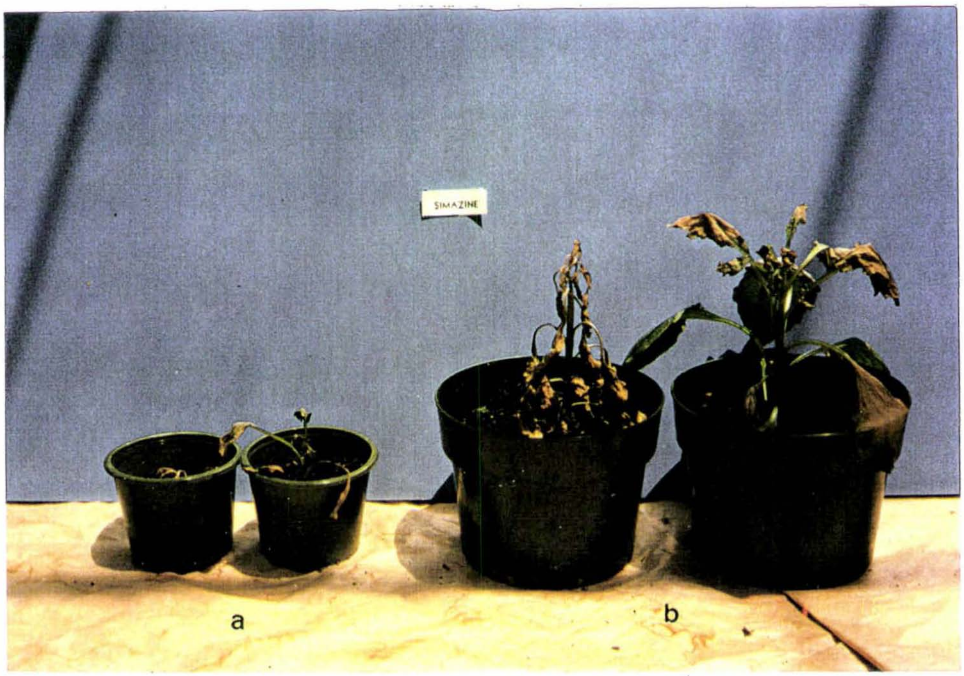


Figure 4.3 Simazine damage on aster seedlings a) 24 day old cv. Powderpuff and b) 44 day old cv. Kurenai at two weeks after spraying.

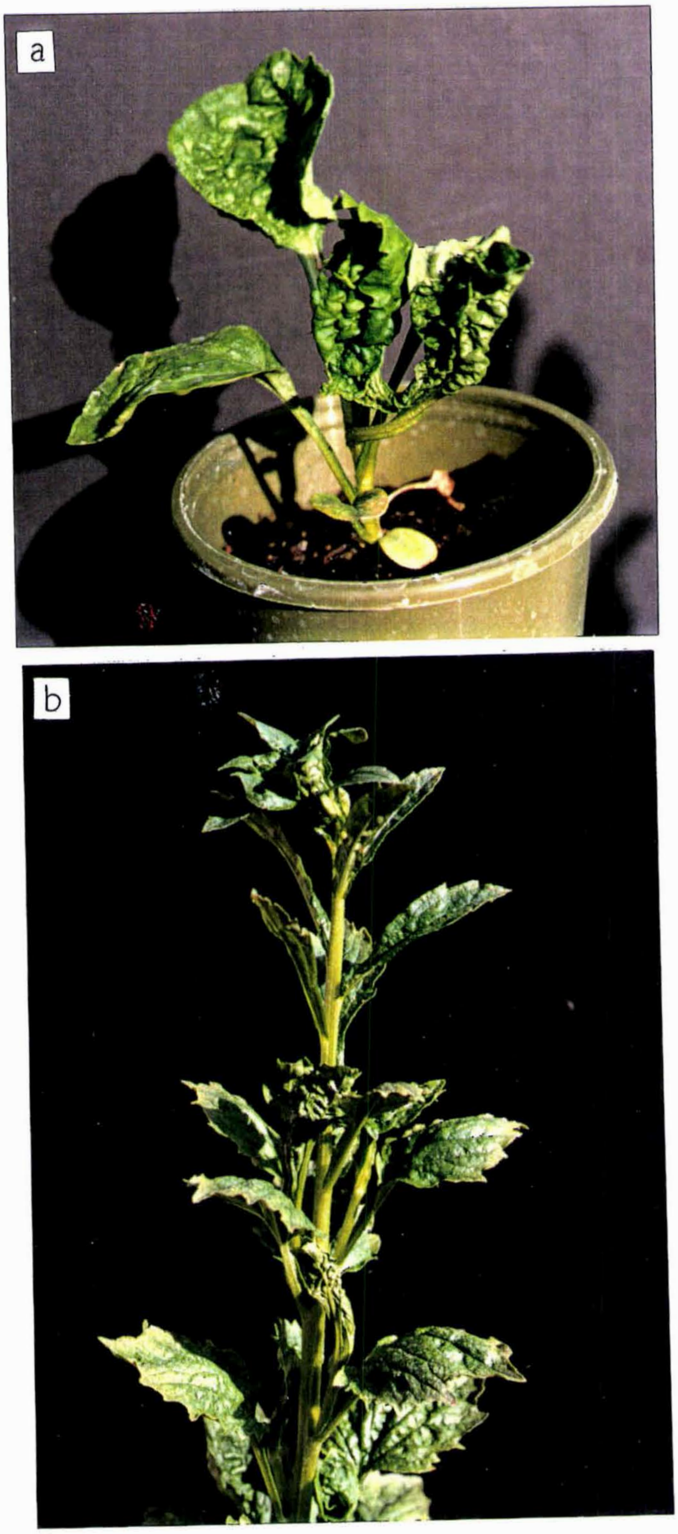


Figure 4.4 Effects of alachlor on aster seedlings a) 24 day old cv. Powderpuff and b) 44 day old cv. Kurenai at four weeks after spraying.

Figure 4.5 No alachlor damage found on a) new shoot growth of aster seedling cv Powderpuff at six weeks after spraying and b) aster flower head of both cv. Powderpuff and cv. Kurenai.

Figure 4.6 Field evaluation trial of herbicide application on 5 day transplanted aster seedlings (cv. Powderpuff) at a) 2 and b) 4 weeks after spraying.

Only simazine caused some damage (discoloration) when applied to seedlings 25 days after transplanting, but this effect disappeared within a short time. None of the herbicides were able to totally control all weeds (Figure 4.8), suggesting that for effective weed control, application must either be very soon after transplanting, or pre-transplanting.

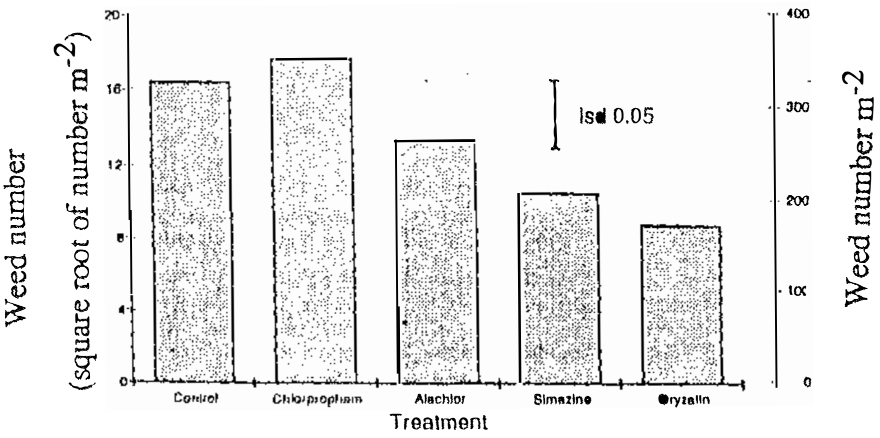


Figure 4.7 Effects of herbicide application (sprayed 5 days after aster transplanting) on weed number in aster cv. Powderpuff at four weeks after spraying.

Figure 4.8 Field evaluation trial of herbicide application on 25 day transplanted aster seedlings (cv. Kurenai) at 4 weeks after spraying.

4.3 EXPERIMENT 2 : WEED CONTROL

4.3.1 MATERIALS AND METHODS

As chlorpropham and oryzalin did not damage transplanted asters in the initial trials, their efficacy for weed control was further evaluated in 1988, with i) transplanted aster and ii) in a further experiment with direct sown asters, to check whether these herbicides had any adverse effects on either germination or early vegetative growth of aster plants.

Higher application rates of these two herbicides were also evaluated, because weed control, particularly with chlorpropham, had not been good in 1987. Trifluralin [400 g litre^{-1} emulsifiable concentrate of 2,6-dinitro-N,N-dipropyl-4-(trifluoro methyl)] benzenamine] which had been used during soil preparation in all plots in the previous year's experiment was omitted from this subsequent trial as a general soil preparation, but was included as one treatment in this experiment to check on its effectiveness and phytotoxicity.

4.3.1.1 Treatments

Transplanted aster

Treatments were

Control : untreated.
Trifluralin at 2 kg a.i. ha^{-1} applied 1 day before transplanting.
Chlorpropham at 2 kg a.i. ha^{-1} applied 1 day before transplanting.
Oryzalin at 3.75 kg a.i. ha^{-1} applied once at 4 days after transplanting.
Oryzalin at 3.75 kg a.i. ha^{-1} applied twice at 4 and 30 days after transplanting.
Trifluralin at 7 kg a.i. ha^{-1} applied 1 day before transplanting plus oryzalin at 3.75 kg a.i. ha^{-1} applied 30 days after transplanting.

Treatments were assigned to 1x2 m^2 plots arranged in a randomized complete block design with three replicates. Field layout is presented in Appendix 5.2. Each plot was separated by a single guard row.

Direct sown aster

Treatments were the same as those for the transplanted aster, except for treatments with oryzalin. Because of the unexpected slow and uneven aster emergence, the first oryzalin application was delayed until 30 days after aster seeds had been sown, and the second was applied at 60 days after sowing.

4.3.1.2 Establishment

Transplanted aster

Powderpuff aster seeds were glasshouse sown on 14 October 1988 and raised in root-trainers as described for the growth retardant experiment (Chapter 5). Details of soil preparation, experiment site and general cultural practices are also given in Chapter 5. Seedlings were planted at a 25x25 cm spacing in the field on 23 November 1988 with 32 plants per plot.

Direct sown aster

An adjacent area was used for direct sowing. Aster seeds [92 % germination at 20 °C TP. (ISTA, 1985)] were thiram dusted and hand sown at 50 seeds per 2 m row. There were four rows in each 1x2 m plot. Row spacing was 25 cm.

All plots of both transplanted and direct sown aster were overhead sprinkler irrigated immediately after planting or sowing, within 30 minutes of herbicide application and weekly thereafter at a rate of 6000 litres water ha^{-1} h^{-1}.

4.3.1.3 Data collection

Transplanted aster

Weed numbers per square metre were obtained by converting the mean of 2 random counts from a 0.1 m^2 quadrat one month after planting as previously described in experiment 1. Seed heads from 0.75 m^2 per plot (excluding border rows) were hand harvested on 7 April 1989, and left to air-dry under shade for 2 weeks before being threshed and separated by hand. Seed yields were corrected to 7% seed moisture content, converted to seed yield per square metre and log transformed before analysis.

Direct sown aster

Assessments of number of weeds per square metre were carried out one month after sowing using the same method as in the transplanted aster experiment. All weeds were hand removed after the number of weeds had been counted. Aster seedlings that showed one true leaf were recorded as emerged on the same day as the weed counting. Seedling emergence data were calculated as a percentage and analysed untransformed. No data were recorded after the second oryzalin application because weed growth was too advanced for oryzalin to be effective.

4.3.2 RESULTS

Transplanted aster

All treatments except chlorpropham significantly decreased weed numbers (Table 4.1) and no treatment injured aster seedlings. Oryzalin was the most effective herbicide, but there was no difference in the degree of control offered by one or two applications. Trifluralin+oryzalin gave better weed suppression than trifluralin alone (Figures 4.9-4.10 and Table 4.1). Oryzalin provided control of all weed species except for docks, while trifluralin did not control black nightshade, docks, white clover or shepherd's purse.

Seed yield was related to the degree of weed control in that oryzalin and trifluralin plus oryzalin significantly increased seed yield, through increasing the number of seed heads m^{-2} (Table 4.1). The single application of oryzalin produced a seed yield (56.8 g m^{-2}) ten times greater than that of the control (5.1 g m^{-2}). Seed head number was reduced by trifluralin and chlorpropham, but seed yield did not differ from the control (Table 4.1).

Table 4.1 Effect of herbicide application on weed control and seed yield in transplanted aster cv. Powderpuff.

Treatment	Rate (kg a.i. ha^{-1})	Weeds (m^{-2})	Aster seed heads (m^{-2})	Aster seed yield (g m^{-2})
Control		1560 a	63 c	5.1 c
Trifluralin[1]	2.0	597 b	20 d	1.8 c
Chlorpropham[1]	2.0	1540 a	34 d	2.8 c
Oryzalin[2]	3.75	23 d	329 a	56.8 a
Oryzalin[2] + oryzalin[3]	3.75 3.75	23 d	317 a	44.5 a
Trifluralin[1] + oryzalin[3]	7.0 3.75	137 c	153 b	22.0 b

Values with the same letter(s) indicate no significant difference ($P \leq 0.05$) based on analysis after transformation. Actual data given.

[1] applied 1 day before planting and washed into the soil via sprinkler irrigation

[2] applied 4 days after planting

[3] applied 30 days after planting

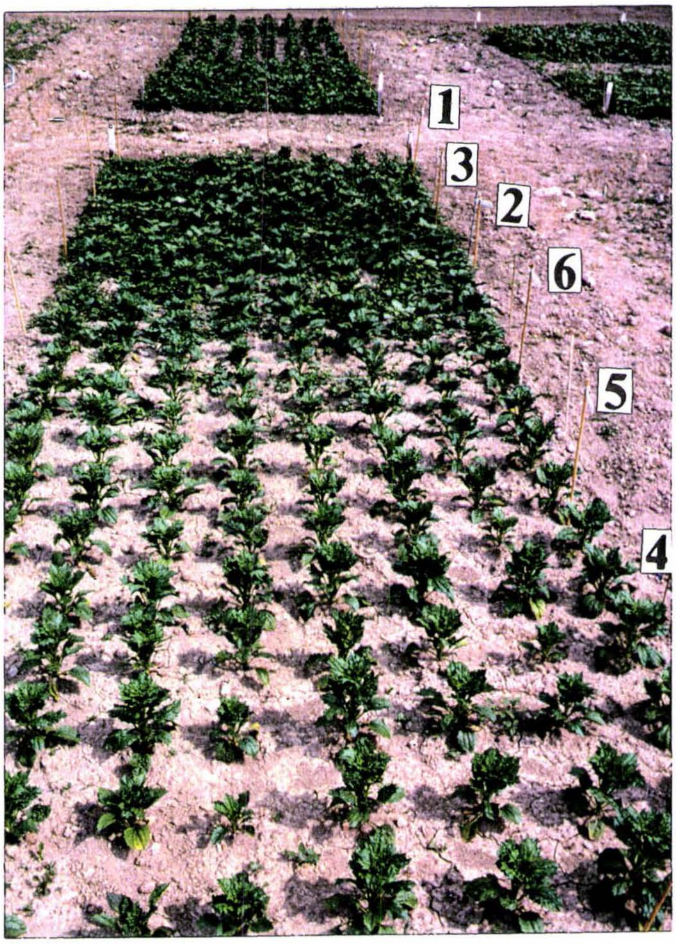


Figure 4.9 Effects of herbicide application on transplanted aster cv. Powderpuff.

1 = untreated control
2 = trifluralin 2.0 kg ai ha^{-1}
3 = chlorpropham 2.0 kg ai ha^{-1}
4 = oryzalin 3.75 kg ai ha^{-1}
5 = oryzalin 3.75 kg ai ha^{-1} + oryzalin 3.75 kg ai ha^{-1}
6 = trifluralin 7.0 kg ai ha^{-1} + oryzalin 3.75 kg ai ha^{-1}

Figure 4.10 Effects of herbicide application on transplanted aster cv Powderpuff at peak flowering.

1 = untreated control
2 = trifluralin 2.0 kg ai ha^{-1}
3 = chlorpropham 2.0 kg ai ha^{-1}
4 = oryzalin 3.75 kg ai ha^{-1}
5 = oryzalin 3.75 kg ai ha^{-1} + oryzalin 3.75 kg ai ha^{-1}
6 = trifluralin 7.0 kg ai ha^{-1} +oryzalin 3.75 kg ai ha^{-1}.

Direct sown aster

For direct sown aster, trifluralin and trifluralin plus oryzalin provided the best weed control (Table 4.2 and Figure 4.11). Trifluralin at an application rate of 2 kg ha^{-1} did not harm young plants and seedling numbers did not significantly differ from the control, but the higher rate (7 kg ha^{-1}) was phytotoxic (Table 4.2), significantly reducing seedling emergence. Chlorpropham also reduced seedling numbers. In contrast to the transplant trial, oryzalin provided no control. Although it was not phytotoxic to the well established aster seedlings, the delay in application meant that weed growth was too advanced for oryzalin to be effective.

Table 4.2 Effect of herbicide application on weed control and seedling emergence in direct sown aster cv. Powderpuff.

Treatment	Rate (kg a.i. ha^{-1})	Weeds (m^{-2})	Aster seedlings (%)^4
Control		840 ab	40 ab
Trifluralin^1	2.0	390 c	32 bc
Chlorpropham^1	2.0	650 b	25 cd
Oryzalin^2	3.75	950 a	49 a
Oryzalin^2 + oryzalin^3	3.75 3.75	880 a	44 ab
Trifluralin^1 + oryzalin^2	7.0 3.75	110 d	16 d

Values with the same letter(s) indicate no significant difference ($P \leq 0.05$) based on analysis after transformation. Actual data given.

[1] applied 1 day before sowing and washed into the soil via sprinkler irrigation

[2] applied 30 days after sowing

[3] applied 60 days after sowing

[4] seedlings as a percentage of seed sown.

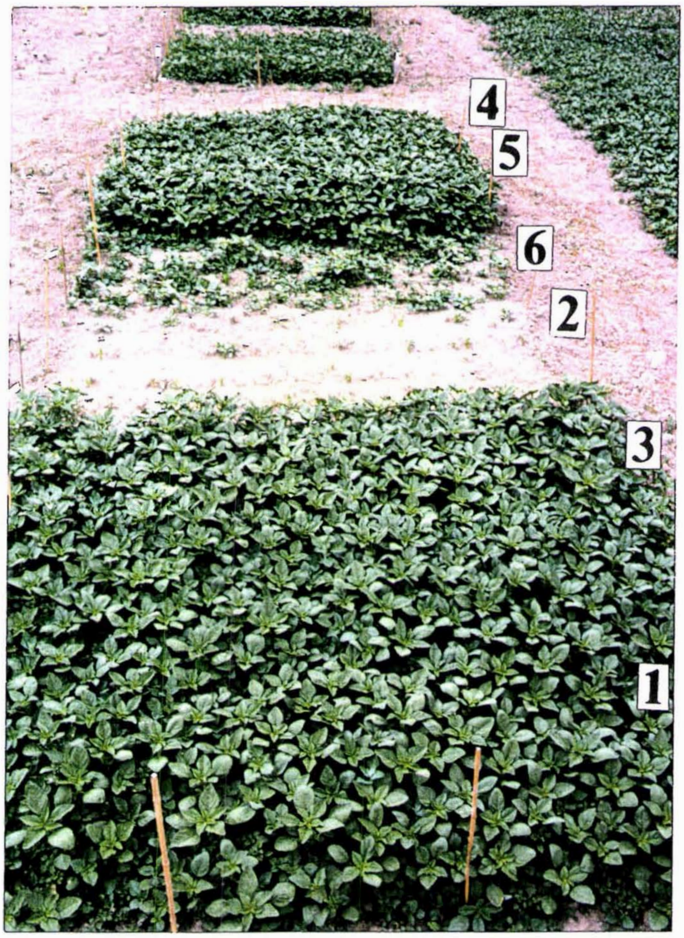


Figure 4.11 Effects of herbicide application on direct sown aster cv. Powderpuff.

1 = untreated control
2 = trifluralin 2.0 kg ai ha^{-1}
3 = chlorpropham 2.0 kg ai ha^{-1}
4 = oryzalin 3.75 kg ai ha^{-1}
5 = oryzalin 3.75 kg ai ha^{-1} + oryzalin 3.75 kg ai ha^{-1}
6 = trifluralin 7.0 kg ai ha^{-1} + oryzalin 3.75 kg ai ha^{-1}

4.4 EXPERIMENT 3 : ORYZALIN IN DIRECT SOWN ASTER

Oryzalin showed no adverse effects on transplanted aster seedlings and provided excellent weed control which lasted the entire season. It would be useful if oryzalin could also be used in direct sown aster. However, as a pre-emergence herbicide, oryzalin can inhibit aster as well as weed seed germination, while delaying oryzalin application until aster seeds had germinated and seedlings were well established (one month after sowing) was also too late for effective weed control as shown in the previous experimental results. A further experiment was therefore set up to find out how early oryzalin could be applied to aster seedlings after emergence, and what rates could be used.

4.4.1 MATERIALS AND METHODS

4.4.1.1 Treatments

Treatments were:

Control : untreated.
Oryzalin : 3.0 kg a.i. ha^{-1} applied immediately after sowing.
Oryzalin : 3.75 kg a.i. ha^{-1} applied immediately after sowing.
Oryzalin : 4.5 kg a.i. ha^{-1} applied immediately after sowing.
Oryzalin : 4.5 kg a.i. ha^{-1} applied at 4 days after sowing (DAS).
Oryzalin : 4.5 kg a.i. ha^{-1} applied at 10 DAS.

4.4.1.2 Establishment

Powderpuff aster seeds were direct sown into the field on 30 December 1988 using the same method and design as in the first direct-seeded experiment (Experiment 2).

4.4.1.3 Data collection

Aster seedling emergence was recorded on 24 January 1989 (25 DAS) and weed counts were made 2 days later. Survival of aster seedlings was recorded again on 22 February 1989 (54 DAS) and then four seedlings per plot were removed at random, washed, and leaf number and root and shoot length (including leaf) were recorded.

Plants were then dried to a constant weight (3 days at 65 °C). Means of four plants (DW) were transformed as log of DW+1 before analysis. Data for weed number were transformed and analysed, as for experiment 2. Seedling emergence and survival percentage, leaf number, length and width and root and shoot length were analysed untransformed.

4.4.2 RESULTS

Oryzalin at 4.5 kg ha^{-1} applied 4 days after sowing gave the best weed control but resulted in lower seedling emergence and poorer aster plant survival (Table 4.3). Oryzalin at the same rate applied 10 days after sowing provided only moderate weed control but had no negative effects on aster seedling emergence or survival, and allowed the production of larger and more vigorous aster plants (Figure 4.12 and Table 4.4) in that shoot length, root length, leaf length and leaf width were increased. Oryzalin applied at sowing significantly reduced both weed numbers and aster seedling emergence, irrespective of application rate. However more of those aster seedlings which did emerge survived (Table 4.3).

Table 4.3 Effect of oryzalin application rate and time on weed control, field emergence and seedling survival of direct sown aster cv. Powderpuff.

Treatment	Rate (kg a.i. ha^{-1})	Weeds (m^{-2})	Aster emergence[4]	Aster survival[5]
Control		843 a	100.0	56.5
Oryzalin[1]	3.0	133 c	43.8	81.9
Oryzalin[1]	3.75	150 c	39.0	74.8
Oryzalin[1]	4.5	80 cd	35.6	74.1
Oryzalin[2]	4.5	33 d	63.5	40.0
Oryzalin[3]	4.5	577 b	94.6	83.2

Values with the same letter(s) indicate no significant difference ($P \leq 0.05$) based on analysis after transformation. Actual data given.

[1] applied at sowing

[2] applied 4 days after sowing

[3] applied 10 days after sowing

[4] percentage of control

[5] percentage of emerged seedlings

Table 4.4 Plant dry weight, leaf number, shoot length, root length, leaf length and leaf width of direct sown Powderpuff aster seedling.

Treatment	Rate ($kg ai ha^{-1}$)	Plant DW (g)	Leaf number	Shoot length (cm)	Root length (cm)	Leaf length (cm)	Leaf width (cm)
Control		0.15 c	6.3 b	11.1 bc	3.9 c	9.4 c	3.5 c
Oryzalin[1]	3.0	0.49 ab	11.0 a	13.8 ab	6.7 b	12.2 ab	5.1 ab
Oryzalin[1]	3.75	0.45 b	11.3 a	10.7 bc	7.2 b	9.4 c	4.6 b
Oryzalin[1]	4.5	0.41 b	10.0 a	10.4 c	7.2 b	10.0 bc	4.4 bc
Oryzalin[2]	4.5	0.42 b	10.7 a	10.1 c	6.4 b	9.4 c	4.4 bc
Oryzalin[3]	4.5	0.63 a	11.3 a	15.4 a	8.8 a	13.5 a	5.8 a

Values with the same letter(s) indicate no significant difference ($P \leq 0.05$) based on analysis after transformation. Actual data given.

[1] applied at sowing
[2] applied 4 days after sowing
[3] applied 10 days after sowing

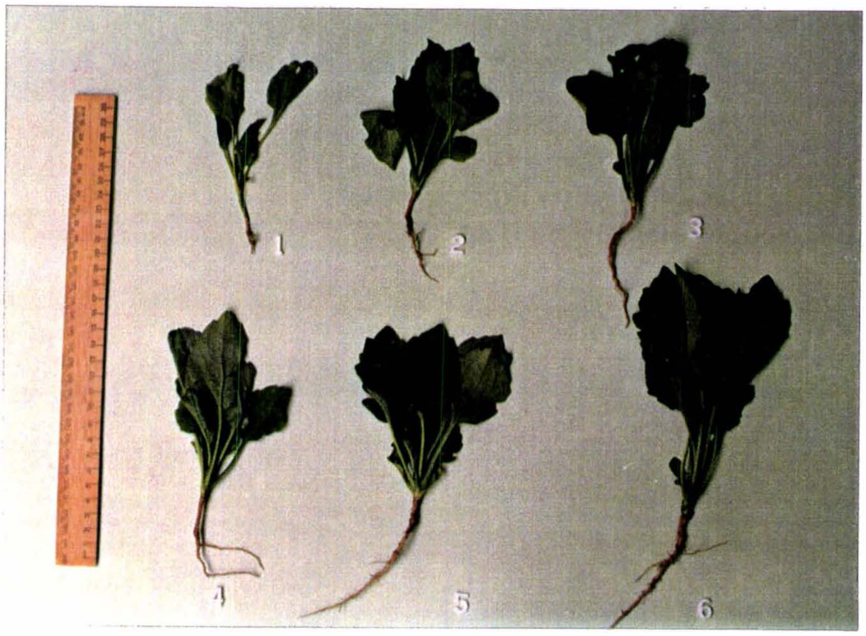


Figure 4.12 Effects of oryzalin application on seedling growth of China aster cv. Powderpuff.

1 = no application
2 = oryzalin 3.0 kg a.i. ha^{-1} immediately after sowing
3 = oryzalin 3.75 kg a.i. ha^{-1} immediately after sowing
4 = oryzalin 4.5 kg a.i. ha^{-1} immediately after sowing
5 = oryzalin 4.5 kg a.i. ha^{-1} 4 days after sowing
6 = oryzalin 4.5 kg a.i. ha^{-1} 10 days after sowing

4.5 DISCUSSION

4.5.1 Herbicides for transplanted aster

4.5.1.1 Injury effects

Both glasshouse and field studies showed that aster seedlings of all ages tolerated oryzalin and chlorpropham, confirming results by Haramaki and Kuhn (1984). On the other hand, alachlor and simazine injured aster seedlings. Neither young (24 day old) or old (44 day old) seedlings tolerated simazine at 0.25 kg a.i. ha^{-1}. Direct contact with alachlor produced malformation of young plant parts. Although subsequent vegetative plant growth and flower heads were unaffected by alachlor particularly in the field, both alachlor and simazine can not be recommended for post transplant application to aster because droplet drift may occur during spraying. Moreover a highly significant reduction in germination and early growth of direct sown aster has been also reported (Lamont, 1986). Trifluralin as has been previously demonstrated (Brosh *et.al.*, 1973; Brosh *et.al.*, 1976 and Mestre, 1981) was non phytotoxic to aster when applied pretransplant.

Damage symptoms on aster plants following simazine and alachlor application were less severe following application in the field than in the glasshouse. This may have simply reflected differences in herbicide application method. In the glasshouse herbicides were sprayed directly onto the plants and watering was not done until the following day. In the field, herbicide was sprayed directly onto the soil between plants to minimize direct contact followed by immediate overhead sprinkler application of water which would have washed herbicide from the plants.

4.5.1.2 Weed control

Application of oryzalin proved effective in controlling most weeds present at this site. A single application of oryzalin (3.75 kg a.i. ha^{-1} at 4 days after planting) provided residual effects long enough to control weeds until harvest. Marked reduction in the weed population lead to the better growth of the crop. In plots which were not treated with herbicide, plant growth was severely suppressed due to the presence of a larger number of weeds which competed with the crop for nutrients, moisture and particularly light (Figure 4.10). Seed yield also increased in treated plants due to the improved plant growth which ultimately resulted in the production of a greater number of seed heads. A ten-fold reduction in seed yield in untreated plots showed the importance of weed control in aster grown in this area.

Trifluralin also provided safe, efficacious weed control in aster (Figure 4.9) but an application rate of 2 kg a.i. ha^{-1} did not provide complete weed control and did not last the entire season. The higher rate of trifluralin (7 kg a.i. ha^{-1}) provided more weed control but the product did not control black nightshade or shepherds's purse. The taller weed plants suppressed aster plant growth, resulting in fewer seed heads and a significantly lower seed yield than in the oryzalin treatment.

Trifluralin and oryzalin are two of the top three herbicides recommended for use in ornamentals (based on price, weeds controlled and registrations) (Molinar, 1987). Both give good control of many grasses and broad leaved weeds. Oryzalin however has an advantage in terms of management simply because watering is not necessary for up to 3 weeks after application and it can provide effective residual control activity for up to 8 months depending on the rate. Trifluralin, however, provides residual weed control for 4-6 months and is registered for a larger number of ornamental species (Molinar, 1987).

The lack of control of late germinating weed seeds in the field trial (Experiment 1) indicated the need for either a higher rate at the initial application, or a second residual herbicide application to provide season-long weed control (Phetpradap and Hampton, 1991). Frequent irrigation which may be necessary to encourage vigorous plant growth also stimulates weed seed germination, and may reduce herbicide residual activity, due to excessive leaching (Whitcomb and Butler, 1975) and increased herbicide degradation (Elam-Wenzel, 1988). However late oryzalin application following both oryzalin or trifluralin did not further improve weed control, because vigorous weeds grew very rapidly and escaped from the activity of oryzalin by the time of the later oryzalin application (30 DAP). Some weeds (e.g. *Rumex sp.*) which grew from a strong regenerating crown, were not controlled by any rate of oryzalin or any of the other pre-emergence herbicides in this study. Spot spraying by a non residual post emergence herbicide may be needed for the removal of weeds not killed by the initial oryzalin application.

4.5.2 Herbicides for direct sown aster

4.5.2.1 Phytotoxicity

None of the herbicides used with direct sown aster provided effective weed control without also reducing aster emergence or establishment. Only trifluralin (2 kg ha^{-1} applied pre-sowing) was 'safe', but weed control was not complete. Oryzalin, which produced no adverse effects on transplanted aster, significantly inhibited aster germination, a result similar to that reported in other direct sown flower species (Lamont and O'Connell, 1986). No significant differences were found for aster seedling emergence between the three rates of oryzalin (3.0, 3.75 and 4.5 kg a.i. ha^{-1}) applied at sowing, but a delay in oryzalin application allowed aster seedling roots to grow deeper and escape the oryzalin activity. Oryzalin is registered as a pre emergence herbicide, which in general, is non-selective, killing both grass and broad leaved weeds by either inhibiting the germination process or by killing the very young weed seedlings, and may act similarly on germinating aster.

The low percentage field emergence obtained in the direct sown aster experiments was possibly due to environmental factors, particularly soil temperature and moisture. Small seeds need a fine seed bed to provide good water supply for germination, but in this experimental area small stones and gravel in a porous and unevenly compacted soil caused uneven germination, and aster seedlings developed slowly. This meant that the first oryzalin application in experiment 2 was delayed and the weeds were in a more advanced stage than would normally be expected.

4.5.2.2 Weed control

All herbicides used in direct sown experiments significantly reduced weed numbers, similar to the situation found in transplanted aster. Both 2 and 7 kg ha^{-1} of trifluralin gave moderate to good weed control but did not last the entire season. 'Escaped' weeds competed with aster plants in the same way as in transplanted asters.

Lower weed numbers were counted in the direct sown than in the transplanted experiment because of a difference in weed content and environment. High soil moisture retained by the transplant medium (the soil mix containing peat used for raising aster seedlings can hold more moisture than soil alone) and less moisture loss compared to the exposed soil surface in direct sown plots provided more favourable conditions for weed seed germination.

Due to the long growing season and slow aster growth, particularly during early plant establishment, direct sown aster crops may require multiple applications of herbicides, at least until the crop is itself able to offer some competition to further weed growth. In a further unreplicated investigation from this study, trifluralin at 2 kg ha^{-1} applied pre sowing followed up by oryzalin at 4.5 kg ha^{-1} 10 days after sowing provided good weed control without aster seedling damage (Phetpradap and Hampton, 1991). However, this herbicide combination requires further experimental confirmation. Where crops are grown on small areas and there is no labour problem, application of a mixture of oryzalin and a non residual post-emergence herbicide would be another alternative provided the application of this mixture was delayed until after aster seeds had germinated and seedlings were covered to avoid herbicide damage. A mixture of oryzain (4.5 kg a.i. ha^{-1}) and paraquat (0.2 kg a.i. ha^{-1}) offered effective weed control in direct sown aster in the following year's experiment (Chapter6).

4.6 CONCLUSION

For transplanted aster, a single application of oryzalin (3.75 kg a.i. ha^{-1} at 4 days after transplanting) provided excellent weed control and a tenfold increase in seed yield (to 568 kg/ha).

For direct sown aster, only trifluralin (2 kg a.i. ha^{-1}) applied pre-sowing did not significantly reduce aster emergence while oryzalin (4.5 kg a.i. ha^{-1} applied 10 days after sowing) provided the best aster seedling survival. However weed control from both treatments was only partial and further work is required on herbicide use in direct sown aster.

CHAPTER 5

EFFECTS OF PLANT GROWTH MANIPULATION ON CHINA ASTER SEED PRODUCTION

5.1 INTRODUCTION

5.1.1 Plant growth regulators

Chemical manipulation by the use of plant growth regulators has been reported to increase seed yield in several crop species; for example chlormequat chloride in *Triticum aestivum* (wheat), *Avena sativa* (oats) and *Hordeum vulgare* (barley) (Fletcher and Kirkwood, 1982; Kust, 1986); daminozide in *Trifolium pratense* L. (red clover) (Jakesova and Svetlik, 1986); paclobutrazol in *Lolium perenne* (perennial ryegrass) (Hampton and Hebblethwaite, 1985a), *Oryza sativa* (rice) (Early, 1982; Street *et.al.*, 1986), and in *Lotus corniculatus* L. and *Lotus uliginosus* Schkuhr (Hampton *et.al.*, 1989; Li, 1989). The significant effects of these growth regulators usually occur by reducing stem lodging following stem shortening and thickening, increasing fertile tiller numbers, increasing the synchrony of branching or tillering (Fletcher and Kirkwood, 1982; Kust, 1986), or by increasing seed numbers (Hampton, 1988).

5.1.2 Plant growth regulators in floriculture

The use of plant growth regulators for the manipulation of growth and development in floriculture is more intensive than in edible crops because of less stringent legislative requirements for chemical applications to non food crops, and the high economic value of floriculture crops. The desirable size and shape of flower, length and strength of stems, or the need for a product to be accurately timed for specific occasions, such as *Euphorbia pulcherrima* (poinsettias) for Christmas and *Lilium longiflorum* (Easter lily) for Easter, has also made them tempting targets for growth regulator applications.

Plant growth retardants, a group of plant growth regulating chemicals which primarily inhibit sub-apical cell division and elongation and hence reduce plant growth (Dicks, 1979), have been used commercially for height control in order to produce compact potted plants particularly in *Chrysanthemum* x *morifolium* (chrysanthemum), poinsettia and *Pelargonium* x *hortorum* (geranium), and for restricting plant size to extend the duration of attractiveness or saleable period of bedding plants (Cathey, 1975; Ball, 1985; Halevy, 1985; Larson, 1985; Mastalerz and Holcomb, 1985). They are also used as aids for manipulating the shape, size and form of many potential or new floricultural crops for more interesting options as potted plants (Hentig, 1985) such as *Camellia* x *Williamsii* (Wilkinson and Richards, 1988), *Dicentra spectabilis* (bleeding heart) (Davis and Anderson, 1989); *Zantedeschia rehmannii hyb.* (Tjia, 1987), *Clarkia amoena* (Anderson and Hartley, 1990) and *Freesia hybrida* (Wulster *et.al.*, 1989), as well as many native plants particularly from Australia and New Zealand.

Of the growth retardants available, daminozide, chlormequat chloride, ancymidol and paclobutrazol are used commercially in floriculture. All these growth retardants have been used with varying degrees of success on different plant species (Cathey and Stuart, 1961; Cathey, 1975; Shanks, 1980; Larson, 1985; Wilfret,1986; Bailey and Miller, 1989).

Physiological and biological effects of plant growth retardants have been studied extensively, and reviewed by Cathey (1964), Dicks (1979) and Davis *et.al.*, (1988). The primary effects of plant growth retardants are to inhibit the synthesis of gibberellins, although the sites of interference may be different with different chemicals (e.g. chlormequat chloride affects *ent*-kaurene synthetase A, while paclobutrazol inhibits the oxidation of *ent*-kaurene to *ent*-kaurenoic acid in the gibberellins biosynthesis pathway; Sponsel, 1987). In addition to inhibiting shoot elongation, many growth retardants exhibit other biological properties. As one example, the flowering of hybrid geranium cv. Sprinter Scarlet is accelerated by chlormequat chloride regardless of the time or number of applications (Miranda and Carlson, 1980). Growth retardant treated plants generally appear darker green than untreated controls (Armitage *et.al.*, 1984; Tezuka *et.al.*, 1989), and leaf senescence is delayed (Upadhyaya *et.al.*, 1985) which is an advantage in foliage plants (e.g. *Pilea cadierei*) used in interior landscapes (Cox and Whittington, 1988). Better resistance to environmental stresses and atmospheric pollution has also been reported (Cathey, 1964; Nickell, 1982). For example daminozide has been reported to increase drought resistance in sunflowers (Martin and Lopushinsky, 1966), and smog resistance in petunias (Cathey *et.al.*, 1965), and paclobutrazol has been found to protect *Phaseolus vulgaris* plants from damaging levels of sulphur dioxide (Lee *et.al.*, 1985).

Chlormequat chloride

Chlormequat chloride (2 chloroethyl trimethylammonium chloride; CCC, cycocel, chlormequat) is used commonly for height regulation of hybrid geraniums (Semenuik and Taylor, 1970; Semenuik, 1978; Miranda and Carlson, 1980), and is effective when applied either as a foliar spray, or as a drench to the growing medium. White (1970) reported that 5000 ppm chlormequat applied as a soil drench 31 days after sowing reduced the height of the F_1 geranium cv. Carefree Scarlet by 8-10 cm when compared with plants which had not been treated. Spray application of 1500 ppm also significantly reduced plant height of cv. Yours Truely (Tayama and Carver, 1990). Chlormequat is translocated in both the xylem and phloem (Lord and Wheeler, 1981).

