Hybrid Dahlia (*Dahlia hybrida* L.) Seed Production

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ABSTRACT

Three experiments related to dahlia seed production were conducted at the Seed Technology Centre, Massey University, New Zealand in the 1995/1996 season, with the objectives being to: evaluate herbicide toxicity to dahlia; determine the effect of establishment method and plant density on dahlia seed yield and yield components; and determine the effect of sowing date on dahlia seed yield.

Thirteen herbicides applied pre-emergence or post-emergence were evaluated in the herbicide experiment. EPTC (4.32 kg a.i/ha), oxyfluorfen (0.72 kg a.i/ha), oryzalin (4.5 kg a.i/ha), oxadiazon (1.52 kg a.i/ha), simazine (1.0 kg a.i/ha) and terbacil (0.96 kg a.i/ha) all caused some injury to direct sown and transplanted dahlias, and can not therefore be used safely on the dahlia crop. Of the pre-emergence herbicides, alachlor (1.92 kg a.i/ha), chlorpropham (3.2 kg a.i/ha), chlorthal-dimethyl (7.5 kg a.i/ha), pendimethalin (1.32 kg a.i/ha) and trifluralin (1.2 kg a.i/ha) did not injure either direct-sown or transplanted plants. Methabenzthiazuron (1.05 kg a.i/ha) did inhibit the early growth of direct sown dahlia, but plants recovered very quickly. All five herbicides could be used as pre-emergence herbicides for dahlia, but on a cost and weed control spectrum basis, alachlor or trifluralin are recommended. Terbacil (0.96 kg a.i/ha), while not affecting transplanted seedlings did damage direct sown dahlia, and should only be used as a pre-emergence herbicide in transplanted dahlia.

From the post-emergence herbicides, chlorpropham (3.2 kg a.i/ha) did not injure either direct-sown or transplanted dahlia. Chlorthal-dimethyl (7.5 kg a.i/ha), haloxyfop (0.3 kg a.i/ha), and methabenzthiazuron (1.05 kg a.i/ha) caused some plant injury to early

growth of direct-sown seedlings, but injured plants recovered quickly. Therefore, these herbicides can be recommended for both direct-sown and transplanted dahlia when applied post-emergence. Of these, the cheapest is methabenzthiazuron, and on this basis it is recommended for use in dahlia post-emergence.

Method of establishment (transplanted seedlings or tubers) did not affect seed yield. Of five plant densities (0.8, 0.6, 0.4, 0.3 and 0.2 m square spacings), seed yield per square meter from a harvest when 80% of the seedheads had turned brown was greatest from the 0.4 m square spacing (12.3 g/m^2). However, when seedheads were harvested as they ripened (i.e. over several weeks), the highest yield was at the 0.3 m square spacing (15.97 g/m^2). Individual plant yield was highest (4.49 g/plant) at the lowest density (0.8 m square spacing), and the lowest (0.105 g/plant) at the highest density (0.2 m square spacing). Seedheads per plant contributed most to the differences, as more branches per plant at lower densities produced more seedheads per plant. Seed weight was slightly bigger at lower densities, while seed number per seedhead was greater at higher densities than at lower densities.

The feasibility of direct seed sowing for dahlia seed production was confirmed in Palmerston North, New Zealand. Sowing dates from 7 November to 5 December did not produce any difference in seed yield and yield components. However, a 19 December sowing produced a significantly lower seed yield per plant, seedheads per plant and thousand seed weight. Later sowing delayed flowering time, shortened flowering duration and made seedheads ripen later. All sowing were harvested after frosts, and the seedheads in the latest sowing were very immature when harvested. In this environment, seed showed not be sown later than 7 November.

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GENERAL INTRODUCTION

The production of flower seed is an important part of the seed industry (Leslie and Leonard, 1954). However, the history of commercial flower seed production only goes back to the second half of the last century when seed companies in Germany, France, UK, and later in the Netherlands, started the growing and marketing of some flower seed species, in addition to their production and commercialisation of vegetable seed. The major expansion occurred in the 1930s (Vis, 1980), but always in the regions with the most suitable climate and soil conditions for particular species. Today, flower seeds are grown commercially in many different countries (Vis, 1980).

Flower seed production presents a number of problems not encountered by other crop seed growers. One of the big differences is that with many flower-seed crops, the quantity of seed required to satisfy the market demand is much less than the amount normally produced of even some minor vegetable crops. In some instances a few rows or a small block is sufficient. It may not be necessary to produce every flower item each year; instead it may be more feasible, in those crops which retain their viability over a fairly long period, to grow enough seed one year to last for several years (Leslie and Leonard, 1954).

Seed yields per unit area for many species are quite low and hand-labour requirements are high. With some crops the total amount of seed handled is so small that the use of seed cleaning machines is impractical (Leslie and Leonard, 1954). The entire supply of certain items which a company produces may be no more than several kilograms, as commercial plantings of certain flower seeds are often less than one third of a hectare in size (Leslie and Leonard, 1954). Also, some flower seeds are so minute that they need to be cleaned by special methods. The industry as a whole has found that the growing of flower seed is frequently more exacting and expensive than is the growing of other crop seeds (Leslie and Leonard, 1954).

Since the turn of this century, the development of new flower varieties has been an important phase of the flower seedsman's business. By breeding and selection it has been possible to develop new attractive forms and colours of many flowers, and so increase the market demand for them (Leslie and Leonard, 1954).

Dahlias are popular in many parts of the world and used as garden plants, for borders, back ground exhibitions, and as cut flowers, bedding and potted plants because of their remarkable diversity of form, colour and size (Mastalerz, 1976; Phetpradap[1], 1992; De Hertogh and Le Nard, 1993). In Colombia, flower exports only began in the late 1960s, but by 1979, dahlia was 21% of export production (Palacios et al, 1979). The Netherlands is a major producer of tuberous-rooted dahlias. It produced 368 hectares in 1989. Japan produced 24 hectares in 1987 and France produced 55 hectares in 1990. Other countries such as Great Britain, Italy, South Africa, United States, and Germany also produced dahlias, but no areas were reported (De Hertogh and Le Nard, 1993).

Dahlia can be propagated by tuberous roots, plant cuttings or seeds to grow as bedding plants, garden plants, and cut flowers (Brondum and Heins, 1993). However, few dahlia producers appear to produce dahlia seeds commercially, even though seed propagation may be the cheapest option.

Little information exists for dahlia seed production. As for any seed production, agronomic management for flower seed production is also mainly related to plant density, fertilizer, weed control, pest and disease control and harvest. Flower seed production is more costly than field crop seed production, and the cost and labour expended on an inferior seed lot are almost equal to those expended on a good lot (Vis, 1980). More than 40% of the cost can be for field labour (Bodger, 1961). When or if the market growth slows, the key to profit will be volume sales and cost efficiency, rather than increasing price (Voigt, 1994). Thus, any technology which reduces energy consumption and labour costs, while maintaining higher productivity, has become the first priority. Many papers have been published on the production of agricultural and horticultural seeds, but comparatively few on flower seeds, due to the highly competitive nature of this business (Phetpradap[1], 1992), and the small size of commercial production.

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[1] refers S. Phetpradap

Weeds are always a problem for crop production. They can smother crops reducing yields (Vis, 1980). Traditionally, for flower seed crops, weed control has been a highly labour intensive operation because it often was by non-chemical methods (Stephens, 1982). Chemical weed control is now playing an important role (Vis, 1980) and may reduce the cost of weed control. However, 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).

The potential herbicide damage to crops strongly concerns farmers. "If we think we are going to damage the crop by spraying, we don't. If we feel the conditions are not correct for a chemical to work, we don't. If we feel we have to apply a herbicide that may damage the crop to the detriment of yield, just to make the crop look pretty, we try not." said Forsyth (1983). Therefore, it is not sufficient to carry out trials which demonstrate that by removing weed populations crop yields are increased. Such results could well hide an adverse effect of the herbicide on the crop, which would be manifest if weeds were absent or at such low numbers that the presence of the weeds was not affecting crop yields (Caldicott, 1983). Also, in many cases a reasonably low weed density does not require any herbicide at all in terms of return of value in crop yield (Scarr, 1983).

Although the manufacturers have described which herbicides can kill what weeds, it is still difficult to determine whether herbicides can be used on a specific species under certain conditions without damaging crops. Few papers have been published on herbicide application to dahlia, perhaps due to the highly competitive nature of this business, or probably because the industry is too small to attract this type of work.

This project concentrates on some of factors which affect the commercial production of dahlia seeds. Although some aspects of the agronomic management of dahlia have been studied by previous researchers, there is little information about the production of dahlia seed on a commercial scale. There are many agronomic management gaps for commercial dahlia seed production. For instance, plant density is a very important factor affecting seed yield and quality, but there is limited information on the effects of density on dahlia seed production. Conventionally, dahlias are grown from stem cuttings and tuber division to produce cut flowers, bedding and garden plants, and seeds, which are relatively expensive methods compared with growing from seeds. But few growers grow dahlia from seeds or seedlings. Herbicides, as a primary method for controlling weeds are available for many crops. Very little information, however, exists about their application for dahlias. Therefore the research objectives were:

1. To determine the effect of plant density on dahlia seed yield in both tuber to seed and seedling to seed production systems.
2 To determine the optimum sowing date for seed production in the Manawatu environment in a direct sowing system.
3. To determine whether selective herbicides are toxic to dahlia plants when grown under transplanted seedlings-to-seed, and seed-to-seed systems, and to therefore determine which herbicides are potentially usable for dahlia seed production.

CHAPTER 1

LITERATURE REVIEW

1.1 General background

Dahlias are a member of the family Compositae/Asteraceae and native of the highlands (1500-4300 meters) of Mexico, Central America (Rünger and Cockshull, 1985; De Hertogh and Le Nard, 1993), and South America (Potter, 1965). 'Dahlia' was named after Andreas Dahl (an eminent Swedish botanist living in Berlin, who had been a pupil of the great Linnaeus) by Antonio Jose Cavanilles, Director of the Royal Garden in Madrid (Emasweller et al, 1937; Hammett, 1980; Phetpradap[1], 1992).

Dahlias were first introduced to Spain in 1789, entered England at the end of the eighteenth century, and then spread to other countries in the western hemisphere (Salunkhe et al, 1987). They have been popular bedding and garden plants in many parts of the world for many years (Rünger and Cockshull, 1985; Brondum and Heins, 1993). In the 1970s, garden dahlias were recommended as a commercial cut flower crop due to their wide range of flower size, form, and colour (Mastalerz, 1976). Dahlia are now field grown for cut-flower production in Europe, Japan, and North America (Rünger and Cockshull, 1985). Some cultivars are forced for use as potted plants for spring markets (De Hertogh and Le Nard, 1993).