Early flowering of plants receiving chlormequat, compared with control plants, has also been reported (White, 1970; Armitage *et.al.*, 1978; Miranda and Carlson, 1980; Wetzstein and Armitage, 1983). Work by Armitage (1986) showed that foliar application of 1500 ppm chlormequat prior to flower initiation advanced flowering by 14 days in hybrid geranium cv. Sprinter Scarlet. This promoting action is thought to depend on the ability of this chemical to suppress endogenous gibberellin levels.

Other morphological and physiological changes following chlormequat application have also been observed. In *Althaea rosea* (hollyhock) cv. Summer Carnival, shoot elongation was retarded by chlormequat, and shoot thickness was also increased 120-130% over that of the control. This increase was due to the retardation of cell division and/or cell elongation. Leaf thickness and size (or volume) of leaf mesophyll cells were also increased. There was little or no difference in the number of nodes and internodes, but the number of flowers per plant was increased because more flower buds at each node were induced and flower abortion was reduced. Net photosynthesis, transpiration and chlorophyll concentration were increased and photorespiration was decreased after 0.3% chlormequat has been applied to geranium cv. Sprinter Scarlet (Armitage *et.al.*, 1984).

Daminozide

Daminozide (succinic acid, 2,2 dimethyl hydrazide; SADH, B-nine, Alar) has been recommended for inhibiting shoot growth, inducing flower bud initiation, increasing fruit set and preventing pre-harvest drop in fruit crops such as apples, peaches, cherries, and kiwifruits (O'Connor, 1989). It is also an effective and popular growth retardant used for the modification of stem length and shape of ornamental plants, particularly in commercial production of potted chrysanthemums. Application of 2500-5000 ppm daminozide as a foliar spray at 10-15 days after pinching or when the lateral shoots on pinched plants are 2.5-4.0 cm long is normally used. Applications are often repeated every three weeks and sometimes more often than that depending on cultivar response and environmental conditions (Ball, 1985). This chemical acts as an inhibitor in the synthesis of endogenous gibberellins which influence internode extension (Cathey, 1964).

Although daminozide offers the greatest benefits in the production of potted chrysanthemums, it is also beneficial with some cultivars and under certain conditions in cut chrysanthemum production. Excessive stem elongation from the uppermost leaf to the base of the flower creates a sparse appearance, referred to as 'neckiness'. Spray application of 2500 ppm daminozide just after removal of the lateral flower buds (disbudding) will inhibit cell elongation and division in the upper portion of the stem, causing the uppermost leaf and the base of the flower to be in close proximity to each other (Kofranek, 1980). Application of 2500 and 5000 ppm daminozide once or for three consecutive weeks when the main stems started to elongate provided an advantage in height control of American marigold and larged flowered *Zinnia elegans* (zinnia) which usually require staking and often blow over during rain or strong winds (Cathey, 1976).

Daminozide is translocated in both the xylem and phloem (Moore, 1968) and has been effective only when used as a foliar spray. Its efficacy can be reduced if treated plants are washed by overhead irrigation or rain. For maximum uptake, daminozide foliar sprays must be applied to dry foliage of fully turgid plants which then must be allowed to remain dry for at least 24 hours (Underaga, 1970; Cathey, 1975).

Differences in cultivar responses were reported in *Petunia hybrida* Vilm. (petunia) by Cathey (1976). A foliar spray of 5000 ppm daminozide when the main stem started to elongate reduced the stem height of cv. White Cascade by one-third the height of the untreated plants, but only slightly or not at all in cv. Blue Magic, Pink velvet, Snowbird and Calypso. Three weekly sprays of a double dose (10,000 ppm daminozide) also had little effect on these four less sensitive cultivars. On the other hand, only a half dose (2500 ppm) of daminozide produced plants with two-thirds the height of the untreated plants in the more sensitive cultivars Red Satin, Ballerina and Comanche Improved. This treatment also delayed flowering. Increased time to flowering was also found in *Zinnia elegans* (zinnia) plants treated with 5000 ppm daminozide. The time increase (3-11 days) depended on cultivars and number of applications (Armitage *et.al.*, 1981). Number of total flowers and buds following a 1500 ppm daminozide application did not differ from untreated *Aquilegia spp* cv. Cardinal, Tanager, and Goldfinch, but they increased in a late planting of the same cultivar Cardinal (White *et.al.*, 1989).

Paclobutrazol

Paclobutrazol (2RS, 3RS)-1-(4-chlorophenyl)-4,-4-dimethyl-2-(1,2,4-triazol-1-yl) pentan-3-ol, PP333, Bonzi, Cultar), a triazole derivative, has shown growth controlling activity in a wide range of ornamental species (Shanks, 1980; Goulston and Shearing, 1985; Davis *et.al.*, 1988). The major biochemical effect of paclobutrazol is suppression of gibberellin production and hence reduced rates of cell division and expansion (Dalziel *et.al.*, 1984) which results in a reduction in vegetative growth. Another effect is an alteration in sink strength within the plant, allowing a greater partition of assimilates to reproductive growth (Lever, 1988). It can also increase the carbohydrate, soluble protein and mineral levels in leaf tissue (Wang *et.al.*, 1986).

Paclobutrazol has been reported to retard stem elongation of many plant species (Goulston and Shearing, 1985; Shanks, 1980; Barrett and Bartuska, 1982; Wilkinsons and Richards, 1988), and can be applied either as a soil drench or a foliar spray. Zinnia height was reduced by either single drench applications of 0.5 or 1.0 mg a.i./pot or single spray applications of 250, 500 or 1000 ppm paclobutrazol (Cox and Keever, 1988). The applied chemicals were translocated from the roots, primarily through the xylem (Sterrett, 1985), to the target site (the sub-apical meristem), following soil application. Stem and shoot uptake are particularly important following a foliar spray (Barrett and Bartuska, 1982). No phloem mobility was shown in the studies of Quinland and Richardson (1986).

Application rate, time and method vary between species and/or cultivars. McDaniel (1983) showed that plant height of four cultivars of chrysanthemum: Bright Golden Ann (tall), Golden Crystal (tall), Mountain Snow (medium) and Puritan (medium) was decreased by paclobutrazol applied as a soil drench only, foliar sprays were ineffective. Paclobutrazol rates of 0.25-0.75 mg a.i. per 15 cm pot produced plants of commercially acceptable heights for the tall cultivars while 0.125-0.250 mg a.i. per pot appeared optimal for growth reduction of medium-height cultivars. Different results were obtained with *Bouvardia humboldtii* in which sprays inhibited growth more than drenches (Wilkinson and Richards, 1987). Both foliar application and soil drenches of paclobutrazol limited plant height of three cultivars of poinsettias: Eckespoint C-1 Red, Gutbier V-14 Glory and Annette Hegg Dark Red at 0.50 mg per 15 cm pot as soil drenches and at 25-50 mg litre^{-1} as a foliar application (McDaniel, 1986).

5.1.3 Plant growth retardants in China aster

Published information on the effects of growth retardants on China aster is limited. Cathey and Stuart (1960) reported that a soil drench application of chlormequat (140, 350, and 700 mg m^{-3} potting soil) retarded internode length of cv. American Branching but no response to quaternary ammonium and phosphonium compounds was reported by Cathey (1961). The work of Cathey (1975) showed that cv. Ball White was responsive to 2500 and 5000 ppm daminozide and 100 ppm ancymidol applied once or three times at weekly intervals when the main stems started to elongate. No detailed study has been reported on the effect of growth retardants on aster plant structure, and non for seed production.

5.1.4 Pinching

The removal of the shoot apex to overcome apical dominance and promote lateral shoot development is referred to as pinching in the United States and stopping in England (Larson, 1985). Pinching of cut flower crops may be to either produce more stems or multiple-branches on plants of rose and carnation (Laurie *et. al.*, 1979) or to control the timing of the flower crop to catch the most profitable market. Flowering of pinched chrysanthemum is generally delayed approximately two weeks (Laurie *et.al.*, 1979). In carnation, side shoots will produce flowers ready for cutting in eight to nine weeks after pinching (Bewley, 1963). Some kinds of plants may or may not be pinched, depending on the planting management. Chrysanthemums used to be more commonly grown as pinched plants that were pruned to two or three stems, but now frequently they are grown with single stems. The pinched plants are usually spaced at 15x20 cm and the single-stem plants at 10x15 cm, although there are variations in this spacing according to season (Laurie *et.al.*, 1979). In geranium, although pinched plants were short and well branched, this method of height reduction was not acceptable for commercial use (White, 1970) because of a long delay in flowering (21-48 days after the terminal was pinched) (Craig and Walker, 1963).

Asters are normally grown as self-branching plants for flower production in a glasshouse. Each plant produces about six shoots under natural conditions, and each shoot eventually develops a terminal flower (Walls, 1982). However, some growers prefer to pinch to achieve more uniform flowers (McKay, 1984).

5.1.5 Lodging

Lodging is considered to be a consistent and substantial problem in many graminaceous crops. The effect of lodging on yield and seed quality depends on its severity and time of occurance, with lodging at anthesis identified as the most detrimental, giving yield reductions of up to 40 % in barley (Pinthus, 1973), and up to 60 % in perennial ryegrass (Hebblethwaite *et.al.*, 1978). Lodging of a crop may cause more difficulty in harvesting and/or processing because the flattening of the crop may allow secondary vegetative growth. Excessive moisture will often delay harvest and probably require more care in drying (Herbert, 1982).

Lodging may also become a problem in aster seed production due to the plant's structure. The complete flowering shoot consists of a large terminal inflorescence and several small axillary inflorescences. Thin long stems and heavy heads particularly in the long petal double-flower type, cv. Powderpuff make it prone to lodging. Strong winds at this study site aggravated by heavy rain during the reproductive phase (Appendix 3.1) increased the lodging tendency and caused severe crop losses in the 1987/88 experiment (Chapter 3).

5.1.6 Objectives

The effects of pinching and growth regulators on china aster grown for seed are not known. Crop manipulation by hand pinching and growth retardant application was selected for this study to determine whether the morphological structure of China aster cv Powderpuff could be altered to improve seed yield.

Hand pinching was included to determine if it would help to increase branch number and produce greater flower synchrony for uniformity in seed quality and ease of harvest.

Paclobutrazol, a very potent growth retardant for many commercial floriculture crops (Halevy, 1985; Larson, 1985; Barrett and Nell, 1986) was chosen to compare with other aster responsive chemicals, chlormequat chloride (Cathey and Stuart, 1960) and daminozide (Cathey, 1975) to evaluate

i) the ability to restrict stem extension
ii) whether assimilate partitioning would be altered
iii) their effects on seed yield and yield components.

5.2 MATERIALS AND METHODS

5.2.1 Experimental site

The experiment was conducted on a Tokomaru silt loam soil at the same site and adjacent to the area used in the 1987/88 plant density experiment (Chapter 3) at The Seed Technology Centre. This whole paddock had been ploughed on 26 July 1988 and ryegrass (*Lolium perenne* L.) was sown for soil conservation. The field was ploughed again on 20 October 1988 and harrowed two weeks later. A broad spectrum granular insecticide, Thimet 20 G (phorate, 200 g kg^{-1}) was applied at a rate of 1 kg a.i. ha^{-1} to control chewing insects. Snail and slug bait, Mesurol (Methiocarb, 20 g kg^{-1} bait) was also broadcast at about 100 baits m^{-2}. Fertilizer 18-20-0 (150 kg ha^{-1}), sulphate of potash (500 kg ha^{-1}) and calcium ammonium nitrate (150 kg ha^{-1}) were broadcast and soil incorporated on 17 November 1988. Weather data at Palmerston North during the planting months are presented in Appendix 5.1

5.2.2 Establishment

Seeds of China aster cv. Powderpuff were thiram dusted (1 g product (80 % wettable powder)/100 g seed), sown at 4 seeds per cell in root trainers (45 mm x 30 mm x 80 mm deep) containing soil mix (80 l peat, 20 l pumice, 10 l sand, 240 g dolomite and 180 g 28N-2.6P-10K Osmocote) on 14 October 1988, and raised in a 30/20±5 °C glasshouse at the Nursery Research Centre, Massey University. Thinning to one plant per cell was done seven days after aster emergence. Foliar fertilizer, 'Happy Garden' 12-8-16 (Nylex New Zealand Ltd, Auckland) was applied via a fertilizer dispenser attached to a soft spray wand at the rate of 35 kg ha^{-1} on 12 November 1988 and fungicide, benlate (Benomyl, 500 g kg^{-1}) was sprayed at 0.25 kg a.i. ha^{-1} two days later. Insecticide, lannate (Methomyl, 200 g $litre^{-1}$) was sprayed at 0.24 kg a.i. ha^{-1} when the seedlings were moved to the field for hardening, five days before planting.

Seedlings were hand transplanted into the field on 21 November 1988. Strings marked and crossed at 25 cm were used to obtained the required square spacing of 16 plants m^{-2} plant density. Some surplus seedlings were planted near the experimental area for replacing plants which failed to establish. Irrigation was applied immediately after planting and then every 7-10 days up to two weeks after peak flowering with the same garden sprinkler as used in the plant density experiment (Chapter 3) which provided 6000 litres water ha^{-1} h^{-1}. A herbicide, oryzalin (4.5 kg a.i. ha^{-1}) was applied once at 5 days after transplanting. Perennial weeds (i.e. docks) or escaped weeds were hand removed. Foliar fertilizer 12-8-16 (35 kg ha^{-1}) was applied 10 days after planting and ammophos (12:10:10:8) fertilizer was added at 100 kg ha^{-1} one month later (17 December 1988). Crop protection was achieved by alternate use of the same products and rates as described in chapter 3 except that orthocide 80 W (captan, 800 g kg^{-1}) (10 kg a.i. ha^{-1}) and benlate (1 kg a.i. ha^{-1}) were mixed with sand and then dusted onto the soil in an attempt to prevent the spread of fusarium wilt which had been observed in some spots.

5.2.3 Treatments

Hand pinching and three plant growth retardants (PGR): chlormequat chloride (Cycocel), daminozide (Alar) and paclobutrazol (PP333) were the treatments used. Pinching was done by hand removal of 1 cm of the apical shoot tip. Each growth retardant was applied at two rates: 1.5 and 3 kg a.i. ha^{-1} chlormequat, 2.5 and 5.0 kg a.i. ha^{-1} daminozide and 0.5 and 1.0 kg a.i. ha^{-1} paclobutrazol via a 5 litre pressure sprayer in one litre of water per plot. Stage of growth was visually observed every 2 days. Treatments were applied when 50 % of the plants in each plot (excluding the border) had reached the desired growth stage i.e. visible terminal bud stage (19 December 1988) and main stem elongation stage (29 December 1988 for paclobutrazol which was applied just before rain and 31 December 1988 for chlormequat and daminozide application and the pinching treatment). Twenty hours after the chlormequat and daminozide application 6000 litres water ha^{-1} was applied via sprinkler irrigation. Plant size (mean of 4 plants taken at random from the untreated plots) at these two application stages is shown in Table 5.1.

Table 5.1 Plant size of China aster cv. Powderpuff at the two growth stages when treatments were applied.

	Visible terminal bud (19 December 1988)*		Main stem elongation (31 December 1988)*	
Stem length (cm)	10.3	(1.4)	33.5	(1.4)
Leaf number (leaves)	27.0	(1.1)	33.0	(1.7)
Leaf area (cm^{-2})	385.0	(29.0)	820.5	(50.3)
Branch number (branches)	-		16.0	(2.7)
Plant dry weight (g)	4.7	(0.1)	11.1	(0.95)

( ) = standard error

* = date of application

There were therefore 15 treatments altogether as follows.

Control: untreated
Pinching at visible terminal bud stage
Pinching at stem elongation stage
Chlormequat chloride 1.5 kg a.i. ha^{-1} at visible terminal bud stage
Chlormequat chloride 1.5 kg a.i. ha^{-1} at stem elongation stage
Chlormequat chloride 3.0 kg a.i. ha^{-1} at visible terminal bud stage
Chlormequat chloride 3.0 kg a.i. ha^{-1} at stem elongation stage
Daminozide 2.5 kg a.i. ha^{-1} at visible terminal bud stage
Daminozide 2.5 kg a.i. ha^{-1} at stem elongation stage
Daminozide 5.0 kg a.i. ha^{-1} at visible terminal bud stage
Daminozide 5.0 kg a.i. ha^{-1} at stem elongation stage
Paclobutrazol 0.5 kg a.i. ha^{-1} at visible terminal bud stage
Paclobutrazol 0.5 kg a.i. ha^{-1} at stem elongation stage
Paclobutrazol 1.0 kg a.i. ha^{-1} at visible terminal bud stage
Paclobutrazol 1.0 kg a.i. ha^{-1} at stem elongation stage

5.2.4 Experimental design and statistical analysis

Treatments were assigned in a randomized complete block design with 3 replicates. Plot size was 1.5x3.0 m. There were 72 plants per plot. Layout of the field design is presented in Appendix 5.2. Data were analysed by analysis of variance (ANOVA) using the SAS program (SAS, 1988). Treatment mean comparisons were performed using the Duncan's Multiple Range Test with 5% probability. Graphs were drawn using a Microsoft Chart programme.

5.2.5 Data collected

5.2.5.1 Growth analysis

Samples for growth analysis were taken at first flowering (31 January to 7 February 1989), peak flowering (27 February 1989) and final harvest (3 April 1989). First flowering was the time when 50 % of the plants in each plot had the first flower opened. Opened flowers from four randomly chosen plants in each plot were counted twice a week to obtain peak flowering date. At each sampling, four plants were taken at random from each plot, washed, counted, measured and then separated into root, stem, leaves, branches, flower heads and seedheads where appropriate, Each fraction was then dried in an oven to a constant weight (3 days at 80 °C) before dry weight was recorded.

Responses to the various treatments were recorded as follows:

Main stem length	-height from ground level to the base of the flower head of the main stem.
Plant height	-height from ground level to the highest point of the plant.
Lateral branch length	-length of the uppermost branch from the stem to the base of the flower head.
Leaf number	-all leaves longer than 1 cm were counted.
Leaf area	-measured by a LI 3100 Li-Cor meter (Li-Cor Inc., Nebraska, USA).
Branch number	-all elongated branches were counted at first flowering and peak flowering; at harvesting, only branches that had seedheads were counted.
Total flower number	-all flowers and buds were counted at first flowering and peak flowering.
Seedhead number	-all seedheads containing seeds were counted at final harvest.

5.2.5.2 Seed yield and yield components

Powderpuff plants from 1.5 m^2 $plot^{-1}$ (excluding border rows) were hand harvested when the average seed moisture content of the control plots was 38 % by cutting the whole plants at ground level on 4 April 1989. Plants were left to air dry in a laboratory at ambient temperature for 2 weeks. Seedheads were then separated before being threshed by a brush machine thresher (Thrige-Titan Asea Cat. No. MkIII 813B) on 20 April 1989. Seeds were then cleaned in a Clipper seed cleaner using a 1.40 mm round perforations screen and further cleaned by passing through different sized (1.27-1.40 mm) laboratory test sieves. Final cleaning was done using a vertical airblast seed blower (Burrows Model No.1836-4), for which the air vent had been set at 80 m min^{-1}. Seed weights per plot were determined and corrected to 7 % seed moisture content to determine the actual cleaned seed yield.

Potential harvestable seed yield was calculated from seedhead numbers per m^{-2} times seed numbers per head and seed weight. Seed yield components were determined from four sample plants per plot taken at the final harvest growth analysis. Number of seedheads were counted before seeds were hand threshed and cleaned by passing through different sized (1.27-1.40 mm) laboratory test sieves and the vertical airblast seed blower. These seeds were oven dried to constant weight at 65 °C for 3 days, then weighed. One gram of seeds were counted and used to calculate the number of seeds per seedhead by multiplying by seed weight per plant and dividing by number of seedheads per plant. Thousand seed weight was ten times the mean weight of four replicates of 100 seeds. Germination percentage was calculated from the normal seedlings of four replicates of 50 seeds per plot. Seeds were germinated on top of paper which had been soaked with 0.2 % KNO_3, in a 20 °C germination cabinet beginning on 15 May 1989. Seedling evaluation was done after 5 and 14 days for the first and final count respectively (ISTA, 1985).

5.3 RESULTS

5.3.1 Morphological structure alteration

Pinching at visible terminal bud stage altered the aster plant structure (Table 5.2) because plant height and main stem length were significantly reduced while branch length was increased. Main stem elongation had stopped totally by first flowering (Appendix 5.3) but was compensated by a significant increase in branch length recorded at both peak flowering and final harvest (Appendix 5.4). The overall plant height after plants were pinched was shorter than the control but significant only at final harvest (Appendix 5.5).

Pinching at the visible terminal bud stage also removed branches and leaf primordia of the upper plant parts, resulting in significantly fewer fertile branch numbers per plant (Appendix 5.6). These branches were bigger and stronger than all other treatments. However, they grew at a wide angle to the stem, and were more readily broken off after rain and strong winds than normal (Appendix 5.7). Total leaf numbers were not significantly different from the control (Appendix 5.8), although fewer leaves were present on the main stem. Branch leaves were bigger and longer than for the other treatments and this was sufficient to compensate for the loss of the main stem leaves, resulting in no significant difference in total leaf area from the control (Appendix 5.9). Total flower numbers did not differ significantly from the control (Appendix 5.10) but flowering was delayed by 15 days (the untreated plants took 73 days from planting or 116 days from sowing to flowering).

Late pinching at stem elongation reduced apical dominance and/or encouraged greater branch growth. Plant appearance did not differ markedly from the unpinched plants at seed harvest, although they did not have a terminal flower (or seed) head. Only the main stem of these pinched plants was significantly shorter than the control (Table 5.2, Appendix 5.3). Branch length and the overall plant height did not differ from the control (Appendices 5.4 and 5.5). Stems continued to elongate up to final harvest, even after the terminal shoot tip was removed. Other plant structures (branch number, leaf number, leaf area and flower number) were not significantly altered (Appendices 5.6-5.10).

The obvious difference between the growth retardant treated plants and the control was that the former were shorter and sturdier plants (Appendix 5.11). Leaves were darker green in colour and had short petioles. The effects were first visually observed at 1- 2 weeks after application, and evident for only 2-3 weeks as treated plants started to overcome the chemical retarding effect, finally becoming approximately equal in height to untreated plants at flowering (Appendices 5.5 and 5.12). All growth retardant treated plants flowered at the same time as the control. Plant structures did not alter significantly but appeared more compact than the control. In general, plant growth recovery of chlormequart chloride treated plants appeared faster than for the other two chemicals, as plant growth and structures were similar to the control from the first flowering sampling. Growth measurements at first flowering, peak flowering and seed harvest showed high variation between sample plants and plant growth results were not consistent over time (Appendices 5.3-5.10) indicating that the efficacy and the effective duration of each growth retardant treatment was different. The differences in the rate at which plant growth was resumed indicate that plant growth response measurements at these times were not only due to the chemical efficacy but were also strongly influenced by other factors.

At seed harvest, main stem length and lateral branch length of growth retardant treated plants did not significantly differ from untreated plants (Table 5.2). However the overall height of plants that were treated with 2.5 kg a.i. ha^{-1} daminozide and 1.0 kg a.i. ha^{-1} paclobutrazol at both application times, and 0.5 kg a.i. ha^{-1} paclobutrazol at the visible terminal bud stage was significantly shorter than the control (Table 5.2). At harvest fertile branch numbers of plants that were treated with 1.0 kg a.i. ha^{-1} paclobutrazol at visible terminal bud stage, 0.5 kg a.i. ha^{-1} paclobutrazol and 5.0 kg a.i. ha^{-1} daminozide at stem elongation stage, and 2.5 kg a.i. ha^{-1} daminozide at both application times, were lower than the control (Appendix 5.6).

Although the general structure of growth retardant treated plants did not differ from the control, paclobutrazol (1.0 kg a.i. ha^{-1}) treated plants had fewer branches than chlormequat chloride treated plants at peak flowering (Appendix 5.6). The basal branches of 1.0 kg a.i. ha^{-1} paclobutrazol treated plants were not fully developed or if developed, they grew as non vigorous branches with only a small flower bud and failed to flower by harvest. The net result was a significant reduction in flower number (Appendix 5.10). Almost all branches in chlormequat chloride treated plants developed and produced flower heads. In general, basal branches of daminozide treated plants developed and produced flower heads (Figure 5.1), but some contained only a few immature seeds at harvest.

5.3.2 Dry matter accumulation and distribution

The total dry weights of pinched plants were not significantly different from the control at all observation times (Table 5.3), but the pattern of dry matter accumulation was altered by mechanical pinching at the visible terminal bud stage. The accumulation of dry matter in these pinched plants increased faster than the control due to the significant increase in branch dry weight recorded at first flowering (Figure 5.2). Although stem dry matter was significantly decreased at first and peak flowering, leaf and flower dry matter accumulation did not differ from the control at all observation times (Figure 5.2).

Plant dry matter accumulation following pinching at the stem elongation stage was similar to that of the control, and total plant dry weight was not significantly different from the control (Table 5.3), although stem dry weight was significantly decreased at first and peak flowering (Figure 5.2).

Table 5.2 Effects of hand pinching and growth retardant application on main stem length, lateral branch length and plant height of China aster cv. Powderpuff at seed harvest.

Treatment		Stem length (cm)	Branch length (cm)	Plant height (cm)
Control		77.7 a	55.4 bc	88.6 a
Pinching	(1)	11.7 c	64.4 a	76.1 c
Pinching	(2)	52.7 b	54.1 bc	85.4 ab
Chlormequat chloride 1.5 kg+	(1)	74.1 a	57.3 b	88.5 a
Chlormequat chloride 1.5 kg	(2)	75.2 a	58.5 ab	91.4 a
Chlormequat chloride 3.0 kg	(1)	74.7 a	55.8 bc	88.6 a
Chlormequat chloride 3.0 kg	(2)	76.8 a	57.7 b	89.4 a
Daminozide 2.5 kg	(1)	69.5 a	53.6 bc	80.1 bc
Daminozide 2.5 kg	(2)	70.8 a	52.9 bc	82.0 bc
Daminozide 5.0 kg	(1)	72.7 a	54.6 bc	85.0 ab
Daminozide 5.0 kg	(2)	73.5 a	53.7 bc	84.0 ab
Paclobutrazol 0.5 kg	(1)	70.6 a	50.2 c	82.3 bc
Paclobutrazol 0.5 kg	(2)	73.7 a	57.1 bc	86.3 ab
Paclobutrazol 1.0 kg	(1)	70.7 a	51.2 bc	79.6 bc
Paclobutrazol 1.0 kg	(2)	72.1 a	51.7 bc	81.2 bc
Significance level		0.0001	0.0075	0.0017
CV (%)		6.83	6.48	4.73

means within a given column with the same letter are not significantly different at P≤0.05 for the Duncan's Multiple Range Comparison test.

+ = application rate (kg a.i. ha^{-1})

(1) = applied at visible terminal flower bud stage,

(2) = applied at main stem elongation stage.

Control Pinch 1 Pinch 2

Chlormequat chloride Daminozide Paclobutrazol

Figure 5.1 Powderpuff plants as affected by mechanical pinching and growth retardant application.

At seed harvest, the total dry matter accumulation in response to the growth retardants did not differ significantly from the control. This occurred despite the fact that lower total dry matter at first flowering was recorded for all paclobutrazol treatments, both 5.0 kg a.i. ha^{-1} daminozide treatments and 2.5 kg a.i. ha^{-1} daminozide applied at the visible terminal bud stage, and by both 1.0 kg a.i. ha^{-1} paclobutrazol treatments and 2.5 kg a.i. ha^{-1} daminozide applied at the visible terminal bud stage at peak flowering (Table 5.3). Growth retardants particularly retarded the growth of stem and branches. The significance of retardation effects decreased with time (Figure 5.2) and was associated with the plant growth responses described in 5.3.1, particularly for plant height. The chlormequat chloride growth retardation effects disappeared faster than those of the other two chemicals. The effective growth suppression by paclobutrazol depended on application rate rather than application time, the higher paclobutrazol rate (1.0 kg a.i. ha^{-1}) being more effective than the lower rate (Figure 5.2). There was an interaction between daminozide application rate and application time. Daminozide 2.5 kg a.i. ha^{-1} applied at the visible terminal bud stage and 5.0 kg a.i. ha^{-1} applied at the stem elongation stage significantly reduced plant dry matter at first flowering whereas the other two daminozide treatments did not (Figure 5.2).

As plant dry weights between treatments at seed harvest were not significantly different (Table 5.3), data were combined and reanalysed regardless of treatment application time and growth retardant rates. The distribution of plant dry weights into root, vegetative (stem+branches+leaves) and reproductive (flowers+seeds) expressed as a percentage of total plant dry weight, and harvest index, are presented in Table 5.4. Pinching and growth retardants did not significantly alter the root, vegetative and reproductive dry weight. However, there was a contrast between the paclobutrazol and pinching treatments. Paclobutrazol treated plants had lower vegetative growth and greater reproductive growth, while pinched plants produced the opposite results (Table 5.4). All treatments increased harvest index but the difference was significant only for paclobutrazol (Table 5.4).

Table 5.3 Effects of hand pinching and growth retardant application on total plant dry weight of China aster cv. Powderpuff at first flowering (FF), peak flowering (PF) and seed harvest (H).

Treatment		Plant dry weight (g)		
		FF	PF	H
Control		69.60 ab	99.37 ab	104.39
Pinching	(1)	78.30 a	82.06 abc	92.09
Pinching	(2)	61.29 bc	82.52 abc	77.66
Chlormequat chloride 1.5 kg$^+$	(1)	57.89 bcd	80.97 abc	86.24
Chlormequat chloride 1.5 kg	(2)	60.14 bc	84.61 ab	88.47
Chlormequat chloride 3.0 kg	(1)	64.35 bc	84.36 ab	94.35
Chlormequat chloride 3.0 kg	(2)	47.74 d	92.99 ab	79.39
Daminozide 2.5 kg	(1)	46.00 d	68.47 c	87.82
Daminozide 2.5 kg	(2)	77.31 a	77.06 bc	89.56
Daminozide 5.0 kg	(1)	57.70 bcd	91.51 ab	89.30
Daminozide 5.0 kg	(2)	44.82 d	76.89 bc	89.29
Paclobutrazol 0.5 kg	(1)	49.41 d	101.40 a	86.21
Paclobutrazol 0.5 kg	(2)	51.45 cd	81.67 abc	83.95
Paclobutrazol 1.0 kg	(1)	45.58 d	69.54 c	74.98
Paclobutrazol 1.0 kg	(2)	53.26 cd	60.53 c	85.55
Significance level		0.0001	0.012	0.731
CV (%)		12.41	14.34	16.50

means within a given column with the same letter are not significantly different at $P \leq 0.05$ for the Duncan's Multiple Range Comparison test.

$^+$ = application rate (kg a.i. ha^{-1})

(1) = applied at visible terminal flower bud stage,

(2) = applied at main stem elongation stage.

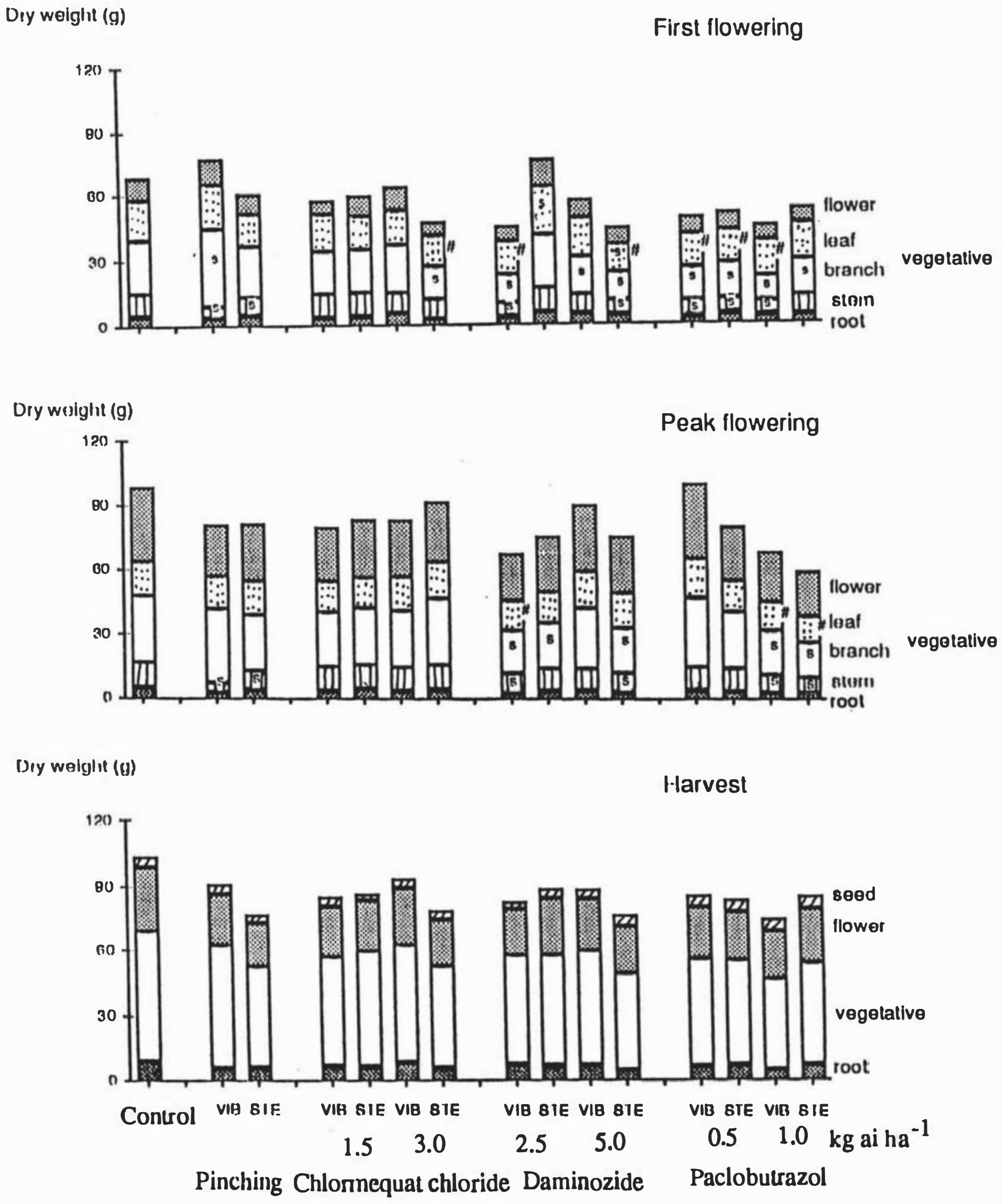


Figure 5.2 Plant dry weight at first flowering, peak flowering and seed harvest of China aster cv. Powderpuff.

['s' within (or '#' beside) a column means the dry weight of that part (or vegetative stem dry weight) was significantly different from the control at $P \leq 0.05$ as separated by the Duncan's Multiple Range Comparison test.]

VIB = visible terminal bud stage.
STE = stem elongation stage.

Table 5.4 Distribution of plant dry weight (as a percentage of total plant dry weight) in China aster cv. Powderpuff at seed harvest.

Treatment	Root	Vegetative	Reproductive	HI (%)
Control	9.2	58.1 ab	32.7 ab	4.4 b
Pinching	8.0	61.0 a	31.0 b	5.0 ab
Chlormequat chloride	8.8	58.2 ab	32.8 ab	4.8 b
Daminozide	8.2	55.9 b	32.2 b	5.1 ab
Paclobutrazol	8.3	55.9 b	35.8 a	7.0 a
Significance level	0.690	0.039	0.016	0.024@
CV (%)	18.41	6.14	8.91	16.45

means within a column with the same letter are not significantly different at P≤0.05 for the Least Significant Differences test.

@ = data were analysed using square root transformation, actual data are given for treatment means.

5.3.3 Seed yield and yield components

Potential harvestable and actual cleaned seed yield were not significantly increased by either pinching or growth retardant application (Table 5.5, 5.6). Seedheads were decreased by pinching at the stem elongation stage and by treatment with 2.5 kg a.i. ha^{-1} daminozide at the visible terminal bud stage, 5.0 kg a.i. ha^{-1} daminozide at the stem elongation stage and both applications of 1.0 kg a.i. ha^{-1} paclobutrazol. Seed numbers were increased only in plants that were treated with 5.0 kg a.i. ha^{-1} daminozide at the stem elongation stage and 1.0 kg a.i. ha^{-1} paclobutrazol at the visible terminal bud stage. Seed weight after pinching and growth retardant application did not differ significantly from the control, but there was a difference between the two pinching times. Germination was not affected by growth retardant or pinching treatments (Table 5.5). Varying amounts of seed loss between potential and actual seed yield suggested variation in seed maturity between treatments (Table 5.6).

Table 5.5 Effects of hand pinching and growth retardant application on potential harvestable seed yield and yield components of China aster cv Powderpuff.

Treatment		Seed yield (g m^{-2})*	Seed heads $plant^{-1}$	Seeds $head^{-1}$	TSW (g)	Germination (%)
Control		89.42 ab	40.5 a	72.3 bc	1.8497	88.0
Pinching	(1)	82.30 ab	36.5 ab	80.3 bc	1.7530	91.0
Pinching	(2)	75.95 ab	29.5 bc	79.8 bc	1.9160	82.7
Chlormequat chloride 1.5 kg+	(1)	80.60 ab	32.0 abc	86.5 abc	1.7873	86.7
Chlormequat chloride 1.5 kg	(2)	64.89 b	30.4 abc	60.6 c	1.9163	81.0
Chlormequat chloride 3.0 kg	(1)	77.78 ab	35.5 ab	74.9 bc	1.8500	83.3
Chlormequat chloride 3.0 kg	(2)	82.47 ab	30.4 abc	89.6 abc	1.9460	83.7
Daminozide 2.5 kg	(1)	59.53 b	29.4 bc	71.8 bc	1.7523	87.7
Daminozide 2.5 kg	(2)	82.39 ab	36.2 ab	76.1 bc	1.8640	91.7
Daminozide 5.0 kg	(1)	83.28 ab	32.5 abc	79.6 bc	1.9850	81.7
Daminozide 5.0 kg	(2)	93.27 ab	25.4 c	125.8 a	1.8280	81.7
Paclobutrazol 0.5 kg	(1)	95.97 ab	31.3 abc	102.9 abc	1.8427	83.0
Paclobutrazol 0.5 kg	(2)	95.89 ab	31.8 abc	100.4 abc	1.8810	87.3
Paclobutrazol 1.0 kg	(1)	104.90 a	27.4 c	128.9 a	1.9130	84.7
Paclobutrazol 1.0 kg	(2)	94.46 ab	28.6 bc	107.2 ab	1.9347	81.7
LSD (0.05)		44.53	8.0	43.0	0.1585	11.4
CV (%)		31.87	15.09@	28.85	5.07	5.73

means within a given column with the same letter are not significantly different at $P \leq 0.05$ for the Least Significant Differences test.

\+ = application rate (kg a.i. ha^{-1})

(1) = applied at visible terminal flower bud stage,

(2) = applied at main stem elongation stage.

@ = data were analysed in log transformation, actual data are given for treatment means.

* = calculated data

Table 5.6 Effects of hand pinching and growth retardant application on potential harvestable seed yield, actual cleaned seed yield and percentage of yield loss of China aster cv. Powderpuff.

Treatment		Seed yield (g m^{-2})		
		potential	cleaned	% loss
Control		89.42 ab	59.50 ab	29.92
Pinching	(1)	82.30 ab	58.85 ab	23.45
Pinching	(2)	75.95 ab	59.94 ab	16.01
Chlormequat chloride 1.5 kg	(1)	80.60 ab	56.33 ab	24.27
Chlormequat chloride 1.5 kg	(2)	64.89 b	60.92 ab	3.97
Chlormequat chloride 3.0 kg	(1)	77.78 ab	64.86 ab	12.92
Chlormequat chloride 3.0 kg	(2)	82.47 ab	52.20 ab	30.27
Daminozide 2.5 kg	(1)	59.53 b	47.67 b	11.86
Daminozide 2.5 kg	(2)	82.39 ab	64.64 ab	17.75
Daminozide 5.0 kg	(1)	83.28 ab	61.84 ab	21.44
Daminozide 5.0 kg	(2)	93.27 ab	53.67 ab	39.60
Paclobutrazol 0.5 kg	(1)	95.97 ab	68.70 a	27.27
Paclobutrazol 0.5 kg	(2)	95.89 ab	69.19 a	26.70
Paclobutrazol 1.0 kg	(1)	104.90 a	61.12 ab	43.78
Paclobutrazol 1.0 kg	(2)	94.46 ab	60.42 ab	34.04
LSD (0.05)		44.53	15.45	
CV (%)		31.87	15.40	

means within a column with the same letter are not significantly different at $P \leq 0.05$ for the Duncan's Multiple Range Comparison test.

$^{+}$ = application rate (kg a.i. ha^{-1})

(1) = applied at visible terminal flower bud stage,

(2) = applied at main stem elongation stage.

5.4 DISCUSSION

5.4.1 Lodging

Lodging did not occur in this experiment until two weeks after peak flowering following rain and high winds (Appendix 5.1). Treatments did not appear to differ in the degree of lodging as based on visual observation. Branch breakage occurred only in the earlier pinching treatment. A flower type that becomes very heavy when soaked by rain water, and a shallow fibrous root system / soft soil interaction were a disadvantage of this cultivar at this site, as previously discussed in Chapter 3. In the present experiment, seed yield from the control plants was 113 % greater than the predicted seed yield from the previous year at the same plant density (i.e. 16 plants m^{-2}). This demonstrated that lodging at first flowering can severely affect reproductive development, as has also been shown in other seed crops (Pinthus, 1973; Hebblethwaite *et.al.*, 1978).

5.4.2 Pinching

Growth manipulation by hand pinching at either the visible terminal flower bud or the stem elongation stage produced no obvious benefit for aster seed production, as seed yield was not improved. Yield components of the earlier pinched plants did not differ from the unpinched plants but later pinching significantly decreased the seedhead numbers per plant. A reduction in the number of seedheads per plant with topping at first anthesis has also been reported in *Raphanus sativus* L. (sprouting radish) (Hampton and Young, 1985).

Pinching at the visible terminal bud stage altered the aster plant structure. Main stem elongation was stopped totally, a smaller number of big strong branches were produced as nodes were limited, and branch growth was accelerated. Although the branches were big and strong, they grew at wide angles to the stem, making the pinched plants look more flat and less floriferous in the centre of the plant compared with the control plants. This wide angle meant that branches were more easily broken off than normal, particularly when flower heads (or developing seedheads) were soaked with heavy rain and then subjected to strong winds. A similar change in plant appearance following pinching has also been reported in *Verbena venosa* (verbena) (Norremark, 1988) and impatiens by Starman (1991). Plant height reduction (-15 %) in this study was also not sufficient to prevent plants lodging. A delay in flowering (by 14 days) following pinching has also been reported in geranium (White, 1970), chrysanthemum (Laurie *et.al.*, 1979), verbena (Norremark, 1988) and impatiens (Starman, 1991).

Late pinching at stem elongation only reduced apical dominance and/or encouraged branch growth. Plant structure (height, and shape) did not obviously differ from the unpinched plants at seed harvest, although pinched plants had a shorter stem and did not have a terminal flower head (or seedhead) and flowering was again delayed (by 8 days). This late pinching effect supports the suggestion by Walls (1982) that pinching to encourage aster flower production is not necessary but can be beneficial in improving the synchrony of flowers for floral display (McKay, 1985, Goldsberry *et.al.*, 1989). Although the terminal bud was removed, stems of late pinched plants continued to elongate and hence there was no overall plant height reduction. These pinching results suggest that once stem elongation occurs or has been stimulated, it is difficult to stop. The only way to inhibit this elongation is by the early removal of the terminal bud. Unfortunately, the resulting structure of these early pinched plants (i.e. at visible terminal bud stage) is not suitable for open field growing conditions (as discussed above), because they may require staking or other means of support to prevent branch breakage (Appendix 5.7).

5.4.3 Plant growth retardants

5.4.3.1 Effects on plant height

Vegetative growth suppression following the application of the plant growth retardants (PGR), chlormequat chloride, daminozide and paclobutrazol to aster plants when the terminal flower bud was visible and at stem elongation was obvious visually, but transient. Plant growth was suppressed initially, but recovered after 4-6 weeks, resulting in no difference in general plant structure at flowering. Plant height retardation was evident at seed harvest, but the extent varied with treatment.

The differences between PGR treated plants and the control as observed during the 1-2 weeks after application appeared similar to those previously reported in bedding plants (Cathey, 1975; Halevy, 1985; Larson, 1985; Mastalerz and Holcomb, 1985). All treated plants were shorter, sturdier, with darker green and shorter petiole leaves. This vegetative growth suppression was evident for only 2-3 weeks before treated plants started to overcome the chemical retarding effect. The temporary height (or length) retarding ability of these three growth retardants has also been reported in other flower crops used for gardening or landscaping such as marigold cv. Honey comb and First Lady (Keever and Cox, 1989) and clarkia (Anderson and Hartley, 1990), and in other crops grown for seed such as *Brassica napus* L. (oil seed rape; Scarisbrick *et.al.*, 1982; Bowerman, 1984).

In potted carnation cv. Snowmass, final height reduction after application of chlormequat chloride and paclobutrazol failed to reach the desired degree (Pobudkiewicz and Goldsberry, 1989). Similary in the present experiment, paclobutrazol and daminozide decreased plant height at seed harvest by 7-10 % but this was insufficient to prevent lodging. All treatments had similar levels of lodging based on visual observation. Further work on the most appropriate application rate and time is obviously required to encourage chemical growth suppression and prevent lodging by reducing plant height.

It is likely that the response of China aster cv. Powderpuff to growth retardants (paclobutrazol, chlormequat chloride and daminozide) is similar to that of barley. A series of papers on barley as reviewed by Herbert (1982) showed that initial stem shortening at the early growth stage followed by elongation at the ear-bearing stage was observed following chlormequat application, indicating that spring barley responded to growth retardant (chlormequat) application similarly to wheat, but only at much higher dosages than used on wheat, and the responses in terms of crop height reduction and lodging control were small.

In China aster, plant growth and flowering occurs most rapidly when long days are followed by short days (Halavy, 1985) as long days promote vegetative growth (Biebel, 1936; Hughes and Cockshull, 1965; Cockshull and Hughes, 1969) and accelerate flower initiation (Doorenbos, 1959; Kinet and Sachs, 1984; Cockshull, 1985) while short days accelerate flower development (Cockshull, 1985). The critical daylength is not known, but appears to lie between 12 (Withrow and Withrow, 1940) and 14 h (Post, 1934). Moreover this daylength effect may be modified by temperature. Increasing temperatures from 13 to 20 °C under long days (16 h natural day light + incandescence lamp) has been reported to increase stem extension, leaf area and plant dry weight and advance flowering (Biebel, 1936). In this experiment, seeds were sown on 14 October, seedlings transplanted into the field on 21 November 1988, and first flowering occurred from 31 January to the the end of the first week of February 1989. Rapid elongation of stem and branch growth therefore occurred during December and January when both daylength (15.13 and 14.47 hours.minutes) (Appendix 5.13) and mean temperature (18.2 and 19.7 °C) were apparently favourable for stem elongation. Long days promote gibberellin biosynthesis (and stem elongation), and shoot growth inhibition induced by PGRs can effectively be reversed by the application of gibberellins. This reverse effect has been shown in sunflower (Wample and Culver 1983), marigold (Moore and Schekel, 1985), poinsettias (Davis *et.al.*, 1988) and geranium (Cox, 1991). This suggests that the application of PGR in cv. Powderpuff initially suppressed endogenous gibberellin biosynthesis, but failed to maintain this effect during subsequent growth. Hillman (1962) noted that large amounts of endogenous gibberellin are stimulated during stem elongation. Any further exogenous application of gibberellin had only little effect on China aster plant growth (Doorenbos, 1959) but greatly changed plant height when grown under short days. Treated plants following daily application of 25 ppm gibberellic acid (GA) until runoff for 10 days under long days were only about 2 cm longer than the control, but under short days the difference was greater, about 15 cm. It is therefore possible that the applied PGRs (particularly paclobutrazol at 1.0 kg a.i. ha^{-1}), may have continually competed with gibberellin and that the retardation effect reappeared only when gibberellin biosynthesis was reduced. Further work on the most appropriate rate and time of application is required, but the lack of information on the amount of gibberellin produced when stem elongation occurs and how much the paclobutrazol applied can counteract this endogenous gibberellin effect, makes it difficult for further study. A difficulty in supplying high enough rates or concentrations of various chemicals to produce the desired effects on stem elongation of some vegetable crops under field trials has also been noted by Cathey (1964).

The results of this experiment suggest that the effectiveness of the applied PGRs appeared to be strongly influenced by environment and that the success of PGR retardation may depend on the level of endogenous gibberellins (Lever 1986). It also appears that cv. Powderpuff is very highly sensitive to environment, particularly daylength and the interaction between daylength and temperature. Results from Chapter 3 demonstrated that Powderpuff plants were more sensitive to light competition as affected by plant density and also more greatly influenced by the environment than cv. Kurenai. Cultivar and photoperiod dependence in China aster has also been noted by Post (1950). It is possible that the environment at this production site was very favourable for stem elongation of this cultivar. Choices of cultivar and climatic conditions may be important as they may influence PGRs effectiveness (Seeley, 1979; McDaniel, 1983). A wide range of responses of Brussels sprouts cultivars to PGR have been shown by Thomas (1972). The reasons for the differences in response are not known but Thomas (1972) assumed that these may be related to differences in uptake, movement and metabolism of the PGR involved. Thus, variability in the response of different cultivars to PGR treatments requires investigation for China aster.

The results of this experiment also indicate that the efficacy and the effective duration of each growth retardant treatment was different. The longevity of chlormequat chloride activity in treated plants is shorter compared to paclobutrazol and daminozide. This may be presumably reflecting the individual modes of action of each PGR (Lever, 1986). Variation between PGR effectiveness has also been reported in other flower crops. For example, daminozide effectively retarded plant height in *Antirrhinum majus* (snapdragon) and *Delphinium belladonna* (delphinium) (Shedeed, 1987a), in marigold and zinnia (Shedeed, 1987b) and is commercially used in chrysanthemum production (Ball, 1985). But daminozide was ineffective while chlormequat retarded growth of several cultivars of *Hibiscus rosa-sinensis* (Shanks, 1972). Chlormequat has also been found to be more effective than daminozide for poinsettia (Larson, 1967) but less effective than paclobutrazol for carnation (Pobudkiewicz and Goldsberry, 1989). These conflicting results seem likely to be species and cultivar specific (Seeley, 1979; Kust, 1986; Davis and Andersen, 1989). The possible reasons for the variation in response of different plants to different chemicals has been given by Menhenett (1980); for example, differences in the chemical absorbing and translocating ability of leaves, stem and roots of different species, differences in plant metabolism or inactivation mechanisms and differences in mode of action of growth regulating chemicals.

In the present experiment, shorter plants were found at seed harvest in paclobutrazol treatments (0.5 kg a.i. ha^{-1} applied at visible terminal flower bud stage and 1.0 kg a.i. ha^{-1} at both application times) and for daminozide (both application times at 2.5 kg a.i. ha^{-1}). Chlormequat chloride treated plants, although not significantly differing from the control, tended to appear bigger than plants that were treated with the other two PGRs. Contrary effects between PGRs have been reported in *Verbena venosa*, when treatment with chlormequat (0.5 or 1.0 %) resulted in taller growth, while paclobutrazol (0.125 %) gave shorter shoots and a more bushy habit (Norremark, 1988).

Application rate and time or growth stage may also result in different plant responses (Seeley, 1979; Pobudkiewicz and Goldsberry 1989). Armitage (1986) showed that application of chlormequat after flower initiation did not retard plant height of geranium as much as that applied prior to flower initiation. In this experiment plant height retardation occurred following application of both rates at visible terminal flower bud stage, but only for the higher rate (1.0 kg a.i. ha^{-1}) when applied late at stem elongation. Tall chrysanthemum cultivars have also shown very little response to paclobutrazol application (McDaniel, 1983) and early application was suggested (Goulston and Shearing, 1985). However, only the lower rate of daminozide (2.5 kg a.i. ha^{-1}) retarded China aster plant height. This was the first experiment on the use of PGRs in field grown seed production of China aster and as the effectiveness of PGRs can be complicated by cultivar sensitivity, application rate and time, soil types, climates and cultural management (Seeley, 1979; Goulston and Shearing, 1985; Kust, 1986; Davis and Andersen, 1989), the correct PGR time and rate require further investigation.

5.4.2.2 Effects on branching and flowering

Flowering and the other plant morphological structures measured in this study i.e. number of branches and leaves, were less affected by PGR. Long days have also been shown to promote other aspects of plant growth apart from stem extension and flower initiation (Doorenbos, 1959; Hughes and Cockshull, 1964; 1965; 1966; Cockshull and Hughs, 1969). For these plant parts, initiation is a function of the apical meristem, and growth proceeded normally; only stem elongation, a function of the subapical meristem was retarded by the application of paclobutrazol. This selective action of a growth retardant in the apical and subapical regions of the shoot was demonstrated in chrysanthemum using Amo-1618 (Sachs *et.al.*, 1960). The action of the flowering process (the time of flower initiation and anthesis) is known to be controlled by phytochrome and strongly dependent on the environment (Atherton, 1987). Thus, all treatments in this study flowered at the same time and had the same numbers of branches and leaves. Similar results with other growth retardants have also been reported in chrysanthemum and petunia (Cathey, 1964).

Although branch numbers were not significantly different, there was a tendency for basal branch growth suppression by paclobutrazol (1.0 kg a.i. ha^{-1}) (Figure 5.1) and the net result was a significant reduction in total flower numbers (Appendix 5.10). Assimilate partitioning can be altered by application of PGR (Thomas *et.al.*, 1982). The effect of pinching (manual removal of the growing point) to increase the movement of assimilates to the lateral buds thereby increasing both uniformity and yield can be simulated in brussels sprouts by the use of PGRs such as daminozide and PP413 (ethyl-2-(3-chloro-phynylcarbamoyloxy) propionate) (Thomas *et.al.*, 1982). However, considerable increases in yield and improved uniformity can be achieved only when hand pinching is done at the right time (Thomas, 1966). The time of PGR application is also critical and should be carried out about a fortnight before hand pinching would normally be employed (Thomas, 1972). Results from dry matter partitioning in the present experiment have also shown longer vegetative growth suppression for the two paclobutrazol treatments and the three treatments with daminozide (Figure 5.2). This may suggest that the earlier reproductive parts might have some advantage for the available assimilates, but this advantage may be inconsistent between the number of fertile branches, seedheads or seed numbers depending on the duration of growth suppression by each treatment. However paclobutrazol showed a higher tendency to improve seed yield as shown in the greater harvest index and higher seed numbers of all paclobutrazol treatments, although a statistically significant difference was found only for the 1.0 kg a.i. ha^{-1} rate applied at the visible terminal flower bud stage. As paclobutrazol showed a tendency to partition the dry matter in favour of the reproductive part (seed), earlier application of this chemical is of interest and requires investigation as to whether it can improve seed yield.

5.4.2.3 Effects on seed yield

The results from Chapter 3 suggested that high seed yield in China aster was based on a higher number of branches and flowers and reports by Shedeed (1987a) in snapdragon and delphinium and by Shedeed (1987b) in zinnia have also shown that seed yield increases following daminozide application were due to increases in the number of inflorescences per plant. In this study, all treatments failed to increase branch and flower head numbers, and in contrast some treatments, particularly the high rate of paclobutrazol (1.0 kg a.i. ha^{-1}), tended to decrease branch numbers and significanly decreased the number of flowers. However, this decrease of flower numbers and hence seedheads did not affect final seed yield due to compensation by an increase in the number of seeds per seedhead. Late branches on untreated plants may have a detrimental effect on seed yield because they grow simultaneously with the developing flower (or seed) heads on early branches. Competition between reproductive growth and later elongating branches is likely to occur and possibly this competition may affect final seed yield (Chapter 3; Chanprasert, 1989). Assimilate competition between the seedheads which have already set, the flowers and the buds may cause abortion of the latter two (Ward *et.al.*, 1985). It is possible that flower bud abortion in the later developing flowers was due to the stronger sink strength of the earlier flowers induced by the high paclobutrazol rate. Higher rates of growth retardants have also been reported to decrease flower and fruit yields in most horticultural plants (Cathey, 1964).

Early lodging of China aster at the start of flowering can cause major reductions in seed yield (Chapter 3 and 5.4.1). Two growth retardant chemicals, paclobutrazol and daminozide showed potential value for height restriction. However, this advantage was not obvious visually, possibly because lodging did not occur at the start of flowering but began two weeks after peak flowering, and final plant height reduction after growth resumed was not enough for plants to fully exhibit the advantage of reduced canopy height. Plant growth regulators are normally associated with a reduction of plant height and lodging (Ward *et.al.* 1985). Dawkins and Almond (1984) reported that growth retardants could enhance seed yield in oil seed rape by changing the canopy structure which would allow greater penetration of light into the canopy, giving better utilisation of available light. Seed yield increases following PGR application due to a reduction in lodging have been reported in wheat (Kust, 1986) and perennial ryegrass (Hampton, 1983). However, variable seed yield results have also been reported following PGR application. Application of chlormequat chloride at the same rates used in this experiment did not improve seed yield in birdsfoot trefoil (Supanjani, 1991). Reports in other seed crops such as white clover (Marshall and Hides,1984); red clover (Niemelainen, 1987; Rayback and Walczak, 1988), also indicated that this chemical did not show promise for enhancing seed production. However, it has also been reported to increase seed yield in wheat and oats (Kust, 1986); perennial ryegrass (Hampton, 1986); ***Bromus willdenowii*** Kunth. cv Grasslands Matua (Hampton *et.al.*, 1989) and ***Lotus uliginosus*** Schk. cv Grasslands Maku. (Tabora, 1991). Daminozide application has also been reported to not increase seed yields in birdsfoot trefoil (White, *et.al.*, 1989; Supanjani, 1991), but it has been successfully used in red clover

(Jakesova and Svetlik, 1987; Christie and Choo, 1990); snapdragon and delphinium (Shedeed, 1987a) and zinnia (Shedeed, 1987b) seed crops. These conflicting results may be attributed to differences in species and cultivar responses, seasonal and site variation or different conditions at the time of the experiments e.g. temperature, rainfall, soil types and soil fertility which may further interact with the method, rate and time of PGR application (Seeley, 1979; Goulston and Shearing, 1985; Kust, 1986; Davis and Andersen, 1989).

Seed yield potential of paclobutrazol treated plants (1.0 kg a.i. ha^{-1} at the visible terminal flower bud stage) was greater than that of daminozide (2.5 kg a.i. ha^{-1} applied at the visible terminal bud stage) and chlormequat chloride (1.5 kg a.i. ha^{-1} applied at the stem elongation stage) because of a significant increase in seed numbers per head. The difference in seed number per head between the control and the paclobutrazol treatment was 56.6 (78 %), but seed yield did not differ from the control because there were 13 fewer seedheads per plant. The tendency was for both daminozide and paclobutrazol to increase seed number per seedhead but decrease seedhead numbers and fertile branches (Table 5.5, Appendix 5.6). However the results were not always consistent. Seed number was the most strongly correlated with seed yield out of all the components of yield [correlation coefficient (r) = 0.847 (significant at P=0.001)], while the correlation for seedhead numbers with seed yield was 0.301 (significant at P=0.001) and that for seed weight was non significant]. In perennial ryegrass Hampton and Hebblethwaite (1983) showed that seed numbers often explained over 90 % of the variation in seed yield recorded, and that fertile tiller numbers were poorly related to seed yield in lodged crops. In non-lodged crops, increases in yield were associated with increases in the number of seeds per spikelet (seed set) and consequently seeds per fertile tiller (Hampton, 1983).

Variation in the amount of seed loss between potentially harvestable and cleaned seed yield suggested variation in seed maturity between treatment (Table 5.6) and indicated a requirement for more accurate harvest timing for each treatment. It is likely that treatments that gave high seed numbers had higher seed yield loss due to higher amounts of immature seeds. Shortening the flowering period is another general aim in using PGRs as a shorter flowering period would also lead to more even maturity of the crop which in turn could be expected to ease the problems of harvesting, reduced seed shedding and other sources of seed loss (Ward *et.al.*, 1985). None of the PGR treatments in this experiment provided this advantage, and flowering appeared photoperiod dependent. Thus, the high variation in seed maturation as shown in Chapter 3 was still present in this experiment.

5.5 CONCLUSION

Results from this study support the suggestion in Chapter 3 that increased branching to increase flower numbers can be advantageous in improving seed yield. None of the treatments for both hand pinching and chemical manipulation (at visible terminal flower bud and stem elongation stage) increased branching and flower numbers per plant. Hand pinching, particularly the earlier treatment, did not increase branches due to a reduced node number, and also delayed flowering. Physical loss due to branch breakage also occurred in this treatment and this may prevent seed yield improvement. The chemical manipulation results, although not successful, showed a potential for seed yield improvement, but further experimentation is required to determine the most effective treatment. Plant growth of China aster was retarded by all chemical treatments during the vegetative growth stage. During stem elongation and flowering, the response was greatly influenced by temperature and photoperiod. Two chemicals, paclobutrazol and daminozide showed potential value for height restriction, but only paclobutrazol increased harvest index. Paclobutrazol (1.0 kg a.i. ha^{-1}) also reduced flower heads but seed yield did not decrease due to a compensatory increase in seed numbers per seedhead. Seed weight and germination were not affected by any treatments. The longer growth suppression of paclobutrazol resulted in more compact plants during late vegetative growth and also made the plant density too low to cover the ground area. The absence of the flower heads on later developing branches suggested that increasing plant density in paclobutrazol treatments may be beneficial in compensating for the reduction in flower numbers per plant and lead to increased seed yield per unit area if high seed numbers are also maintained. The magnitude of the response may be affected by season and application rate and timing (Seeley, 1979; Goulston and Shearing, 1985). Different cultivar responses to growth retardants have also been reported (McDaniel, 1983), and cultivar and photoperiod dependence in China aster has also been noted (Post, 1950). It would therefore be beneficial to examine the effects of paclobutrazol on different cultivars of china aster, to assess its effectiveness following relatively early application, and the response of cultivars grown at different plant densities.

CHAPTER 6

EFFECTS OF PACLOBUTRAZOL ON CHINA ASTER GROWN FOR SEED

INTRODUCTION

Results from the 1988/89 experiment (Chapter 5) have suggested some possibilities with chemical manipulation for improving seed production in China aster. Paclobutrazol (1.0 kg a.i. ha^{-1}) increased seed numbers per seedhead, but seed yield did not differ significantly from the untreated plants due to a decrease in seedhead numbers. Plant height reduction by shortening stem length was also demonstrated in the previous chapter but this height reduction was insufficient to prevent lodging. Despite this paclobutrazol application has been reported to prevent lodging in perennial ryegrass by reducing stem internode length and strengthening the stem base (Hampton, 1985). Lodging reduction and seed yield increase following retardant treatment have also been reported in perennial ryegrass (Hampton, 1983), in oil seed rape (Child *et.al*., 1985) and in *Vicia faba* L. (field beans; Attiya, 1983). In the latter crop increased yield was associated with significant increases in pods per plant and seeds per unit area (Attiya, 1983). Correct time and rate is important for growth retardant application (Seeley, 1979; Goulston and Shearing, 1985; Kust, 1986; Davis and Andersen, 1989). Higher retardation effects have been reported following earlier retardant treatment (prior to flower initiation compared with after flower initiation) in geranium (Armitage, 1986) and in tall chrysanthemum cultivars (Goulston and Shearing, 1985). Results from pinching treatments in the previous chapter showed that stem elongation could only be prevented by pinching at the rosette stage. There is normally a delay between the time a growth retardant is applied to the plant and the exhibition of growth retardation (Lever, 1986). In brussels sprouts, Thomas (1972) showed that daminozide could be used to increase the movement of assimilates to the lateral buds for increasing uniformity and bud yield when this chemical was applied about a fortnight before hand pinching would normally be employed. Larter (1967) showed that stem shortening can be achieved if sufficient retardant is maintained in barley during stem elongation. This suggests the possibility that, to be effective in China aster, paclobutrazol should be applied early enough to ensure the chemical is translocated to the shoot apex before elongation, and therefore available to maintain gibberellin biosynthesis suppression, and allow earlier assimilate movement to the lateral buds to increase seed yield.

Objectives

Two separate experiments were conducted in this study. The first (6.1) was carried out to determine whether an earlier paclobutrazol application could be used to increase seed yield. As growth regulator effects can depend on cultivar, environment and/or management (Cathey, 1969; Barrett and Nell, 1986; 1990), the second experiment (6.2) was extended to investigate the effects of paclobutrazol on plant growth and seed yield of two different cultivars of China aster grown at two different plant densities.

6.1 PACLOBUTRAZOL APPLICATION TIME

6.1.1 MATERIALS AND METHODS

6.1.1.1 Experimental site

The experiment was conducted at the Seed Technology Centre in the same field area as described in Chapter 5 (5.2.1) and adjacent to the area used in the 1988/89 experiment. This area had been used for seed production of several different plant species for many years. Weather data at Palmerston North during the season are presented in Appendix 6.1.1.

6.1.1.2 Establishment

Seeds of China aster cv. Powderpuff were thiram dusted (1 g product (80% wettable powder)/100g seed), and sown in a 30x40x6 cm tray filled with Smith's potting mix containing peat, pumice and sand (Smith Soil Industries Limited, Auckland, New Zealand) on 16 October 1989 in a 25±5 °C glasshouse at the Seed Technology Centre, Massey University. Seedlings were transplanted into root trainers (45x30x80 mm) containing the same soil mix on 24 October 1989 and raised in a glasshouse at the Seed Technology Centre under ambient temperature. Foliar fertilizer, 'Happy Garden' 12-8-16 (Nylex New Zealand Ltd, Auckland) was applied via a fertilizer dispenser attached to a soft spray wand at the rate of 35 kg ha^{-1} on 7 and 18 November 1989.

The field was ploughed on 26 October 1989 and harrowed two weeks later. A broad spectrum granular insecticide, Thimet 20 G (phorate, 200 g kg^{-1}) was applied at a rate of 1 kg a.i. ha^{-1} to control chewing insects. Fertilizer 18-20-0 (150 kg ha^{-1}), sulphate of potash (500 kg ha^{-1}) and calcium ammonium nitrate (150 kg ha^{-1}) were broadcast and soil incorporated on 17 November 1989.

Seedlings were hand transplanted into the field on 20 November 1989. Strings marked and crossed at 25 cm were used to obtain the required square spacing density of 16 plants m^{-2}. Replacement of about one hundred seedlings was done on 24 November 1989 because the original seedlings had been pinched and/or blown out of the ground by strong winds two days after they had been planted. Surplus seedlings were planted near the experimental area for growth stage determination and for the later replacement of plants which failed to establish. Irrigation was applied immediately after planting and then every 7-10 days up to two weeks after peak flowering by means of a garden sprinkler which provided 6000 litres water ha^{-1} h^{-1}. A herbicide, oryzalin 4.5 kg a.i. ha^{-1}, was applied once at 4 days after transplanting. Perennial weeds (i.e. docks) or other weeds not controlled by oryzalin were hand removed. Foliar fertilizer 12-8-16 (35 kg ha^{-1}) was applied 10 days after planting and ammophos (12:10:10:8) fertilizer was added at 100 kg ha^{-1} one month later (24 December 1989). Crop protection was by alternate use of the same products and rates as described in Chapter 3.

6.1.1.3 Treatments

Paclobutrazol was applied at three plant growth stages: during the vegetative stage (26 November 1989), at terminal flower bud initiation (6 December 1989) and at the first visible terminal bud stage (23 December 1989). Two rates of paclobutrazol, 0.5 and 1.0 kg ha^{-1} were applied as a single soil application with a 5 litre pressure sprayer in one litre of water per plot. Samples taken every 3 days from the surplus plants were observed under a microscope for the appearance of the flower bud initiation stage. After paclobutrazol application, 6000 litres water ha^{-1} was applied by sprinkler irrigation. Plant size (mean of 4 plants taken at random from the untreated plot) at these three application stages is shown in Table 6.1.1.

There were 7 treatments altogether as follows.

Control, untreated
Paclobutrazol 0.5 kg a.i. ha^{-1} at the vegetative stage
Paclobutrazol 1.0 kg a.i. ha^{-1} at the vegetative stage
Paclobutrazol 0.5 kg a.i. ha^{-1} at the flower bud initiation stage
Paclobutrazol 1.0 kg a.i. ha^{-1} at the flower bud initiation stage
Paclobutrazol 0.5 kg a.i. ha^{-1} at the first visible terminal bud stage
Paclobutrazol 1.0 kg a.i. ha^{-1} at the first visible terminal bud stage.

Table 6.1.1 Plant size of China aster cv. Powderpuff at the three growth stages when treatments were applied.

	Vegetative (26 Nov.1989)*		Flower bud initiation (6 Dec.1989)*		Visible terminal bud (23 Dec.1989)*	
Stem length (cm)	2.0	(0.1)	2.0	(0.04)	5.7	(0.4)
Root length (cm)	5.7	(0.4)	9.6	(0.5)	14.3	(1.4)
Leaf number (leaves)	7.0	(0.6)	13.0	(0.6)	30.0	(1.6)
Leaf length (cm)	7.0	(0.2)	7.0	(0.1)	9.8	(0.3)
Leaf width (cm)	3.0	(0.1)	3.1	(0.1)	4.4	(0.2)
Plant dry weight (g)	0.35	(0.07)	1.15	(0.11)	4.44	(0.49)
Stem dry weight (g)	0.03	(0.005)	0.04	(0.01)	0.52	(0.06)
Leaf dry weight (g)	0.30	(0.06)	0.99	(0.09)	3.31	(0.42)
Root dry weight (g)	0.03	(0.01)	0.12	(0.02)	0.59	(0.06)

( ) = standard error
* date of application

6.1.1.4 Experimental design and statistical analysis

Treatments were assigned in a randomized complete block design with 3 replicates. Plot size was 1.5 m x 3.0 m. There were 72 plants plot^{-1}. Layout of the field design is presented in Appendix 6.1.2. Statistical analysis and treatment mean comparisons were as described in Chapter 5.

6.1.1.5 Data collected

Growth analysis

Samples for growth analysis were taken at first flowering (4 February 1990), peak flowering (25 February 1990) and final harvest (5 April 1990). At each sampling, four plants were taken at random from each plot, washed, counted, measured and then separated into root, stem, leaves, branches, flower heads and seedheads where appropriate. Each fraction was then dried in an oven to a constant weight (3 days at 80 °C) before final weighing.

Responses to the various treatments were measured and recorded for total main stem length, plant height, lateral branch length, flower and seedhead number as described in Chapter 5, except for the following characters:

Vegetative stem length	-length from ground level to the joining of the vegetative part of the stem and the base of the terminal reproductive part (peduncle).
Leaf number	-all leaves longer than 1 cm were counted at first flowering and peak flowering. Leaves that were produced on stems and on branches were counted separately.
Node number	-all nodes on the main stem were counted at first flowering.
Branch number	-all elongated branches were counted at first flowering. Big branches (elongated with opened flowers) and small branches (elongated with flower buds) were separated and counted at peak flowering. At harvest, only branches that had seedheads were counted.

Seed yield and yield components

Powderpuff plants from 1.5 m^2 $plot^{-1}$ (excluding border rows) were hand harvested by cutting at ground level on 5 April 1990. Plants were bagged and left to air dry in the shade at ambient temperature for 12 days. Seedheads were then separated, threshed and cleaned on 18 April 1990 using the same methods as used in the 1988/89 experiment (Chapter 5).

Actual cleaned seed yield, potential harvestable seed yield and seed yield components were determined using the same procedures as described in Chapter 5 except that eight replicates of 100 seeds were used to determine thousand seed weight and germination was tested during 21 May to 10 June 1990.

6.1.2 RESULTS

6.1.2.1 Morphological structure and plant growth

All paclobutrazol treated plants had smaller leaves with a shorter petiole and darker green leaf colour at 10 days after application. These effects became more obvious during the second and third weeks after application (Appendix 6.1.3). Treated plants started to overcome the chemical retarding effect at four weeks after application and finally did not differ from untreated plants in leaf colour and overall plant structure (Appendix 6.1.4). Plant height was significantly retarded at final harvest in all paclobutrazol treatments (Table 6.1.2) because all paclobutrazol rates and application times significantly retarded vegetative stem length (Table 6.1.2 and Appendix 6.1.5). However, total stem length and branch length did not differ (Appendices 6.1.6 and 6.1.7). Results for vegetative stem length showed that the paclobutrazol retardation effect was transient. Retardation appeared early following the earliest application and disappeared before the later applications, as shorter vegetative stem lengths were recorded for the first (1.0 kg a.i. ha^{-1}) and the second (both rates) applications at first flowering, and in the second (both rates) and the third (1.0 kg a.i. ha^{-1}) application at peak flowering (Appendix 6.1.5). The duration of retardation was more dependent on the application rate if the application time was less appropriate, as plants receiving 1.0 kg a.i. ha^{-1} at the vegetative stage were shorter at first flowering than 0.5 kg a.i. ha^{-1} treated plants at the same application time and for the plants treated at visible terminal bud stage recorded at peak flowering, but there were no significant differences between the two paclobutrazol application rates applied at the flower bud initiation stage. The application of paclobutrazol at the flower bud initiation stage was the most appropriate time, as the retardation effect was consistent at all three assessment times (Appendix 6.1.5).

The reduction in vegetative stem length was presumably compensated for by increased reproductive stem length (peduncle) as there were no significant differences in total stem length at final harvest (Appendix 6.1.6). At peak flowering, only plants treated with 1.0 kg a.i. ha^{-1} paclobutrazol at the flower bud initiation and visible terminal bud stages had shorter stem lengths than the control (Appendix 6.1.6). Branch length of all paclobutrazol treated plants did not differ significantly from the control (Appendix 6.1.7).

Table 6.1.2 Effects of paclobutrazol on vegetative stem length, total main stem length, branch length and plant height of China aster cv. Powderpuff at seed harvest.

Treatment			Vegetative	Total	Branch length (cm)	Plant height (cm)
			stem length (cm)			
Control			35.8 a	72.9	56.2	92.0 a
Paclobutrazol	0.5^{+}	VEG	32.8 b	72.6	50.3	83.0 b
Paclobutrazol	1.0	VEG	29.9 bc	68.0	51.9	81.8 bc
Paclobutrazol	0.5	TBI	28.7 c	71.3	52.7	82.1 bc
Paclobutrazol	1.0	TBI	24.8 d	64.2	51.9	76.6 c
Paclobutrazol	0.5	VTB	32.1 b	69.3	52.7	84.4 b
Paclobutrazol	1.0	VTB	29.1 c	66.8	51.5	80.6 bc
Significance level			0.0001	0.171	0.217	0.001
CV (%)			5.39	5.88	4.75	3.28

$^{+}$ = application rate (kg a.i. ha^{-1})

TBI = flower bud initiation stage

VEG = vegetative or rosette stage

VTB = visible terminal flower bud stage

means within a column with the same letter are not significantly different at $P \leq 0.05$ for the Duncan's Multiple Range Comparison test.

(These indications apply for all tables.)

Plant height results did not always follow those for vegetative stem length, indicating that paclobutrazol also had some retardation effect on branch growth. The effect on branch growth appeared to be the same as for stem length (i.e. a retardation of vegetative branch length compensated by increased reproductive branch length) resulting in no significant effect on total branch length. Only the 1.0 kg a.i. ha^{-1} rate at the terminal flower bud initiation and at the visible terminal bud stages retarded plant height at all observation times (Appendix 6.1.8).

The other plant structures including the number of nodes, branches (both big and small lateral branches and total side branches), leaves (both those were produced on the stem and lateral branches) and flowers did not differ from the control (Appendices 6.1.9-6.1.12). Flowering was not altered by paclobutrazol as all treatments flowered at the same time. Although total branch numbers at peak flowering did not differ from the control, application of paclobutrazol at terminal flower bud initiation and 1.0 kg a.i. ha^{-1} at the visible terminal bud stage significantly decreased the number of branches that had seedheads (fertile branches) at harvest (Appendix 6.1.9).

6.1.2.2 Dry matter accumulation and distribution

Total plant dry weight of paclobutrazol treated plants was not significantly different from the control at all observation times (Appendix 6.1.13). Paclobutrazol retarded the stem only, particularly the vegetative stem (Fig. 6.1.1).

Vegetative stem dry weight was decreased by all applications of 1.0 kg a.i. ha^{-1} and 0.5 kg a.i. ha^{-1} applied at flower bud initiation when recorded at first flowering, by application of paclobutrazol at flower bud initiation when recorded at peak flowering and by 1.0 kg a.i. ha^{-1} applied at flower bud initiation and the visible flower bud stage when recorded at seed harvest. However, only 1.0 kg a.i. ha^{-1} paclobutrazol applied at flower bud initiation significantly decreased total stem dry weight at all observation times, while 1.0 kg a.i. ha^{-1} paclobutrazol applied at visible flower bud decreased total stem dry weight at final harvest (Fig. 6.1.1).

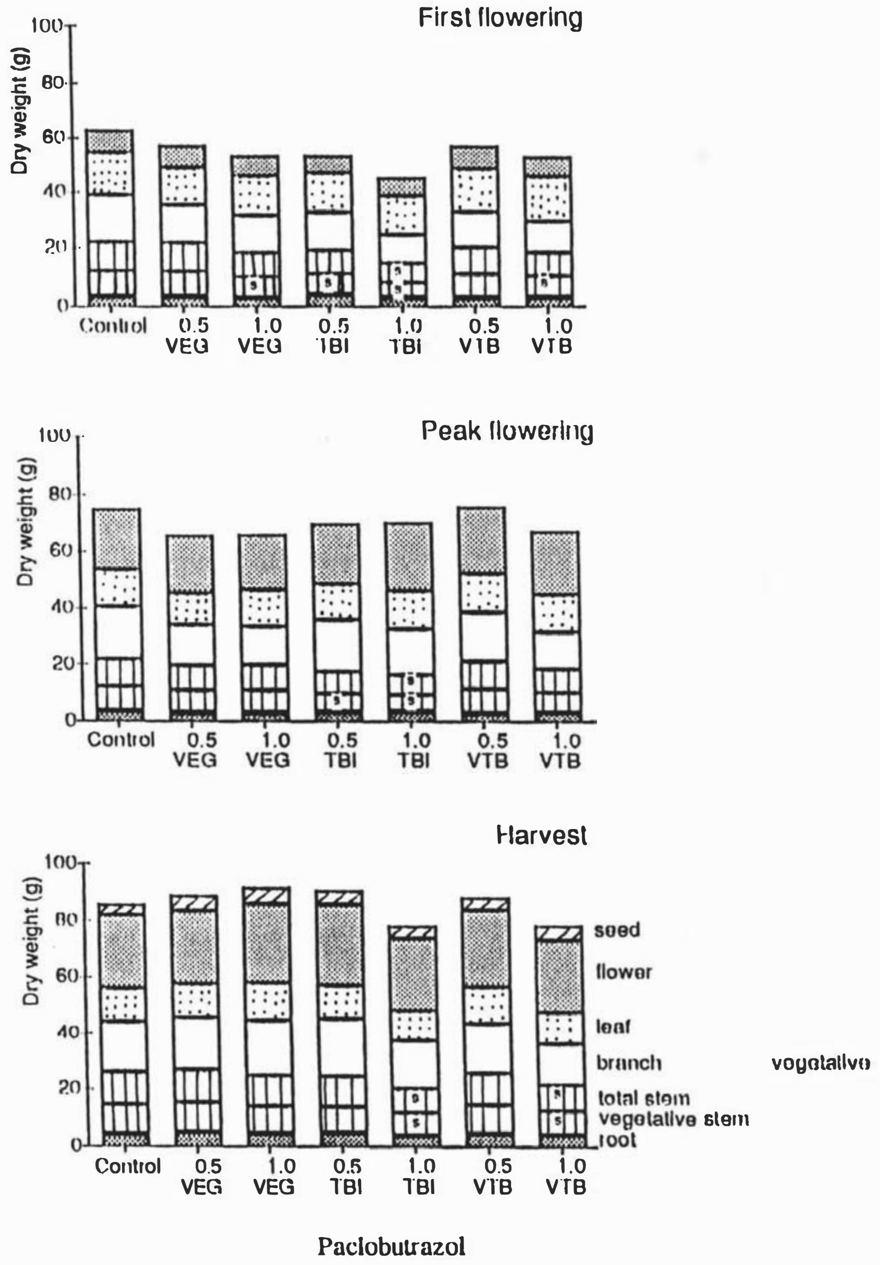


Figure 6.1.1 Plant dry weight at first flowering, peak flowering and seed harvest of China aster cv. Powderpuff.