Bedding plants sales have kept increasing in the U.S.A. since the 1970s, with market shares of the sale pie being 13.5% in 1970, 18.7% in 1979 and 36.2% in 1988. In 1992, for 36 states in the U.S.A, the bedding plants' share was 40.4% (Table 1.1). Among those bedding plants (including flowering and vegetable bedding plants), dahlia occupied 1% in 1988 and 1991, and 1.6% in 1992 (Voigt, 1994). Apart from uses as a flower crop, other uses of dahlia have also been studied by some researchers. Dahlia tubers contain significant amounts of inulin and fructose and small quantities of medicinally active compounds such as phytin and benzoic acid. They have been used as medicine and food in South America from the sixteenth century to the present day, and could be a potential root crop (Whitley, 1985). Dahlia seed contains more than 16%

oil. The defatted seed meals from dahlia are rich in protein(20.9-47.1%), and therefore dahlia could also be a source of oil and fat (Nigam et al, 1992).

Table 1.1 Bedding plants' percentage market share in the U.S.

	1970	1979	1988	1992*
Bedding plants	13.5	18.7	36.2	40.4
Cut flowers	50.5	23.3	20.5	16.7
Foliage	8.4	30.6	19.6	15.5
Pot flowers	27.6	27.4	23.7	27.4
Totals	100	100	100	100

* Including only 32 states in the U.S. (Voigt, 1994).

1.2 Botanical description of dahlia

The dahlia genus consists of 29 species (Redgrove, 1991). It is a perennial, herbaceous plant. The aerial plant parts die each winter and in favourable climates are replaced by new growth from ground level each spring. In less favourable climates the dahlia is mainly treated as an annual (Hammett, 1980). It is an herbaceous plant with a tuberous root system which supports stout, erect, branched stems bearing pinnate leaves in opposite pairs and a terminal, brightly coloured, capitate inflorescence.

1.3 Floral morphology

As with other members of the Compositae, such as Chrysanthemum, the individual inflorescence of dahlia is a raceme while the flowering shoot as a whole is a cyme, with the oldest inflorescence terminating in the growth of the main shoot (Rünger and Cockshull, 1985). Each dahlia 'flower' is a capitulum inflorescence which consists of a swollen receptacle carrying a few hundred florets. The head is surrounded by involucral bracts and the outer layer reflexes during the later stages of flower bud development. The florets are generally of two types, though intermediate types and other variants do occur, and each floret arises in the axil of a receptacular bract. The outer ray florets (the outermost florets) are either pistillate or nonfunctional and the corolla is extended on one side to form a coloured tongue or ligule, while the central disc florets are hermaphrodite and the symmetrical corolla is divided into five teeth (Rünger and Cockshull, 1985). The total number of florets formed on each capitulum varies between cultivars as does the proportion of ray to disc florets. The fruits are achenes (Rünger and Cockshull, 1985).

Each flowering stem normally produces a central terminal bud and two ancillary lateral buds (Hammett, 1980). There also appears to be a basipetal gradient of increasing incompetence along the shoot axis, so that axillary buds near the shoot apex flower earlier and with fewer leaves than those near the base (Phetpradap[1], 1992). The inflorescence can be loosely classified as 'single' and 'double'. In a 'single' flower, there is only an outer ring of coloured, showy florets which surrounds a central disc of smaller, yellow florets, while in the double flower, the coloured florets predominate. When more than one row of ray florets occurs, even the central disc remains visible, and it could be considered as a semi-double flower (Hammett, 1980).

The florets around the edge of the receptacle of the dahlia inflorescence develop earlier than those at the centre. Pollen is shed first by the outermost florets of the disc (Hammett, 1980).

1.4 Propagation:

Dahlias can be propagated by tuber root division, stem cuttings and seeds.

Tuber root division: Old clumps are divided in spring when the growth roots fatten and become prominent on the neck of the plant where the enlarged roots join the old stem; each root is cut from the clump with a small portion of the old stem attached. Each must have at least one healthy, undamaged bud; 'blind' roots are discarded. This method is used when a few plants of true stock are required (Rowell, 1986). Dahlias grown from tubers are larger than the seed grown annual types and can reach heights of 150 cm (Still, 1982).

Stem cuttings: Dahlias can be grown from cuttings of new shoots taken early in the growing season. Such cuttings will flower and produce good-sized tubers in their first season (Hobbs and Hatch, 1994). Stem cuttings are regarded as the best method for prize plants and are also used commercially as this enables growers to multiply dahlias most freely (Potter, 1965; Eliovson, 1967). This method is used to produce large quantities of true stock and is often preferred by exhibition growers who claim they produce better flowers than by other means (Rowell, 1986). The tall dahlias which are normally double-flowered types and grown for cut flower purposes have to be propagated vegetatively (mainly by stem cuttings) because plants of the double forms raised from seeds will produced a proportion of single and semi-double types in addition to double blooms (Hammett, 1980).

Seeds: Seed is a relatively simple method of increasing many species, although hybrids may result where different species are grown together. One advantage of bulbs raised from seed is that they are free from virus disease (Hobbs and Hatch, 1994). Propagation by seed is used by those who want to produce quantities of dahlias without particularly caring about their special qualities (Eliovson, 1967), and it is also used by hybridists seeking new cultivars (Rowell, 1986). Dahlia can be in flower the same year as the seed is sown, which is an advantage compared to other bulb flowers (Bryan, 1989). Therefore, the dwarf bedding dahlias which may be single, double or semi-double flowered, like Coltness and Unwin hybrids, are sown generally as annuals and the tubers customarily discarded (Eliovson, 1967) because it is the best and easiest way for bedding flowers with mixed colours (Ball, 1985).

1.5 Photoperiodic response

Dahlias are daylength sensitive. Daylength is the environmental signal regulating flower initiation in dahlias. Flower buds are initiated when the daylength is shorter than 14 hours; most cultivars or cultivated varieties remain vegetative at daylengths longer than 16 hours (Mastalerz, 1976). The optimum day length for inflorescence formation may be as long as 12 to 14 hours (Rünger and Cockshull, 1985). Short days reduce the total number of florets formed and increase the proportion of disc florets. In very short (8 hours) or long daylengths (over 16 hours), the development to anthesis tends to be delayed or even arrested. Daylength has not only a direct influence on flowering but also an indirect one through its effects on vegetative growth, dormancy, and tuber formation. In daylengths of 12 hours or less, shoot extension is inhibited, growth in weight of leaves and stems is greatly reduced, axillary buds become dormant and fail to sprout, and few side shoots are produced (Konishi and Inaba, 1967). In addition, tuber formation is promoted by short days and the presence of tubers can also affect the dormancy of axillary buds and the speed with which they initiate flowers (Konishi and Inaba, 1966).

1.6 Crop management

1.6.1 Light intensity

Light intensity can influence dahlia vegetative growth. Strong sunshine may inhibit dahlia vegetative growth. For instance, the number of shoots was reduced in 100% natural light intensity when compared to either 70% or 50% levels (Durso and De Hertogh, 1977). Internode length of dahlia stock plants increased when grown under 50% and 28% light levels in Israel (Biran and Halevy, 1973). Plant height was increased by 50% and 75% natural light (Durso and De Hertogh, 1977).

1.6.2 Temperature

Seed-grown dahlias are not very heat tolerant (Still, 1982). Temperature is an important environmental factor influencing flowering. Night temperatures between 10 to 26.7°C do not affect flower initiation, but flower development proceeds more slowly at the lower temperatures, giving rise to later flowering. Flowering is further delayed at night temperatures of 5°C as compared with either 10 or 15°C, and the date of anthesis of the first flower became later as both the day and night temperatures were lowered from 29°C day/20°C night to 24°C day/12°C night (Rünger and Cockshull, 1985). Durso and De Hertogh (1977) reported that dahlia responds to temperature by producing shorter plants at higher temperature. Also more flowers are formed at 5°C than at 15°C night temperature (Konishi and Inaba, 1966).

Temperature can also influence tuber dormancy. More than 40 days at a temperature of 0°C, means that the dormancy of tubers will be broken and they can sprout (Rünger and Cockshull, 1985).

1.6.3 Soil and fertility

The soil requirements of flower crops grown for seed vary little from those for the same crops when grown for market. Heavier soils, such as clay loams, usually have a higher natural fertility than the lighter soils; it is often preferable to grow seed crops on them if other factors affecting growth are satisfactory (Leslie and Leonard, 1954). However, with some crops, very rich soil may stimulate vegetative growth and plants may fail to flower or produce seed normally (Leslie and Leonard, 1954). While dahlias can be grown on a wide variety of soils (Phetpradap, 1992), they prefer well drained, moist soil (Still, 1982). The soil pH should be around 6.5, and the soil should be rich in humus, phosphorous and potassium (Hammett, 1980; Bodley, 1981). In a field trial, plant growth, number of flowers, flower size and flower longevity were best with the highest NP rates (Bhattacharjee and Mukherjee, 1983). Jana (1974) also considered that N and P deficiencies reduced plant height. Branching and flowering were increased by high N and suppressed by low N. Low P affected flower number and size adversely, and low K also reduced flowering (Jana, et al., 1974).

However it was also reported that while high levels of nitrogen promote the earlier flowering of dahlia, other nutrients are not apparently involved directly in the control of flowering (Rünger and Cockshull, 1985).

1.6.4 Sowing date

Many seeds require a period of cold, as they receive in the wild. The need to undergo a period of cold to break dormancy ensures germination in the spring, producing growth and the gaining of strength to survive the first winter after germination (Bryan, 1989).

Dahlia seeds can be sown from spring to early summer (Bodman and Hughes, 1986). In India, dahlia seeds germinated in 3-4 days between 15 July and 15 September and in 6-12 days between 15 November and 15 December. Although some seeds germinated in 18 days during January, none of the seedlings survived. None of the seeds which germinated in the period between February and June survived due to high temperatures and low humidities. Normal growth of seedlings raised during July to October and seedling height and leaf number per plant were greatest from sowing in July. Seed yield was highest (0.52 g per plant) from sowing on 14 September (Samant and Das, 1990).

In the USA, dahlias (cultivars Redskin and Verdi) were sown at intervals between December and May. Armitage (1983) found the time between sowing and first visible bud, and between first visible bud and anthesis decreased with later sowing dates. The total flowering time of photoperiodic species was influenced by increasing photoperiods during winter and spring production (Armitage, 1983).

In Korea, seeds of dahlia were sown at monthly intervals from February to July. It was found that the later the sowing date the shorter was the time required before the first flowers were produced, but late sowing resulted in a shorter duration of flowering. Dahlia hybrids were tolerant of the high summer temperatures and RH characteristics of Korea and flowered over a long period, even with the latest sowings (Hong and Jeong, 1988).

1.6.5 Density

Density is always of primary importance in seed production because it will influence crop micro-environment and seed yield components which determine seed yield.

Information on dahlia density studies is very limited. Reilly (1978) stated dahlia could be sown at a plant spacing of 30-90 cm apart. Fifty and 30 cm square spacings was used by Phetpradap[1] (1992). However, tall and dwarf cultivars were used at 50 and 30 cm spacing respectively, it is difficult to determine which density was better.

Some other members of the *Asteraceae* have been studied by some previous researchers. In China aster, increasing plant density decreased seed yield per plant due to decreases in seedhead number per plant, seed number per seedhead and seed weight (Phetpradap[2], 1992). However, at a density range of 4.2 to 44.7 plants per square meter, the highest seed yield per square meter occurred at a density of 27.8 plants per square meter for cv. Kruenai and 17.4 plants per square meter for cv. Powderpuff, but these yields did not differ significantly from those over a wider range of densities (12.7 to 44.7 plants per square meter) due to a high ability for compensatory reproductive growth (Phetpradap[2], 1992).