['s' within a column means the dry weight of that part is significantly different from the control at $P \leq 0.05$ as separated by the Duncan's Multiple Range Comparison test.]

6.1.2.3 Seed yield and yield components

Paclobutrazol 1.0 kg a.i. ha^{-1} applied at the vegetative stage significantly increased potential harvestable seed yield (by 56%) due to an increase in seed numbers (Table 6.1.3). Actual cleaned seed yield, although increased 25 % by the same treatment just failed to differ significantly from the control (Table 6.1.4). Seed numbers were also increased significantly by 1.0 kg a.i. ha^{-1} applied at the visible terminal bud stage (Table 6.1.3). Seedhead numbers, seed weight and germination did not differ among treatments (Table 6.1.3). The amount of seed loss between the potential harvestable and cleaned seed yield was very high (Table 6.1.4).

Table 6.1.3 Effects of paclobutrazol on potential harvestable seed yield and yield components of China aster cv. Powderpuff.

Treatment			Potential seed yield g m^{-2}	Seed heads $plant^{-1}$	Seeds $head^{-1}$	TSW (g)	Germination (%)
Control			83.78 b	32	72 b	2.2149	93
Paclobutrazol	0.5	VEG	92.24 b	30	86 ab	2.2644	94
Paclobutrazol	1.0	VEG	130.61 a	33	110 a	2.2445	92
Paclobutrazol	0.5	TBI	104.89 ab	32	93 ab	2.2251	92
Paclobutrazol	1.0	TBI	99.31 ab	29	99 ab	2.1811	90
Paclobutrazol	0.5	VTB	96.80 ab	30	87 ab	2.2181	96
Paclobutrazol	1.0	VTB	106.32 ab	27	111 a	2.2116	92
LSD (0.05)			37.29	9	32	0.1752	6
CV (%)			20.56	20.08	18.55	4.43	3.60

Table 6.1.4 Effects of paclobutrazol on potential harvestable seed yield, actual cleaned seed yield and yield loss of China aster cv. Powderpuff.

Treatment			Seed yield (g m^{-2})			
			potential	cleaned	loss	% loss
Control			83.78 b	52.33 ab	31.45	37.5
Paclobutrazol	0.5	VEG	92.24 b	49.80 b	43.16	46.0
Paclobutrazol	1.0	VEG	130.61 a	65.40 a	65.21	49.9
Paclobutrazol	0.5	TBI	104.89 ab	58.80 ab	46.09	43.9
Paclobutrazol	1.0	TBI	99.31 ab	55.46 ab	43.85	31.0
Paclobutrazol	0.5	VTB	96.80 ab	57.06 ab	39.74	41.1
Paclobutrazol	1.0	VTB	106.32 ab	55.37 ab	50.95	47.9
LSD (0.05)			37.29	13.58		
CV (%)			20.56	13.56		

6.1.3 DISCUSSION

6.1.3.1 Paclobutrazol effects on plant growth and development

The plant height result confirmed that of the previous year i.e. that the paclobutrazol effect on cv. Powderpuff was transient. Plant height was retarded during vegetative growth, but not always during flowering (Appendices 5.5 and 6.1.8). However by seed harvest, height was once more significantly reduced by both application rates, with the exception of the stem elongation application time (Appendix 5.5). Application of 1.0 kg a.i. ha^{-1} at terminal flower bud initiation was the most consistent paclobutrazol treatment as retardation always occurred and persisted until final seed harvest (Appendix 6.1.8). For the visible terminal flower bud application, the difference between the 1988/89 and 1989/90 results was possibly due to the slightly earlier application time in the latter experiment. Application was when the first terminal bud in each plot became visible in 1989 while the application in the previous year was delayed until the terminal flower buds could be seen on half of the plants in each plot. It seems unlikely that lodging in cv. Powderpuff can be prevented by a single application of 1.0 kg a.i. ha^{-1} paclobutrazol, as the significant height reduction from paclobutrazol application recorded in both the previous chapter and this chapter was not enough to prevent lodging. In the present experiment lodging occurred one week after peak flowering following high rainfall during early March (Appendix 6.1.1), but was not as severe as that which occurred in previous years after both rain and wind.

Paclobutrazol reduced plant height by reducing main stem length, particularly vegetative stem length (Appendix 6.1.5). Shorter stems in paclobutrazol treated plants were due to shorter internodes, rather than any reduction in internode numbers (Appendx 6.1.11). This agrees with reports for other plants such as sunflower (Wample and Culver, 1983); perennial ryegrass (Hampton and Hebblethwaite, 1985); birdsfoot trefoil (Li, 1989); *Raphanus sativus* L. (Hampton and Young, 1988); and *Holcus lanatus* L. (Tolentino, 1990).

6.1.3.2 Paclobutrazol effects on plant dry matter accumulation

There was a specific duration of plant growth suppression induced by paclobutrazol as the growth suppression from the earlier application had always appeared and then disappeared before the later application was made. The higher rate appeared to have a longer duration of suppression. Growth suppression of both stem and lateral branches occurred but depended on application time. Paclobutrazol applied early reduced main stem dry weight, in particular the vegetative part of the stem (Figure 6.1.1). If applied late, dry weight of both the stem and branches was reduced, as shown in the previous chapter (Figure 5.4). This supports the results for plant height and further study should determine whether increasing the paclobutrazol application rate or repeat applications could provide longer retardation effects. Larter (1967) showed that stem length in barley was reduced by 25 % and lodging was controlled only by repeated spraying of chlormequat. Repeated spraying has also been reported to be necessary for succesful height control of many flower crops, such as geranium (Miranda, 1980), chrysanthemum (Manhenett, 1984) and *Bouvardia* (Wilkinson and Richard, 1987). More than one application may also be required for Powderpuff aster. However, this suggestion requires further study.

6.1.3.3 Paclobutrazol effects on seed yield

Results from paclobutrazol applications at different growth stages suggest that early application of the 1.0 kg a.i. ha^{-1} rate during the vegetative stage was more suitable for enhancing seed yield than any later application, as seed yield potential was increased by 56 %. This increase in seed yield was due to an increase in seed numbers as other yield components were not altered. Early main stem growth removal or growth retardant application can increase the movement of assimilates to lateral buds (Thomas, 1972; Chapter 5) making more assimilate available, which is possibly an advantage for seed set or seed retention. Later application, during terminal flower bud initiation and up to first visible terminal flower bud, although not affecting lateral branch and flower numbers, did not increase seed yield as it decreased fertile branch numbers. It was observed that the number of fertile branches was always similar to the number of big lateral branches counted at peak flowering. Small lateral branches failed to become fertile, possibly due to the stronger competitive ability of the earlier developed branches. This was confirmed from results in the previous experiment (Chapter 5) which showed that paclobutrazol applied at a relatively later growth stage (when the terminal flower bud became visible and during stem elongation), resulted in a response where both branches and flowers were inhibited or failed to become fertile.

The 8-34 g m^{-2} greater seed yield loss from paclobutrazol treated Powderpuff plants (Table 6.1.4) is likely to reflect an incorrect harvest time. Harvesting time may be different from year to year and depend on the climatic conditions during post maturation pre-harvest period (Delouche, 1980). Hare and Lucas (1984) investigated seed development of *Lotus uliginosus* over two contrasting seasons (hot and dry in 1981/1982 season and moist and cooler season in 1982/1983 season) and reported that seed ripening was much more rapid in the first (27 days) rather than in the latter season (35 days). It may also be possible that paclobutrazol treated plants needed a longer time for seed development, since a greater number of sinks were stimulated and competing for the same available assimilates (as there were no differences in leaf numbers and plant dry weight). The work of Supanjani (1991) in birdfoot trefoil showed that average seed yield following paclobutrazol application was increased 27 % by a six days delay in harvesting, because in that season cool temperature and high relative humidity between the two harvest times were not conducive to pod shattering of mature pods, and this delay advantaged seed development and maturity in late flowers which exhibited low inflorescence abortion.

6.1.4 CONCLUSION

Early application of paclobutrazol (1.0 kg a.i. ha^{-1}) at the vegetative stage increased the seed potentially available to harvest by 56 %. This increased seed yield was presumebly due to an earlier movement of assimilate to the reproductive parts which favoured seed set, rather than any alteration in dry weight partitioning between plant parts or a reduction in plant height.

Application of paclobutrazol at terminal flower bud initiation reduced plant height but did not prevent lodging and did not advantage seed yield. Early application at the high paclobutrazol rate retarded only main stem dry weight while later application at stem elongation retarded both stem and branch growth (Chapter 5). This suggests some possibilities for further investigation for successful height control, such as increasing the rate applied at terminal flower bud initiation, or with the same rate used in this study but applied one more time, at or after stem elongation, to retard branch growth. However, treatment with 1 kg a.i. ha^{-1} applied at stem elongation decreased seed yield (Chapter 5). Thus it may be necessary to considerably increase the number of plants per unit area to compensate for the lower flower head numbers per plant.

6.2 PACLOBUTRAZOL, CULTIVAR AND PLANT DENSITY

6.2.1 MATERIALS AND METHODS

6.2.1.1 Experimental site

The experiment was carried out in the same field and adjacent to the area used in section 6.1. Soil preparation had been done at the same time as for the experiment in section 6.1.

6.2.1.2 Treatments and establishment

Four sets of experiments were conducted separately for cultivar and plant density responses to paclobutrazol. The same cultivars of China aster, Powderpuff and Kurenai used in the plant density experiment (Chapter 3) were used for this study. For the optimum and high density plant responses, each cultivar was planted at two different plant densities; 16 and 36 plants m^{-2} for the tall cultivar Powderpuff and 25 and 49 plants m^{-2} for the more compact medium-tall cultivar Kurenai.

Seeds of China aster cv. Powderpuff and cv. Kurenai were thiram dusted (1 g product (80% wettable powder)/100 g seed), and directly hand sown at 3-4 seeds per hole into the field on 27 November 1989. Strings marked and crossed at 25 and 16.7 cm were used for sowing cv. Powderpuff and 20 and 14 cm for cv. Kurenai to obtain the required square plant spacing for each cultivar. Water was applied immediately after sowing with the garden sprinkler used previously which provided 6000 litres water ha^{-1} h^{-1}. To ensure good establishment twenty minutes of watering was given every evening for up to two weeks after sowing and then every 7-10 days until two weeks after peak flowering. Foliar fertilizer 12-8-16 was applied at the rate of 35 kg ha^{-1} via a spray wand at 7 days after aster seedling emergence and one week thereafter (on 11 and 18 December 1989). Aster seedlings were covered with plastic cups before a mixture of oryzalin 4.5 kg a.i. ha^{-1} and glyphosate 2 kg a.i. ha^{-1} was sprayed over the experimental plots on 20 December 1989. Thinning of aster seedlings was done on 4 January 1990 to meet the required plant density. Fertilizer (ammophos, 12:10:10:8) was applied at 100 kg ha^{-1} on the day after thinning followed by one hour of sprinkler irrigation. Crop protection was as described in Chapter 3.

Two rates of paclobutrazol, 0.5 and 1.0 kg a.i. ha^{-1} were applied on 21 January 1990 for cv. Kurenai and 24 January 1990 for cv. Powderpuff via a 5 litre pressure sprayer in one litre of water per plot. Details of these four sets of experiments are given in Table 6.2.1. At application, plants of cv. Powderpuff were at the flower bud initiation growth stage, but were between flower bud initiation and early stem elongation in cv. Kurenai due to the more advanced growth of this cultivar. Stage of growth was determined as described in 6.1.2.3. Plant size (mean of 4 plants taken at random from the untreated plot) of the two cultivars at application time are shown in Table 6.2.2. After paclobutrazol application, 6000 litres water ha^{-1} was applied.

The three treatments in each experiment were as follows:

Control: untreated
Paclobutrazol 0.5 kg a.i. ha^{-1}
Paclobutrazol 1.0 kg a.i. ha^{-1}

Table 6.2.1 Cultivar, plant density, spacing and number of plants per plot used in each experiment.

Experiment	Cultivar	Density (plants m^{-2})	Spacing (cm)	Plants plot^{-1}
1	Powderpuff	16	25 x 25	48
2	Powderpuff	36	16.7 x 16.7	108
3	Kurenai	25	20 x 20	75
4	Kurenai	49	14 x 14	147

Table 6.2.2 Plant size of China aster cv. Powderpuff and cv. Kurenai when paclobutrazol was applied.

	Powderpuff (24 January 1990)*		Kurenai (21 January 1990)*	
Stem length (cm)	2.3	(0.53)	6.9	(0.76)
Root length (cm)	3.8	(0.34)	5.1	(0.74)
Leaf number (leaves)	11.5	(0.50)	18.0	(1.29)
Leaf length (cm)	8.4	(0.72)	9.3	(0.25)
Leaf width (cm)	3.7	(0.21)	4.1	(0.14)
Plant dry weight (g)	0.70	(0.08)	1.86	(0.24)

( ) = standard error

* date of application.

6.2.1.4 Experimental design and statistical analysis

A randomized complete block design with 3 replicates was used for each experiment. Plot size was 1 x 3 m. Number of plants per plot are presented in Table 6.2.1. Layout of the field design is presented in Appendix 6.1.2. Data were analyzed by analysis of variance (ANOVA) using the SAS program (SAS, 1988). Treatment mean comparisons were performed using the Least Significant Difference test with 5 % probability. Graphs were drawn using a Microsoft Chart programme.

6.2.1.5 Data collected

Growth analysis

Samples for growth analysis were taken at peak flowering (14 March 1990 for cv. Kurenai and 26 March 1990 for cv. Powderpuff) and final harvest (11 April 1990 for cv. Kurenai and 30 April 1990 for cv. Powderpuff). At each sampling, four plants were taken at random from each plot, washed, counted, measured, separated, dried and weighed, using the same methods as described in 6.1.1.5

Responses to the various treatments were measured and recorded for vegetative and total stem length, plant height, branch length, number of leaves, nodes, branches, flowers and seedheads as described in 6.1.1.5.

Seed yield and yield components

All plants in each plot (excluding border rows) were hand harvested when the average seed moisture content of the control plots of each experiment was around 40-42 % by cutting at ground level on 14 April 1990 for cv. Kurenai and 30 April 1990 for cv. Powderpuff. The plants were left to air dry in open shade at ambient temperature for 10-14 days before seedheads were separated, threshed and cleaned using the same procedure as described in 6.1.1.5. Seed yield and all components of yield were also determined by the methods described in 6.1.1.5 except that germination testing was done during 13-27 July 1990.

6.2.2 RESULTS

6.2.2.1 Powderpuff (16 plants m^{-2})

Plant growth following paclobutrazol application was initially retarded and then resumed in the same way as described in the previous experimental results (6.1.2). Paclobutrazol did not alter the overall morphological structure or flowering pattern. Plant height of paclobutrazol treated plants was significantly shorter than the control only at the final harvest (Table 6.2.3), because of shortening of the main stem (Table 6.2.4) particularly the vegetative stem (Table 6.2.5, Appendix 6.2.6). Vegetative stem length was retarded by both paclobutrazol rates as all treated plants were significantly shorter than the control. The stem length restriction for the high paclobutrazol rate (1.0 kg a.i. ha^{-1}) was greater than the lower rate (0.5 kg a.i. ha^{-1}) only at the final harvest, as the vegetative stem length of the 1.0 kg a.i. ha^{-1} treated plants was shorter than the 0.5 kg a.i. ha^{-1} treated plants (Table 6.2.5). Vegetative and total branch length was not significantly different from the control (Appendix 6.2.1). The number of nodes, branches, leaves and flowers (Appendices 6.2.2-6.2.4), and leaf size (Appendix 6.2.5) did not differ significantly from the control.

There were no significant differences between treatments in total plant dry weight and the dry weight of any plant parts at either assessment time (Figure 6.2.1, Appendix 6.2.5).

Paclobutrazol at both rates significantly decreased seedhead numbers but the high rate (1.0 kg a.i. ha^{-1}) increased seed numbers (Table 6.2.6). However, both potential harvested seed yield and actual cleaned seed yield did not differ significantly from the control. Seed weight and germination were not affected by paclobutrazol application. The high percentage of seed yield loss between the potential and the cleaned seed yield (Table 6.2.7) again suggested an incorrect time of harvest.

6.2.2.2 Powderpuff (36 plants m^{-2})

The response of Powderpuff plants grown at 36 plants m^{-2} to the paclobutrazol application was similar to those grown at 16 plants m^{-2}. Plant growth was initially retarded and then growth resumed without altering the overall plant structure and flowering pattern (Appendix 6.2.7). The number of lateral branches, nodes, leaves and flowers did not differ significantly from the control (Appendices 6.2.2-6.2.5). Fertile branch numbers were increased by the treatments but significantly so only by the rate of 0.5 kg a.i. ha^{-1} (Appendix 6.2.3). Both paclobutrazol rates had the same ability to restrict plant height as all treated plants were shorter than the control at both assessment times, but significant so only at peak flowering (Table 6.2.3). The main stem length of treated plants was significantly shorter than the control only at final harvest. The ability to restrict vegetative stem length was similar to that for the low density (16 plants m^{-2}) experiment. All paclobutrazol treated plants had shorter vegetative stems than the control at peak flowering and the response to the high paclobutrazol rate (1.0 kg a.i. ha^{-1}) was greater than the lower rate (0.5 kg a.i. ha^{-1}) at the final harvest. However the effectiveness of paclobutrazol in the high density plants (36 plants m^{-2}) appeared lower than its effectiveness in the plants grown at low density (16 plants m^{-2}) as 0.5 kg a.i. ha^{-1} treated plants were no longer significantly shorter than the control at final harvest (Table 6.2.5).

There were no significant differences between treatments in total plant dry weight and the dry matter of any plant parts at both assessment times (Figure 6.2.1, Appendix 6.2.6).

The potential harvested seed yield increase (24-48 %) was significant only at the low paclobutrazol rate (0.5 kg a.i. ha^{-1}), although seed numbers were increased significantly by both rates (Table 6.2.6). Actual cleaned seed yield did not differ from the control (Table 6.2.7). Seedhead numbers, seed weight and germination were not affected by paclobutrazol application (Table 6.2.6). Seed yield loss was also high as found in plants grown at 16 plants m^{-2}.

6.2.2.3 Kurenai (25 plant m^{-2})

Paclobutrazol effectively controlled plant height of cv. Kurenai as treated plants being approximately two thirds the height of untreated plants (Table 6.2.3, Appendix 6.2.7). The higher rate (1.0 kg a.i. ha^{-1}) retarded plant height more than the lower rate (0.5 kg a.i. ha^{-1}) but the differences were significant only at final harvest (Table 6.2.3). The main stem length of all the treated plants was significantly shorter than the control and the plants that were treated with 1.0 kg a.i. ha^{-1} paclobutrazol had a shorter main stem than the 0.5 kg a.i. ha^{-1} treated plants at both peak flowering and final harvest (Table 6.2.4). The vegetative stem length of treated plants was shorter than the control (Table 6.2.5, Appendix 6.2.7). The higher rate (1.0 kg a.i. ha^{-1}) was more effective than the lower rate (0.5 kg a.i. ha^{-1}) as 1.0 kg a.i. ha^{-1} treated plants had a shorter vegetative stem than the 0.5 kg a.i. ha^{-1} treated plants. However these differences were only significant at the final harvest (Table 6.2.5). Branch length was not affected by paclobutrazol application (Appendix 6.2.1). The number of branches, nodes, leaves and flowers did not significantly alter (Appendices 6.2.2-6.2.5) but fertile branches were increased (Appendix 6.2.4).

Total plant dry weight of paclobutrazol treated plants was not significantly different from the control at both observation times (Appendix 6.2.6). Only the stem dry matter of the 1.0 kg a.i. ha^{-1} paclobutrazol treated plants was significantly decreased at final harvest (Figure 6.2.2). A decrease in root dry matter was recorded only at peak flowering (Figure 6.2.2). The differences in the dry matter of all other plant parts were not significant for both assessments.

Seed yield potential obtained from the control plots was 128.31 g m^{-2}, but the paclobutrazol increases (10-16 %) were not greater than the control (Table 6.2.6). Seed numbers were increased but only significantly by the 1.0 kg a.i. ha^{-1} treatment. All other components of seed yield were not altered by paclobutrazol application (Table 6.2.6). Seed yield loss between the potential and cleaned seed yield was not as high as for cv. Powderpuff but was still greatest for paclobutrazol treatments (Table 6.2.7). The difference between the treated and untreated plants was greater than that in cv. Powderpuff.

6.2.2.4 Kurenai (49 plant m^{-2})

The effects of paclobutrazol on plant growth and plant structure of cv. Kurenai grown at 49 plants m^{-2} were similar to those described for the low density plants (25 plants m^{-2}) of this cultivar, but the ability to restrict vegetative stem length, main stem length and plant height differed in that there were no significant differences between the two paclobutrazol rates at both assessment times (Table 6.2.3-6.2.5). The number of nodes, leaves and flowers in the treated plants were not altered by paclobutrazol (Appendices 6.2.2-6.2.4). Although the total lateral branch numbers were not affected, the numbers of branches produced from the first flush before first flowering recorded at peak flowering, and harvested fertile branches, were increased by the 1.0 kg a.i. ha^{-1} paclobutrazol rate (Appendix 6.2.3).

Significant dry matter accumulation differences between treatments were recorded only at final harvest (Figure 6.2.2). Although total dry matter was not different, both paclobutrazol rates significantly decreased stem dry matter. Branch and leaf dry matter were increased but this was significant only for the 1.0 kg a.i. ha $^{-1}$ paclobutrazol treated plants (Figure 6.2.2).

Paclobutrazol at both rates significantly increased potential harvestable seed yield by 32-42 % from the 177.90 g m^{-2} of the control plots (Table 6.2.6) due to increased seed numbers and seed weight. Seed numbers were increased by both paclobutrazol rates but the increase in seed weight was significant only for the 1.0 kg a.i. ha^{-1} treatment. Seedhead numbers were not different from the control. Germination was not affected by paclobutrazol application (Table 6.2.6). Actual cleaned seed yield did not increase due to a greater seed loss than from the control treatment (Table 6.2.7).

Table 6.2.3 Effects of paclobutrazol on plant height of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2} and cv. Kurenai grown at 25 and 49 plants m^{-2}.

Treatment	Plant height (cm) peak flowering	 harvest
Powderpuff (16 plants m^{-2})		
Control	59.7	60.8 a
Paclobutrazol 0.5 kg	52.5	53.8 b
Paclobutrazol 1.0 kg	48.9	49.7 b
Significance level	0.060	0.017
CV (%)	7.22	4.88
Powderpuff (36 plants m^{-2})		
Control	68.4 a	68.8 a
Paclobutrazol 0.5 kg	57.1 b	60.2 b
Paclobutrazol 1.0 kg	54.4 b	56.5 b
Significance level	0.020	0.048
CV (%)	4.77	9.03
Kurenai (25 plants m^{-2})		
Control	56.0 a	57.8 a
Paclobutrazol 0.5 kg	42.1 b	45.0 b
Paclobutrazol 1.0 kg	38.8 b	37.6 c
Significance level	0.0003	0.0003
CV (%)	3.35	3.59
Kurenai (49 plants m^{-2})		
Control	53.1 a	60.8 a
Paclobutrazol 0.5 kg	42.4 b	45.8 b
Paclobutrazol 1.0 kg	41.5 b	44.0 b
Significance level	0.0227	0.0006
CV (%)	7.28	3.55

means within a given column with the same letter are not significantly different at $P \leq 0.05$ for the Least Significant Differences Test. - applies all tables.

Table 6.2.4 Effects of paclobutrazol on total main stem length of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2} and cv. Kurenai grown at 25 and 49 plants m^{-2}.

Treatment	Main stem length (cm) peak flowering	 harvest
Powderpuff (16 plants m^{-2})		
Control	57.0	58.0 a
Paclobutrazol 0.5 kg	50.6	49.7 b
Paclobutrazol 1.0 kg	47.7	48.3 b
Significance level	0.088	0.003
CV (%)	7.28	3.00
Powderpuff (36 plants m^{-2})		
Control	61.5	65.5 a
Paclobutrazol 0.5 kg	56.5	55.8 b
Paclobutrazol 1.0 kg	54.3	55.1 b
Significance level	0.082	0.006
CV (%)	2.42	4.30
Kurenai (25 plants m^{-2})		
Control	50.1 a	52.4 a
Paclobutrazol 0.5 kg	38.7 b	40.0 b
Paclobutrazol 1.0 kg	33.1 c	36.0 c
Significance level	0.001	0.001
CV (%)	3.70	4.09
Kurenai (49 plants m^{-2})		
Control	50.0 a	53.8 a
Paclobutrazol 0.5 kg	39.6 b	41.3 b
Paclobutrazol 1.0 kg	40.1 b	40.4 b
Significance level	0.006	0.011
CV (%)	4.78	6.90

Table 6.2.5 Effects of paclobutrazol on vegetative stem length of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2} and cv. Kurenai grown at 25 and 49 plants m^{-2}.

Treatment	Vegetative stem length (cm)	
	peak flowering	harvest
Powderpuff (16 plants m^{-2})		
Control	31.3 a	31.1 a
Paclobutrazol 0.5 kg	24.7 b	25.7 b
Paclobutrazol 1.0 kg	21.2 b	21.0 c
Significance level	0.010	0.002
CV (%)	8.11	4.76
Powderpuff (36 plants m^{-2})		
Control	36.5 a	36.9 a
Paclobutrazol 0.5 kg	26.8 b	30.0 ab
Paclobutrazol 1.0 kg	25.0 b	27.1 b
Significance level	0.015	0.043
CV (%)	7.29	8.31
Kurenai (25 plants m^{-2})		
Control	35.0 a	36.6 a
Paclobutrazol 0.5 kg	21.0 b	23.8 b
Paclobutrazol 1.0 kg	19.3 b	17.9 c
Significance level	0.0001	0.001
CV (%)	4.47	8.33
Kurenai (49 plants m^{-2})		
Control	34.2 a	42.2 a
Paclobutrazol 0.5 kg	23.2 b	26.5 b
Paclobutrazol 1.0 kg	22.8 b	25.3 b
Significance level	0.004	0.001
CV (%)	7.93	7.08

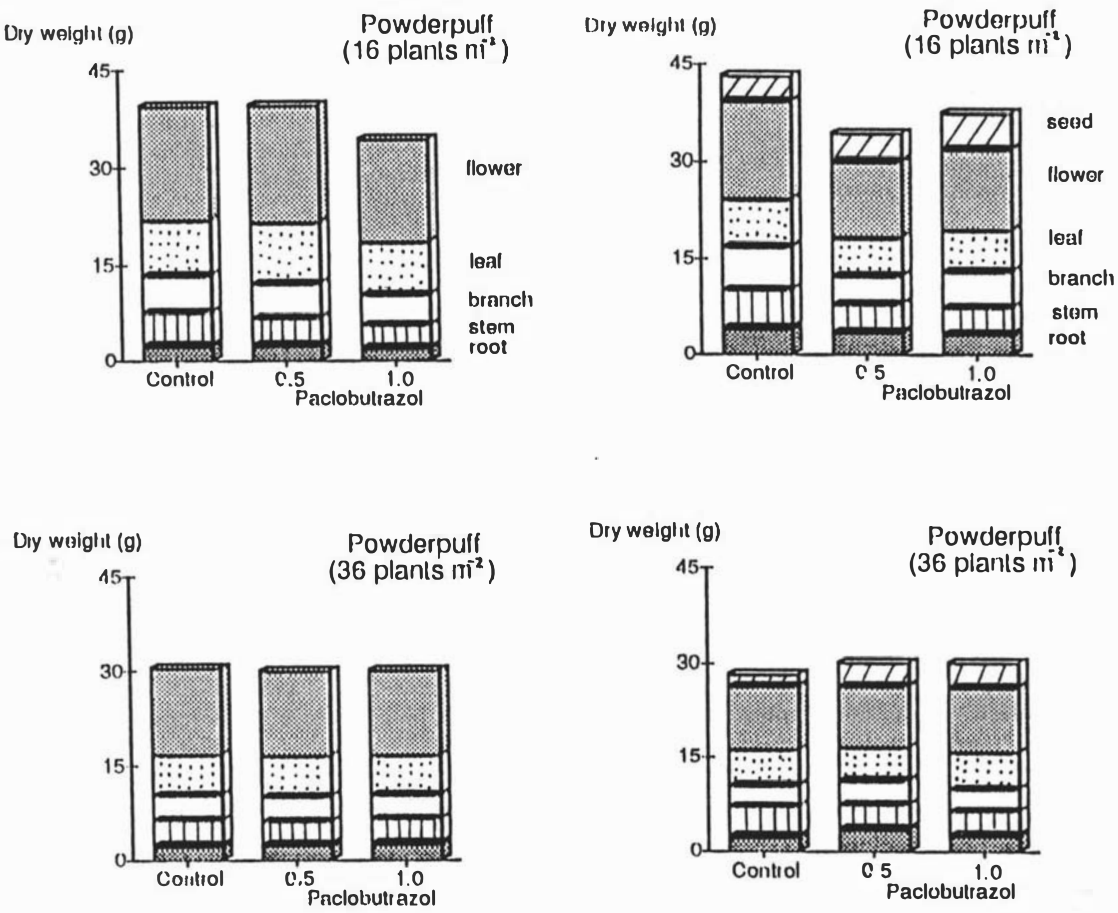


Figure 6.2.1 Plant dry weight at peak flowering and seed harvest of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2}.

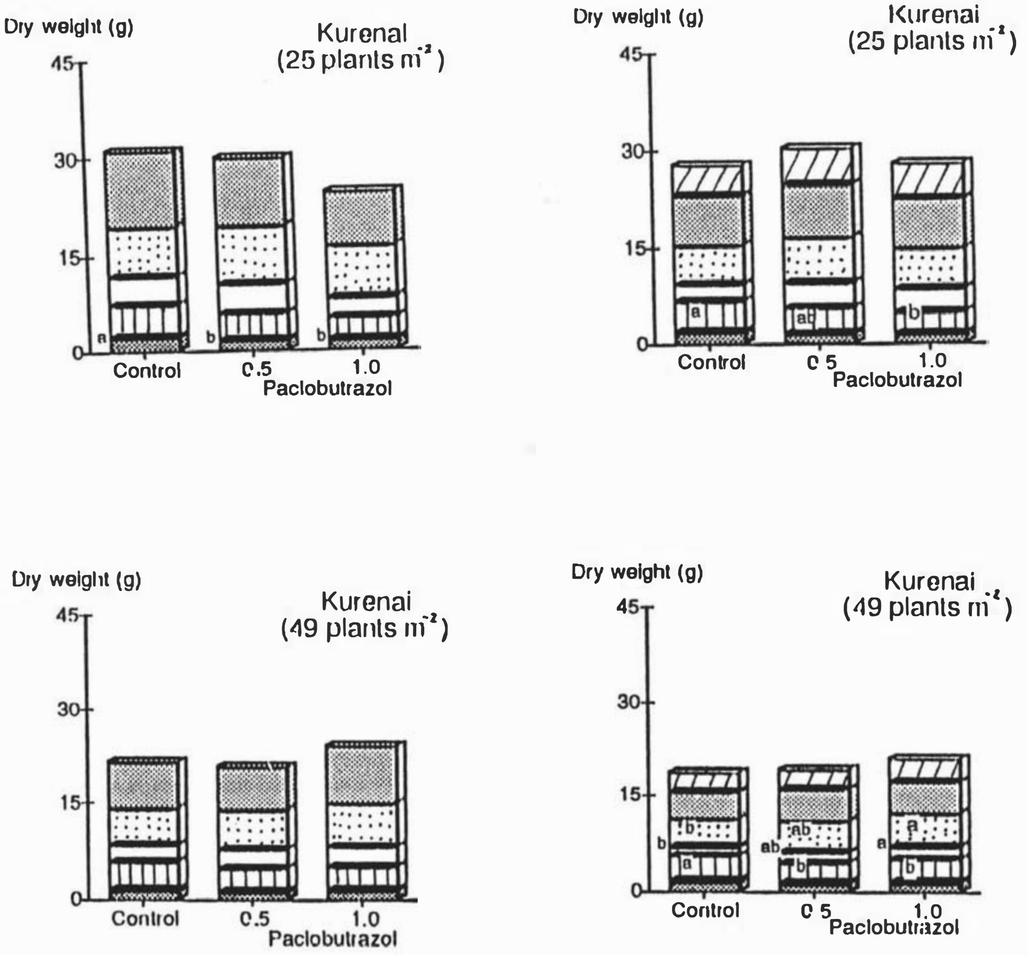


Figure 6.2.2 Plant dry weight at peak flowering and seed harvest of China aster cv. Kurenai grown at 25 and 49 plants m^{-2}.
(The same letter within or beside each column indicates the dry weights of that part are not significantly different at $P \leq 0.05$ for the Least Significance Difference Test.)

Table 6.2.6 Effects of paclobutrazol on potential harvestable seed yield and yield components of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2} and cv. Kurenai grown at 25 and 49 plants m^{-2}.

Treatment	Seed yield (g m^2)	Seed heads	Seeds head^{-1}	TSW (g)	Germination (%)
Powderpuff (16 plants m^{-2})					
Control	122.84	34 a	112 b	2.040	88.0
Paclobutrazol 0.5 kg	119.37	27 b	110 b	2.174	90.0
Paclobutrazol 1.0 kg	140.55	27 b	151 a	2.120	94.7
LSD (0.05)	37.84	4	23	0.213	13.2
CV (%)	13.08	16.24	16.85	4.45	6.43
Powderpuff (36 plants m^{-2})					
Control	135.91 b	22	86 b	2.019	93.0
Paclobutrazol 0.5 kg	201.73 a	22	119 a	2.144	92.3
Paclobutrazol 1.0 kg	169.57 ab	21	115 a	1.990	92.7
LSD (0.05)	50.66	6	27	0.331	13.3
CV (%)	13.22	8.32	22.60	5.35	6.35
Kurenai (25 plants m^{-2})					
Control	128.31	29	105 b	1.662	99.3
Paclobutrazol 0.5 kg	140.84	31	115 ab	1.681	99.7
Paclobutrazol 1.0 kg	148.44	26	123 a	1.760	99.0
LSD (0.05)	34.12	7	14	0.321	1.8
CV (%)	10.81	10.33	5.44	8.32	0.82
Kurenai (49 plants m^{-2})					
Control	177.90 b	21.3	109 b	1.565 b	98.7
Paclobutrazol 0.5 kg	235.70 a	20.7	143 a	1.619 ab	96.7
Paclobutrazol 1.0 kg	253.24 a	20.7	148 a	1.647 a	97.0
LSD (0.05)	63.87	4	21	0.070	7.8
CV (%)	12.68	7.48	8.65	1.92	3.52

Table 6.2.7 Effects of paclobutrazol on potential harvestable seed yield, actual cleaned seed yield and yield loss of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2} and cv. Kurenai grown at 25 and 49 plants m^{-2}.

Treatment	Seed yield			
	potential	cleaned	loss	% loss
Powderpuff (16 plants m^{-2})				
Control	122.84	60.26	62.58	50.9
Paclobutrazol 0.5 kg	119.37	47.28	72.09	60.5
Paclobutrazol 1.0 kg	140.55	59.36	81.19	57.8
LSD (0.05)	37.84	34.12		
CV (%)	13.08	27.06		
Powderpuff (36 plants m^{-2})				
Control	135.91 b	45.09	90.82	66.8
Paclobutrazol 0.5 kg	201.73 a	64.14	137.59	68.2
Paclobutrazol 1.0 kg	169.57 ab	55.75	113.82	67.1
LSD (0.05)	50.66	32.20		
CV (%)	13.22	27.98		
Kurenai (25 plants m^{-2})				
Control	128.31	110.46	17.85	13.9
Paclobutrazol 0.5 kg	140.84	101.56	39.28	27.9
Paclobutrazol 1.0 kg	148.44	104.07	44.37	29.9
LSD (0.05)	34.12	15.76		
CV (%)	10.81	6.60		
Kurenai (49 plants m^{-2})				
Control	177.90 b	135.70	42.20	23.7
Paclobutrazol 0.5 kg	235.70 a	128.87	106.83	45.3
Paclobutrazol 1.0 kg	253.24 a	127.55	125.69	49.6
LSD (0.05)	63.87	12.32		
CV (%)	12.68	4.16		

6.2.3 DISCUSSION

6.2.3.1 Paclobutrazol effects on plant growth and development

There was considerable variation between cultivars in the response to paclobutrazol. Although both cultivars responded to the growth retardant, Kurenai was more responsive than Powderpuff. Kurenai plant height was effectively retarded (-31 %) which was enough to prevent lodging (Appendix 6.2.9). The effect was persistent and the height at harvest was approximately two-thirds the height of the control. In cv. Powderpuff, only an 18 % height reduction was found and lodging still occurred. Differences in cultivar responses to paclobutrazol in height restriction were also found in poinsettias. Hammer and Kirk (1987) reported that poinsettia cv. Dark Red was much more responsive to this chemical than cv. Glory. The same amount of active ingredient per plant or pot, retarded the growth of Dark Red almost twice as much as that of Glory.

In both cultivars paclobutrazol reduced plant height by reducing the main stem length, particularly vegetative stem length, as already reported in the two previous experiments (Appendices 5.3.5, 6.1.6-6.1.9 and 6.2.3-6.2.5). Shorter stems of paclobutrazol treated plants were due to shorter internodes rather than to reduction in internode numbers (Appendices 6.2.2, 6.2.7 and 6.2.8) which confirmed previous results. This effect has already been discussed in 6.1.3.1.

The success of plant height reduction in cv. Kurenai but not in cv. Powderpuff may suggest a difference in the chemical rate requirement of these two cultivars. This may be because the amount of gibberellin biosynthesis in cv. Kurenai was lower than in cv. Powderpuff. Only 0.5 kg a.i. ha^{-1} effectively controlled the height of cv. Kurenai, but even the double rate (1.0 kg a.i. ha^{-1}) was insufficient to compete with the endogenous gibberellin in cv. Powderpuff. Similar results have also been reported by Hicklenton (1990) who found that the magnitude of chrysanthemum response to uniconazole (another triazole growth retardant) was cultivar dependent; two tall-growing cultivars Tip and Tara showed similar sensitivities but the short stemmed cultivar Deep Luv responded to a rate one-quarter of that required to reduced stem length in the tall cultivars. Varied growth retardant rate requirements between cultivars have also been reported in zinnia by Armitage *et.al.* (1981) and in many other plants by Davis *et.al.* (1988). Tayama (1991) also reported that poinsettia cultivars Eckespoint Lilo and Gutbier V-14 do not require as much growth retardant as cv. Annette Hegg because they are genetically shorter.