In sunflower, although density had no effect on rate or duration of dry matter accumulation in the seed, it affected seed yield and yield components (Almeida *et al* 1994). Number of achenes per head and 1000 achene weight were lower at higher density (50,000 plants per hectare) than at lower density (25,000 plants per hectare), but achene yield per hectare was higher at higher density (Silva and Schmidt, 1986).

Thirty and 40 cm square spacings of African marigold (*Tagetes erecta* L) were studied by Chanda and Roychoudhury (1991). Plant height, number of primary branches, number of flowers and flower yield per plant were higher at a 40 cm square spacing, but a higher flower yield per hectare was obtained at a 30 cm square spacing. However, no seed yield data were reported.

1.6.6 Diseases and insects:

Botrytis blight, powdery mildew, stem rot, aphids, leafhoppers, thrips and mites can all occur in dahlia (Still, 1982). Like other compositae family species, the dahlia seed head can retain high humidity. Therefore, the seed head gives a perfect environment for fungal disease if it suffers wet weather conditions for too long a period, causing

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[2] refers to L. Phetpradap

deterioration in seed quality (Vis, 1980). Fungi such as *Botrytis* spp. not only affect the seed growing on the mother plant, but the seed-borne fungus will affect seed germination and viability as well.

1.6.7 Pollination

Some studies have indicated that seed yields of insect-pollinated crops may often be lower than they need be, not because of climatic, soil, or cultural factors, but simply because the population of certain essential insects is low (Leslie and Leonard, 1954). The level of pollinating insect activity in an anemophilous species grown as a seed crop will have a direct effect on seed yield (George, 1985; Guen *et al,* 1992). Therefore, enough insects such as honeybees and bumblebees will be important to ensure high seed yield of dahlia.

1.6.8 Harvest

Harvesting is the last stage of seed production and is one in which many mistakes can be made, leading to spoiling of the seed quality and reduction or complete loss of yield. This is at a time when much money has already been spent (Vis, 1980). Ample sunshine, relatively low rainfall and the absence of strong winds have a decided advantage during the harvesting of seed. As the seed crop approaches maturity it becomes increasingly susceptible to shattering. Strong winds and heavy rainfall at or near harvest-time may cause large losses of seed, particularly in crops which have a tendency to shatter their seed readily (FAO, 1961).

Therefore, it is of great importance to harvest a seed crop at the time that will allow both the greatest yield and the best quality seed (FAO, 1961). The losses from harvesting immature seed crops are shown in smaller seed yields and a reduction in seed quality (FAO, 1961). Because of the diversity of seed maturation in dahlia, optimum harvest time is difficult to judge (Phetpradap[1], 1992). At Massey University, Phetpradap[1] (1992) found that seedheads needed around 33 days from the first flower opening to reach seed physiological maturity, and seed could remain in the seedhead for a further 9 days before shedding began. The optimum harvest time was between 33-42 days after first flowering (or 120-129 days after sowing), because during this time the maximum number of mature seedheads was recorded, seeds had reached full viability, and seed shedding had not begun.

The methods of harvesting dry seeds include cutting off individual seed heads; cutting the majority of the plant and leaving the material in windrows to dry further before the seed is extracted; or the use of a combine harvester which extracts the seed from the seedheads and separates it from the remainder of the plant debris in one operation (George, 1985). Combines are now widely used for seed harvesting due to lower harvesting costs and labour requirements (FAO, 1961). In respect of seed quality, manual harvesting is still in many cases the best method, but due to high labour costs there is an ever increasing tendency to mechanical methods (Vis, 1980). However, hand harvesting and threshing are still done for very high value seeds, when the total area to be harvested is very small or in areas where adequate hand labour is available (George, 1985). Also, hand harvesting and threshing are a relatively cheap method for small seed-lots (George, 1985).

Desiccants, such as diquat, facilitate mechanical harvesting of seed by reducing the amount of plant debris, increasing the rate of seed drying, bringing all the seed material to a closer range of moisture content, and avoiding loss from windrows (George, 1985). A desiccant could be used to make dahlia ripen relatively uniformly (Phetpradap[1], 1992) no matter whether machine harvest or hand picking harvest is the harvest method.

According to Phetpradap[1] (1992), dahlia seed harvest should be timed to coincide with the date on which 80% or more of the seedheads have turned brown. This occurred from 43-51 days after peak flowering at Massey University. But some (10% of the population) of the early heads had begun to shatter at this time.

1.6.9 Yield components

Yield is a complex character determined by several interacting components (Graf and

Rowland, 1987). The primary components of yield could be considered to be seed weight, number of seeds per seedhead and number of seedheads per plant (Graf and Rowland, 1987). In dahlia, seed yield was most strongly related to seedhead number rather than seed number or weight, and thus the uniformity of seedhead maturation is important for a high yield of quality seed (Phetpradap[1], 1992).

1.7 Weed control and herbicides

1.7.1 Weed control

Weeds are undesirable in any crop but particularly so in a seed crop. Weeds not only compete with the crop for moisture and nutrients, but many of their seeds are likely to be harvested, along with those of the crop being grown, in spite of all the precautions which may be taken at harvest time. Once weed seeds are mixed with the flower seed crop, they have to be separated before the crop can be offered for sale. Although there are many ingenious machines available today to separate one kind of seed from another, few, if any, separations can be made without some loss. Care thus needs to be taken when growing seed crops to keep the weed growth down to a minimum (Leslie and Leonard, 1954).

Weed control is often most difficult in crops which are in flower or which have already set seed (Leslie and Leonard, 1954). Herbicides are widely used around the world now, but the result does not depend only on the chemical per se, but also on the time or method of its application (Leslie and Leonard, 1954). There are not many herbicides that increase yield in a zero weed situation and the majority would depress yield to some extent or other, depending on the conditions at application (Forsyth, 1983).

It is often the case that the potential for a chemical to cause crop damage is only manifest under certain conditions. In a crop growing under optimum conditions of soil, weather and fertilization, adverse effects of a chemical may not be seen (Caldicott, 1983).

1.7.2 Information about herbicides used in the experiment

A wide range of literature was reviewed to find some potentially useable herbicides for dahlias. However, very few articles were found to be directly related to the use of herbicides on dahlias or some species close to dahlia. Furthermore, the results may differ with changing of planting methods, medium and application rate. Therefore, the herbicides chosen here are commonly available, and have been used either on dahlias or on some species close to dahlias by previous researchers.

Alachlor: used for selective pre-emergence weed control in maize, sweetcorn, soyabean, onion, kumara, squash, pumpkin and transplanted cabbage, cauliflower and Brussels sprout. It provides 6-8 weeks residual control of many annual grasses and some broadleaf weeds. Alachlor is taken up by the shoots of germinating seeds, interfering with protein formation and plant growth. Alachlor remains active in the soil until it is broken down by microbial action 6-8 weeks after application (Walton and Walton, 1993).

It is safe on aster, carnation, chrysanthemum, gypsophila, helichrysum, zinnia, poppy, statice and stock at rates of 1.125 and 2.25 kg a.i/ha, but not on direct transplanted seedlings of gypsophila, stock, and zinnia (Lamont, 1986). However, it stunted the growth of poppies when used at higher rates (Lamont, 1986). Lamont (1986) also found that alachlor affected the germination and early growth of direct-seeded aster, calendula and helichrysum at rates of 1.125 and 2.25 kg a.i/ha, but it was safe on transplanted aster, carnation, chrysanthemum, gypsophila, helichrysum, poppy, statice and stock. However, Phetpradap[2] (1992) reported that alachlor caused china aster leaf necrosis in seedlings at a rate of 1.125 kg a.i/ha, but no effects on new shoot growth or the flower head. Laureti (1986) reported that it performed well in sunflower. Alachlor was also very efficient in controlling weeds in sunflower when applied 15-20 days before sowing (Peric, 1986).

Chlorpropham: a pre- and post-emergence herbicide for use in onions and lettuce, and pre-emergence in daffodils, tulips, leeks, carrots, parsnips, lucerne and deciduous nursery stock. Where possible it should be applied when rain is expected, or otherwise irrigation is required. Lower rates should be used on light sandy or silty soils and higher rates on clay loams and peat. It is taken up by the emerging shoots of seedlings and through the roots of older plants and translocated in an upward movement from root and foliar uptake. It disrupts cell division, respiration, transpiration and protein synthesis. The recommended use in lettuce is for 1.2-3.2 kg a.i/ha applied immediately after sowing, or 2.4-4.4 kg a.i/ha applied to freshly cultivated land immediately prior to transplanting. Soil disturbance must be kept to a minimum during planting. After applying, 15 mm rain or irrigation is needed (Walton and Walton, 1993).

Chlorthal dimethyl: a selective herbicide for the control of annual grasses and many broadleaf weeds in onion, forest nurseries and ornamentals. It will provide 2-3 months residual action. It is almost entirely root absorbed with little or no contact action and effective only on germinating seedings (Walton and Walton, 1993). The recommended use for ornamental and container grown plants is 7.5-10 kg a.i/ha, but lower rates should be used in light soils and higher rates for loams or clay soils.

Lamont (1986) reported that it was safe on germination and early growth of aster and calendula at rates of 7.5 and 15 kg a.i/ha, but not on gypsophila and helichrysum. It was safe on transplanted aster, carnation, chrysanthemum, helichrysum, zinnia, poppy, statice, and sweet william but not gypsophila.

EPTC: an incorporated pre-plant herbicide for selective weed control in maize, sweetcorn, potatoes, lucerne and green beans. It controls many annual grasses, some perennials such as couch, and some broadleaf weeds. It will not control established weeds. It must be incorporated into the soil immediately after application to avoid loss by volatilisation. It is absorbed by roots of seedling plants and translocated to the leaves and stems to inhibit cell division at growing points. It also inhibits the development from underground portions of some perennial seeds (Walton and Walton, 1993). It was successfully used in sunflower (Tei, 1986; Konstantinovic, et al, 1986).

Oxadiazon: for the control of grass and broadleaf weeds in stonefruits, brambles, raspberries, bushfruits, vineyards, shelterbelts and woody ornamentals. It is primarily a pre-emergence herbicide and should be applied to bare, moist, clod free soil. It forms a film on the soil surface which should not be disturbed by cultivation. If soils become very dry and open, pre-emergence activity will be reduced. It is very crop safe as it fixes to the soil surface and is almost resistant to leaching. Under favourable conditions the recommended use rate will provide weed control for 3 months. It is a surface acting residual herbicide which is absorbed by the emerging shoots of weeds, preventing further development above the soil surface. It is strongly fixed on to soil colloids to resist leaching -- its solubility in water is 0.7 ppm. At application rates of 2.0 and 4.4 kg a.i/ha, oxadiazon was safe on transplanted aster, carnation, chrysanthemum and gypsophila and direct-seeded gypsophila (Lamont, 1986). Also, it was safely used in sunflower (Favier, 1986). At rates of 2 and 4 kg a.i/ha, it was also safe on transplanted aster, carnation, chrysanthemum and gypsophila, but not on their germination and early growth (Lamont, 1986). In potted dahlia (with clay loam soil, plaster sand and sphagnum peat, 1:1:2 by vol), it controlled more than 99% of weeds at 4.5 and 9.0 kg a.i/ha without damaging crops (Staats and Klett, 1993).