Plant height reduction following paclobutrazol (1.0 kg a.i. ha^{-1}) application at the terminal flower bud initiation stage for cv. Powderpuff in the present experiment did not persist (as it did in the previous experiment, Chapter 6.1), but again appeared transient. This may be due to the effect of different planting date, suggesting that chemical effectiveness was influenced by the environment. Under high light intensity and long days plants may overcome any retardant effects by increased production of endogenous gibberellins (Cathey 1975). Similarly, it has been suggested that varying amounts of active ingredients in growth retardants are needed for different seasons (Pemberton, 1980). For example, when daminozide was used on chrysanthemum, a higher concentration and/or more than one application was required in the summer to get the same reduction in height as occurred when application was in the winter. This is probably related to the optimal growth conditions and vigorous growth of plants in the summer (Pemberton, 1980). Similarly a difficult to restric plant height during warm summer periods to produce high quality dwarf potted plants has also been reported in *Beloperone guttata* by Andriansen (1985). For China aster, plants which germinated in mid spring (16 October 1989, Chapter 6.1) and were planted in the field five weeks later, were big, tall and flowered at approximately the same time. In the present study, plants which were direct sown in late spring 42 days later (27 November 1989) were shorter (-28.1 cm) and smaller (-28 % plant dry weight) than those earlier planted plants due to a shorter vegetative growth period. Paclobutrazol reduced plant height at both planting times but was only slightly more effective in the late planted plants (by 4 %; Table 6.1.2 and 6.2.3). The effect of paclobutrazol height reduction efficacy in late planting plants was less than would be expected, which suggests that an interaction with temperature may be involved. Application of paclobutrazol in the previous experiment (early planting) was on 6 December 1989 and the mean monthly temperature in December was 15.7 °C. In this experiment paclobutrazol was applied on 24 January 1990 and the mean monthly temperature was 18.0 °C. Reduced effectiveness of growth retardants when used under high temperature conditions has also been reported in many other flowering annuals (Cathey, 1969; Barrett and Nell, 1986 and Wulster *et.al.*, 1989).

The different plant growth response of these two cultivars (Powderpuff and Kurenai) when plant height was the parameter recorded depends initially on their primary sensitivity to daylength, and may also have been modified by air temperature. It was difficult therefore to counteract this primarily environmental sensitivity by crop manipulation. Thus cultivar selection should be the prime consideration for the success of chemical manipulation in China aster.

6.2.3.2 Paclobutrazol effects on seed yield

Results from these four experiments showed that chemical manipulation using paclobutrazol can improve seed yield of China aster grown at high plant density. Potential harvestable seed yield per m^{-2} of cv. Kurenai and cv. Powderpuff was increased 50 and 13 g with increasing plant density from 25 to 49 and 16 to 36 plants m^{-2} respectively. Paclobutrazol at 0.5 kg a.i. ha^{-1} significantly increased seed yield of cv. Powderpuff (36 plants m^{-2}) by 48 % while seed yield of cv. Kurenai (49 plants m^{-2}) was increased 32-42 % following 0.5 and 1.0 kg a.i. ha^{-1} paclobutrazol application.

Paclobutrazol effects in the low density plants of cv. Powderpuff in this experiment were similar to the effect obtained when the chemical was applied at the visible terminal flower bud stage (Chapter 5). Only the 1.0 kg a.i. ha^{-1} rate effectively increased seed numbers per seedhead, but potential seed yield did not increase because seedhead numbers were reduced. A reduction in seedhead numbers did not occur when paclobutrazol was applied to the high density plants of cv. Powderpuff in this experiment. This resulted in an increased seed yield potential but this was only for the low rate (0.5 kg a.i. ha^{-1}). Application of this chemical at an earlier stage (vegetative stage, Chapter 6.1) also did not decrease seedhead numbers but seed yield increased significantly only with the high rate (1.0 kg a.i. ha^{-1}). These results confirm the suggestion from the earlier experiment (Chapter 5) that seed yield following paclobutrazol application can be increased even if seedheads are decreased because high seed numbers are also maintained.

In cv. Kurenai, a significantly increased seed yield potential was also obtained only from the high density plants. This was due not only to increased seed numbers but also to seed weight. Paclobutrazol appeared to modify the partitioning of assimilate in favour of the seed fraction, as seed numbers were increased. The interaction between paclobutrazol and high plant density is likely to reduce the assimilate competitiveness of the later formed branches resulting in increased fertile branch number and greater seed set, thus increasing seed yield. Seed yield increases in perennial ryegrass were also obtained through increasing the survival of fertile tillers and increasing the number of seeds harvested per spikelet (Hampton, 1985). Fruit from paclobutrazol treated strawberry plants have been reported to have more achenes than fruit from untreated plants (McArthur and Eaton, 1987). In *Vicia faba* L. grain yield was increased by paclobutrazol through an increase in pods per plant and seeds per unit area (Attiya *et.al.*, 1983).

Cultivar / environment interactions have been reported in safflower *Carthamus tinctorius* (Silva and Gordon, 1986). Different cultivar responses to planting date within a season have also been reported among cultivars of celosia (*Celosia cristata*) and zinnia (*Zinnia elegans*) (Aker and Healy, 1988). Two cultivars of these two species were transplanted on 19 May, 27 May, 4 June, 30 June or 16 July. The flower production of celosia was increased by planting after 4 June with a net increase in productivity for a 30 June planting of 50 % for cv. Kurume Corona and 76 % for cv. Century compared to a 19 May planting. Zinnia production was optimised by a 19 May planting. A 16 July planting resulted in a net decrease in yield of 88 % for cv. Cactus Flowered and 57 % for cv. State Fair compared to a 19 May planting. The response of various oil seed rape cultivars to spring growth retardant application has also been reported to be very variable (Scarisbrick and Daniels, 1986). Similarly, variable dose rate responses and dependence on timing and cultivars have been reported in field bean (Batts *et.al.*, 1991). It therefore seems likely that the variable seed yield responses found in China aster in this study may be due to the genetic capability of individual plants in response to the environment (i.e. gibberellin biosynthesis), and may also be due to different times of planting which affected plant growth and development as discussed in 6.3.1. The plant density used in this study may not have been high enough to reduce this variation. Plot size and sample size may also need to be increased considerably in the more highly sensitive cultivar Powderpuff, as high variation (% CV) was recorded in actual cleaned seed yield.

The high yield loss (Table 5.6, 6.1.4 and 6.2.7) between potentially harvestable and cleaned seed yield may have resulted from several factors. The flowering duration in the untreated plants of cv. Powderpuff caused seed yield losses in the control treatments of 33 and 37.5 % (Chapter 5 and 6.1). Late planting caused a further 16 % yield loss when compared with that of earlier planted plants (Table 6.1.7, 6.2.8).

Late sown plants took 24 days longer from first flowering to reach peak flowering. This may indicate that flowering was triggered by a required day length but that flower development was possibly dependent on the assimilate supply capability of the plant itself. Higher loss of seed may also be due to greater competition between early flowers and late branch production. In contrast, early sown plants grew under a longer period of long days, which inhibited flowering and allowed the later branches to grow enough to produce a greater synchrony of flowers once they were triggered by the required day length.

Seed loss in the control treatment of cv. Kurenai was relatively smaller than in cv. Powderpuff (Table 6.2.7), but greater seed yield losses from paclobutrazol treated plants were found in both cultivars, as already recorded from the previous experiments. It seemed likely that the extended flowering which is an advantage of this species for cut flower or bedding plants use becomes a problem in seed production. Individual flower heads took 18 days to complete flowering and the duration of flowering from the first to the last flower head did not differ between 4.2 to 38.2 plants m^{-2} (Chapter 3) or between the two densities used in the present experiment (16 and 36 plants m^{-2} for cv. Powderpuff and 25 and 49 plants m^{-2} for cv. Kurenai). High variation in seed maturity and physiological age will always occur from a single harvest. Greater numbers of immature seeds in paclobutrazol treated plants possibly occurred because of a greater number of set seeds had to compete with the same available assimilates, which may have extended the time needed to complete seed development (as discussed in 6.1.3.3). This problem is similar to that reported by Gray (1987) in carrot where the inflorescence is highly branched, flowering is prolonged and seeds mature at different times. Seeds on the terminal or primary umbels flower, set seed and reach maximum seed yield and germination about two and four weeks before those on the lateral branches (secondary and tertiary umbels respectively). Thus accurate timing of the harvest to obtain high yield of seed as well as optimum germination is difficult (Gray, 1987). Increasing carrot plant density from a traditional plant density of 10 plants m^{-2} to 80 plants m^{-2} for the root to seed method and to 256 plants m^{-2} for the seed to seed method shortened the overall flowering period and increased evenness in umbel ripening (Gray, 1981). It may be possible that the high plant density used in this experiment was not high enough to limit this variable response. As paclobutrazol showed potential for improving seed yield in high density planted China aster, paclobutrazol application at even higher plant density may be suggested for further evaluation.

In this study, harvest time was based on the seed moisture content of the control plots. There is evidence that paclobutrazol can delay seed development in other species (e.g. Hampton, 1983; Tolentino, 1990), and it is possible that by harvesting all plots on the same day, seed yield of paclobutrazol treated asters was lowered because of the presence of a high proportion of immature seeds which were subsequently cleaned out of the seed lot. A study on seed development of individual seedheads of paclobutrazol treated plants may also be necessary for determining a precise harvest time.

6.2.4 CONCLUSION

Application of the growth retardant paclobutrazol increased potential harvestable seed yield of cv. Powderpuff by significantly increasing the number of seeds per plant when it was applied (i) at 1.0 kg a.i. ha^{-1} at the vegetative stage to a population of 16 plants m^{-2} (Chapter 6.1) and (ii) at 0.5 kg a.i. ha^{-1} at the terminal flower bud initiation stage to a population of 36 plants m^{-2} planted 42 days later. Seed yield improvement in cv. Kurenai was obtained only at 49 plants m^{-2} through an increase in the number of seeds per plant and seed weight (1.0 kg a.i. ha^{-1} rate only). Although seed yield increases were always associated with an increase in seed numbers, the statistically significant difference were obtained only when there was no reduction in seedhead numbers after paclobutrazol treatment. The even higher seed loss between the potentially harvestable and the cleaned seed yield indicated the advantage of early spring planting and the need for a more precise determination of correct harvesting time.

Paclobutrazol at both rates effectively retarded plant height of cv. Kurenai through shortening internodes on the main stem. This effect also occurred on cv. Powderpuff when treatments were applied during the vegetative to stem elongation stage, but the effect was either transient and/or insufficient to prevent lodging, confirming the previous suggestion (Chapter 6.1) that a higher rate for effective height control needs to be investigated in this cultivar. Any interaction between paclobutrazol application timing, planting date and plant populations should also be taken into consideration, particularly for the more highly environmentally sensitive cultivar, Powderpuff.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSION

7.1 Plant growth and development of China aster in relation to seed production

An understanding of plant development and the effects of the environment upon it is important for seed production (Langer, 1984). Publications on flower crops have predominantly been concerned with the production of high quality plants at specified plant growth stages, such as vigorous seedlings for the nursery trade (Ball, 1985; Mastalerz and Holcomb, 1985), floriferous flowers for pot plants (Boodley, 1981; Ball, 1985) and big flowers with high quality and long vaselife for cutting (Janick, 1972; Larson, 1980), but there have been very few publications on flower seed production (Vis, 1980).

Chapter 3 contains information on the effects of plant density on vegetative growth and development, reproductive development, flowering, seed development, seed yield and quality in two cultivars of China aster, Kurenai and Powderpuff grown under field conditions. This study was designed as a means of understanding the factors involved and their relationship to seed production. The two cultivars were chosen because they meet Thai consumer requirements relating to flower size, colour, and longevity, and most importantly because they grow well under Thailand conditions and give good returns for cut flower production to farmers (Department of Agriculture Extension, 1981).

Both cultivars exhibited two flushes of branching, the first during stem elongation, and the second after first flowering. Plants grown at low density (4.2 plants m^{-2}) showed the greatest branch development and as leaf number per branch was relatively constant, the production of leaves and the increase in leaf area and subsequently plant dry weight always followed branching capacity. Increasing plant densities from 4.2 to 44.7 plants m^{-2} increased branch numbers m^{-2} and led to increased flower production which resulted in increased number of potential seed production sites. The number of flower heads m^{-2} was the most important component determining final seed yield in both cultivars, suggesting that the number of flower heads is an important plant characteristic to be manipulated for improving seed yield in China aster.

Because of the two flushes of branching, a double-peak flowering pattern was recorded in this study, with different magnitudes between densities (greater flower head numbers at lower plant density). The first peak was the most important and contained around 65-75 % of the total flower heads produced. The second peak of cv. Powderpuff was not as clear as in cv. Kurenai, particularly in high density plants. These later flowers may have adversely affected seed yield, as they grew at the same time as the seed filling period of the early flower heads. Management to inhibit these late flowers requires investigation.

Assimilate competition is likely to have occurred between vegetative and reproductive plant parts, and among reproductive plant parts, as lateral branches and leaves grew rapidly at the same time as the onset of main stem terminal flower development during stem elongation. The overlap in flowering between the primary flower head of the main stem and the terminal flower heads of lateral branches, and the overlap in flowering between lateral branches, may also have caused competition for assimilates required for seed setting. However it was also evident that compensatory growth occurred between the components of seed yield. Increasing plant density from 4.2 to 44.7 plant m^{-2} decreased seedhead number of cv. Kurenai from 66 to 20 seedheads per plant, seed number from 135 to 118 seeds per head and seed weight (1000 seeds) from 1.6419 to 1.5499 g. In cv. Powderpuff, seedhead number was decreased from 46 to 9, seed number from 66 to 42 and seed weight from 2.2220 to 2.0290 g. The lower number of seedheads, seed numbers and lower seed weight of the height density plants were compensated for by the increased number of plants per unit area which resulted in no significant seed yield differences over a wide range of densities (a 3-fold range of densities in cv. Kurenai and a 9-fold range of densities in cv. Powderpuff). These data suggest that one advantage of this species is the ability to produce under a wide range of densities, but suitable management / cultural practices at any particular locality are still lacking, and need further study.

7.2 Seed yield limitation resulting from sequential flowering

China aster is popular because of the great variation of plant types and colours of the flowers, as well as its long keeping quality (Ball, 1985). Long lasting flowers are one of the prime selection criteria for any flower species. But extended flowering, which is an advantage of this species for cut flower or bedding plant use, becomes a problem for seed production. Perhaps because of this problem in aster and other species, hand harvesting has become a common practice in many flower seed crops.

Flowering in individual aster flower heads was sequential, opening from the outer through to the innermost florets and took 18 days to complete. This flowering sequence was made more complex with overlapping flowering from the lateral branches and side branches, and the duration of flowering from the first to the last flower head which did not differ between 4.2 to 44.7 plants m^{-2} (Chapter 3) or between the two densities (16 and 36 plants m^{-2} for cv. Powderpuff and 25 and 49 plants m^{-2} for cv. Kurenai) with or without paclobutrazol application (Chapter 6.2). This resulted in high variation in seed maturity and physiological status from a single harvest and therefore high immature seed losses after seed cleaning.

7.3 Seed yield limitations due to cultivar differences.

Seed yield of cv. Kurenai was always higher than cv. Powderpuff (Chapter 3, 6.2; Topunyanont and Phetpradap, 1985). This may be due to differences in plant branching capacity. At the lowest density (4.2 plants m^2), plants of cv. Kurenai had 11 lateral branches and 26 flower heads more than cv. Powderpuff (Chapter 3). This greater number of floral sites may be one reason for the higher seed yield in this cultivar.

Different flower types may be another cause of seed yield differences between cultivars. The short tubes of disk florets (which are formed from five diminutive petals and are fused together on all edges) of cv. Kurenai may allow pollination to occur through both selfing and crossing between the florets within or between flower heads. On the other hand, as a result of plant selection to elongate the disk florets for the double flower type, Powderpuff plants have disk florets with longer tubes. This may limit cross pollination (Gloyer, 1931) because the stigma and filaments are closed inside this tube, although there is a hole at the end of it. This may also have affected bee activity. Receptive timing and other pollination limitations have not yet been studied.

7.4 The influence of environment on flowering in China aster.

All experiments in the present study were carried out in the seven months from October to April when mean monthly daylengths were 13.07, 14.25, 15.13, 14.47, 13.55, 12.55 and 10.59 hours.minutes (h.m) respectively (Appendix 5.13). Night temperatures during December and January varied between 12.7-15.2 °C (Appendix 5.13) which was the time that stem elongation and flower initiation occurred. Aster plants always flowered in February (when the daylength was 13.55 h.m), regardless of whether the seeds were germinated in October or November. This situation is a photoperiodic phenomenon; i.e. a response which is controlled by the duration of light as first shown by Garner and Allard (1920, 1922) in *Glycine max* var Biloxi and *Nicotiana tabacum* Maryland Mammoth. The flowering process can be divided into two stages: the initiation of flowers and the development of these into open blooms. These two processes may have different daylength requirements (Cathey, 1969). China aster is a quantitative long day plant for flower initiation (Doorenbos, 1959; Kinet and Sachs, 1984; Cockshull, 1985), although at temperatures of 13 °C or less it demonstrates an almost qualitative long day response (Biebel, 1936; Halevy 1985). In contrast, it is a quantitative short day plant for flower development (Cockshull, 1985). However the critical day length is not known (Halevy 1985), although it appears to lie between 12 h (Withrow and Withrow, 1940) and 14 h (Post, 1934). The basic aim for early photoperiod manipulation studies was to develop a method to grow two aster generations within one year to speed up a breeding project for wilt resistance (Doorenbos, 1959). Satisfactory long day effects were always obtained by extending the day to 16 h or more with light from incandescence lamps and creating an 8 h night with black cloth (Biebel, 1935; 1936; Doorenbos, 1959; Hughes and Cockshull, 1965; Cockshull and Hughes, 1969) provided the night temperature in the greenhouse was controlled at 10 °C. This photoperiod manipulation is sometimes still used for year-round commercial flower production (Ball, 1985).

A summary of dates of sowing, planting, flowering and harvest for all experiments (Appendix 7.1) showed that the earlier the sowing, the longer the time taken to flowering. However flowering occurred more simultaneously for early sowings as time from first flowering to peak flowering was shorter than that for later sowings (e.g. 21 days for cv. Powderpuff sown in October 1989 versus 45 days for the same cultivar sown in November 1989 - Appendix 7.1). Early sown plants grew under a longer period of long days, which inhibited flowering, and allowed the plant to produce more large branches, and more floral sites to respond at the same time. Thus a greater synchrony of flowers was produced once they were triggered by the required day length. Early sowing was therefore more suitable for simultaneous flower production or for once over harvesting, but an effective growth retardant was required to prevent lodging. Late sown Powderpuff plants were subjected to a shorter duration of long days, which meant that flower development occurred rapidly after floral initiation. First flowering therefore began earlier (i.e. 74 days after planting in November 1989 versus 110 days after planting in October 1989 - Appendix 7.1) but as final flower number did not differ, it took a longer number of days to reach the same flower number at peak flowering. This irregular flowering in late sowings may be one of the causes of higher seed yield losses, as seeds of the first flower head had already matured and started to shed while the majority of the flower heads had just started to flower. This situation made it very difficult to judge correct harvest timing.

7.5 The influence of environment on seed yield in China aster.

A comparison of plant height, dry weight and seed yield (average from all treatments of each experiment; Appendix 7.2) clearly showed that early sown Powderpuff plants were taller and heavier than those sown 42 days later. However although flower synchrony was greater (as already discussed in 7.4) seed yield potential obtained from the late sowing was higher (e.g. there was a 39 g m^{-2} difference between control treatments of Chapter 6.1 (early sown) and 6.2 (late sown)). This is because long days also stimulated vegetative growth, and thus 65 % of total plant dry matter in early sown plants was accumulated in the vegetative plant parts, compared with only 45 % in the late sown plants. Waring (1979) pointed out that any increase in yield depends on the partition of dry matter to the harvested part rather than to increased production of total dry matter. Therefore while early sowing may be suitable for the production of vigorous and long stemmed flowers, it may not be suitable for seed production unless this excessive vegetative plant growth is limited. However this response may be different in cv. Kurenai and needs to be studied as its growth and dry weight partitioning was differed from that of cv. Powderpuff (Chapter 3).

Seed yields obtained from this study were high for all experiments, particularly for cv. Kurenai, when compared with other reported yields for these two cultivars in Thailand (Topunyanont and Phetpradap, 1985), for other cultivars in the same height group (Kobza, 1987) and for average seed yield in Europe and U.S.A. (FAO, 1961). This may be due to the environment at this site which was favorable for plant growth and flowering of this species. Long days promote vegetative growth (Biebel, 1936; Hughes and Cockshull, 1965; Cockshull and Hughes, 1969) and accelerate flower initiation (Doorenbos, 1959; Kinet and Sachs, 1984; Cockshull, 1985) while short days accelerate flower development (Cockshull, 1985) in China aster. When long days for vegetative growth and flower induction are followed by short days, plant growth and flowering occurs most rapidly (Halevy, 1985). In Thailand, seed production of this species is only successful during the winter when the night temperatures become cool (Appendix 7.3), which means that plants are grown entirely in short days. The short vegetative period and early competition between the vegetative and reproductive growth may result in lower seed yields. However there are still many uninvestigated factors which may also influence seed yield such as pollinator limitations (Bierzychudeck, 1981). Pollen function limitation has also been suggested; for example, high temperature stress reduces pollen germination and pollen tube growth in corn, eggplant and cucumber (Hayase, 1955; Herrero and Johnson, 1980). Low temperature stress reduces pollen germination and function in tomato (Zamir *et.al.*, 1981). Decreasing seed numbers with older stigma age has also been reported in *Clarkia unguiculata* (Smith-Huerta and Vasek, 1987).

7.6 Plant growth retardant effects on seed yield.

Manipulation of the aster seed crop using the growth retardant paclobutrazol increased potential harvestable seed yield by significantly increasing the number of seeds per plant when it was applied i) at the vegetative stage at 1.0 kg a.i. ha^{-1} to cv. Powderpuff grown at 16 plants m^{-2} (56 % seed yield increase from 83.8 to 130 g m^{-2}) (Chapter 6.1).

ii) at the terminal flower bud initiation stage at 0.5 kg a.i. ha^{-1} to late sown plants of cv. Powderpuff grown at 36 plants m^{-2} (48 % increase from 136 to 202 g m^{-2}) (Chapter 6.2).

iii) during flower bud initiation and early stem elongation with 0.5 and 1.0 kg a.i. ha^{-1} in cv. Kurenai grown at 49 plants

m^{-2} (32 and 42 % increase from 178 to 236 and 253 g m^{-2} for the low and high rate respectively (Chapter 6.2).

The combination of a changed 'plant architecture' and a shift in growth and developmental rates is probably one of the main reasons for the yield increasing effect of plant growth regulator applications in general (Bruinsma, 1982). The information from this study showed that there is a chance of increased seed yield when plants are grown at high density (Chapter 6) probably due to the high compensating capability of this plant at high density (Chapter 3) and the efficiency of paclobutrazol in increasing assimilate movement to favour the reproductive parts. However, the seed yield increase was inconsistent possibly because the plant density used in this study was not high enough to inhibit the fluctuations of individual plant responses.

The high plant densities (Chapter 6.2) and also treatment with paclobutrazol (1.0 kg a.i. ha^{-1} applied at stem elongation stage; Chapter 5) appeared to restrict late flower growth, suggesting that a very high plant density (i.e. 10 times greater than the normal plant densities used in this study or so high that only a single stem plant is produced) with a relatively late paclobutrazol application (i.e. after main stem elongation or at flowering) to inhibit later vegetative growth and shorten the flowering period could increase seed yield per unit area. However this suggestion may not be successful without good disease control (see 7.14).

7.7 Effects of growth retardant on seed yield components and germination capacity

Potential seed yield increases were always associated with increased seed numbers (Appendix 7.4, experiments 6.1, 6.2b and 6.2d). However increased seed numbers did not always bring about an actual seed yield increase, because seedheads were decreased (Appendix 7.4, experiments 5 and 6.2a), or harvest losses were increased.

None of the growth regulating chemicals used in cv. Powderpuff improved seed weight. Only the high paclobutrazol rate increased seed weight in cv. Kurenai presumably as a result of a reduction in total plant height and a longer stem growth suppression when compared to the lower paclobutrazol rate. This effect was contrary to that reported in *Holcus lanatus* cv. Massey Basyn (Tolentino, 1990) and in perennial ryegrass cv. Grassland Nui (Hampton, 1986) where depressed seed weight has been observed following paclobutrazol application. This difference in results was probably because in the two grass species, seed numbers per spikelet were significantly increased at the expense of seed filling.

Seed germination percentage was not affected by any growth retardant used in this study, a result which agrees with observations in *Lotus uliginosus* Schk. (Clifford and Hare, 1987; Tabora, 1991) in *Lotus corniculatus* (Li and Hill, 1989), in onion (Globerson *et.al*., 1989) in perennial ryegrass (Hampton, 1986) and in white clover (Marshall and Hides, 1986).

7.8 Paclobutrazol effect on flowering and flowering pattern

Paclobutrazol generally has no influence on floral initiation or flower number in herbaceous species (McDaniel, 1983; Menhenett, 1984), although there are some exceptions such as *Episcia cupreata* (Stamps and Henny, 1986), *Hydrangea macrophylla* (Bailey *et.al*., 1986) and *Bouvardia humboldtii* (Wilkinson and Richards, 1987) where paclobutrazol stimulated floral initiation. Flower initiation and flowering period of China aster in this study were not altered by paclobutrazol. However, the high paclobutrazol rate (1.0 kg a.i. ha^{-1}) decreased flower head numbers at harvest when applied at the visible terminal bud and stem elongation stages. Although this reduction in flower numbers led to a reduction in seedhead numbers it did not affect seed yield because of compensation by an increase in seed number.

7.9 Problems with wind.

One of the disadvantages at this experimental site was wind, which severely damaged aster plants at all stages of growth. Transplants were pinched out and blown away as experienced in cv. Powderpuff (Chapter 6.1) and stem were broken at ground level leaving wounds which may easily be infected by pathogens, particularly *Fusarium* and *Sclerotinia*. This problem can be serious, because plants normally did not show any sign during vegetative growth, but suddenly wilted and collapsed at flowering (Chapter 5). Lodging due to strong wind is another serious problem in this crop. Flowering plants of aster are prone to lodging because of the top heavy plant structure of the tall, big flower heads of cv. Powderpuff. At low density, plants lodged more readily than plants grown at higher density where plants provided mutual structural support. China aster has a shallow fibrous root system which may anchor the plant to the ground but is not firm enough to tolerate strong wind. Moreover, the lodging effect of wind can be increased by heavy rain which both increases the flower head weight and softens the soil. This study also demonstrated that lodging at first flowering can severely affect reproductive development. Seed yield from the control plants in Chapter 5 in which lodging occurred two weeks after peak flowering was 113 % greater than when lodging occurred at first flowering (Chapter 3). That this is a critical growth stage has also been shown in other seed crops (Pinthus, 1973; Hebblethwaite *et.al.*, 1978). Lodging was reduced by using plant densities between 17.3 and 44.2 plants m^{-2} for cv. Kurenai. Plants at these densities were less susceptible to lodging as branches were interlocked and supported each other. In Powderpuff however, plants could only tolerate these conditions for a limited period of time (Chapter 3). Preventing lodging in cv. Kurenai by paclobutrazol application was successful due to a 33 % reduction in plant height (Chapter 6.2). Plant height of cv. Powderpuff also decreased following paclobutrazol application but not enough to prevent lodging due to a cultivar environment interaction (Chapter 6.2). Effective lodging control in this cultivar still requires further studies.

7.10 Plant growth retardant effect on lodging control

The use of growth retardants in aster seed crops in this study was primarily aimed at retarding plant height to prevent lodging and improve seed yield. All three growth retardants, paclobutrazol, daminozide and chlormequat chloride retarded plant growth initially, during the vegetative stage, but the effects disappeared during flowering, although they reappeared after flowering in some treatments. This transient effect was found in cv. Powderpuff (Chapter 5) but not in cv. Kurenai (by paclobutrazol) (Chapter 6.2). The influence of the environment differs with cultivar sensitivity (e.g. Kurenai versus Powderpuff)and different management may be required for each particular cultivar.

Paclobutrazol effects

Paclobutrazol effects on China aster plant height were cultivar dependent (Chapters 5 and 6). Both paclobutrazol rates used in this study effectively controlled plant height of cv. Kurenai, but produced no significant difference in plant dry weight and flower numbers. In cv. Powderpuff, plant height retardation was transient, except for the application of the high paclobutrazol rate (1.0 kg a.i. ha^{-1}) during terminal flower initiation and at the first visible flower bud stage. However, this height reduction was not enough to prevent lodging. A more effective treatment is required for this cultivar.

Reduction in plant height was due to the shortening of the internodes as observed in many different plant species (Wample and Culver, 1983; Wood, 1984; Lever 1986; Li and Hill, 1989; Tolentino 1990). Shortening of internode length of stems of perennial ryegrass following paclobutrazol application decreased lodging at all stages of plant growth (Hampton, 1983). The shorter internodes were those earlier-formed at the base of the stem. The upper stem internodes were less affected (Chapter 6, Froggatt *et.al.*, 1982).

Daminozide effects

Daminozide acts by inhibiting the synthesis of endogenous gibberellins (Cathey 1964, Izumi *et.al.*, 1988) which influences internode extension. It has been used in the commercial production of azaleas, chrysanthemums, hydrangeas, bedding plants, and other greenhouse crops to inhibit excessive stem elongation and produce more compact plants with darker green foliage (Cathey *et.al.*, 1965; Jaffe and Isenberg, 1965). It has generally been found to be most effective when applied just before or at the initiation of the first flowers. Control of stem elongation usually does not persist until flowering if plants are treated earlier than this stage. Treatment of plants with flower buds already initiated usually distorts the development of the flowering axis and delays flowering without significantly retarding stem elongation (Cathey 1975). However, activity varies in different plant species (Barrett and Nell, 1989).

As with paclobutrazol, daminozide retardation effects in China aster were inconsistent and did not improve the branching or the numbers or length of flowering, and subsequently failed to increase seed yield.

Chlormequat chloride effects

Chlormequat can restrict internode elongation and overall height in many cultivars of hybrid geranium (Armitage *et.al.*, 1978; Miranda and Carlson, 1980). Flowering is also accelerated (Holcomb and White, 1968; Armitage *et.al.*, 1978; Miranda and Carlson, 1980) regardless of the number of applications, or the time of application (Miranda and Carlson, 1980). In gladiolus (Halevy, 1970) and roses (Mor *et.al.*, 1977) chlormequat enhances flower production by reducing the incidence of flower abortion. In contrast chlormequat applied to dwarf carnations resulted in initial dwarfing following the treatment, but later retardation was not evident (Pobudkiewicz and Goldsberry, 1989). The longevity of chlormequat activity in treated plants was shorter compared to paclobutrazol, and applications may need to be repeated to achieve the desired effect (Pobudkiewicz and Goldsberry, 1989). In this study (Chapter 5), chlormequat chloride retardation effects were similar to that reported in carnation by Pobudkiewicz and Goldsberry (1989), and subsequent plant growth tended to be increased.

7.11 Effects of time and rate of growth retardant application.

Timing and rate of chemical application is particularly important since plant response is often related to climatic influences. It is important to know the correct plant growth stage at which the plant is most responsive to chemical manipulation. Problems with inconsistent responses in the use of growth retardants were found among the experiments in this study, since their effects may depend on other factors such as the level of endogenous gibberellins (Cleland, 1969). It is possible that the PGR rates used in this study for cv. Powderpuff were too low to compete with the endogenous gibberellins which were stimulated by daylength. The plant height response of cv. Powderpuff to paclobutrazol application was more rate dependent than time (growth stage) dependent. The lower rate of paclobutrazol (0.5 kg a.i. ha^{-1}) was sufficient for effectively controlling plant height in cv. Kurenai, but even the double rate did not decrease Powderpuff plant height to the desired degree. Further investigations on higher rates to control plant height and shorten flowering duration are obviously required. Repeated or more frequent applications of lower rates of growth retardant, particularly as foliar sprays, have been used in ornamentals to overcome the difficulty in obtaining uniform results from year to year. This technique might also be considered for field grown crops.

7.12 Pinching effects

Pinching Powderpuff plants at the visible terminal bud stage definitely altered aster plant structure. Main stem elongation was stopped totally but plant height was compensated by lateral branch growth. Late pinching at stem elongation only reduced apical dominance and/or encouraged branch growth. Plant structure (height and shape) did not obviously differ from the unpinched plants at seed harvest, although they had no single terminal flower (or seed) head and a shorter stem.

The purpose of pinching, or manual removal of the apical point, was to increase the movement of assimilates to lateral buds thereby increasing branching and subsequently flower numbers, and resulting in greater flower synchrony. This is a common floricultural practice (Love, 1976; Ecke, 1976; Larson, 1980). However, in China aster flower heads did not increase following pinching because fewer branches were produced from limited node numbers. Moreover, physical loss due to branch breakage also occurred in the early treatment (at visible terminal bud stage) and this may have prevented seed yield improvement (Chapter 5). These pinching results support the suggestion of Walls (1982) that pinching is not necessary for aster, but pinching can be used to achieve more uniform flowers (McKay, 1984).

7.13 Weeds and herbicide evaluation.

Weeds reduce yield and profits of all crops and also the quality of the seedlot for subsequent sowing (Hampton, 1988). Since weed pressure at the site used in this study was very high, and young aster plants grow slowly and compete poorly with weeds, effective herbicide treatments were necessary for successful seed production. Limited information is available on herbicides for effective weed control in aster crop production, and none was available for this experimental site. It is also clear from the experiment of Lamont (1986) that flower species belonging to the same plant family may be affected in different ways by a particular herbicide. Some selected herbicides from the available published information (alachlor, chlopropham, oryzalin, simazine and trifluralin) were therefore evaluated for their safety for use at this site. Herbicides that showed no injury damage to aster seedlings (Chapter 4 experiment 1) were further evaluated in field trials. Results from the present study (Chapter 4 experiment 2) showed that for transplanted aster, a single application of oryzalin (3.75 kg a.i. ha^{-1} at 4 days after transplanting) provided excellent weed control and a tenfold increase in seed yield (to 568 kg/ha).

Although herbicides can generally give more complete weed control in transplanted annual flowers (Fretz, 1976), they are particularly effective in the establishment of young direct seeded crops (Kinsella, 1978). A herbicide investigation for direct sown aster was conducted as modern production techniques (precision seeding, bed shaping, mechanical thinning and mechanical harvesting) require highly efficient weed control. Only trifluralin (2 kg a.i. ha^{-1}) applied pre-sowing did not significantly reduce aster emergence, while oryzalin (4.5 kg a.i. ha^{-1} applied 10 days after sowing) provided the best aster seedling survival. However the results for direct sown aster found in this study (Chapter 4 experiments 2 and 3) were not conclusive because weed control from both treatments was only partial and further work is required. Due to the long growing season and slow aster growth, particularly during early plant establishment, direct sown aster crops may require multiple applications of herbicides, at least until the crop is itself able to offer some competition to further weed growth. Vis (1980) suggested spraying before emergence of the crops with paraquat 20 % at 20-30 ml per 100 m^2 for weed control including grasses and diquat 20 % 20-30 ml per 100 m^2 to control weeds except grasses. This procedure may be followed by oryzalin application after aster seedlings are well established, but all these suggestions require experimental confirmation.

7.14 Other problems in seed production

Pests and diseases

Control of pests and diseases is essential in the production of high yields of good quality seeds. Seed yield of *Lolium perenne* following fungicide application was significantly increased through a reduction in seed abortion, resulting in more seeds per spikelet at harvest (Hampton and Hebblethwaite, 1984). Application of bromophos (500 g a.i. ha^{-1}) at anthesis to control mirid (*Calocoris norvegicas*) increased seed yield of *Lotus uliginosus* cv. Grasslands Maku by 40 % (to 850 kg ha^{-1}) through increasing flower heads per stem and pods per flower head (Clifford *et. al.*, 1983).

It must be always kept in mind that China asters have lost some of their popularity due to disease problems, particularly fusarium wilt, although most of the present commercial cultivars are wilt resistant strains. Soil sterilization or fumigation is normally used in commercial greenhouse or cloth house flower production to prevent this serious problem (Ball, 1985). A regular spraying programme is also essential for controlling disease transmitting insects, particularly leafhopper, to prevent aster yellows, another serious disease (Ball, 1985). Much of the U.S. seed industry is located in semiarid western states largely because of reduced disease losses in seed fields and lessened seed transmission (i.e. China aster seed free from *Botrytis cinerea* and *Stemphylium callistephi* -Baker, 1980). Disease and pest control in all experiments of this study was attempted by dusting aster seeds with Thiram before sowing and regularly applying broad spectrum fungicides (Orthocide alternately with Benlate) and insecticides (Lannate rotated with Attack and Mavrik). Fusarium wilt was the only disease problem found in some spots in the 1988/89 experiment (Chapter 5), and was controlled by spraying plants and washing into the soil with a mixture of Orthocide and Benlate. Tomato fruit worm (*Heliothis armigera*) can also be important and although very little was found in the 1989/90 experiment (Chapter 6.1), it may cause serious seed loss since seeds in young seedheads are eaten. High plant density to reduce variation in seed maturity may limit the success of chemical disease control and create a high crop moisture which favours disease growth. High soil temperatures during summer are also favourable for *Fusarium* (Baker, 1980). If aster seeds bearing surface spores of *Fusarium oxysporum* f.sp.*callistephi* are sown, the spores germinate and infect near the tips of seedling roots; the mycelium spreads upward through the xylem, killing the plant, the fungus spreads outward into the stem cortex at the base of the aster stem near the soil level and produces abundant spores (which are sticky when moist) that may adhere to seeds in threshing and transfer to other seed fields (Baker, 1980). *Fusarium* is also reported to persist for long periods in field soil (Baker, 1980). This needs to be considered as it may be just as important as seed-born inoculum.

Fertilizer

Fertility requirements for seed production of China aster are not known, as little nutrition trial work has been published for either seed or crop production. Generally for flower production, any balanced fertilizer can be applied pre-plant (Post, 1950) with another application at three or four weeks after transplanting (Boodley, 1981) repeated again one month later or when flower buds appear (McKay, 1984; Salunkhe *et.al.*, 1987). Results from the crop development study (Chapter 3) agree with these general suggestions on the time of fertilizer application. The first fertilizer application after planting is at the time of rapid stem elongation and lateral branch growth before first flowering, and the second supports the growth of secondary branches and the basal lateral branches. However, in this study fertilizer was applied only pre-plant and one month later. The second post emergence fertilizer application was not used as late nitrogen application has been reported to increase vegetative growth (Nordestgaard, 1983) which may compete with fertile branches for assimilate exported from the leaves and stem (Hampton *et.al.*, 1985).

Nitrogen and phosphorus have been reported to increase plant height, capsules per plant, seeds per capsule and seed yield in *Viola tricolor* (John, 1989). In *Calendula officinalis*, Nordestgaard (1990) reported that seed yield of cv. Orange King increased significantly with increasing nitrogen from 0 to 40 kg ha^{-1} but 60 kg showed no further advantage. Thus, determination of fertilizer requirements for China aster grown for seed may be necessary for successful seed crops.

Harvest

The correct time to harvest is difficult to assess, particularly for the once over harvest method. Various seed maturities can occur at harvest because it takes 18 days to complete flowering within each individual flower head as florets open sequentially from the outside ring through to the centre. The blooming period lasted for 5-6 weeks for the first peak flowering or 8 weeks for the whole flowering period. In 1987/88 each seedhead needed 30 (cv. Kurenai) and 39 (cv. Powderpuff) days from first opening to obtain maximum seed dry weight and germination and could remain for a further 9 days (cv. Kurenai) or 12 days (cv. Powderpuff) before seed shedding started to occur. Thus at least for that year the best time for optimum harvest of aster seeds was not before 30 and 39 days after peak flowering for cv. Kurenai and cv. Powderpuff respectively. At these times, seed had reached physiological maturity, had already gained maximum seed germiability, and seed moisture content was around 41 %. The environment at seed ripening is important and can greatly influence seed development. For example, higher temperature and lower relative humidity enhances seed maturity and shattering (Sukprakarn, 1985). Hare and Lucas (1984) investigated seed development of *Lotus uliginosus* over two contrasting seasons (hot and dry in 1981/1982 season and moist and cooler in 1982/1983 season) and reported that seed ripening was much more rapid in the first (27 days) than in the second season (35 days). High rainfall before harvesting causes rapid decreases in germination and can lead to sprouting damage (Chapter 3). This latter point is of great importance because asters bear the type of head which gives a perfect environment for *Botrytis* fungal infection if they suffer wet weather conditions for too long, again causing deterioration in seed quality (Baker, 1980). As harvest approaches crops should be checked daily and a careful eye kept on the weather.

Thomson (1979) stated that a choice of sowing dates should be chosen which will provide the best possible conditions for the reproductive phase. In China aster, early sowing during spring produced more simultaneous flowering, although seed yield was lower due to greater vegetative growth. Later sown crops are also more at risk from frost damage if seed ripening and harvest is delayed until late April (Chapter 3).

Growth retardant effects on seed development may also need to be considered for adjusting precise harvesting time, as crop maturity may be delayed (Hampton and Hebblethwaite, 1985; Chapters 5 and 6). Wiltshire and Hebblethwaite, 1990 reported that maximum seed yield of *Lolium perenne* L. did not differ between triapenthenol and untreated plots, but triapenthenol [(E)-(RS)-1-cyclohexyl-4,4-dimethyl-2-(1H-1,2,4-triazole-1-e-n-3-ol] significantly increased seed yield as harvest was delayed because crop maturity was delayed and more seed was shed from untreated plots. Cultivar differences in seed yield responses were also reported (Wiltshire and Hebblethwaite, 1990).

Hand harvesting was employed throughout this study but mechanical harvesting is necessary for larger scale commercial production. The correct harvesting technique for obtaining high seed yield and quality is important and requires further investigation. Suitable methods of harvest with or without chemical pre-treatment of the crop, may also need to be studied. In calendula (*Calendula officinalis*) cutting in swathes, allowing to dry for 12-14 days, and threshing from the swathes, proved better than threshing either directly after desiccation using Reglone (diquat) or without desiccation (Nordestgaard, 1990).

Seed threshing and cleaning also require further investigation, as there may be mechanical damage to the seed or seed losses due to incorrect sieve sizes (Vis, 1980).

7.15 Possibility for producing China aster in New Zealand.

The findings from this study suggest that China aster could be grown for seed in New Zealand in areas with good shelter or where windbreaks are provided. Soil type and drainage should also be considered. Cultivar selection is important and should be the first thing to be decided. Seed yield can obviously be increased through suitable management but information is still scarce, and more research is required. Aster seedlings raised in a glasshouse (October) and transplanted into the field (November) as used in this study gave a good yield of high quality seed (Chapter 5 and Chapter 6.1) but still require treatment which will inhibit excessive vegetative plant growth (i.e. fertilizer, irrigation or growth regulator). Late plants, although producing a higher seed yield had irregular flowering and greater seed yield loss and may suffer from rain or frost damage (Chapter 3, cv. Powderpuff). As plant growth and flowering is photoperiod and temperature dependent, earlier planting means that crops will have a longer vegetative period and will need a longer time to look after, but flowering is more simultaneous which is a particular advantage for mechanical harvest and may reduce seed yield loss. Thus, early sowing during mid spring is more attractive for seed production of China aster than later sowings.

This study also showed that China aster could be direct sown into the field providing the seedbed was well prepared and effective herbicides are available (Chapter 4 and Chapter 6.2). However, the sowing date needed to be delayed until late October or early November to ensure no damage from frost, as asters are quite susceptible to frost injury (McKay, 1984; Salunkhe *et.al.*, 1987; Chapter 3). Suitable sowing dates and the optimum seed rate are not known. A report by FAO (1961) showed that direct drilling has been used in Europe and U.S.A. with varying seed rates and row spacing depending on local preference.

Paclobutrazol application provided seed yield improvement in cv. Kurenai by a reduction in lodging and increase in seed numbers (Chapter 6.2). However plant height reduction in cv. Powderpuff still requires further experiments (i.e. increased chemical rate, multiple application of this chemical or the evaluation of other new chemicals from the triazole group etc.)

Correct harvesting time is still a problem if machine harvesting is desired, and this obviously requires further experiments. However, as a guideline from the information obtained in this study, seeds may be harvested after 30 and 39 days after peak flowering (for cv. Kurenai and Powderpuff) depending on environment, particularly temperature during seed maturation and ripening.

7.16 Possibility for producing China aster in Thailand.

Thailand is a tropical south-east Asian country located between 5-22°N. Temperatures vary considerably within the country from 35/25 °C (average day/night temperature) in the dry summer season (March-May) and wet season (May-October) to 25/15 °C in the cool dry season (November-February). At higher altitudes, the temperature is lower, particularly at night, dropping to about 5 °C in the coldest months of December and January. The daylength varies from 11 h (December) in the dry season to 13.5 in the wet season (June).

China aster can be grown for cutting throughout the year in certain areas with more reliable climate (Pitchayakul, 1980; Teravet, 1984; Dittachaivong, 1985). However, seed production of this species is only successful during the dry period of winter and early summer (November-April) when the night temperatures become cool (Appendix 7.3). The influence of temperature (particularly the difference between day and night temperature) on plant stem elongation becomes more important as plants are grown entirely in short days (daylengths are about 11 h in December to 12.5 h in April; Appendix 7.3). Short days have been reported to inhibit stem extension (Biebel, 1936; Hughes and Cockshull, 1965; Cockshull and Hughes, 1969) but accelerate flower development (Cockshull, 1985) in China aster. Increases in stem elongation as the difference between day and night temperature increases have been reported in many plant species such as chrysanthemum (Karlsson et.al., 1989), poinsettia (Berghage and Heins, 1991) and fuchsia (Erwin and Heins, 1988).

Seeds should be raised in a seedbed (September or October) and transplanted into the field or direct sown during October and November. This would allow plants to develop seed during the dry season (November-March). If planting is carried out earlier, plants might not survive due to heavy rain (June-September). On the other hand, if planting is delayed until the dry season, seed maturity and ripening might have problems caused by the onset of the rainy season.

Hand harvesting is the best way to harvest aster particularly in areas where local labour is not expensive and freely available. Seedheads may be dried very fast during March and early April as the weather is hot and dry. Harvesting may need to be done regularly, early in the morning or late afternoon, once or twice a day, to obtain high seed yield and quality.

High plant density and the use of plant growth regulators may also be required for manipulating plant structure for seed production purposes only. This could eliminate problems that always occur when the price of fresh cut flowers is high; all the good quality flowers are sold and only the lower quality plants are left for seed production.

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APPENDICES

Appendix 2.1 Glossary of botanical terms.

Achene	: A small, dry, indehiscent, 1-seeded fruit having a thin pericarp that is free from the seed.
Anther	: The distal part of the stamen, bearing the pollen.
Anthesis	: The time of blooming or flowering.
Bracts	: A more or less modified leaf subtending a flower or flower cluster.
Capitulum	: An inflorescence composed of many sessile flowers arranged densely together in a flat disk.
Cultivar	: A variety of cultivated crop.
Cyme	: A broad, more or less flat-topped, determinate flower cluster, with central flowers opening first.
Determinate	: A habit of growth in which the terminal growing point produces an inflorescence or flower, and any further growth of the plant develops from lateral buds.
Disc	: The central part of the head.
Disk flowers	: Those produced in the central part of the head; they are tubular in shape.
Double flower	: Flowers that have more than the usual or normal number of floral envelopes, particularly of petals.
Floral induction:	The physiological changes in response to external stimuli (light quality, daylength, etc.) that occur in vegetative meristems and subsequently allow them to become reproductive meristems and undergo floral initiation.
Floral initiation:	The morphological changes in the development of a reproductive meristem from a vegetative meristem.
Glabrous	: Without pubescence; smooth.
Head	: An inflorescence in which the floral units on the peduncle are tightly clustered, surrounded by a group of flowerlike bracts call an involucre.

Involucral bracts	A close collection of of bracts surrounding an inflorescence or flower.
Lax	: loose, the opposite of congested.
Ovate	: Egg-shaped,the broadest part below the middle.
Pappus	: The modified and late-maturing calyx of the Asteraceae, arising from the summit of the achene, and consisting of hairs, bristles, scales, or awns.
Pompon	: A spray-type, having a flower shaped like a ball.
Ray florets	: A marginal strap-like floret of a daisy flower head.
Receptacle	: The enlarged summit of the peduncle of a head to which the flowers are attached.
Reflexed	: Bent sharply backwards.
Rosette	: A basal cluster of leaves produced on a very short stem.
Spatulate	: Shaped like a spatula, oblong, sometimes a little broader toward the upper end, and with a round apex.

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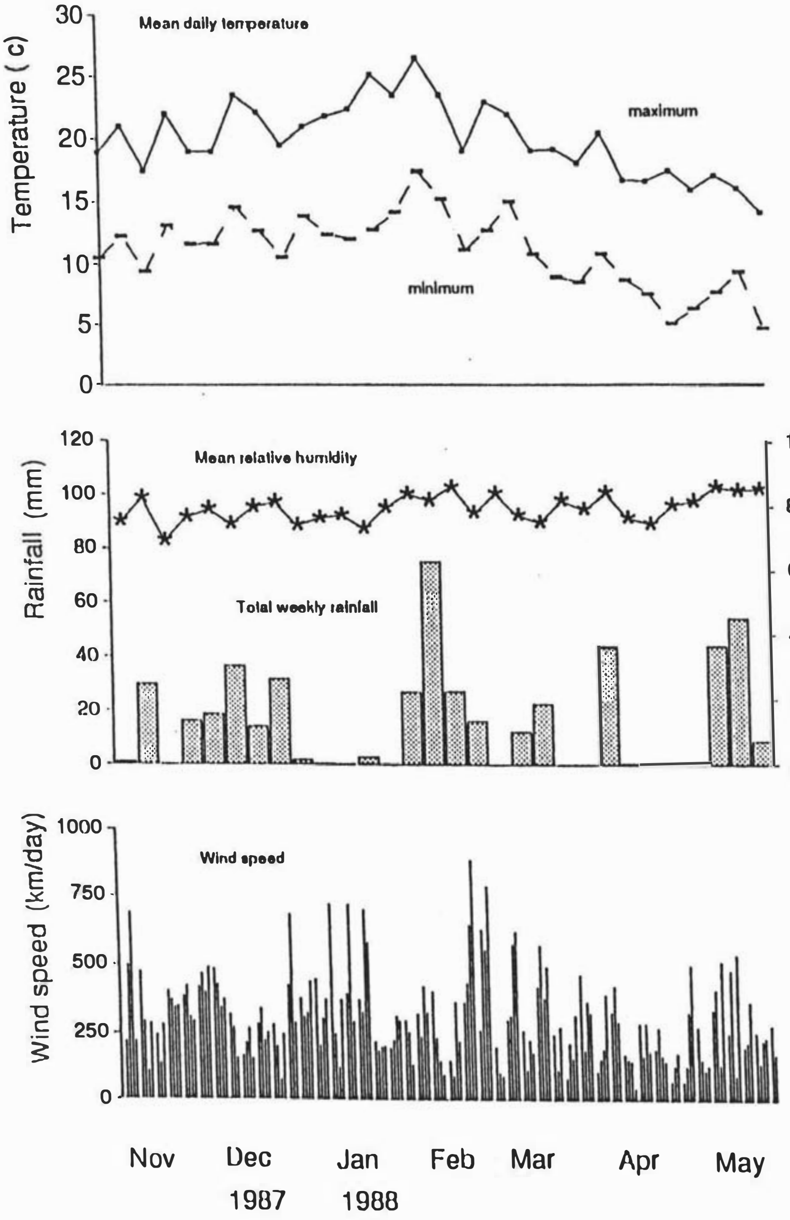


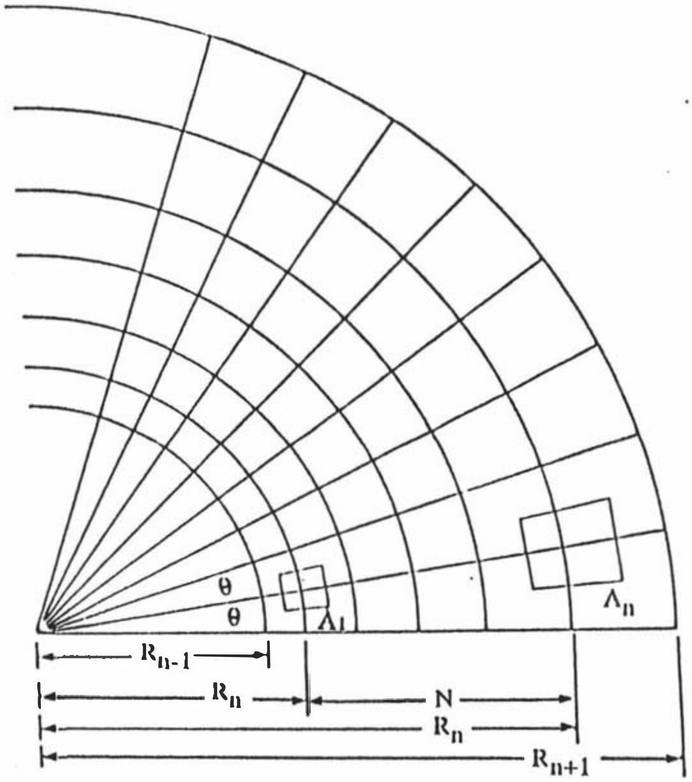
Appendix 3.1 Weather data at Palmerston North, New Zealand during November 1987-May 1988.

Appendix 3.2 Description of Tokomaru silt loam soil (Cowie, J.D.. 1978. Soils and Agriculture of Kairanga Country, North Island, New Zealand. **NZ Soil Bureau Bulletin** 33:92.)

Tokomaru silt loam soil is a moderately leached and moderately acid soil, classified as a yellow grey earth (Typic fragiaquaf) derived from a parent material of lightly consolidated siltstone or fine sandstone (Late tertiary or Pleistocene in age). It is composed of a 15-20 cm deep grey, friable topsoil and a 15-20 cm deep pale yellow firm subsoil with a yellowish brown compact third horizon.

Appendix 3.3 Soil sample test results (MAF Computerised Fertiliser Advisory Service.)

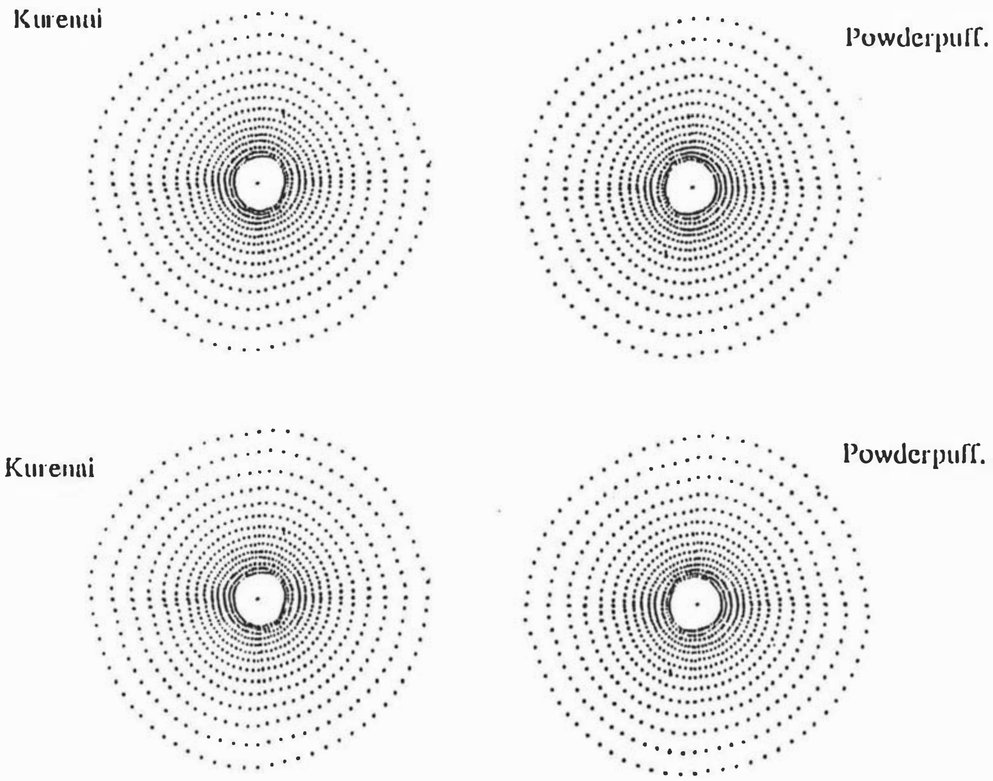
Element	Figure obtained
pH	6.5
Phosphorus	51
Potassium	9
Magnesium	21
Calcium	12
Sodium	6



θ = Angle between radii (constant)
A_1 = Area plant^{-1} at the highest plant density
A_n = Area plant^{-1} at the lowest plant density
R_n = Radius at the Nth arc
R_{n-1} = Distance of the inner guard row from the centre of the circle
R_{n+1} = Distance of the outer guard row from the centre of the circle
N = Number of arcs (or plant densities)

Appendix 3.4 A diagramatic representation of Nelder's radial spacing design (Type Ia).

Chapter 3 Plant density



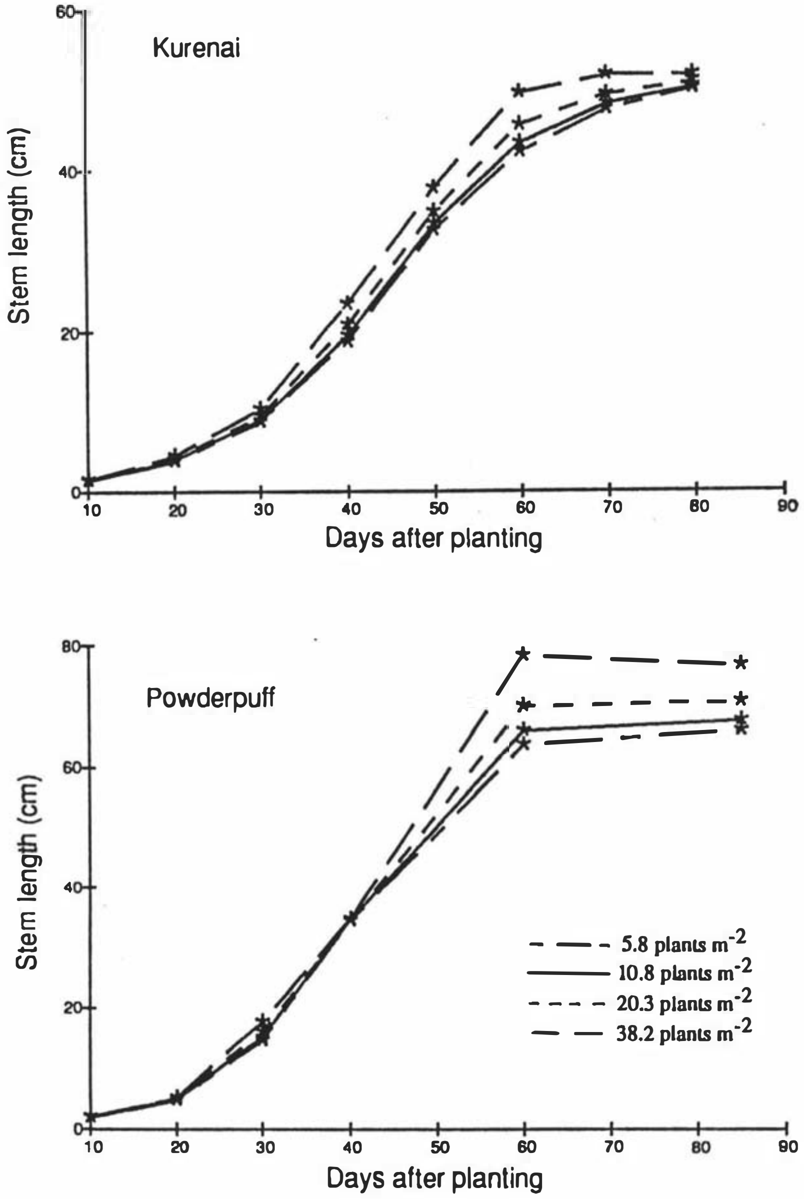
Powderpuff	T_1 R_1	T_3 R_1	T_4 R_2	T_5 R_2	T_4 R_3	T_1 R_3	T_3 R_2	T_5 R_1	T_2 R_1	T_2 R_3	T_3 R_3	T_1 R_2	T_4 R_1	T_5 R_3	T_2 R_2
Kurenai	T_2 R_1	T_1 R_3	T_1 R_1	T_3 R_2	T_4 R_1	T_1 R_2	T_5 R_3	T_3 R_1	T_3 R_3	T_5 R_2	T_2 P_2	T_4 R_2	T_2 R_3	T_5 R_1	T_4 R_3

Chapter 4 (experiment 1)
Herbicide trial

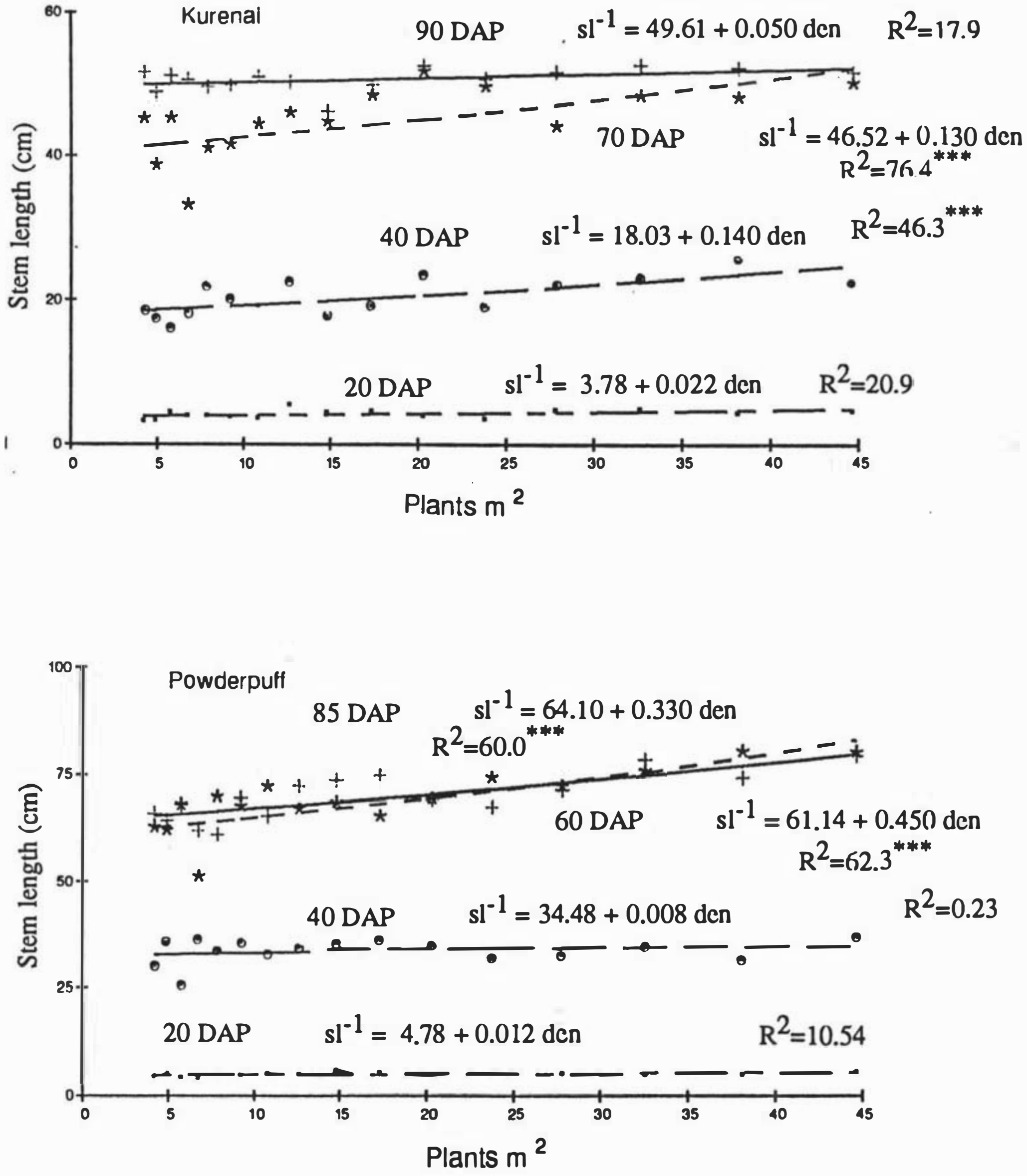
1 Control
2 Alachlor
3 Oryzalin
4 Simazine
5 Chlorpropham

Plot size 1x2.5 m
40 plants plot^{-1}
spacing 25x25 cm

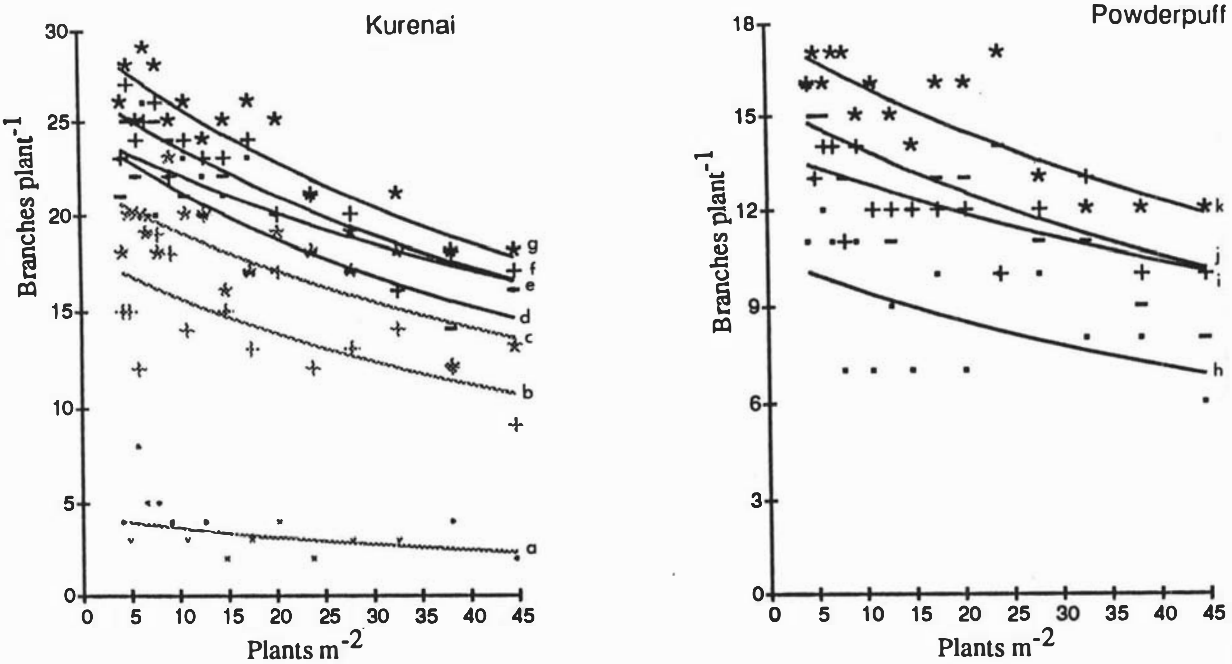
Appendix 3.5 Field layout of the 1987-1988 experiments.



Appendix 3.1.1 Effect of plant density on main stem length of China aster cv. Kurenai and cv. Powderpuff.



Appendix 3.1.2 Predicted curves and observed values of main stem length at four growth stages: vegetative (20 DAP), stem elongation (40 DAP), first flowering (70 and 60 DAP) and peak flowering (90 and 85 DAP) for China aster cv. Kurenai and cv. Powderpuff.
(sl = stem length; den = plant density)
(*** = significance at $P \leq 0.001$)



Kurenai

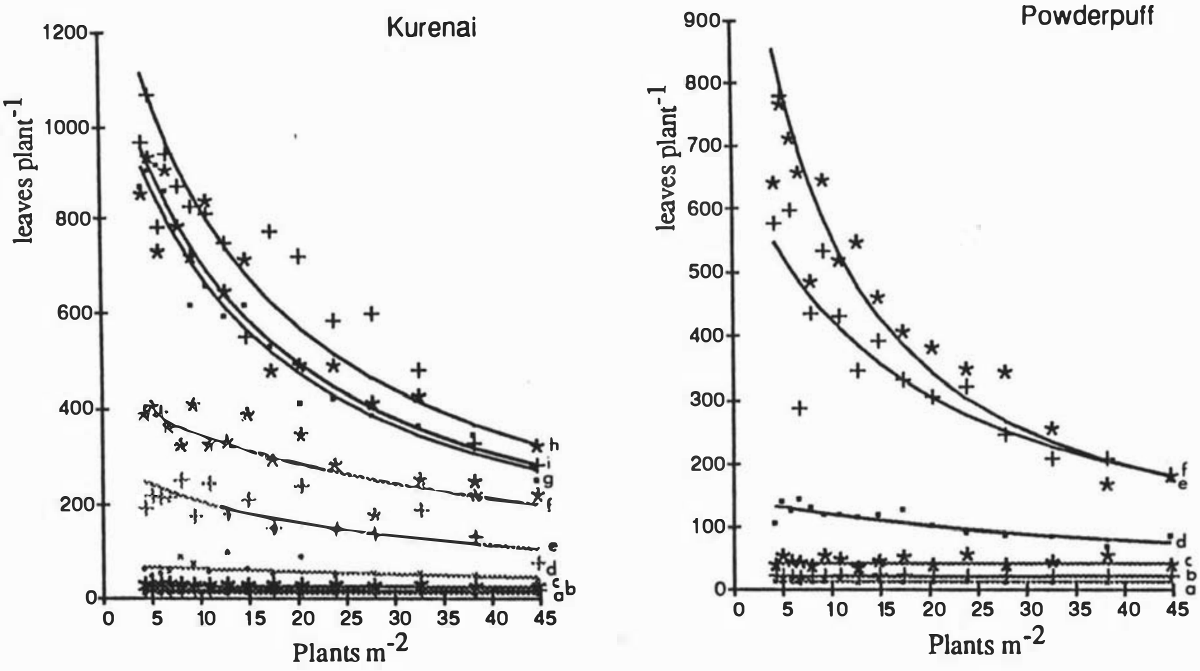
a:	30 DAP	$br^{-1} = 0.2300 + 0.004450$ den	R^2=25.1*
b:	40 DAP	$br^{-1} = 0.0550 + 0.000870$ den	R^2=47.5**
c:	50 DAP	$br^{-1} = 0.0459 + 0.000628$ den	R^2=60.3***
d:	60 DAP	$br^{-1} = 0.0406 + 0.000631$ den	R^2=76.7***
e:	70 DAP	$br^{-1} = 0.0408 + 0.000446$ den	R^2=79.3***
f:	80 DAP	$br^{-1} = 0.0371 + 0.000524$ den	R^2=80.6***
g:	90 DAP	$br^{-1} = 0.0336 + 0.000510$ den	R^2=85.0***

Powderpuff

h:	30 DAP	$br^{-1} = 0.0944 + 0.001140$ den	R^2=28.6*
i:	50 DAP	$br^{-1} = 0.0718 + 0.000615$ den	R^2=49.2**
j:	60 DAP	$br^{-1} = 0.0645 + 0.000754$ den	R^2=64.6***
k:	85 DAP	$br^{-1} = 0.0566 + 0.000620$ den	R^2=71.0***

(br = branch numbers; den = plant density)

Appendix 3.1.3 Predicted curves and observed values of branch numbers per plant at different observation times for China aster cv. Kurenai and cv. Powderpuff.



Kurenai

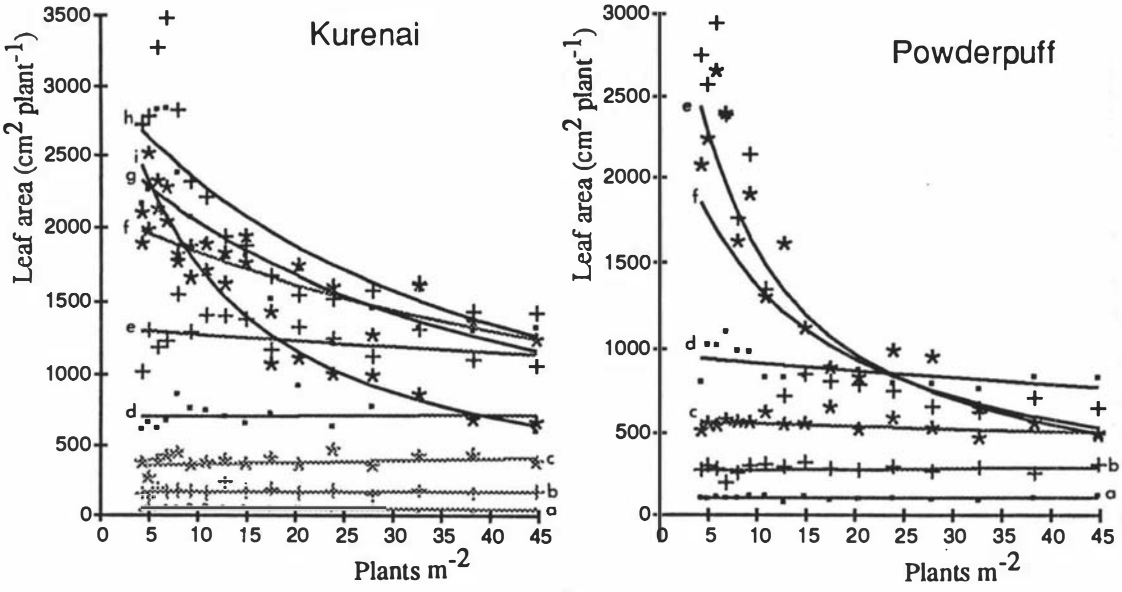
a:	10 DAP	$l^{-1} = 0.07360 + 0.000349$ den	$R^2=14.0$
b:	20 DAP	$l^{-1} = 0.05130 + 0.000158$ den	$R^2=23.3$
c:	30 DAP	$l^{-1} = 0.03540 + 0.000110$ den	$R^2=26.9^{*}$
d:	40 DAP	$l^{-1} = 0.01390 + 0.000179$ den	$R^2=30.2^{*}$
e:	50 DAP	$l^{-1} = 0.00340 + 0.000143$ den	$R^2=61.4^{***}$
f:	60 DAP	$l^{-1} = 0.00227 + 0.000062$ den	$R^2=68.0^{***}$
g:	70 DAP	$l^{-1} = 0.00083 + 0.000064$ den	$R^2=95.6^{***}$
h:	80 DAP	$l^{-1} = 0.00067 + 0.000054$ den	$R^2=85.0^{***}$
i:	90 DAP	$l^{-1} = 0.00079 + 0.000061$ den	$R^2=84.8^{***}$

Powderpuff

a:	10 DAP	$l^{-1} = 0.07680 + 0.000053$ den	$R^2= 1.9$
b:	20 DAP	$l^{-1} = 0.04760 - 0.000041$ den	$R^2= 2.4$
c:	30 DAP	$l^{-1} = 0.02400 - 0.000008$ den	$R^2= 0.1$
d:	40 DAP	$l^{-1} = 0.00686 + 0.000145$ den	$R^2=74.6^{***}$
e:	60 DAP	$l^{-1} = 0.00145 + 0.000091$ den	$R^2=85.7^{***}$
f:	85 DAP	$l^{-1} = 0.00071 + 0.000109$ den	$R^2=90.5^{***}$

(l = leaf numbers; den = plant density)

Appendix 3.1.4 Predicted curves and observed values of leaf numbers per plant at different observation times for China aster cv. Kurenai and cv. Powderpuff.



Kurenai

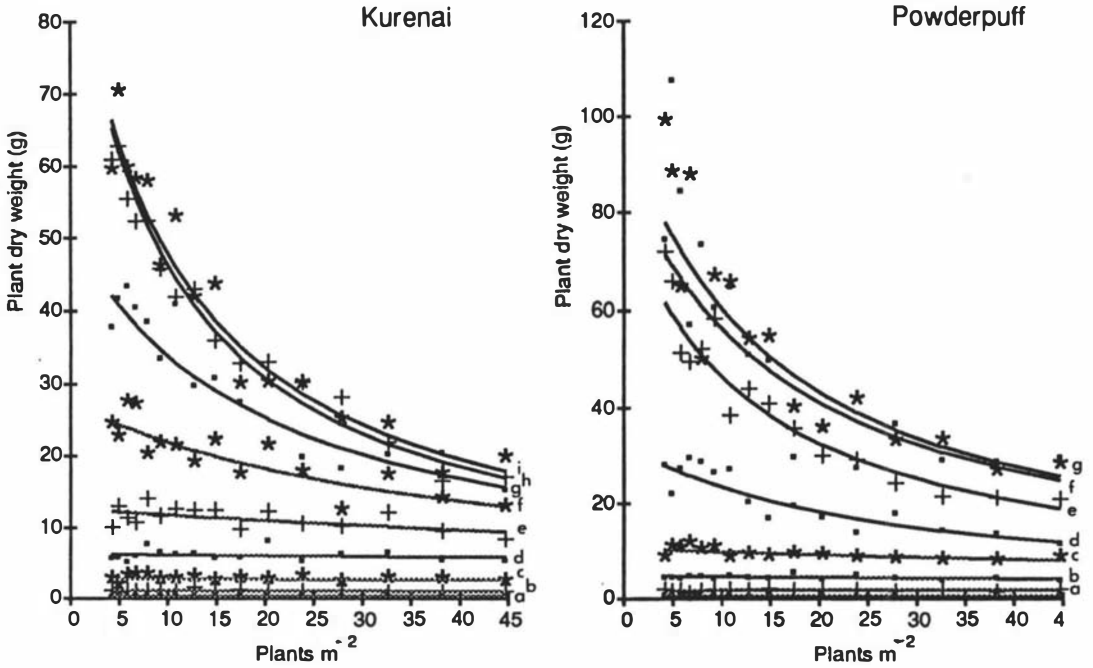
a:	10 DAP	$a^{-1} = 0.018500 + 0.000098$ den	$R^2=14.6$
b:	20 DAP	$a^{-1} = 0.006050 - 0.000007$ den	$R^2=1.0$
c:	30 DAP	$a^{-1} = 0.002830 - 0.000009$ den	$R^2=9.1$
d:	40 DAP	$a^{-1} = 0.001420 - 0.000001$ den	$R^2=0.1$
e:	50 DAP	$a^{-1} = 0.000756 + 0.000003$ den	$R^2=14.8$
f:	60 DAP	$a^{-1} = 0.000474 + 0.000007$ den	$R^2=70.7^{***}$
g:	70 DAP	$a^{-1} = 0.000386 + 0.000011$ den	$R^2=77.0^{***}$
h:	80 DAP	$a^{-1} = 0.000330 + 0.000010$ den	$R^2=78.8^{***}$
i:	90 DAP	$a^{-1} = 0.000291 + 0.000029$ den	$R^2=95.5^{***}$

Powderpuff

a:	10 DAP	$a^{-1} = 0.009430 + 0.000002$ den	$R^2=0$
b:	20 DAP	$a^{-1} = 0.003700 - 0.000005$ den	$R^2=2.3$
c:	30 DAP	$a^{-1} = 0.001750 + 0.000006$ den	$R^2=20.8^{*}$
d:	40 DAP	$a^{-1} = 0.001030 + 0.000006$ den	$R^2=36.4^{*}$
e:	50 DAP	$a^{-1} = 0.000399 + 0.000033$ den	$R^2=73.0^{***}$
f:	60 DAP	$a^{-1} = 0.000245 + 0.000039$ den	$R^2=93.7^{***}$

(a = leaf area; den = plant density)

Appendix 3.1.5 Predicted curves and observed values of leaf area per plant at different observation times for China aster cv. Kurenai and cv. Powderpuff.