Haloxyfop: selectively controls grasses in white clover, forestry, orchards, nurseries, non crop areas and in certain broadleaf crops. Low rates are recommended for seedling plants or actively regenerating rhizomes after cultivation, but higher rates are needed for tillering plants or on established sod bound rhizomatous grasses.

Oxyfluorfen: controls a wide range of broadleaf weeds and some annual grasses in apples, stonefruit and grapevines. It is a contact herbicide with medium-long residual life in soils low in organic matter. Soil life is greatest when applied to bare or near bare moist soil. To be effective as a residual treatment it must cover the soil surface in an uninterrupted layer. It is nearly insoluble in water. It is a contact herbicide with greatest activity when applied before weed emergence. It also has post-emergence activity, but to be effective weeds must be very small. The chemical is taken up by the emerging shoot and is activated in the presence of light. It is important to have an uninterrupted layer of chemical on the soil surface. Its solubility in water is 0.1 ppm (Walton 1993). Oxyfluorfen is very toxic to sunflowers and other crops (Dhanapal, 1987).

Lamont (1986) found that it affected germination and early growth of aster, gypsophila, helichrysum and zinnia, as well as causing severe scorching followed by death or stunted growth on their transplants, but it was safe for carnation transplants.

As a pre-emergence herbicide, oxyfluorfen controlled weeds in sunflower (Horvath, 1993), but safety on sunflower was not reported. At 3.4 and 6.8 kg a.i/ha. in the form of a granule, it was safely used in dahlia in containers with clay loam soil, plaster sand and sphagnum peat (1:1:2 by vol) and controlled more than 99% of the weeds (Staats and Klett, 1993).

Simazine: a selective pre-emergence herbicide for weed control in lucerne, orchards, vineyards, forestry and certain horticultural crops. It is very effective in preventing the emergence of a wide range of annual and perennial grasses and broadleaf weeds. The soil residual life ranges from 3-12 months depending on rate, soil type and rainfall. It has little or no activity on existing vegetation. It is absorbed only through the roots of plants as they germinate, with symptoms of yellowing then death. Its solubility in water is 5 ppm (Walton and Walton, 1993). Phetpradap[2] (1992) discovered that simazine killed 24 and 44 day old china aster seedlings in a glasshouse experiment.

Terbacil: a broad spectrum herbicide for weed control in apples, peaches, raspberries and bramble. It is best applied in spring before or shortly after seed emergence. Moisture is necessary to activate the chemical and best results will be obtained where rainfall or irrigation occurs within 2 weeks after application. It is not recommended on light soils or soils low in organic matter. The main activity is from root uptake through the soil but it also possesses moderate foliar activity. The greatest effect is against germinating seedling weeds. Its solubility in water is 710 ppm, and it is therefore leached in high rainfall areas.

Pendimethalin: a selective herbicide for the control of annual grasses and broadleaf weeds in maize, onions, peas, carrots, transplanted lettuce and certain fruit crops. Effectiveness will be reduced where soil organic matter exceeds 6%, or no rain falls within 7-10 day of application. It is absorbed by roots and shoots and inhibits growth processes relating to cell division and elongation. The affected plants die shortly after germination or following emergence from the soil (Walton and Walton, 1993).

Oryzalin: a selective pre-emergence surface applied herbicide for the control of most annual grasses and certain broadleaf weeds. It is safe for use in kiwi fruit, grape vines, fruit trees and shelter species. Oryzalin is taken up by the roots of germinating weeds. It does not control established vegetation. Solubility in water is 2.5 ppm (Walton and Walton, 1993). It was safe on transplanted calendula, poppy, statice, sweet william and wallflower but not on direct-seeded species, at rates of 2.25 and 4.5 kg a.i/ha (Lamont, 1986). At a rate of 3 kg a.i/ha, it lowered china aster seedling emergence if applied 4 days after the direct sowing of seeds (Phetpradap[2], 1992). And at 2.3 and 4.6 kg a.i/ha, and even 6.8 kg a.i/ha, it safely gave 92% and 95%, or 99% weed control in dahlia in a container of clay loam soil, plaster sand and sphagnum peat (1:1:2 by vol) (Staats and Klett, 1993).

Trifluralin: a pre-plant incorporated herbicide for selective weed control in many crops including barley, peas, oilseed rape, lucerne, linseed, French beans and many other vegetable crops. It also controls a wide range of annual grass and broadleaf weeds as they germinate. It is taken up by emerging roots of susceptible species as the seedlings germinate (Walton and Walton, 1993). This chemical at a rate of 4.5 and 9.0 kg a.i/ha gave 88% and 96% weed control without damaging dahlia in a container of clay loam soil, plaster sand and sphagnum peat (1:1:2 by vol) (Staats and Klett, 1993). It also has been used for weed control in sunflowers (Favier, 1986).

Methabenzthiazuron: a selective herbicide for broadleaf weed control in asparagus, garlic, leeks, onions, peas, potatoes and wheat. It provides knockdown plus soil residual action to control later germinating weeds. For post-emergence use best results are obtained from applications made to actively growing young weeds. It is absorbed through foliage and roots. It has a soil residual life to control subsequent weed germinations. Its solubility in water is 59+ ppm.

CHAPTER 2
HERBICIDE TRIAL

2.1 Introduction

Weeds are undesirable in any crop, but particularly so in seed crops where weed seeds are an adulteration following harvest. Weeds not only compete with the crop for moisture and nutrients (Vis, 1980), but many of their seeds are likely to be harvested, along with those of the crop being grown, despite all the precautions which may be taken to prevent this at harvest time. Once weed seeds are mixed with the flower seed crop, they have to be removed before the crop can be offered for sale (Leslie and Leonard, 1954). Although there are many ingenious machines available today to separate one kind of seed from another, few, if any, separate impurities without also causing some loss of crop seeds. Care thus needs to be taken when growing seed crops to keep weed growth to a minimum (Leslie and Leonard, 1954).

Weed control is often most difficult in crops which are in flower or which have already set seed (Leslie and Leonard, 1954). This suggests that early weed control should be carried out. Traditionally, weed control has been a highly work intensive operation in crop production (Stephens, 1982). There is a possibility that the chemical control of weeds may ultimately be the solution to this difficulty in some crops. The effectiveness of chemical weed control depends on the chemical used and on the time or method of its application (Leslie and Leonard, 1954). The choice of herbicides 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).

Although chemical herbicide manufacturers have defined which herbicides can be used to kill which weeds, it is still often difficult to determine which herbicides can be used on specific crop species under certain conditions without causing crop damage.

Often, the potential for a chemical to cause crop damage is only manifest under certain conditions. In a crop growing under optimum conditions of soil, weather and fertilization, adverse effects of a chemical may not be seen (Caldicott, 1983).

Although some herbicides have been successfully used in bedding flowers, such as alachlor, chlorthal-dimethyl, EPTC, oxyfluorfen, oryzalin, oxadiazon, simazine, pendimethalin, trifluralin (Fretz, 1976; Kuhns and Haramaki, 1985; Lamont, 1985, 1986; Phetpradap[2], 1992), only a few have been evaluated specifically for use in dahlia (Lamont, 1986; Staats and Klett, 1993).

The purpose of the present study was to determine which herbicides are safe for application to dahlia crops and to specifically determine the effects of toxicity of herbicides on dahlia plants grown either from transplanted seedlings or from direct sown seed.

2.2 MATERIALS AND METHODS

2.2.1 Materials

Seeds and seedlings were obtained from clone 55/3 of a semi-dwarf dahlia ('F' series) (for information about the seed source, see Section 3.2.2).

The seedlings used for the transplant herbicide trial were from seeds sown in cell trays on 8 December 1995 at ambient temperature in a glasshouse at the Seed Technology Centre, Massey University.

Thirteen herbicides (Table 2.2.1) and a pendulum swing herbicide sprayer (Appendix 2) used in this experiment were all supplied by Dr. Kerry Harrington (Plant Science, Massey University).

2.2.2 Experimental design

Of the thirteen herbicides, twelve were used as pre-emergence herbicides and six were used as post-emergence herbicides for the two establishment methods, i.e. seedling transplanting and direct seed sowing, to evaluate the safety of these herbicides (Table 2.2.1).

A complete randomised design with four replications was employed in these two experiments, i.e. direct seed sowing, and seedling transplants. Both trials were

Table 2.2.1 The herbicides used in the experiment

Herbicides		Active ingredient	Amount /ha	*Treatments	
Trade name	Active Ingredient			Seeds	Seedlings
Lasso Mt	alachlor	480 g/L	4 L	AS	AT
Eradicane Super	EPTC	720 g/L	6 L	BS	BT
Surflan Flo	oryzalin	500 g/L	9 L	BS	BT
Foresite 380	oxadiazon	380 g/L	4 L	AS	AT
Gesatop 500 FW	simazine	500 g/L	2 L	AS	BT
Stomp 330E	pendi-methalin	330 g/L	4 L	AS	AT
Treflan	trifluralin	400 g/L	3 L	BS	BT
Chloro-IPC	chlorpropham	400 g/L	8 L	AS + 2L	BT + 18D
Dacthal	chlorthal dimethyl	750 g/kg	10 kg	BS + 2L	BT + 18D
Goal	oxyfluorfen	240 g/L oxyfluorfen + 350 g/L xylene	3 L	AS + 2L	AT + 18D
Sinbar	terbacil	800 g/kg	1.2 kg	BS + 2L	BT + 18D
Tribunil	methabenz-thiazuron	700 g/kg	1.5 kg	AS + 2L	AT + 18D
Gallant	haloxyfop	100 g/L	3 L	2L	18D

* Herbicides applied AS: after seed sowing; AT: after seedling transplanting; 2L: at two pair leaf stage; 18D: 18 days after transplanting.

conducted at the Plant Growth Unit, Massey University (Appendix 1). Each treatment replicate consisted of one plant grown in a black plastic bag (PB 8) with 27 cm circumference and 20 cm depth for the seedling transplanting herbicide trial, and ten seeds sown in one plastic bag (PB 8) for the direct-seeded herbicide trial. Each plastic bag was filled with sandy loam soil, which was free from residual herbicides (C.R. Johnstone, personal communication).

2.2.3. Application of herbicides.

A pendulum swing sprayer (Appendix 2) was used to apply the herbicides. One end of the sprayer was fixed to the roof of the spraying room while the other end with the nozzles was allowed to swing freely. The sprayer was connected to an air compressor, which allowed herbicide spray application to be altered and controlled. After filling with herbicide, the sprayer nozzle arm was swung over the top of the plants. After applying one herbicide, the sprayer was taken apart and thoroughly washed before another herbicide was applied. Before applying the herbicides, the sprayer was calibrated by measuring the amount of water which was sprayed on a known area of glass following a swing of the sprayer.