Kurenai

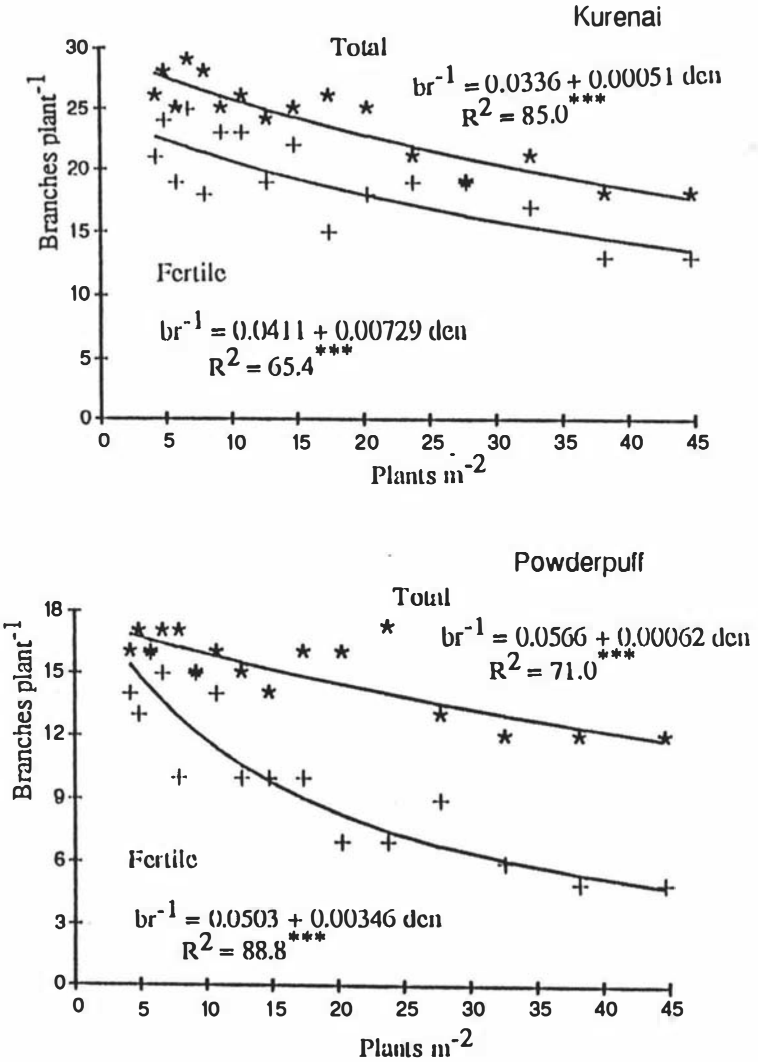
a:	10 DAP	$dw^{-1} = 2.5500 + 0.02030$ den	$R^2=23.8$
b:	20 DAP	$dw^{-1} = 0.8530 + 0.00462$ den	$R^2=20.4$
c:	30 DAP	$dw^{-1} = 0.3620 + 0.00052$ den	$R^2= 1.1$
d:	40 DAP	$dw^{-1} = 0.1580 + 0.00038$ den	$R^2= 5.4$
e:	50 DAP	$dw^{-1} = 0.0789 + 0.00062$ den	$R^2=33.7^{*}$
f:	60 DAP	$dw^{-1} = 0.0363 + 0.00094$ den	$R^2=75.8^{***}$
g:	70 DAP	$dw^{-1} = 0.0195 + 0.00100$ den	$R^2=89.3^{***}$
h:	80 DAP	$dw^{-1} = 0.0107 + 0.00109$ den	$R^2=95.7^{***}$
i:	90 DAP	$dw^{-1} = 0.0108 + 0.00102$ den	$R^2=94.1^{***}$

Powderpuff

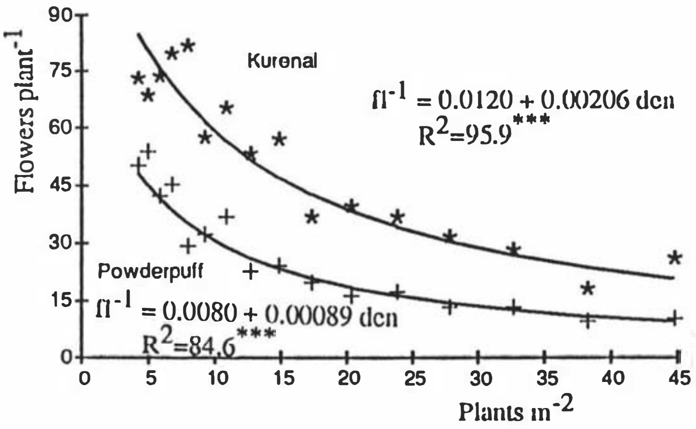
a:	10 DAP	$dw^{-1} = 1.4300 + 0.00346$ den	$R^2= 4.6$
b:	20 DAP	$dw^{-1} = 0.5690 - 0.00036$ den	$R^2= 0.3$
c:	30 DAP	$dw^{-1} = 0.2090 + 0.00083$ den	$R^2=23.8$
d:	40 DAP	$dw^{-1} = 0.0949 + 0.00072$ den	$R^2=52.2^{**}$
e:	50 DAP	$dw^{-1} = 0.0306 + 0.00121$ den	$R^2=86.3^{***}$
f:	60 DAP	$dw^{-1} = 0.0125 + 0.00091$ den	$R^2=94.7^{***}$
g:	75 DAP	$dw^{-1} = 0.0113 + 0.00065$ den	$R^2=75.2^{***}$
h:	85 DAP	$dw^{-1} = 0.0101 + 0.00065$ den	$R^2=89.8^{***}$

(dw = plant dry weight; den = plant density)

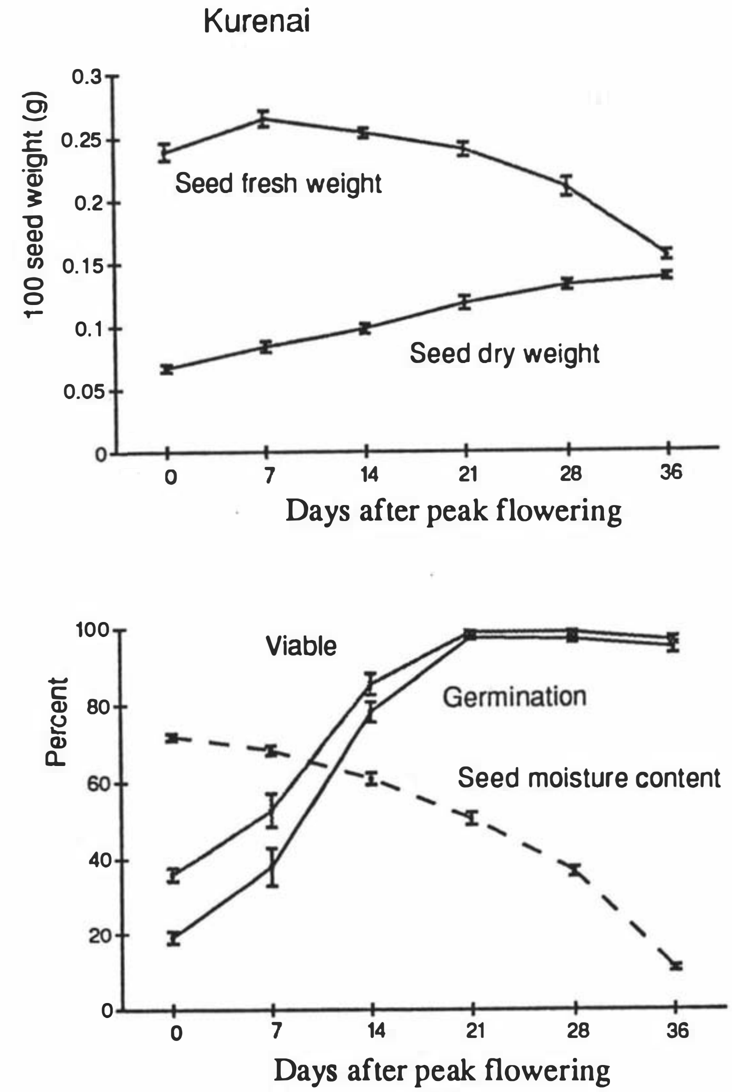
Appendix 3.1.6 Predicted curves and observed values of dry weight per plant at different observation times for China aster cv. Kurenai and cv. Powderpuff.



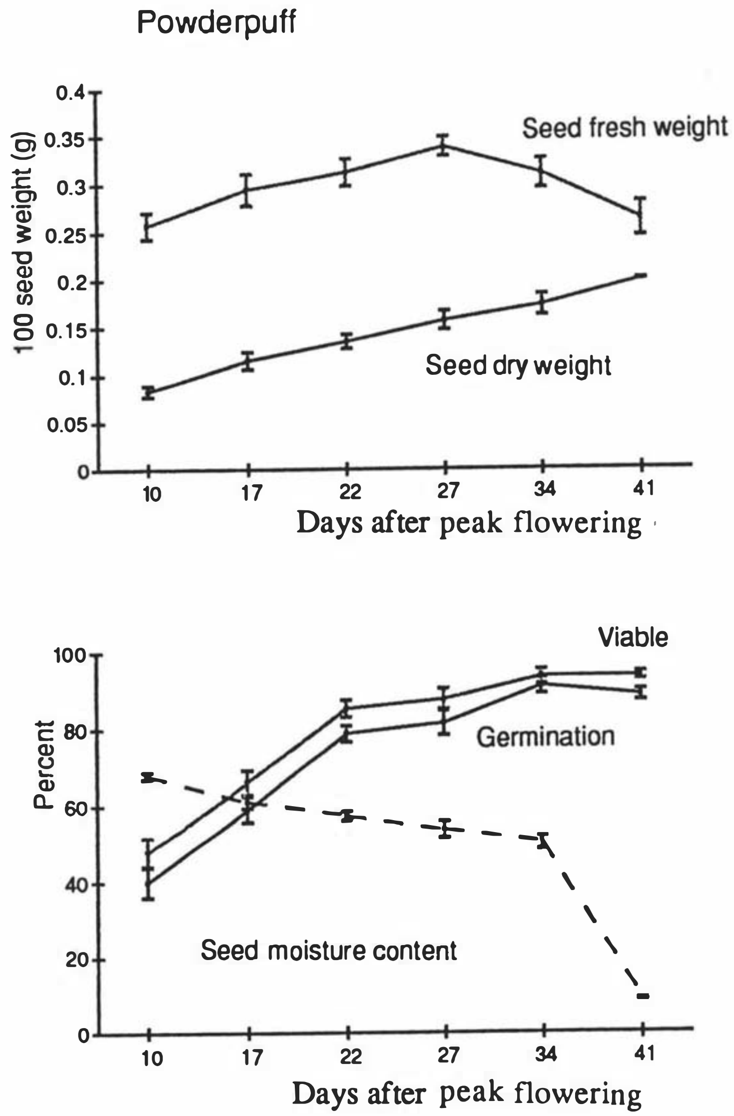
Appendix 3.2.1 Predicted curves and observed values of lateral flowering branches at peak flowering (Total) and seedhead bearing branches at seed harvest (Fertile) for China aster cv. Kurenai and cv. Powderpuff.



Appendix 3.2.2 Predicted curves and observed values of flower numbers at peak flowering for China aster cv. Kurenai and cv. Powderpuff.

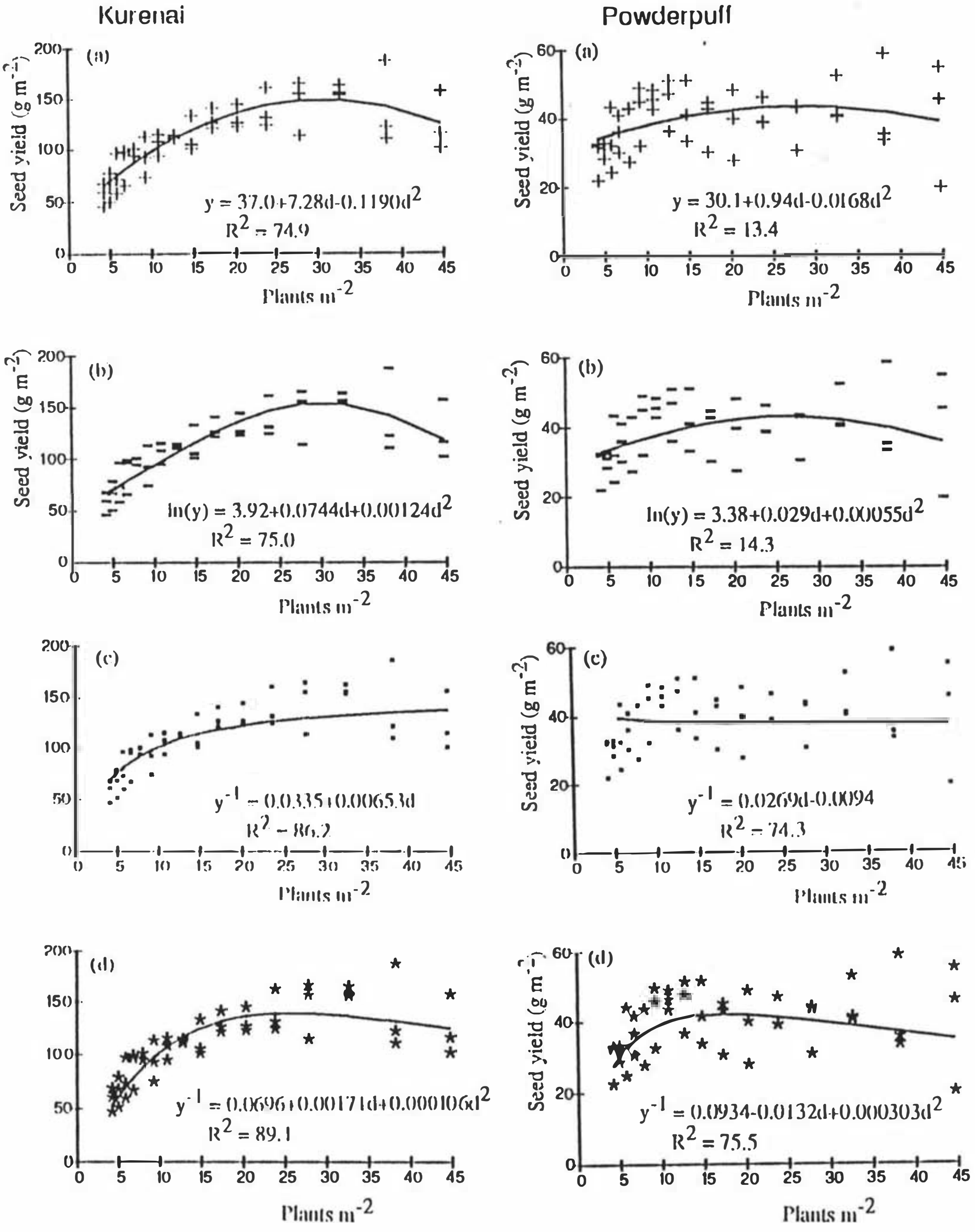


Appendix 3.3.1 Changes in seed fresh weight, dry weight, moisture content, germination and viability (means of the four plant densities: 5.8, 10.8, 20.3 and 38.2 plants m^{-2}) in China aster cv. Kurenai. (Vertical bars represent SE of means.)



Appendix 3.3.2 Changes in seed fresh weight, dry weight, moisture content, germination and viability (means of the four plant densities: 5.8, 10.8, 20.3 and 38.2 plants m^{-2}) in China aster cv. Powderpuff.

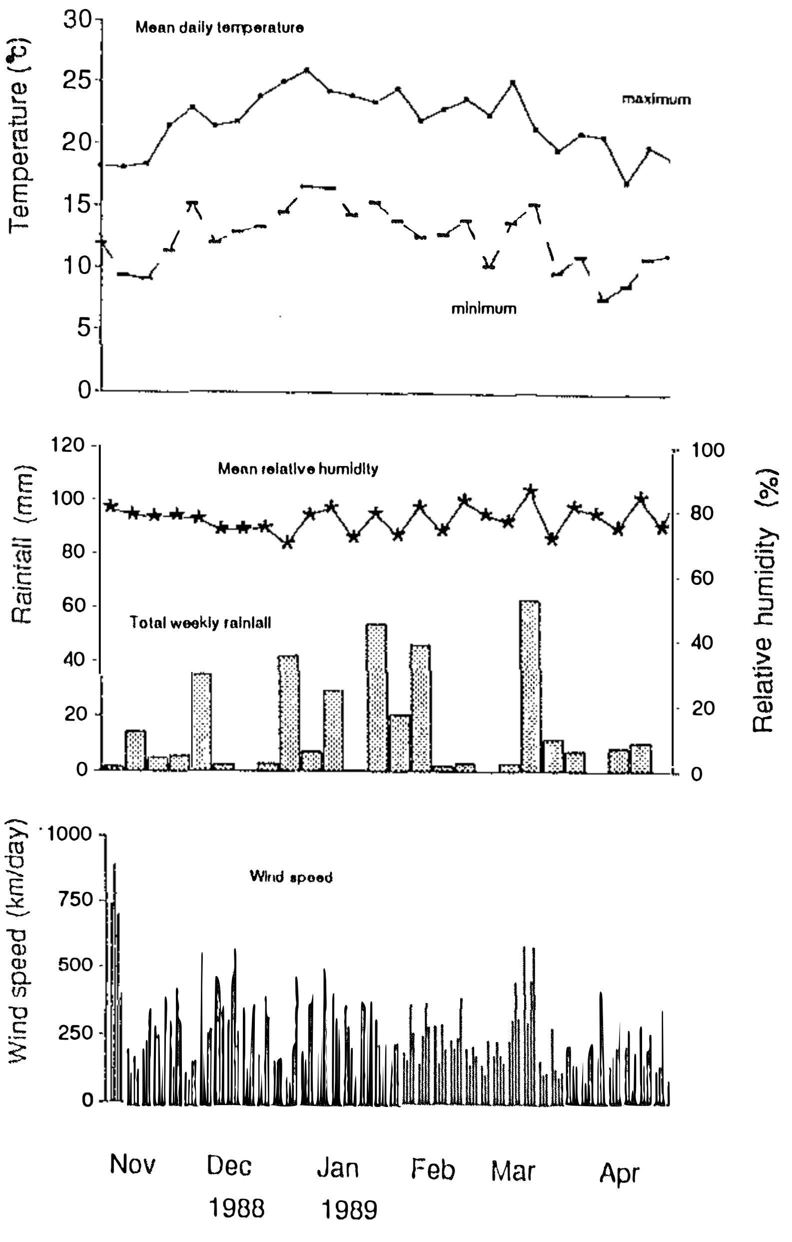
(Vertical bars represent SE of means.)



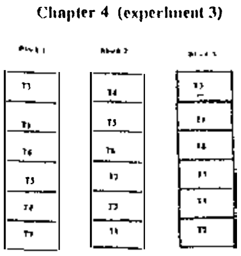
Appendix 3.4.1 Seed yield per m^2 of China aster cv. Kurenai and cv. Powderpuff. (Observed values and plotted curve of predicted values from four different equations: (a) quadratic, (b) natural log quadratic, (c) reciprocal linear and (d) reciprocal quadratic are shown.)

Appendix 3.5.1 Sprouting of seed on China aster seedheads.

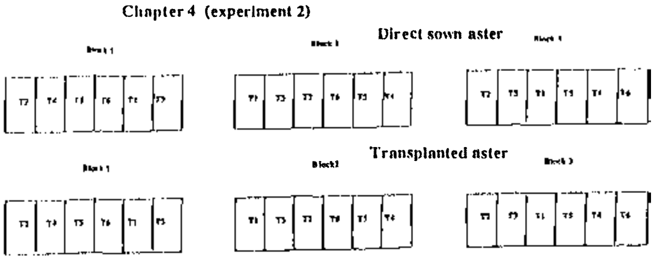
Appendix 3.5.2 Lodged crops of China aster cv. Kurenai and cv. Powderpuff.



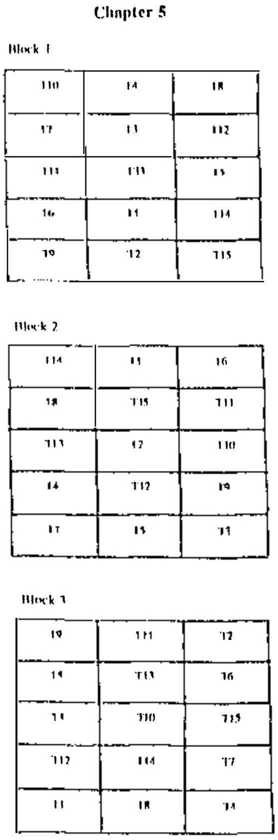
Appendix 5.1 Weather data at Palmerston North, New Zealand during November 1988- April 1989.



Chapter 4 (experiment 3)



Chapter 4 (experiment 2)



Chapter 5

Chapter 4 (experiment 3)

T1 Control
T2 Oryzalin 3.0 kg ai ha^{-1}
T3 Oryzalin 3.75 kg ai ha^{-1}
T4 Oryzalin 4.5 kg ai ha^{-1}
T5 Oryzalin 4.5 kg ai ha^{-1}
4 days after sowing
T6 Oryzalin 4.5 kg ai ha^{-1}
10 days after sowing

Plot size 1 x 2 m
32 plants plot^{-1}
spacing 25 x 25 cm

Chapter 4 (experiment 2)

T1 Control
T2 Trifluralin 2.0 kg ai ha^{-1}
T3 Chlorpropham 2.0 kg ai ha^{-1}
T4 Oryzalin 3.75 kg ai ha^{-1}
T5 Oryzalin 3.75 kg ai ha^{-1}
+ oryzalin 3.75 kg ai ha^{-1}
T6 Trifluralin 7.0 kg ai ha^{-1}
+ oryzalin 3.75 kg ai ha^{-1}

Plot size 1 x 2 m
32 plants plot^{-1}
spacing 25 x 25 cm

Chapter 5

T1 Control
T2 Pinching at VTB
T3 Paclobutrazol 1.0 kg ai ha^{-1} at VTB
T4 Paclobutrazol 0.5 kg ai ha^{-1} at VTB
T5 Chlormequat chloride 3.0 kg ai ha^{-1} at VTB
T6 Chlormequat chloride 1.5 kg ai ha^{-1} at VTB
T7 Daminozide 5.0 kg ai ha^{-1} at VTB
T8 Daminozide 2.5 kg ai ha^{-1} at VTB
T9 Pinching at STE
T10 Paclobutrazol 1.0 kg ai ha^{-1} at STE
T11 Paclobutrazol 0.5 kg ai ha^{-1} at STE
T12 Chlormequat chloride 3.0 kg ai ha^{-1} at STE
T13 Chlormequat chloride 1.5 kg ai ha^{-1} at STE
T14 Daminozide 5.0 kg ai ha^{-1} at STE
T15 Daminozide 2.5 kg ai ha^{-1} at STE

Plot size 1.5 x 3.0 m
72 plants plot^{-1}
spacing 25 x 25 cm

Appendix 5.2 Field layout of the 1988/1989 experiments.

Appendix 5.3 Effects of hand pinching and growth retardant application on main stem length of China aster cv. Powderpuff at first flowering (FF), peak flowering (PF) and seed harvest (H).

Treatment		Main stem length (cm)		
		FF	PF	H
Control		69.4 ab	72.5 ab	77.7 a
Pinching	(1)	13.6 e	12.1 d	11.0 c
Pinching	(2)	31.6 d	36.2 c	52.7 b
Chlormequat chloride 1.5 kg$^+$	(1)	71.1 ab	73.2 ab	74.1 a
Chlormequat chloride 1.5 kg	(2)	74.4 a	75.1 a	75.2 a
Chlormequat chloride 3.0 kg	(1)	70.6 ab	76.6 a	74.7 a
Chlormequat chloride 3.0 kg	(2)	68.8 ab	76.5 a	76.8 a
Daminozide 2.5 kg	(1)	64.0 bc	71.1 ab	69.5 a
Daminozide 2.5 kg	(2)	68.1 ab	69.6 ab	70.8 a
Daminozide 5.0 kg	(1)	68.7 ab	65.6 b	72.7 a
Daminozide 5.0 kg	(2)	64.2 bc	67.1 b	73.5 a
Paclobutrazol 0.5 kg	(1)	65.9 bc	69.8 ab	70.6 a
Paclobutrazol 0.5 kg	(2)	68.1 ab	75.1 a	73.7 a
Paclobutrazol 1.0 kg	(1)	61.7 c	70.2 ab	70.7 a
Paclobutrazol 1.0 kg	(2)	70.6 ab	68.7 b	72.1 a
Significance level		0.0001	0.0001	0.0001
CV (%)		5.44	6.62	6.83

means within a given column with the same letter are not significantly different at $P \leq 0.05$ for the Duncan's Multiple Range Comparison test.

$^+$ = application rate (kg ai ha^{-1})

(1) = applied at visible terminal flower bud stage,

(2) = applied at main stem elongation stage.

These indications apply for all Appendices

Appendix 5.4 Effects of hand pinching and growth retardant application on lateral branch length of China aster cv. Powderpuff at first flowering (FF), peak flowering (PF) and seed harvest (H).

Treatment		Lateral branch length (cm)		
		FF	PF	H
Control		51.1	55.2 b	55.4 bc
Pinching	(1)	55.9	64.6 a	64.4 a
Pinching	(2)	51.6	51.9 bc	54.1 bc
Chlormequat chloride 1.5 kg$^+$	(1)	44.8	51.5 bc	57.3 b
Chlormequat chloride 1.5 kg	(2)	47.9	58.5 ab	58.5 ab
Chlormequat chloride 3.0 kg	(1)	54.7	55.7 b	55.8 bc
Chlormequat chloride 3.0 kg	(2)	47.6	57.2 ab	57.7 b
Daminozide 2.5 kg	(1)	49.7	50.5 bc	53.6 bc
Daminozide 2.5 kg	(2)	46.2	51.0 bc	52.9 bc
Daminozide 5.0 kg	(1)	50.7	54.7 b	54.6 bc
Daminozide 5.0 kg	(2)	50.7	45.7 c	53.7 bc
Paclobutrazol 0.5 kg	(1)	46.1	54.2 b	50.2 c
Paclobutrazol 0.5 kg	(2)	54.5	51.5 bc	57.1 bc
Paclobutrazol 1.0 kg	(1)	45.6	52.7 bc	51.2 bc
Paclobutrazol 1.0 kg	(2)	45.7	52.2 bc	51.7 bc
Significance level		0.412	0.005	0.007
CV (%)		12.14	7.81	6.48

Appendix 5.5 Effects of hand pinching and growth retardant application on plant height of China aster cv. Powderpuff at first flowering (FF), peak flowering (PF) and seed harvest (H).

Treatment		Plant height (cm)		
		FF	PF	H
Control		78.3	84.8 ab	88.6 a
Pinching	(1)	69.5	76.7 b	76.1 c
Pinching	(2)	75.1	81.6 ab	85.4 ab
Chlormequat chloride 1.5 kg$^+$	(1)	76.7	83.3 ab	88.5 a
Chlormequat chloride 1.5 kg	(2)	80.6	89.6 a	91.4 a
Chlormequat chloride 3.0 kg	(1)	81.7	88.7 a	88.6 a
Chlormequat chloride 3.0 kg	(2)	74.7	89.8 a	89.4 a
Daminozide 2.5 kg	(1)	72.5	77.9 b	80.1 bc
Daminozide 2.5 kg	(2)	71.7	81.4 ab	82.0 bc
Daminozide 5.0 kg	(1)	77.2	82.2 ab	85.0 ab
Daminozide 5.0 kg	(2)	71.7	75.0 b	84.0 ab
Paclobutrazol 0.5 kg	(1)	72.6	82.0 ab	82.3 bc
Paclobutrazol 0.5 kg	(2)	76.8	85.7 a	86.3 ab
Paclobutrazol 1.0 kg	(1)	70.5	82.1 ab	79.6 bc
Paclobutrazol 1.0 kg	(2)	74.5	79.2 b	81.2 bc
Significance level		0.127	0.030	0.0017
CV (%)		6.51	6.24	4.73

Appendix 5.6 Effects of hand pinching and growth retardant application on total branch number of China aster cv. Powderpuff at first flowering (FF) and peak flowering (PF), and fertile branch number at seed harvest.

Treatment		Branches plant^{-1} FF	Branches plant^{-1} PF	Fertile branches
Control		13.0 abc	14.5 abc	14.0 a
Pinching	(1)	11.5 ab	11.2 c	11.2 bc
Pinching	(2)	14.3 abc	16.0 ab	12.7 ab
Chlormequat chloride 1.5 kg$^+$	(1)	13.7 abc	15.7 ab	12.1 abc
Chlormequat chloride 1.5 kg	(2)	15.7 a	16.8 a	11.8 abc
Chlormequat chloride 3.0 kg	(1)	12.5 abc	14.8 ab	13.0 ab
Chlormequat chloride 3.0 kg	(2)	10.5 bc	15.2 ab	11.8 abc
Daminozide 2.5 kg	(1)	11.0 bc	14.3 abc	10.3 bc
Daminozide 2.5 kg	(2)	15.5 ab	14.8 ab	10.7 bc
Daminozide 5.0 kg	(1)	12.8 abc	14.0 abc	12.9 ab
Daminozide 5.0 kg	(2)	9.5 c	13.3 bc	9.9 c
Paclobutrazol 0.5 kg	(1)	11.7 abc	14.8 ab	13.3 ab
Paclobutrazol 0.5 kg	(2)	14.7 bc	16.5 ab	11.4 bc
Paclobutrazol 1.0 kg	(1)	12.7 abc	12.2 c	10.7 bc
Paclobutrazol 1.0 kg	(2)	11.3 ab	11.2 c	11.9 abc
Significance level		0.041	0.008	0.028
CV (%)		16.96	12.36	11.36

Appendix 5.7 Branch breakage on a plant that was pinched at the visible terminal flower bud stage.

Appendix 5.8 Effects of hand pinching and growth retardant application on leaf number of China aster cv. Powderpuff at first flowering (FF) and peak flowering (PF).

Treatment		Leaf number	
		FF	PF
Control		511	640 a
Pinching	(1)	530	595 ab
Pinching	(2)	526	598 ab
Chlormequat chloride 1.5 kg$^+$	(1)	432	579 ab
Chlormequat chloride 1.5 kg	(2)	523	647 a
Chlormequat chloride 3.0 kg	(1)	521	621 a
Chlormequat chloride 3.0 kg	(2)	415	710 a
Daminozide 2.5 kg	(1)	383	435 b
Daminozide 2.5 kg	(2)	603	512 b
Daminozide 5.0 kg	(1)	432	691 a
Daminozide 5.0 kg	(2)	392	599 ab
Paclobutrazol 0.5 kg	(1)	425	682 a
Paclobutrazol 0.5 kg	(2)	476	654 a
Paclobutrazol 1.0 kg	(1)	493	525 ab
Paclobutrazol 1.0 kg	(2)	488	466 b
Significance level		0.177	0.041
CV (%)		18.33	16.15

Appendix 5.9 Effects of hand pinching and growth retardant application on leaf area of China aster cv. Powderpuff at first flowering (FF) and peak flowering (PF).

Treatment		Leaf area (cm^3)	
		FF	PF
Control		2379	1877
Pinching	(1)	1602	1569
Pinching	(2)	2085	1817
Chlormequat chloride 1.5 kg$^+$	(1)	2304	1463
Chlormequat chloride 1.5 kg	(2)	2329	2219
Chlormequat chloride 3.0 kg	(1)	2531	1850
Chlormequat chloride 3.0 kg	(2)	1681	2003
Daminozide 2.5 kg	(1)	2552	1397
Daminozide 2.5 kg	(2)	2910	1757
Daminozide 5.0 kg	(1)	2431	2714
Daminozide 5.0 kg	(2)	2264	2099
Paclobutrazol 0.5 kg	(1)	1751	2172
Paclobutrazol 0.5 kg	(2)	2711	1639
Paclobutrazol 1.0 kg	(1)	2414	1933
Paclobutrazol 1.0 kg	(2)	2402	1549
Significance level		0.321	0.196
CV (%)		25.48	26.44

Appendix 5.10 Effects of hand pinching and growth retardant application on number of flowers, buds and total flowers of China aster cv. Powderpuff at peak flowering.

Treatment		Flowers	Buds	Total
Control		29.2	10.2	39.3 a
Pinching	(1)	24.2	10.2	34.3 ab
Pinching	(2)	27.0	11.5	38.5 a
Chlormequat chloride 1.5 kg$^+$	(1)	24.3	8.3	32.7 abc
Chlormequat chloride 1.5 kg	(2)	25.0	8.0	33.0 abc
Chlormequat chloride 3.0 kg	(1)	23.8	10.3	34.2 ab
Chlormequat chloride 3.0 kg	(2)	27.3	12.0	39.3 a
Daminozide 2.5 kg	(1)	19.3	7.8	27.0 bc
Daminozide 2.5 kg	(2)	26.2	8.5	34.7 ab
Daminozide 5.0 kg	(1)	26.3	11.8	38.2 a
Daminozide 5.0 kg	(2)	25.0	5.3	30.3 abc
Paclobutrazol 0.5 kg	(1)	29.0	7.8	36.8 a
Paclobutrazol 0.5 kg	(2)	25.7	10.2	35.8 ab
Paclobutrazol 1.0 kg	(1)	20.3	5.8	26.2 c
Paclobutrazol 1.0 kg	(2)	19.8	4.7	24.5 c
Significance level		0.108	0.095	0.046
CV (%)		16.19	34.30	15.09

Appendix 5.11 Paclobutrazol treated plants (P) compared with untreated (U) at 12 days after application.

Appendix 5.12 Experimental plots at first flowering and peak flowering.

Appendix 5.13 Monthly records of temperature, sunshine and daylength from January 1988 to March 1990.

	Air temperature (°C)				Sunshine	Daylength	
Month	Max (°C)	Min (°C)	Mean (°C)	DifN (°C)	Actual (h)	Actual (h.m)	(h.ts)
1988							
January	22.4	12.7	17.6	-0.1	240	14.47	14.78
February	22.9	14.6	18.8	+0.7	135	13.55	13.93
March	20.3	11.0	15.7	-0.7	130	12.55	12.92
April	17.9	8.1	13.0	-1.1	166	10.59	10.98
May	15.7	7.0	11.4	+0.2	124	9.48	9.80
June	13.7	6.0	9.9	+1.1	67	9.15	9.25
July	13.5	5.7	9.6	+1.5	99	9.31	9.52
August	13.8	5.7	9.8	+0.5	143	10.30	10.50
September	15.6	9.4	12.5	+1.5	69	11.41	11.68
October	17.1	10.2	13.7	+1.1	138	13.07	13.12
November	19.8	10.9	15.4	+1.0	182	14.25	14.42
December	22.9	13.4	18.2	+1.8	225	15.13	15.22
1989							
January	24.1	15.2	19.7	+2.0	223	14.47	14.78
February	23.1	12.9	18.0	+0.1	193	13.55	13.93
March	22.0	12.4	17.2	+0.4	172	12.55	12.92
April	19.2	9.8	14.5	+0.4	175	10.59	10.98
May	15.4	8.4	11.9	+0.7	64	9.48	9.80
June	13.1	4.9	9.0	+0.2	73	9.15	9.25
July	12.3	3.1	7.7	+0.4	141	9.31	9.52
August	14.2	5.3	9.8	+0.5	124	10.30	10.50
September	16.5	8.3	12.4	+1.4	151	11.41	11.68
October	18.0	9.6	13.8	+1.2	130	13.07	13.12
November	20.0	12.0	16.0	+1.6	192	14.25	14.42
December	20.2	11.2	15.7	-0.7	158	15.13	15.22
1990							
January	23.0	13.0	18.0	+0.3	201	14.47	14.78
February	24.9	15.2	20.1	+2.0	223	13.55	13.93
March	22.2	13.6	17.9	+1.1	172	12.55	12.92

The temperature and sunshine data were taken by DSIR, Palmerston North, New Zealand (about 1 km from trial site and 34 m above sea level).

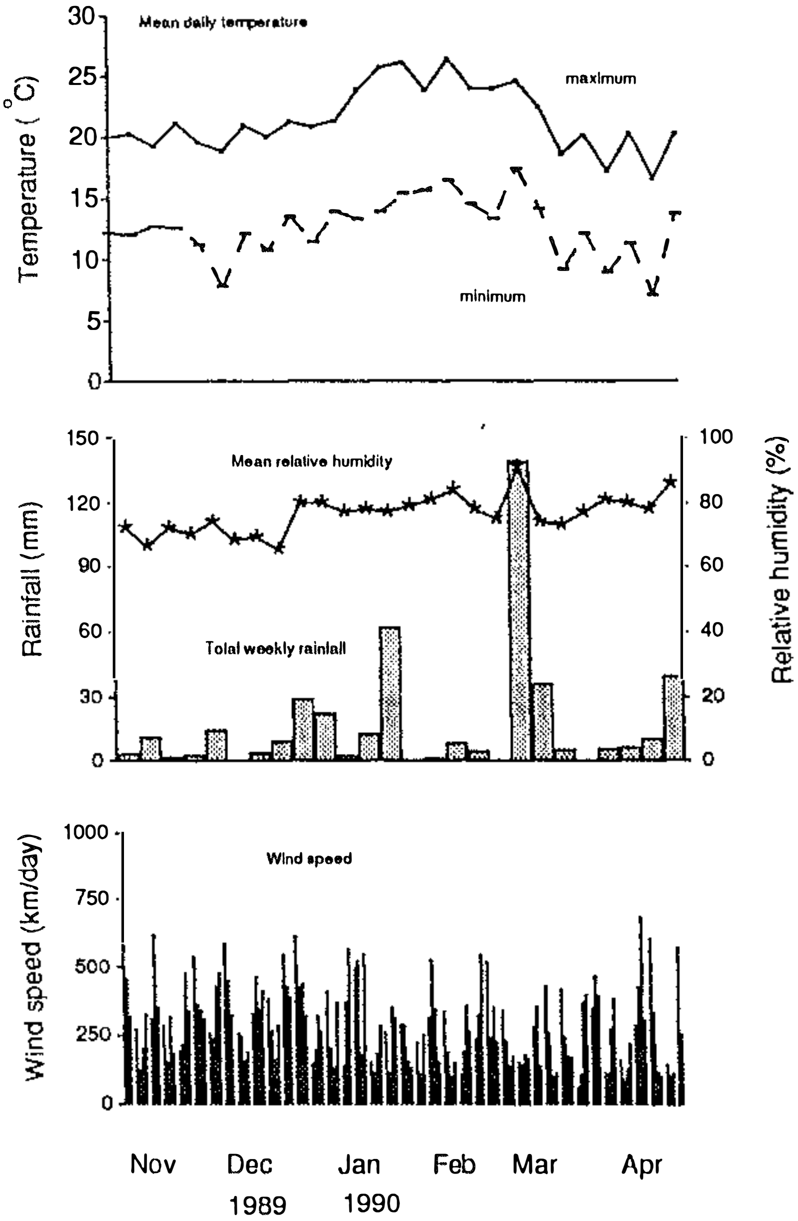
The daylength data were taken from the Carter Observatory, Wellington, New Zealand (about 100 km from trial site).

Normal observation is the mean of thirty years of weather observation.

DifN - difference from normal.

h.m - hours and minute.

h.ts - hours and tenths.



Appendix 6.1.1 Weather data at Palmerston North, New Zealand during November 1989 - April 1990.

Block 1	Block 2	Block 3
T3	T2	T4
T4	T6	T7
T1	T5	T3
T6	T4	T2
T7	T1	T5
T2	T3	T6
T5	T7	T1

Chapter 6.1

Powderpuff
plot size (1.5 x 3) m
72 plants plot^{-1}
spacing (25 x 25) cm

T1 Control
T2 Paclobutrazol 0.5 kg ai ha^{-1} applied at vegetative stage
T3 Paclobutrazol 1.0 kg ai ha^{-1} applied at vegetative stage
T4 Paclobutrazol 0.5 kg ai ha^{-1} applied at flower bud initiation stage
T5 Paclobutrazol 1.0 kg ai ha^{-1} applied at flower bud initiation stage
T6 Paclobutrazol 0.5 kg ai ha^{-1} applied at visible terminal flower bud stage
T7 Paclobutrazol 1.0 kg ai ha^{-1} applied at visible terminal flower bud stage

T3	T2	T1
T1	T1	T2
T2	T3	T3

T2	T1	T2
T3	T3	T1
T1	T2	T3

T1	T1	T3
T2	T3	T1
T3	T2	T2

T1	T2	T3
T3	T3	T1
T2	T1	T2

Chapter 6.2

Powderpuff (16 plants m^{-2})
plot size (1 x 3) m
48 plants plot^{-1}
spacing (25 x 25) cm

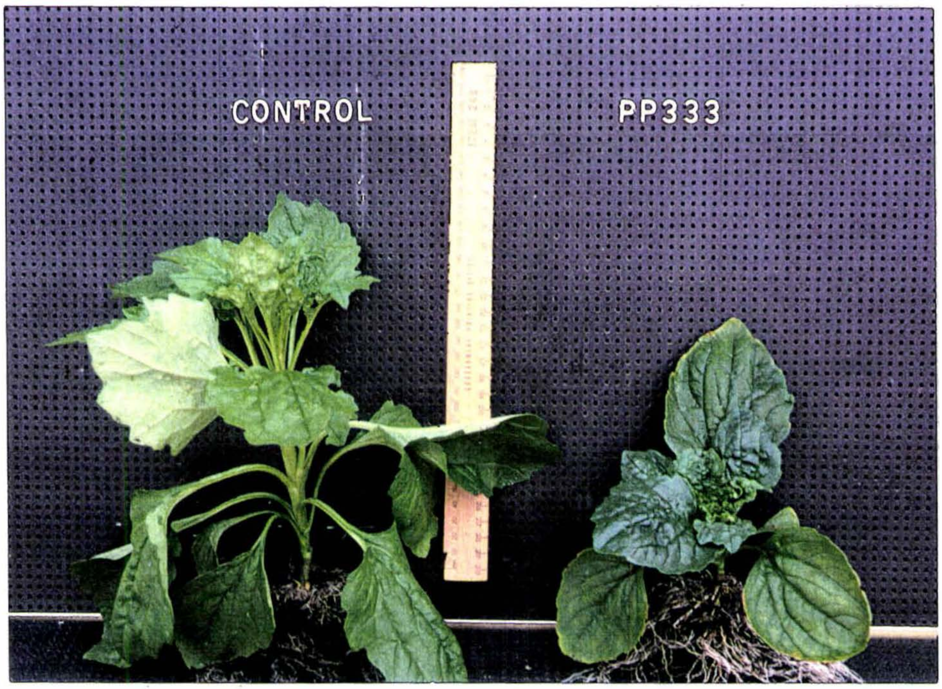
Powderpuff (36 plants m^{-2})
plot size (1 x 3) m
108 plants plot^{-1}
spacing (16.7 x 16.7) cm

Kurenai (25 plants m^{-2})
plot size (1 x 3) m
45 plants plot^{-1}
spacing (20 x 20) cm

Kurenai (49 plants m^{-2})
plot size (1 x 3) m
147 plants plot^{-1}
spacing (14 x 14) cm

T1 Control
T2 Paclobutrazol 0.5 kg ai ha^{-1}
T3 Paclobutrazol 1.0 kg ai ha^{-1}

Appendix 6.1.2 Field layout of the 1989/1990 experiments.



Appendix 6.1.3 Control and paclobutrazol treated plants of China aster cv Powderpuff (20 days after application).

Appendix 6.1.4 Experimental plots at first flowering.
(C = untreated control, PP = paclobutrazol treated plot)

Appendix 6.1.5 Effects of paclobutrazol on vegetative stem length of China aster cv. Powderpuff at first flowering (FF), peak flowering (PF) and seed harvest (H).

Treatment			Vegetative stem length (cm)		
			FF	PF	H
Control			32.6 a	33.5 a	35.8 a
Paclobutrazol	0.5^{+}	VEG	33.0 a	30.1 ab	32.8 b
Paclobutrazol	1.0	VEG	27.1 bc	29.9 ab	29.9 bc
Paclobutrazol	0.5	TBI	27.2 bc	27.1 cd	28.7 c
Paclobutrazol	1.0	TBI	23.3 c	23.0 d	24.8 d
Paclobutrazol	0.5	VTB	32.2 a	31.4 ab	32.1 b
Paclobutrazol	1.0	VTB	29.1 ab	28.5 bc	29.1 c
Significance level			0.0018	0.001	0.0001
CV (%)			7.93	7.81	5.39

$^{+}$ =application rate (kg ai ha^{-1})

VEG = vegetative or rosette stage

TBI = flower bud initiation stage

VTB = visible terminal flower bud stage

means within a given column with the same letter are not significantly different at $P \leq 0.05$ for the Duncan's Multiple Range Comparison test.

(These indications apply for all tables)

Appendix 6.1.6 Effects of paclobutrazol on total main stem length of China aster cv. Powderpuff at first flowering (FF), peak flowering (PF) and seed harvest (H).

Treatment			Main stem length (cm)		
			FF	PF	H
Control			73.0	73.8 a	72.9
Paclobutrazol	0.5	VEG	71.7	71.3 ab	72.6
Paclobutrazol	1.0	VEG	67.1	71.6 ab	68.0
Paclobutrazol	0.5	TBI	70.3	69.6 ab	71.3
Paclobutrazol	1.0	TBI	61.8	62.8 c	64.2
Paclobutrazol	0.5	VTB	71.7	73.8 a	69.3
Paclobutrazol	1.0	VTB	66.1	65.1 bc	66.8
Significance level			0.157	0.020	0.171
CV (%)			7.06	5.32	5.88

Appendix 6.1.7 Effects of paclobutrazol on lateral branch length of China aster cv. Powderpuff at first flowering (FF), peak flowering (PF) and seed harvest (H).

Treatment			Lateral branch length (cm)		
			FF	PF	H
Control			54.27	54.0	56.2
Paclobutrazol	0.5	VEG	48.83	51.7	50.3
Paclobutrazol	1.0	VEG	50.80	51.9	51.9
Paclobutrazol	0.5	TBI	51.93	57.5	52.7
Paclobutrazol	1.0	TBI	45.23	50.4	51.9
Paclobutrazol	0.5	VTB	48.37	52.4	52.7
Paclobutrazol	1.0	VTB	41.97	46.2	51.5
Significance level			0.225	0.078	0.217
CV (%)			11.58	7.17	4.75

Appendix 6.1.8 Effects of paclobutrazol on plant height of China aster cv. Powderpuff at first flowering (FF), peak flowering (PF) and seed harvest (H).

Treatment			Plant height (cm)		
			FF	PF	H
Control			84.9 a	87.5 a	92.0 a
Paclobutrazol	0.5^{+}	VEG^{++}	79.9 ab	81.8 ab	83.0 b
Paclobutrazol	1.0	VEG	75.9 abc	81.8 ab	81.8 bc
Paclobutrazol	0.5	TBI	77.2 abc	82.6 a	82.1 bc
Paclobutrazol	1.0	TBI	66.6 c	73.1 c	76.6 c
Paclobutrazol	0.5	VTB	78.6 ab	83.8 a	84.4 b
Paclobutrazol	1.0	VTB	69.0 bc	74.7 bc	80.6 bc
Significance level			0.035	0.008	0.001
CV (%)			7.86	4.84	3.28

Appendix 6.1.9 Effects of paclobutrazol on total branch number of China aster cv. Powderpuff at first flowering (FF) and peak flowering (PF) and fertile branches at seed harvest.

Treatment			Branches plant^{-1}		Fertile branches
			FF	PF	
Control			16	18	12 a
Paclobutrazol	0.5	VEG	17	16	10 ab
Paclobutrazol	1.0	VEG	17	18	11 a
Paclobutrazol	0.5	TBI	17	17	9 bc
Paclobutrazol	1.0	TBI	18	17	9 bc
Paclobutrazol	0.5	VTB	17	16	11 ab
Paclobutrazol	1.0	VTB	17	18	8 c
Significance level			0.297	0.795	0.015
CV (%)			9.29	11.84	12.88

Appendix 6.1.10 Effects of paclobutrazol on the number of big, small and side branches of China aster cv. Powderpuff at peak flowering.

Treatment			Branches plant^{-1}			
			big	small	total	side
Control			11	7	18	21
Paclobutrazol	0.5	VEG	10	6	16	16
Paclobutrazol	1.0	VEG	11	7	18	20
Paclobutrazol	0.5	TBI	10	7	17	16
Paclobutrazol	1.0	TBI	9	8	17	19
Paclobutrazol	0.5	VTB	10	6	16	20
Paclobutrazol	1.0	VTB	10	8	18	18
Significance level			0.599	0.490	0.795	0.099
CV (%)			14.39	19.90	11.84	19.19

Appendix 6.1.11 Effects of paclobutrazol on node number and number of leaves on main stem and branches of China aster cv. Powderpuff at first flowering and peak flowering.

Treatment			First flowering			Peak flowering	
			nodes	main stem leaves	leaves branch^{-1}	main stem leaves	leaves branch^{-1}
Control			19	39	22	38	22
Paclobutrazol	0.5	VEG	19	39	21	35	21
Paclobutrazol	1.0	VEG	19	39	21	37	22
Paclobutrazol	0.5	TBI	20	38	21	33	20
Paclobutrazol	1.0	TBI	20	36	20	34	22
Paclobutrazol	0.5	VTB	19	39	22	35	21
Paclobutrazol	1.0	VTB	20	38	20	36	22
Significance level			0.916	0.629	0.160	0.221	0.808
CV (%)			8.88	6.88	5.56	7.09	6.51

Appendix 6.1.12 Effects of paclobutrazol on total flower number of China aster cv. Powderpuff at first flowering and the number of flowers, buds and total at peak flowering.

Treatment			First flowering	Peak flowering flowers	buds	total
Control			30	17	19	37
Paclobutrazol	0.5	VEG	28	18	10	28
Paclobutrazol	1.0	VEG	26	18	11	29
Paclobutrazol	0.5	TBI	25	19	9	28
Paclobutrazol	1.0	TBI	22	20	11	32
Paclobutrazol	0.5	VTB	26	19	13	32
Paclobutrazol	1.0	VTB	23	18	14	32
Significance level			0.087	0.126	0.163	0.172
CV (%)			11.60	15.05	34.64	18.25

Appendix 6.1.13 Effects of paclobutrazol on plant dry weight of China aster cv. Powderpuff at first flowering (FF), peak flowering (PF) and seed harvest (H).

Treatment			Plant dry weight (g) FF	PF	H
Control			55.11	66.96	76.42
Paclobutrazol	0.5	VEG	49.53	58.71	79.33
Paclobutrazol	1.0	VEG	47.31	58.80	82.80
Paclobutrazol	0.5	TBI	47.49	64.13	82.33
Paclobutrazol	1.0	TBI	40.61	65.09	71.50
Paclobutrazol	0.5	VTB	49.85	67.71	79.11
Paclobutrazol	1.0	VTB	46.84	60.73	70.79
Significance level			0.328	0.458	0.781
CV (%)			13.69	10.18	14.91

Appendix 6.2.1 Effects of paclobutrazol on vegetative and total branch length at peak flowering of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2} and cv. Kurenai grown at 25 and 49 plants m^{-2}.

Treatment	Branch length (cm)	
	vegetative	total
Powderpuff (16 plants m^{-2})		
Control	9.3	28.4
Paclobutrazol 0.5 kg	11.2	27.8
Paclobutrazol 1.0 kg	8.9	27.8
Significance level	0.861	0.926
CV (%)	18.37	8.32
Powderpuff (36 plants m^{-2})		
Control	10.5	31.9
Paclobutrazol 0.5 kg	9.8	30.2
Paclobutrazol 1.0 kg	11.4	29.4
Significance level	0.570	0.746
CV (%)	24.65	12.34
Kurenai (25 plants m^{-2})		
Control	11.2	21.1
Paclobutrazol 0.5 kg	11.3	21.1
Paclobutrazol 1.0 kg	10.6	19.5
Significance level	0.582	0.140
CV (%)	14.32	4.17
Kurenai (49 plants m^{-2})		
Control	10.5	18.9
Paclobutrazol 0.5 kg	9.7	19.2
Paclobutrazol 1.0 kg	11.1	18.7
Significance level	0.844	0.982
CV (%)	39.68	14.63

Appendix 6.2.2 Effects of paclobutrazol on number of nodes and leaves per stem and per branch at peak flowering of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2} and cv. Kurenai grown at 25 and 49 plants m^{-2}.

Treatment	Nodes	Leaves main $stem^{-1}$	Leaves $branch^{-1}$
Powderpuff (16 plants m^{-2})			
Control	22	36	14
Paclobutrazol 0.5 kg	23	38	14
Paclobutrazol 1.0 kg	20	32	14
Significance level	0.325	0.069	0.640
CV (%)	10.88	7.03	5.83
Powderpuff (36 plants m^{-2})			
Control	22	33	16
Paclobutrazol 0.5 kg	19	35	17
Paclobutrazol 1.0 kg	21	33	14
Significance level	0.599	0.866	0.602
CV (%)	14.13	5.23	13.77
Kurenai (25 plants m^{-2})			
Control	28	45	16
Paclobutrazol 0.5 kg	29	48	19
Paclobutrazol 1.0 kg	27	49	18
Significance level	0.250	0.215	0.176
CV (%)	3.86	4.71	8.91
Kurenai (49 plants m^{-2})			
Control	29	44	14
Paclobutrazol 0.5 kg	30	49	18
Paclobutrazol 1.0 kg	28	45	17
Significance level	0.334	0.065	0.073
CV (%)	4.11	4.40	8.78

Appendix 6.2.3 Effects of paclobutrazol on number of big, small and lateral branches and side branches at peak flowering and number of fertile branches at seed harvest of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2} and cv. Kurenai grown at 25 and 49 plants m^{-2}.

Treatment	Branches plant^{-1} big	small	total	side	Fertile branches
Powderpuff (16 plants m^{-2})					
Control	13	5	17	22	12
Paclobutrazol 0.5 kg	14	5	19	21	11
Paclobutrazol 1.0 kg	10	5	15	18	11
Significance level	0.273	0.907	0.302	0.663	0.132
CV (%)	19.30	22.06	15.93	25.83	7.20
Powderpuff (36 plants m^{-2})					
Control	8	6	15	16	7.7 b
Paclobutrazol 0.5 kg	10	6	15	15	9.0 a
Paclobutrazol 1.0 kg	8	8	16	14	8.0 ab
Significance level	0.757	0.228	0.524	0.366	0.027
CV (%)	22.61	20.36	13.82	10.24	4.59
Kurenai (25 plants m^{-2})					
Control	13	7	20	28	10 b
Paclobutrazol 0.5 kg	11	7	18	29	13 a
Paclobutrazol 1.0 kg	12	4	16	28	12 a
Significance level	0.610	0.254	0.076	0.342	0.014
CV (%)	16.35	29.83	7.01	20.20	4.56
Kurenai (49 plants m^{-2})					
Control	9 b	8	17	22	8.0 b
Paclobutrazol 0.5 kg	9 b	9	19	20	8.3 ab
Paclobutrazol 1.0 kg	11 a	7	19	19	9.0 a
Significance level	0.019	0.410	0.529	0.629	0.049
CV (%)	5.39	20.27	12.83	15.72	3.95

Appendix 6.2.4 Effects of paclobutrazol on number of flowers, buds and total flowers at peak flowering of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2} and cv. Kurenai grown at 25 and 49 plants m^{-2}.

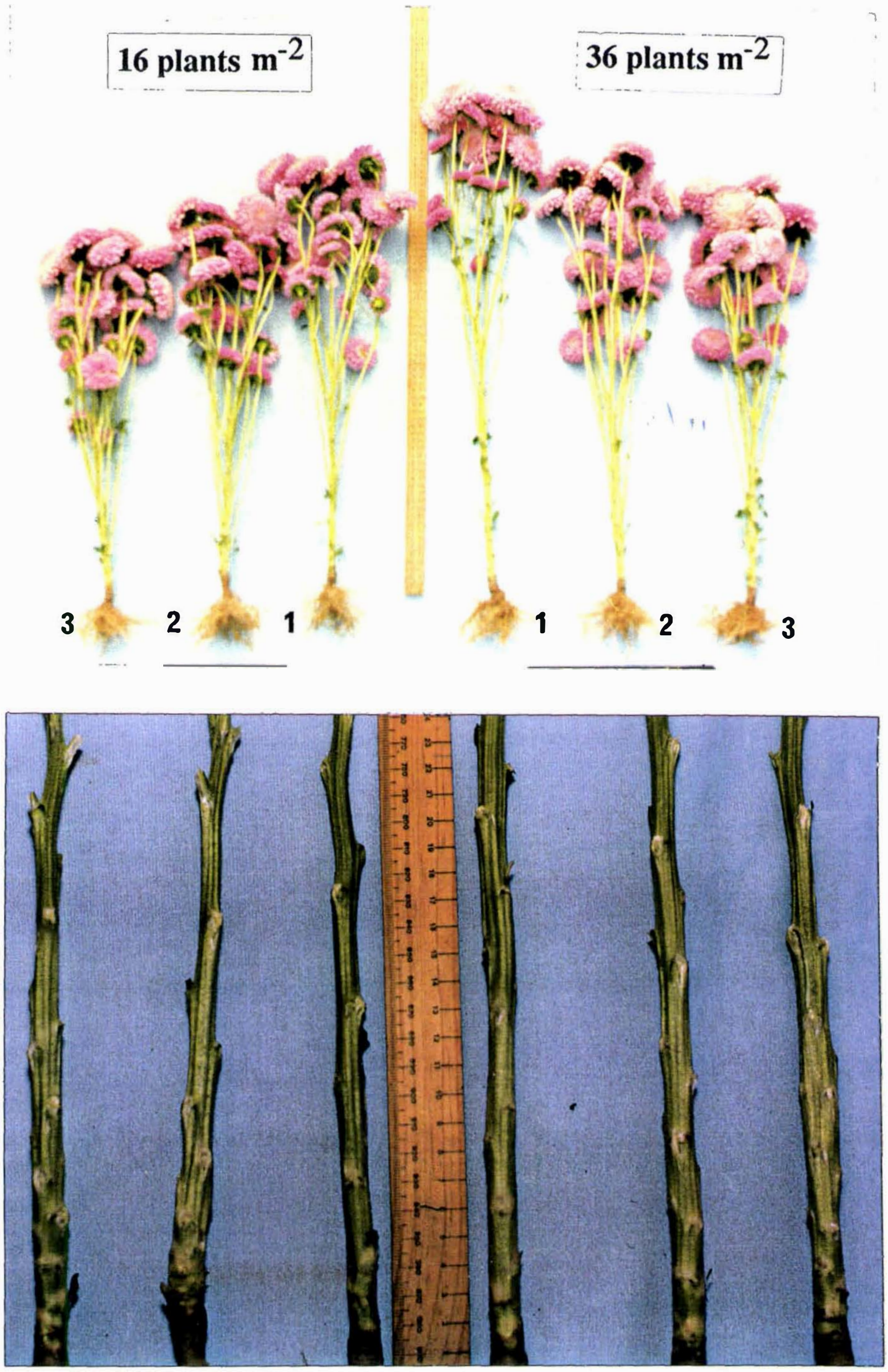
Treatment	Peak flowering		
	flowers	buds	total
Powderpuff (16 plants m^{-2})			
Control	30	9	39
Paclobutrazol 0.5 kg	30	8	38
Paclobutrazol 1.0 kg	25	6	32
Significance level	0.404	0.670	0.490
CV (%)	16.30	40.31	20.56
Powderpuff (36 plants m^{-2})			
Control	22.0	4.0	26.3
Paclobutrazol 0.5 kg	21.5	5.5	27.0
Paclobutrazol 1.0 kg	21.3	5.3	27.0
Significance level	0.914	0.523	0.906
CV (%)	12.83	26.70	11.69
Kurenai (25 plants m^{-2})			
Control	33.0	14.0	47.0
Paclobutrazol 0.5 kg	30.0	11.0	41.3
Paclobutrazol 1.0 kg	24.7	9.7	34.3
Significance level	0.106	0.114	0.110
CV (%)	12.37	16.82	13.38
Kurenai (49 plants m^{-2})			
Control	25.3	8.0	33.3
Paclobutrazol 0.5 kg	24.7	7.7	32.3
Paclobutrazol 1.0 kg	26.3	7.0	33.3
Significance level	0.633	0.846	0.934
CV (%)	7.97	27.90	11.54

Appendix 6.2.5 Effects of paclobutrazol on leaf size on vegetative and reproductive stems and for leaves on branches recorded at peak flowering of China aster cv Powderpuff grown at 16 and 36 plants m^{-2} and cv Kurenai grown at 25 and 49 plants m^{-2}.

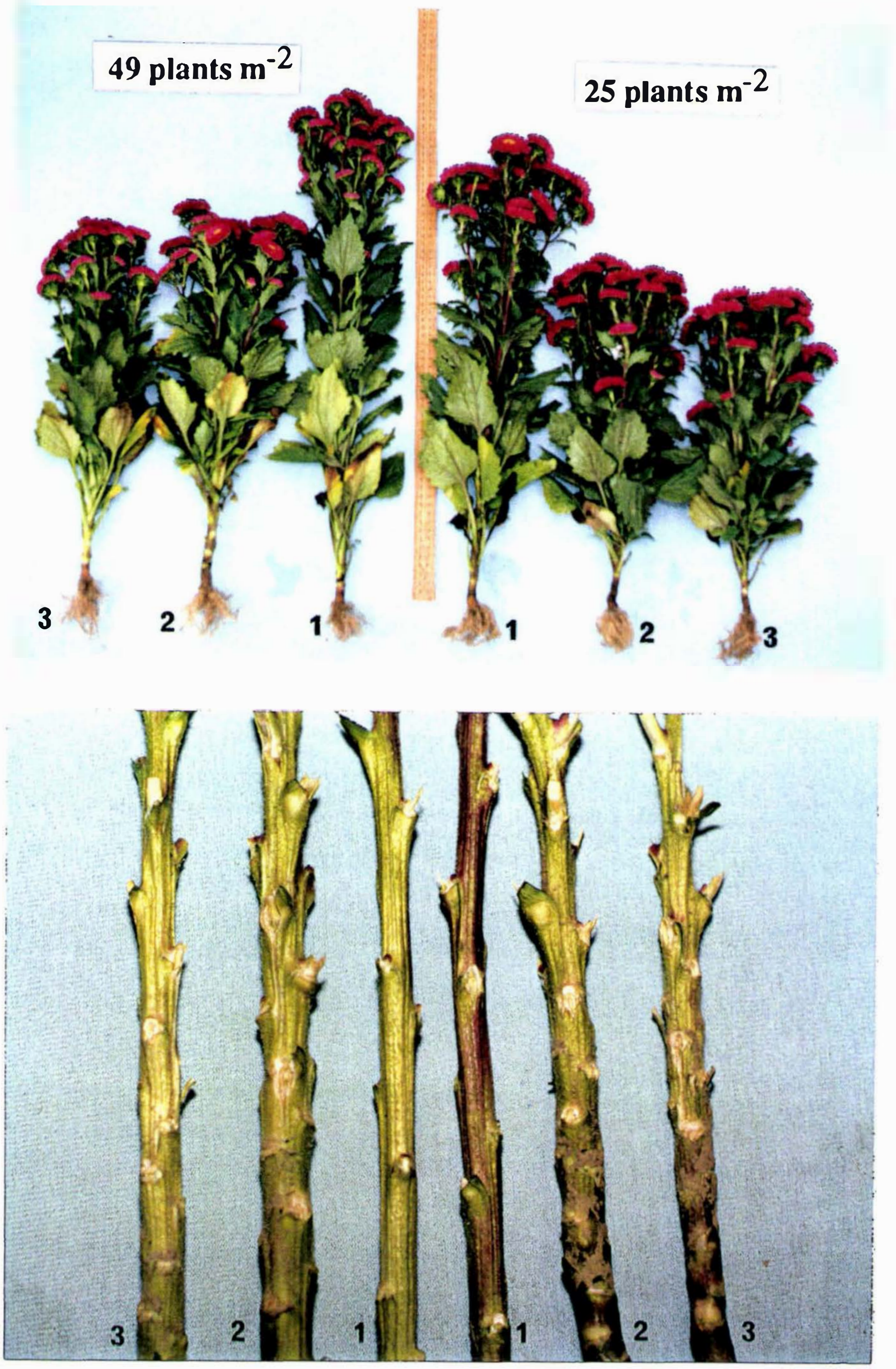
Treatment	Leaf on stem						Leaf on branch	
	vegetative				reproductive			
	blade width	blade length	petiole	total	width	length	width	length
Powderpuff (16 plants m^{-2})								
Control	8.2	10.0	7.1	17.1	4.5	10.7	2.9	8.2
Paclobutrazol 0.5 kg	7.7	9.2	7.1	16.7	4.7	11.0	2.9	8.0
Paclobutrazol 1.0 kg	7.3	8.8	7.2	15.8	4.9	11.2	3.1	8.4
Significance level	0.515	0.301	0.798	0.665	0.715	0.592	0.689	0.833
CV (%)	11.04	8.88	13.14	10.54	11.16	5.81	9.87	8.09
Powderpuff (36 plants m^{-2})								
Control	8.3	10.4	8.0	18.4	4.5	11.2	3.1	8.2
Paclobutrazol 0.5 kg	7.2	9.6	7.2	16.7	4.2	10.9	3.2	8.6
Paclobutrazol 1.0 kg	6.6	9.2	7.6	16.8	4.5	11.4	3.4	9.2
Significance level	0.051	0.207	0.170	0.198	0.873	0.888	0.651	0.210
CV (%)	6.67	6.70	5.78	6.01	16.00	9.08	10.46	6.67
Kurenai (25 plants m^{-2})								
Control	7.3	9.1	7.0	16.1	3.1	8.3	2.4	6.5 b
Paclobutrazol 0.5 kg	7.1	8.5	7.0	15.5	3.7	9.5	2.6	7.6 a
Paclobutrazol 1.0 kg	7.2	8.7	6.8	15.4	3.7	9.4	2.5	6.9 ab
Significance level	0.975	0.700	0.944	0.857	0.097	0.098	0.362	0.045
CV (%)	12.69	9.95	13.08	10.66	7.76	6.37	6.99	4.88
Kurenai (49 plants m^{-2})								
Control	7.4	9.6	7.8	17.4	3.5	8.9	1.9	5.8
Paclobutrazol 0.5 kg	6.7	8.5	6.9	15.4	3.6	9.1	2.1	6.5
Paclobutrazol 1.0 kg	6.8	8.6	7.2	15.8	3.4	8.8	2.4	6.7
Significance level	0.188	0.264	0.343	0.178	0.501	0.818	0.098	0.217
CV (%)	4.40	8.58	9.45	6.81	5.54	5.69	9.78	7.87

Appendix 6.2.6 Effects of paclobutrazol on plant dry weight at vegetative growth stage, peak flowering and seed harvest of China aster cv. Powderpuff grown at 16 and 36 plants m^{-2} and cv. Kurenai grown at 25 and 49 plants m^{-2}.

Treatment	Plant dry weight (g) peak flowering	 harvest
Powderpuff (16 plants m^{-2})		
Control	39.7	43.40
Paclobutrazol 0.5 kg	39.8	37.72
Paclobutrazol 1.0 kg	34.9	34.59
Significance level	0.624	0.400
CV (%)	17.43	18.61
Powderpuff (36 plants m^{-2})		
Control	32.73	29.39
Paclobutrazol 0.5 kg	30.24	30.89
Paclobutrazol 1.0 kg	30.33	30.96
Significance level	0.525	0.686
CV (%)	8.88	12.24
Kurenai (25 plants m^{-2})		
Control	31.33	28.01
Paclobutrazol 0.5 kg	30.16	30.60
Paclobutrazol 1.0 kg	25.19	28.21
Significance level	0.304	0.416
CV (%)	15.32	8.22
Kurenai (49 plants m^{-2})		
Control	22.05	19.04
Paclobutrazol 0.5 kg	21.23	19.46
Paclobutrazol 1.0 kg	24.60	21.30
Significance level	0.422	0.129
CV (%)	12.97	5.52



Appendix 6.2.7 Plant height and internode length at peak flowering of China aster cv Powderpuff.
1 = Control
2 = Paclobutrazol 0.5 kg a.i. ha^{-1}
3 = Paclobutrazol 1.0 kg a.i. ha^{-1}



Appendix 6.2.8 Plant height and internode length at peak flowering of China aster cv Kurenai.

1 = Control
2 = Paclobutrazol 0.5 kg a.i. ha^{-1}
3 = Paclobutrazol 1.0 kg a.i. ha^{-1}

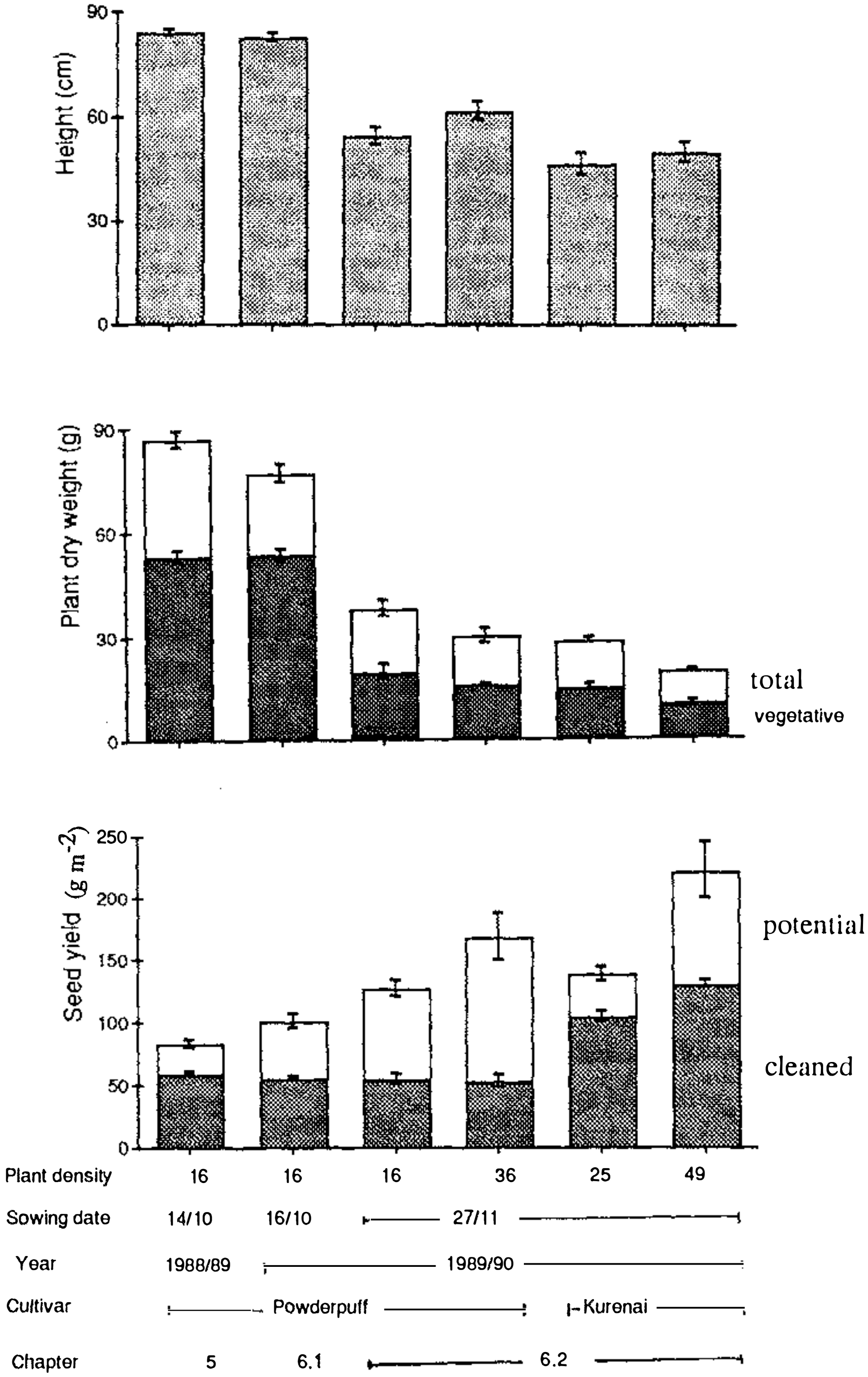
Control **Paclobutrazol** (1.0 kg a.i. ha^{-1})

Appendix 6.2.9 Control and paclobutrazol treated plots at one week after peak flowering.

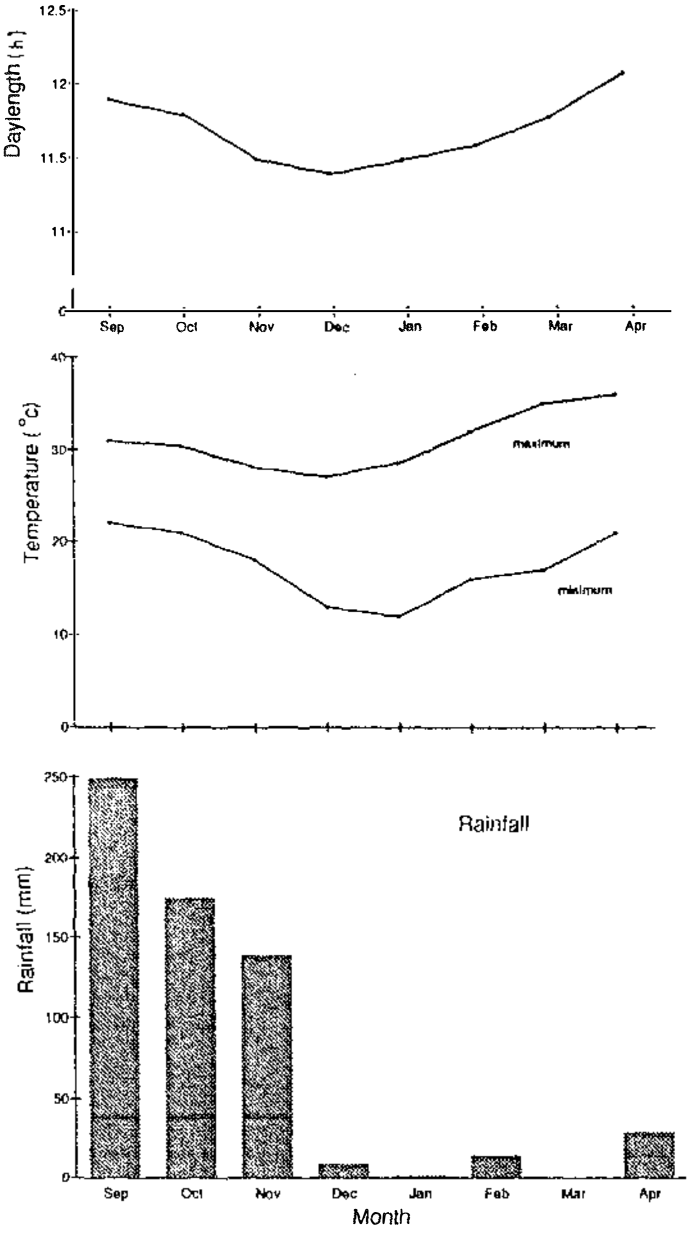
Appendix 7.1 Summary of date of sowing, planting, flowering and harvest for all experiments (1987-1989).

Cultivar	Year	Sowing	Planting	First flowering	Peak flowering	Harvest
Powderpuff						
	1	9.11.87	16.12.87	15.2.88	11.3.88	18.4.88
			(37)	(97)	(122)	(160)
	2	14.10.88	21.11.88	7.2.89	27.2.89	4.4.89
			(38)	(116)	(136)	(172)
	3	16.10.89	20.11.89	4.2.90	25.2.90	5.4.90
			(34)	(110)	(131)	(169)
	3	27.11.89		9.2.90	26.3.90	30.4.90
				(74)	(119)	(154)
Kurenai						
	1	21.10.87	21.11.87	1.2.88	21.2.88	22.3.88
			(33)	(103)	(123)	(153)
	3	27.11.89		9.2.90	14.3.90	11.4.90
				(74)	(107)	(135)

( ) days from sowing.



Appendix 7.2 Crop comparison (average over all treatments) for plant height, dry weight and seed yield of China aster.



Appendix 7.3 Climate data at Chiangmai Field Crop Research Centre, Chiangmai, Thailand during October 1983 to May 1984.

Appendix 7.4 Summary of paclobutrazol effects on seed yield and yield components of China aster.

EXP	VEG		TFI		VTB		STE	
	0.5 FPH	1.0 FPH	0.5 FPH	1.0 FPH	0.5 FPH	1.0 FPH	0.5 FPH	1.0 FPH
Seed yield potential								
5					o	o	o	o
6.1	o	↑	o	o	o	o		
6.2a			o	o				
6.2b			↑	o				
6.2c			o	o				
6.2d			↑	↑				
Seed heads								
5					o	↓	o	↓
6.1	o	o	o	o	o	o		
6.2a			↓	↓				
6.2b			o	o				
6.2c			o	o				
6.2d			o	o				
Seed numbers								
5					o	↑	o	o
6.1	o	↑	o	o	o	↑		
6.2a			o	↑				
6.2b			↑	↑				
6.2c			o	o				
6.2d			↑	↑				
Seed weight								
5					o	o	o	o
6.1	o	o	o	o	o	o		
6.2a			o	o				
6.2b			o	o				
6.2c			o	o				
6.2d			o	↑				

EXP: 5 = 1988/89 experiment on Powderpuff 16 plants m^{-2} (Chapter 5).
6.1 = 1989/90 experiment on Powderpuff 16 plants m^{-2} (Chapter 6.1).
6.2a = 1988/89 experiment on Powderpuff 16 plants m^{-2} (Chapter 6.2).
6.2b = 1988/89 experiment on Powderpuff 36 plants m^{-2} (Chapter 6.2).
6.2c = 1988/89 experiment on Kurenai 25 plants m^{-2} (Chapter 6.2).
6.2c = 1988/89 experiment on Kurenai 49 plants m^{-2} (Chapter 6.2).
0.5, 1.0 = paclobutrazol application rate (kg a.i. ha^{-1}).
VEG = vegetative stage. F = first flowering.
TFI = terminal flower bud initiation stage. P = peak flowering.
VTB = visible terminal bud stage. H = seed harvest.
STE = stem elongation stage.
o ↑ ↓ = no significant different, significantly increased and decreased at $P \leq 0.05$ respectively.