2.2.3.1 Direct seed sowing herbicide trial:

Seeds in the direct-sowing herbicide trial were sown in plastic bags on 13 December, 1995, and pre-emergence herbicides were sprayed on the soil surface using the pendulum swing sprayer before or after seed sowing (Table 2.2.1). Plants which were not sprayed with any herbicide were used as a control treatment.

Post-emergence herbicides were sprayed over the top of the plants from direct sown seeds on 8 January, 1996, which at that time were in the four (two pair) leaf stage. Before spraying, the seedlings were thinned to one per pot, leaving the biggest one.

2.2.3.2 Transplanted seedling herbicide trial:

Four leaf (two pairs) seedlings were transplanted for the pre-emergence herbicide trial on 8 January, 1996. Pre-emergence herbicides were sprayed on the top of plant bags before or after transplanting (Table 2.2.1). There was also an untreated control.

On 6 January 1996, at the four leaf stage, 24 pots of seedlings were transplanted. On 24 January, 1996, 18 days after transplanting, post-emergence herbicides for transplanted seedlings were sprayed over the transplanted seedlings.

After being treated with herbicides, all the plant bags were placed on weed mats at the Plant Growth Unit, Massey University under natural conditions (Appendix 3).

2.2.4 Crop management:

Pots were irrigated every two days after sowing or transplanting by overhead automatic sprinkler. Pots were weeded by hand pulling when required. A fungicide, iprodione at a rate of 3.7 kg a.i./ha was sprayed to protect from fungal infection on 27 February and 7 March; and a miticide, dicofol at a rate of 3 kg a.i./ha and a insecticide, taufluvalinate at a rate of 2 kg a.i./ha were sprayed over all pots on 27 February and 7 March 1996 as well, because some injury symptoms suspected to be a result of insect or mite activity been observed on the untreated plants.

2.2.5 Data collection and analysis

Herbicide injury symptoms were visually scored weekly after herbicide application. The score ranged from 0 to 10, where 0 means no visible injury symptoms and 10 meant plant death. Besides injury symptom scoring, flower number per plant was recorded weekly after the first flower opened. Seedheads from each plant were collected after they turned brown. The seedheads were dried at ambient temperature in the glass house at the Seed Technology Centre for one to two weeks, then hand threshed and cleaned. The seed numbers per plant were recorded. Tubers were dug out and their fresh weights measured after washing. All the data were subjected to an analysis of variance using SAS programme.

2.3 Results

2.3.1 Effects of pre-emergence herbicides on direct-sown dahlias.

Seventeen and 24 days following seed sowing, emerged seedlings were counted in the pre-emergence herbicide trial pots. Leaf number was also counted after 24 days. The results showed significant differences between plants according to which of the 12 herbicides was used (Table 2.3.1). At 17 days after sowing (DAS), oxadiazon, simazine, and terbacil treatments had significantly fewer seedlings than the untreated control, and at 24 DAS, seedlings further had died in the treatments oxadiazon and simazine treated pots. This indicated that they all inhibited the emergence of dahlia seedlings. At 24 DAS, plant numbers in the methabenzthiazuron treated pot was significantly greater than the control but whether this was be due to the variation of seed vigour in each pot, or that this herbicide might improve the emergence of seeds remains unknown. Leaf numbers for the EPTC, oryzalin, oxadiazon, simazine, oxyfluorfen, and terbacil treated plants were all significantly fewer than the control, which indicated they inhibited the early growth of dahlias.

Injury scoring (Table 2.3.2) 4 weeks after spraying showed that EPTC, oryzalin, oxadiazon, simazine, oxyfluorfen, and terbacil all caused obvious injury to early dahlia growth, even though oryzalin, oxyfluorfen and EPTC had not shown deleterious effects on the emergence of dahlia seedlings. Subsequent scoring showed that the injury symptoms of EPTC, oryzalin, and oxyfluorfen disappeared with continued plant growth. However, the scores obtained were variable in some individual treatments. With oxadiazon, for example, plants in two of the four replicates died, but the other two recovered very well. Similarly, two replicate plants recovered but the other two did not recover following application of EPTC. With simazine, all plants died, but only three out of four plants died following spraying with terbacil.

Table 2.3.1 The effect of pre-emergence herbicide on emergence and early growth of direct sown dahlias

Herbicides	Seedlings per pot		Leaves/plant
	17 days after sowing	24 days after sowing	24 days after sowing
alachlor	4.7ab*	4.8abc	4.0a
chlorpropham	4.0abc	4.5abc	4.0a
chlorthal-dimethyl	5.3ab	4.5abc	4.0a
EPTC	4.0abc	4.0abc	2.6bc
methabenz-thiazuron	5.0ab	6.0a	3.5ab
oryzalin	4.5ab	5.3abc	1.25d
oxadiazon	1.0d	0.8e	0.0e
oxyfluorfen	2.0cd	1.8de	1.8cd
pendimethalin	3.8ab	3.8bcd	4.0a
simazine	1.0d	0.0e	0.0e
terbacil	0.8d	0.8e	0.0e
trifluralin	4.8ab	5.0abc	4.6a
untreated	3.8abc	3.8bcd	4.0a

* Values with the same letters in the same column do not differ significantly at $P \leq 0.05$.

Plant above ground dry weight and plant height were not significantly different from the untreated control (Table 2.3.3). However, alachlor, chlorpropham, oxyfluorfen and pendimethalin treated plants were significantly taller than EPTC treated plants; and pendimethalin treated plants had significantly greater above ground plant dry weight than trifluralin treated plants (Table 2.3.3).

Tuber number and fresh weight per plant for all treatments did not significantly differ from the untreated control. However, the pendimethalin treated plants had significantly heavier tubers per plant than chlorthal dimethyl, oxyfluorfen, and oryzalin treated plants (Table 2.3.3). Methabenzthiazuron and oxyfluorfen treated plants had significantly more tubers per plant than alachlor and EPTC treated plants (Table 2.3.3).

Table 2.3.2 Scoring[1] of pre-emergence herbicide injury on direct sown dahlias

Weeks after application of herbicides	4	7	12	18
alachlor	3.25cd[2]	0.50f	1.25cd	1.50d
chlorpropham	3.50cd	1.75def	2.50cd	1.00d
chlorthal-dimethyl	2.75cd	0.50f	1.00cd	1.50d
EPTC	7.25b	4.25bcd	3.00c	2.75cd
methabenzthiazuron	4.25c	2.50cdef	2.50cd	0.50d
oryzalin	8.00ab	3.75cde	3.50c	2.25d
oxadiazon	8.25ab	5.25bc	6.50b	6.25b
oxyfluorfen	8.00ab	5.25bc	3.25c	1.25d
pendimethalin	3.25cd	0.25f	1.00cd	0.5d
simazine	10.00a	10.00a	10.00a	10.00a
terbacil	9.75a	9.50a	8.50ab	7.75ab
trifluralin	1.75d	0.00f	0.00d	0.75d
untreated	2.25cd	0.75ef	1.00cd	0.5d

1. Scores range from 0 (unaffected) to 10 (death)
2. Means with the same letters in the same column do not differ significantly at $P \leq 0.05$.

Only oryzalin treated plants showed significantly fewer seedheads per plant than the untreated control (Table 2.3.3). Seed numbers of all treatments but oxyfluorfen did not significantly differ from the untreated control (Table 2.3.3). Oxyfluorfen treated plants had greater seed numbers per plant than alachlor, EPTC, pendimethalin treated plants and the untreated control (Table 2.3.3).

Data in all four replicates for seed number per plant, seedheads per plant, tuber size and number, and dry weight of the plant above ground were very variable, and the treatment effects may therefore be masked.

2.3.2 Effects of post-emergence herbicides on direct sown dahlias

One week after applying post-emergence herbicides to direct-sown dahlias, chlorthal-dimethyl, oxyfluorfen, and terbacil appeared to cause significant injury symptoms on plants compared with the untreated control (Table 2.3.4). The injury symptoms of chlorthal dimethyl largely disappeared in another two weeks. Terbacil caused complete plant death and oxyfluorfen caused death in one of the four replicates. The other herbicides i.e. chlorpropham, methabenzthiazuron and haloxyfop, did not caused significant injury to plants.

Table 2.3.3 The effect of pre-emergence herbicide on the seed and tuber yield of direct sown dahlias

*Herbicides	Plant height (cm)	Seed-heads per plant	Dry weight of plant above ground (g)	Tuber weight per plant	Tuber number per plant	Seeds per plant
alachlor	32.5	1.8	2.4	63.5	3.3	0.5
chlorpro-pham	33.3	1.8	3.2	83.4	4.0	16.5
chlorthal-dimethyl	28.0	2.3	1.5	63.7	3.8	6.3
EPTC	20.8	1.5	3.2	80.4	3.5	0.0
methabenz-thiazuron	24.5	1.8	2.1	82.8	5.3	9.8
oryzalin	20.8	1.0	1.9	53.8	4.3	19.3
oxyfluorfen	34.5	1.8	2.3	59.7	5.0	25.5
pendi-methalin	34.5	2.3	3.9	104.8	4.5	3.5
trifluralin	32.3	1.3	1.1	101.7	4.3	7.0
untreated	27.8	2.3	2.5	74.9	4.5	2.3
LSD $\leq$ 0.05	11.5	1.25	1.82	32.7	1.64	22.2

* Oxadiazon, simazine and terbacil caused some replicate deaths. Their results are not presented in this table because the results of surviving replicates may not be zero.

Plant height, tuber number per plant, tuber weight per plant, plant dry weight and seedheads per plant of all treatments did not differ from the untreated control (Table 2.3.5). The methabenzthiazuron treated plants had significantly more seeds per plant than the untreated control (Table 2.3.5).

Table 2.3.4 Scoring[1] of post-emergence herbicide injury on direct sown dahlias

Weeks after herbicide application	1	3	5	9	13
chlorpropham	2.5ghi[2]	0.50de	0.75cd	0.50de	0.50d
chlorthal dimethyl	5.0defg	1.75ed	1.50cd	1.50de	1.00d
haloxyfop	4.5defgh	1.25de	2.25cd	1.00de	0.50d
methabenzthiazuron	3.5efghi	0.75de	1.5cd	0.75de	1.25d
oxyfluorfen	8.8abc	6.75ab	5.75b	5.00bc	5.25bc
terbacil	8.8abc	10.00a	10.00a	10.00a	10.00a
untreated	2.0hi	0.75de	1.50cd	0.75de	0.50d

1. Scores range from 0 (unaffected) to 10 (death)
2. Means with the same letters in the same column do not differ significantly at $P \leq 0.05$.

Table 2.3.5 The effect of post-emergence herbicide on the seed and tuber yield of direct sown dahlias

Herbicide*	Plant height (cm)	Seed-heads per plant	Dry weight of plant above ground	Tuber number per plant	Tuber weight per plant	Seeds per plant
chlorpropham	30.3	1.8	2.3	4.0	66.8	4.8
chlorthal dimethyl	32.0	2.5	3.0	6.0	79.5	17.8
haloxyfop	23.8	2.3	2.6	4.0	83.9	14.0
methabenz-thiazuron	33.0	2.5	2.9	5.0	79.9	29.8
untreated	27.8	2.3	2.5	4.5	74.8	2.3
LSD $P \leq 0.05$	11.55	1.25	1.82	1.6	32.7	25.73

* Oxyfluorfen and terbacil caused some replicates death. Therefore, their results are not presented in this table although the results of some survived replicates are not zero.

2.3.3 Effects of pre-emergence herbicides on transplanted dahlia plants

Scoring for injury one week after spraying with pre-emergence herbicide onto transplanted dahlia seedlings showed that oxyfluorfen and oxadiazon caused significant plant injury (Table 2.3.6). Plants sprayed with simazine and EPTC also showed injury two weeks after spraying with one plant death in each treatment (Table 2.3.6). However, plants in all treatments (except the simazine treatment and dead plants) subsequently recovered three to four weeks after spraying (Table 2.3.6).

Table 2.3.6 [1]Scoring of pre-emergence herbicide injury on transplanted dahlias

Weeks after herbicide application	1	3	6	10	13
alachlor	1.00def[2]	0.80gf	1.80cde	1.50cd	0.50cd
chlorpropham	1.50cdef	0.50fg	1.30cde	0.50cd	0.50cd
chlorthal dimethyl	0.80def	0.00g	0.50e	0.30d	0.50cd
EPTC	1.50cdef	4.00cd	3.50bcd	2.80dc	3.00bc
methabenzthiazuron	1.25cdef	0.00g	0.50e	0.50cd	1.00cd
oryzalin	1.25cdef	2.30def	2.25bcde	1.25cd	0.25c
oxadiazon	5.00b	3.30cde	0.50e	0.50cd	1.30cd
oxyfluorfen	7.30a	5.00bc	1.80cde	1.30cd	0.50cd
pendimethalin	1.25cdef	0.75fg	1.00de	1.50cd	0.75cd
simazine	2.00cd	7.00ab	4.80b	5.00b	4.00b
terbacil	1.80cde	1.50efg	1.00de	0.00d	0.00d
trifluralin	1.30cdef	0.50fg	0.30e	0.30d	0.50cd
Untreated	2.50c	0.00g	0.30e	0.80cd	0.50cd

1. Scores range from 0 (unaffected) to 10 (death)
2. Values with the same letters in the same column do not differ significantly at $P \leq 0.05$.

The flower numbers in all herbicide treatments showed some significant differences from the control three weeks after flowering although they did not differ significantly in the first two weeks after spraying. EPTC, oryzalin, pendimethalin and oxyfluorfen treated plants had fewer flowers than the untreated control on 9 April (Table 2.3.7). At the final assessment, EPTC, pendimethalin, and terbacil treated plants had significantly fewer flowers (including wilted flowers) than the control (Table 2.3.7).

[1]Table 2.3.7 The pre-emergence herbicide effect on flower number per plant of transplanted dahlias

Date	19/3	26/3	9/4	15/4	22/4
alachlor	0.25ab	1.5abc	2.5abcd	3.3abc	3.3abc
chlorpropham	0.5ab	1.8ab	2.3abcde	3.0abc	2.8bcd
chlorthal-dimethyl	1.0a	1.8ab	3.3ab	3.8a	4.3a
EPTC	0.0b	0.3d	1.3def	2.0cde	2.0cde
methabenz-thiazuron	0.8ab	2.3a	2.8abc	2.8abcd	2.8bcd
oryzalin	0.3ab	0.5cd	1.8cdef	2.5abcd	2.3bcd
oxyfluorfen	0.0b	0.3d	1.8cdef	2.3bcde	2.3bcde
pendimethalin	0.3ab	0.8bcd	1.0ef	1.5de	1.5de
terbacil	0.3ab	1.3abcd	2.5abcd	3.0abc	2.0cde
trifluralin	0.8ab	2.3a	2.8abc	2.8abcd	2.8bcd
untreated	0.5ab	1.3abcd	3.5a	3.5ab	3.5ab

1. Values with the same letters in the same column do not differ significantly at $P \leq 0.05$.

Of the pre-emergence herbicides, oxadiazon, simazine, oxyfluorfen and EPTC caused obvious injury to transplanted dahlia plants. Pendimethalin and terbacil had no apparent injurious effect on dahlia, but seemed to delay flowering and reduced flower numbers (Table 2.3.7).

Terbacil treated plants were significantly taller and heavier than untreated plants while all other pre-emergence herbicide treated plants did not show significant difference from the control for plant height and plant dry weight (Table 2.3.8). Tuber fresh weight of the untreated control was the smallest and significantly less than trifluralin, oryzalin, pendimethalin and terbacil treated plants. The untreated control also had the least tubers per plant and significantly fewer than pendimethalin treated plants (Table 2.3.8).

However, pendimethalin treated plants had significantly fewer seedheads per plant (2.3.8). The oxyfluorfen treated plants had significantly more seeds per plant than all other pre-emergence herbicide treated plants as well as the untreated control (Table 2.3.8).

Table 2.3.8 The effect of pre-emergence herbicide on the seed and tuber yield of transplanted dahlias

Herbicides	Plant height (cm)	Seed-heads/ plant	Dry weight of plant above ground (g)	Tuber weight per plant (g)	Tuber number per plant	Seeds per plant
alachlor	21.3	3.50	3.91	75.3	4.8	15.8
chlorpropham	33.8	2.80	3.26	85.8	4.3	27.3
chlorthal-dimethyl	38.8	4.00	4.67	89.8	4.3	29.0
EPTC	34.3	2.25	3.48	64.6	4.5	12.3
methabenz-thiazuron	34.5	2.5	3.14	78.0	4.5	32.2
oryzalin	35.8	2.5	4.3	102.0	3.8	20.0
oxyfluorfen	37.3	2.3	5.1	76.3	4.3	62.8
pendimethalin	36.0	1.5	3.9	111.8	5.5	15.3
terbacil	45.3	3.8	6.5	114.2	4.8	21.3
trifluralin	34.3	2.50	4.90	94.4	4.8	6.0
untreated	29.8	3.25	2.65	57.67	3.3	19.8
LSD $P \leq 0.05$	10.87	1.43	2.55	31.15	1.84	31.9

2.3.4. Effects of post-emergence herbicide on transplanted dahlias

Post-emergence herbicides were applied to transplanted dahlia seedlings on 24 January, 1996. Of the six herbicides used, oxyfluorfen and terbacil treated plants showed significantly more injury symptoms than the control in the first week (Table 2.3.9), and terbacil had caused the death of three of the four plants sprayed. The initial injury caused by oxyfluorfen was only short lived and plants recovered slowly over a period of 2-3 months (Table 2.3.9).

Table 2.3.9 The [1]Scoring of post-emergence herbicide injury on transplanted dahlias

Weeks after herbicide application	1	2	4	8	12
chlorpropham	0.50fg[2]	0.75f	0.25e	0.25d	0.00d
chlorthal-dimethyl	1.75efg	0.00f	0.75e	0.50cd	0.00d
haloxyfop	0.00g	0.50f	0.75e	0.75cd	0.80cd
methabenzthiazuron	0.50fg	1.00f	1.25cde	0.50cd	0.50cd
oxyfluorfen	8.50a	8.25ab	3.75bc	2.75bc	1.25cd
terbacil	5.25bc	9.25a	8.75a	8.75a	8.50a
untreated	0.00g	0.50f	0.25e	0.75cd	0.50cd

1. Scores range from 0 (unaffected) to 10 (death).
2. Values with the same letters in the same column do not differ significantly at $P \leq 0.05$.

Flower numbers in plants sprayed with chlorpropham, chlorthal-dimethyl and oxyfluorfen were significantly reduced compared to the control at the late flowering stage (9 April) (Table 2.3.10). But plants treated with chlorthal-dimethyl eventually produced a similar number of flowers to untreated plants (Table 2.3.10).

Table 2.3.10 The effect of post-emergence herbicides on flower number per plant of transplanted dahlias

Date	19/3	26/3	9/4	15/4
chlorpropham	0.25ab*	1.0bcd	2.0bcde	2.0cde
chlorthal-dimethyl	0.50ab	0.5cd	1.8cdef	2.3bcde
haloxyfop	0.75ab	1.5abc	2.3abcde	2.5abcd
methabenzthiazuron	0.50ab	2.3a	2.5abcd	2.5abcd
oxyfluorfen	0.25a	0.3d	0.5f	1.0e
untreated	0.50ab	1.3abcd	3.5a	3.5ab

* Means with the same letters in the same column do not differ significantly at $P \leq 0.05$

Plant height and above ground plant dry weight of all post-herbicide treated plants (except dead plants) did not differ from the untreated control (Table 2.3.11). Chlorpropham and oxyfluorfen treated plants showed a significantly greater plant dry weight than haloxyfop treated plants (Table 2.3.11). Oxyfluorfen treated plants had significantly more tubers per plant than the untreated control (Table 2.3.11), and chlorthal dimethyl, chlorpropham, oxyfluorfen and methabenzthiazuron treated plants had greater tuber fresh weight than haloxyfop treated plants and the untreated control.

Table 2.3.11 The effect of post-emergence herbicide on the seed and tuber yield of transplanted dahlias

Weeks after herbicide application	Plant height (cm)	Seed-heads /plant	Dry weight of above ground	Tuber number per plant	Tuber weight per plant	Seeds per plant
chlorpropham	32.3	2.0	4.9	3.8	112.4	18.5
chlorthal dimethyl	32.5	2.0f	2.3	14.0	89.8	15.0
haloxyfop	33.0	2.3	2.1	4.3	44.5	0.8
methabenz-thiazuron	27.0	1.8	3.2	4.8	88.4	8.0
oxyfluorfen	22.5	1.3	4.9	5.3	96.2	4.0
untreated	29.8	3.3	2.7	3.3	57.7	19.8
LSD $P \leq 0.05$	10.87	1.43	2.55	1.84	31.15	27.85

Oxyfluorfen and methabenzthiazuron treated plants had significantly fewer seedheads per plant than the untreated control. However, there were no significant differences in seed number per plant (Table 2.3.11).

2.4 Discussion

2.4.1 Alachlor is absorbed by the shoots of germinating seeds, interfering with protein formation and plant growth (Walton and Walton, 1993). But it did not affect the emergence and early growth in direct sown dahlias, or the growth of transplanted seedlings when applied as a pre-emergence herbicide at a rate of 1.92 kg a.i./ha in this experiment. This conforms the wide crop plant tolerance to alachlor previously reported in aster, carnation, chrysanthemum, gypsophila, helichrysum, zinnia, poppy, statice, stock (Lamont, 1986) and sunflower (Laureti, 1986; Peric, 1986) at rates of 1.125 and 2.25 kg a.i/ha.

However, it is reported that alachlor can affect the germination and early growth of direct-seeded aster, calendula and helichrysum at rates of 1.125 and 2.25 kg a.i/ha (Lamont, 1986), and even cause china aster leaf necrosis in seedlings when applied at a rate of 1.125 kg a.i/ha (Phetpradap[2], 1992). These reflect the response difference of even plants in the same family to alachlor.

Alachlor provides 6-8 weeks residual control of many annual grasses and some broadleaf weeds (Walton and Walton, 1993) and costs $75/ha (Table 2.4.1). It is recommended for use as a pre-emergence herbicide.

2.4.2 Chlorpropham did not affect dahlia seed germination or plant growth when applied pre- or post-emergence at a rate of 3.2 kg a.i/ha to both direct sown and transplanted dahlias. It has also been used successfully as both a pre- and post-emergence herbicide in onions and lettuce (Walton and Walton, 1993).

It controls some grasses and broadleaf weeds, such as annual ryegrass, fathen, chickweed and dock seedlings (Walton and Walton, 1993). If it is used for dahlia seed production, it may be relatively expensive ($284/ha) (Table 2.4.1) compared with other herbicides.

2.4.3 Chlorthal-dimethyl at a rate of 7.5 kg a.i/ha did not affect the germination of dahlia seed as a pre-emergence herbicide or the growth of transplanted seedlings as a pre- or post-emergence herbicide. It did show some injury to early growth of direct sown seedlings when applied as a post-emergence herbicide (Table 2.3.3), but plants soon recovered.

Chlorthal dimethyl is almost entirely root absorbed, with little or no contact action, and is effective only on germinating seedlings (Walton and Walton, 1993). Lamont (1986) reported that it has no effect on germination and early growth of aster, calendula, and transplanted aster, carnation, chrysanthemum, and helichrysum, but does have a deleterious effect on gypsophila. Chlorthal dimethyl also controls some grasses such as smooth summer grass, witch grass and some broadleaf weeds such as fathen, chickweed, wireweed and redroot. But it is the most expensive herbicide ($546/ha) of all used in this experiment (Table 2.4.1).

2.4.4 EPTC, a pre-emergence herbicide at a rate of 4.32 kg a.i/ha, did not affect the germination of dahlia, but can affect early seedling growth in both direct sown plants and transplanted plants. It is root absorbed by seedling plants and is translocated to the leaves and stems where it inhibits cell division at growing points, and bud development from underground portions of some perennial plants (Walton and Walton, 1993). Therefore, its effect on transplanted dahlias seems to be slow and long term, since its injury symptoms did not disappear until flowering (Table 2.3.4) and resulted in a reduction in flower numbers in transplanted plants (Table 2.3.5). It is not recommended for use in dahlias.

However, it has been successfully used in sunflower (Tei, 1986; Konstantinovic *et al*, 1986), and the dahlia results may be because too high a rate was used in the present study, or there was a different response to EPTC by the different crops.

2.4.5 Haloxyfop was only applied as a post-emergence herbicide in this experiment at a rate of 0.3 kg a.i/ha. It did not show any injury to dahlia plants in both direct sown and transplanted seedlings. This is because it selectively controls grasses in many crops

Walton and Walton, 1993). It can be used in dahlias at a intermediate cost ($129/ha).

2.4.6 Methabenzthiazuron did not inhibit the germination of direct sown dahlia (Table 2.3.1), and did not affect the growth when applied both as a pre- or post-emergence herbicide in transplanted seedlings at a rate of 1.05 kg a.i/ha (Tables 2.3.6, and 2.3.9). However, it did affect the early growth of dahlia when applied as both a pre- and post-emergence herbicide in direct sown dahlia, although plants soon recovered (Tables 2.3.2 and 2.3.4). It is absorbed by foliage or roots and has a soil residual life (Walton and Walton, 1993). Higher rates may cause more severe injury. It mainly controls broadleaf weeds such as black nightshade, charlock, chickweed and fathen. It could be used in dahlia at a intermediate cost ($112/ha).

2.4.7 Oryzalin at a rate of 4.5 kg a.i/ha did not affect the germination of dahlias in this experiment, unlike its reported effect in lowering China aster seedling emergence if applied to direct sown seeds 4 days after planting (Phetpradap[2], 1992). However, Oryzalin did affect early growth (Table 2.3.2) and reduce leaf numbers per plant (Table 2.3.1) in direct sown plants. It also caused some injury of transplanted seedlings but these recovered quickly (Table 2.3.6). This supports Lamont's (1986) research which suggested oryzalin was not safe to use on direct-sown crops of calendula, poppy, statice, sweet william and wallflower at rates of 2.25 and 4.5 kg a.i./ha.

2.4.8 Oxadiazon at a rate of 1.52 kg/ha a.i. affected the emergence of seedlings and early plant growth (Table 2.3.1 and 2.3.2) in direct sown dahlia, to the point of even causing seedling death. This is similar to the response of direct sown asters (Lamont, 1986). This is because oxadiazon forms a film on the soil surface and is a surface acting residual herbicide which is absorbed by the emerging shoot of weeds preventing further development above the soil surface (Walton and Walton, 1993). The dahlia seedlings would be affected by oxadiazon when they emerged. Although it did not cause plant death in transplanted plants, it still caused plant injury (Table 2.3.4), because oxadiazon was applied on the top of pots after seedlings were transplanted in order not to disturb the herbicide film on the soil surface. Oxadiazon has, however, been reported to be safe on transplanted aster, carnation, and chrysanthemum crops and direct-sown gypsophila

Lamont, 1986) at rates of 2.0 and 4.4 kg a.i/ha, and have been safely used in sunflower Favier, 1986). Because whether the spraying was over foliage of plants or underneath he plants was not mentioned in the research of Lamont (1986), whether this difference esulted from different crop response to the chemical or spraying method is unknown.

Also as a form of granule, it has been reported to be a safe and effective weed killer n potted dahlias at rates of 4.5 and 9 kg a.i/ha (Staats and Klett, 1993). Not touching oliage would result in the different response to the chemical.

2.4.9 Oxyfluorfen at a rate of 0.72 kg a.i/ha caused significant injury in all treatments, rrespective of whether it was applied pre- or post-emergence (Tables 2.3.2, 2.3.4, 2.3.6 and 2.3.9). It also caused some plant death as a post-emergence herbicide in direct sown plants. Oxyfluorfen is a contact herbicide and is taken up by the emerging shoot Walton and Walton, 1993). It is therefore not surprising to find plant injury. It is also very toxic to sunflowers and other crops (Dhanapal, 1987), and has been shown to affect germination and early growth in aster, gypsophila, helichrysum and zinnia, as well as cause severe scorching followed by death or stunted growth on transplants of hose crops (Lamont, 1986).

2.4.10 Pendimethalin was safely used in both direct sown and transplanted plants as a pre-emergence herbicide at a rate of 1.32 kg/ha a.i. (Tables 2.3.1, 2.3.2 and 2.3.6). However, it did cause some reduction in the number of flowers per plant in transplanted plants (Table 2.3.7).

Pendimethalin is absorbed by both roots and shoots and inhibits growth processes relating to cell division and elongation. Affected plants die shortly after germination or following soil emergence (Walton and Walton, 1993). The weeds it controls are similar to those controlled by chlorthal dimethyl.

2.4.11 Simazine was applied at a rate of 1.0 kg/ha a.i.. Very few seeds emerged and all seedlings died later for direct sown dahlias (Table 2.3.1). Simazine is absorbed only through plant roots as seeds germinate, with symptoms of yellowing then death (Walton and Walton, 1993). This certainly happened in dahlia in this experiment.

Although it is suggested that simazine has little or no activity on existing vegetation (Walton and Walton, 1993), the chemical killed some transplanted seedlings and those which survived did not recover totally until harvest (Table 2.3.4). Phetpradap[2] (1992) also discovered that simazine killed 24 and 44 day old china aster seedlings in a glasshouse experiment.

Table 2.4.1 Prices of the herbicides used in the experiment

Herbicides		Active ingredient	Amount /ha	Price* $ ha^{-1}
Trade name	Active Ingredient			
Lasso Mt	alachlor	480 g/L	4 L	76
Eradicane Super	EPTC	720 g/L	6 L	-
Surflan Flo	oryzalin	500 g/L	9 L	451
Foresite 380	oxadiazon	380 g/L	4 L	305
Gesatop 500 FW	simazine	500 g/L	2 L	25
Stomp 330E	pendimethalin	330 g/L	4 L	121
Treflan	trifluralin	400 g/L	3 L	43
Chloro-IPC	chlorpropham	400 g/L	8 L	284
Dacthal	chlorthal dimethyl	750 g/kg	10 kg	546
Goal	oxyfluorfen	240 g/L	3 L	160
Sinbar	terbacil	800 g/kg	1.2 kg	141
Tribunil	methabenzthiazuron	700 g/kg	1.5 kg	112
Gallant	haloxyfop	100 g/L	3 L	129

* Cited from Burtt, E.S. **Financial budget manual 1996**

2.4.12 Terbacil at a rate of 0.96 kg a.i/ha caused plant death when applied as a pre- or post-emergence herbicide in direct sown dahlia, and as a post-emergence herbicide in transplanted dahlia (Tables 2.3.2, 2.3.4, and 2.3.9). However, it did not affect transplanted seedlings when used as a pre-emergence herbicide (Table 2.3.6) in this experiment. Its main activity is from root uptake through the soil but it also possesses moderate foliar activity and its greatest effect is against germinating seedling weeds

(Walton and Walton, 1993). The reason why it did not affect transplanted seedlings as a pre-emergence herbicide may be that the herbicide did not contact the foliar parts since it was applied before transplanting, and the roots of transplanted dahlias were old enough to tolerate the attack of terbacil.

2.4.13 Trifluralin at a rate of 1.2 kg a.i/ha had no effect on either germination, or seedling growth in direct sown and transplanted dahlia crops (Tables 2.3.1, 2.3.2 and 2.3.6). It has also been safely used in sunflower weed control (Favier, 1986), and in potted dahlias at rates of 4.5 and 9 kg a.i./ha (Staats and Klett, 1993). It is soil incorporated herbicide and taken up by emerging roots of susceptible species as seed geminates (Walton and Walton, 1993). It is highly recommended as a pre-emergence herbicide because of its safety for dahlias and its low cost ($43/ha) (Table 2.4.1)

2.4.14 Effects of herbicides on seed and tuber yield

Seed production from untreated direct-sown dahlias was significantly lower than from plants treated with oxyfluorfen pre-emergence (Table 2.3.3), or plants treated with methabenzthiazuron post-emergence (Table 2.3.5). Likewise, untreated transplanted dahlias produced significantly fewer seeds per plant than plants treated with oxyfluorfen pre-emergence (Table 2.3.8). However, there were large variations in the data. For example, for transplants treated post-emergence with chlorpropham, one plant produced 72 seeds while another had no seeds at all. These differences may be a result of genotypic variability, rather than the effect of herbicides. The seeds used in this experiment were obtained by open pollination of 14 clones of semi-dwarf dahlias ("F" serials). According to the observation of Robert Southward (personal communication), seed setting was very variable among those 14 clones. With only one plant in a pot, therefore, the genetic separation of the second generation may mask the effects of herbicide on seed yield. This suggests that a much greater number of plants or a pure line should be used to determine the effect of herbicide on seed yield.

Tuber number and fresh weight in transplanted dahlia also showed some unexpected results. The pre-emergence herbicides, chlorthal dimethyl, terbacil, pendimethalin, oryzalin, and trifluralin treated plants had significantly greater tuber fresh weight than the control (Table 2.3.8). Also, pre-emergence pendimethalin treated plants had more tubers per plant than the control (Table 2.3.8). Plants treated post-emergence herbicide with oxyfluorfen produced a significantly greater number and fresh weight of tubers per plant than the control (Table 2.3.11), while post-emergence application of chlorpropham and chlorthal dimethyl also resulted in a greater tuber weight per plant than the control (Table 2.3.11). Just like seed number per plant, the results of tuber yield per may also be caused by genetic variability.

At the early stage of dahlia development, untreated controls showed some injury (Table 2.3.2, 2.3.4 and 2.3.6), which was suspected to be caused by mites or insects. After applying the miticide and insecticide, the symptom seemed to disappear. This also could have caused some negative effects on seed and tuber production of the untreated plants.

All herbicide treatments would have reduced the number of weeds present in plant pots, compared with the untreated control. There could be more competition from weeds for untreated plants than for treated plants, which would affect plant growth. Furthermore, weeds in the untreated pots were removed by hand-pulling, and more intensive and more frequent hand-pulling may have had negative effects on the growth of untreated plants, because of disturbance to the dahlia roots.

2.5. Conclusion:

2.5.1 Pre-emergence herbicides

Of the twelve pre-emergence herbicides used in this study, EPTC, oryzalin, oxadiazon, simazine, and oxyfluorfen caused significant injury to both direct-sown and transplanted dahlias. These chemicals are therefore not recommended for use as a pre-emergence herbicide in dahlia crops.

Alachlor, chlorpropham, chlorthal-dimethyl, pendimethalin and trifluralin could all be used as a pre-emergence herbicide without damaging dahlias in both direct-sown and transplanted plants. Although methabenzthiazuron as a pre-emergence herbicide affected the early growth of direct sown dahlia, plants recovered very quickly. These five herbicides have a similar weed control spectrum, i.e. some grasses such as smooth summer grass and witch grass, and broadleaf weeds such as fathen, chickweed, wireweed and redroot (Walton and Walton, 1993), but alachlor and trifluralin are the cheapest ($75 and $43/ha respectively) (Table 2.4.1). Furthermore, alachlor provides 6-8 weeks residual activity, controlling subsequent weeds.

Terbacil caused plant death as a pre- emergence herbicide in direct-sown dahlias, but it did not affect transplanted seedlings as a pre-emergence herbicide. This suggests it could only be used as a pre-emergence herbicide in transplanted dahlia rather than in direct-sown dahlia crops. If terbacil is applied before transplanting, it can give very good control of grasses and some broadleaf weed at the cost of $141/ha.

2.5.2 Post-emergence herbicides

Chlorpropham did not show any plant injury as a post-emergence herbicide in both direct-sown and transplanted dahlias. It is therefore recommended as a suitable herbicide for use in this crop, but is relatively expensive ($284/ha).

Haloxyfop, chlorthal-dimethyl and methabenzthiazuron caused some plant injury to early growth of direct-sown seedlings when applied as a post-emergence herbicide. However injured plants recovered quickly. These herbicides, however, did not injure transplanted dahlias. Therefore, they also could be recommended for both direct-sown and transplanted dahlias when applied as a post-emergence herbicide. However as the cheapest herbicide of these three post-emergence herbicides is methabenzthiazuron ($112/ha), and haloxyfop only control grasses, thus, methabenzthiazuron may be the suitable post-emergence herbicide.

In conclusion, based on price, safety, and weeds controlled, alachlor is recommended as a pre-emergence herbicide, and methabenzthiazuron as a post-emergence herbicide for weed control in direct sown and/or transplanted dahlia crops.

CHAPTER 3
THE EFFECT OF ESTABLISHMENT METHOD AND PLANT DENSITY ON DAHLIA SEED YIELD

3.1. Introduction

Dahlia can be propagated by tuberous roots, plant cuttings or seeds to grow as bedding plants, garden plants, and cut flowers (Brondum and Heins, 1993). Seeds are easy to handle, store and transport, and thus it would be much cheaper to distribute seeds than to distribute tubers, stem cuttings or seedlings. Also, unlike the planting of tubers, stem cuttings or seedlings raised from seeds, direct sowing of seeds would be less labour intensive and cost less. Apart from that, seeds afford a cheap and convenient method of raising large number of plants. The plants raised from seeds are usually healthy, for the risk of transmitting diseases from parents to offspring is much less than when vegetative methods are employed (Wright, 1974).

Onion seed production by the "seed to seed" method was reported by Branca and Ruggeri (1994). They found that the plants originating from bulbs showed a higher number of umbels per plant than those originating from true seed, and seed yield obtained by the two propagation methods was similar even if the number of umbels per plant and per square meter were different (Ruggeri and Branca, 1994). However, the 'seed to seed' method calls for drilling seeds in mid-summer to allow plants to reach adequate size for vernalization and flower induction, and harvesting the following July. Therefore, the long time required (about 12 months) in the field made this method fail to gain acceptance by growers and seed companies (Branca and Ruggeri, 1994, Dellacecca, *et al.*, 1994). For dahlias, plant size has no effect on flowering (Still, 1982), and like stem cuttings and tubers, direct seeded plants can flower and set seeds the same year as seed is sown (Brayan, 1989), which is an advantage of dahlia seed production by seed to seed compared with other tuber crops. Also, commercial production of dahlia seed is now economically possible due to increased market demand (Voigt, 1994), particularly for dwarf bedding dahlias, like Coltness and Unwin hybrids which are sown generally as annuals and the tubers customarily discarded (Eliovson, 1967).

Yield and yield components response to plant density is a compensatory nature of many crops (Graf and Rowland, 1987). In addition to effects on crop yield, density changes exert significant influences on individual plant morphology (Pratley, 1980). For many *Asteraceae* crops, such as sunflower and china aster and some beans, the primary components of seed yield are considered to be seed weight, number of seeds per seedhead and number of seedheads per plant (Graf and Rowland, 1987; Phetpradap[1], 1992; Phetpradap[2], 1992). Number of seedheads per plant was considered as the major yield determinant in china aster (Phetpradap[2], 1992) and in dahlia (Phetpradap[1], 1992). In china aster, increasing plant density decreased seed yield per plant due to decreases in seedhead number per plant, seed number per seedhead and seed weight (Phetpradap[2], 1992). Although presumedly, the lowest plant density would produce the most seedheads and highest seed yield per plant, seed yield per unit area may not be the highest (Graf and Rowland, 1987; Phetpradap[1], 1992).

The response of dahlia seed yield to plant density has not been reported. Although dahlia can be sown at plant spacings between 30-90 cm (Reily, 1978), no seed yield and yield components responses were reported, and what density produces the maximum seed yield remains unknown. Therefore, the study of plant density and how it affects the plant architecture, seed yield, seed size and germination rate (Bianco and Damato, 1994) is in a priority for dahlia seed commercial production. This study was initiated to determine optimal plant density for maximum seed yield of semi-dwarf dahlia. Two establishment methods i.e. 'tuber to seed' and 'seedling to seed' were studied in this experiment. Because of germination problems (see Chapter 4) and the need to have specific plant densities and early establishment, 'seedling to seed' was used instead of 'seed to seed'. Moreover, seedling transplanting is used in practise, and the growth and development of transplanted seedlings is similar to those of stem cuttings and direct seed sowing.

The objectives of this experiment were therefore:

To compare the effects of establishment methods i.e. tuber-to-seed or seedling-to-seed on dahlia growth and seed yield, and to determine the optimum plant density of each establishment method for maximising seed yield.

3.2. MATERIAL AND METHODS:

3.2.1 Site and land preparation

The experiment was conducted from October 1995 to May 1996 at the Seed Technology Centre research area, Frewen's block, at Massey University, Palmerston North, which is approximately 33 m above mean sea level. The soil at the experimental site was a fine sandy loam (Mesquita, 1996). A sample of soil for analysis was taken on 24 October, 1995, and the results are presented in Table 3.2.1. In the previous season, the field had been used to grow dwarf beans and maize. It was sprayed with Buster at a rate of 4 l/ha on 2 October and ploughed on 11 October, 1995. It was then rotary cultivated twice on 22 and 25 October, 1995 to prepare the seed bed.

***Table 3.2.1 Soil test results from the experimental field**

pH	Olsen P (µg/g)	SO_4 (µg/g)	Exch. K (meq/100g)	Exch. Ca (meq/100g)	Exch. Mg (meq/100g)
5.5	16	5.5	0.54	7.0	1.27

* air-dry soil was used in the test

3.2.2. Materials

Seeds and tubers of *Dahlia hybrida* L, semi-dwarf Figaro (or 'F') series were provided by the Seed Technology Centre, Massy University (Robert Southward personal communication). Originally, in August 1994, a range of "Figaro" or "F" series Dahlia tubers were supplied to Robert Southward by Dr. Keith Hammett who was seeking to increase the amount of "doubleness" of blooms in dwarf plants. Propagation was done with stem cutting from tubers of 14 clones by Robert Southward, and a block of 670 plants was established. Seed production varied greatly among clones. Seed was harvested in May to June 1995, keeping seed from each clone separate.

Seedling preparation: 8 clones of 'F' series semi-dwarf dahlia seeds were used to produce seedlings. The seeds were sown into trays containing potting mix on 10 October, 1995. After sowing, the trays were watered and moved to a 3-5°C room for three days to break seed dormancy. Then the seedling trays were moved to a glasshouse on 14 October at ambient temperature. On 1 and 2 November, in order to make field transplanting easier, the seedlings were transplanted from seedling trays to cell trays (4.5 cm diameter and 5 cm depth) until they were transplanted into the field on 24 November.

3.2.3 Treatment and experimental design:

A randomised block design with four replications was employed to determine the effect of plant density on seed yield and yield components, using seedling-to-seed and tuber-to-seed establishment systems (Appendix 3). There were two factors: establishment system, i.e. tuber planting, and seedling transplanting, and density, i.e. five densities as listed in Table 3.2.2. Previous reports have stated that dahlia could be grown at densities from 0.3 X 0.3 m to 0.9 X 0.9 m. However, no information existed as to how dahlia would perform at any of these densities.

Table 3.2.2 Plant density treatments

Treatment	Plant spacing	plants/m^2	Plot area	Plants/plot
1	0.8X0.8 m	1.56	4.0X7.2 m	60
2	0.6X0.6 m	2.78	2.4X6.6 m	60
3	0.4X0.4 m	6.25	1.6X6.4 m	85
4	0.3X0.3 m	11.1	2.1X5.1 m	144
5	0.2X0.2 m	25.0	2.0X5.0 m	286

In order to protect dahlias from wind, 2-3 rows of maize were planted 2 m away from the plots around the whole experimental field.

3.2.4 Crop planting and management

3.2.4.1 Seedling planting

Seedlings raised in cell trays were kept in the glass house until they reached the 3 pair leaf stage (2-4 pairs). On 24 November 1995, they were transplanted into the field. After transplanting, each plot was watered with a garden sprinkler for half an hour at a rate of 600 litres per hour. Also, a total of 34.8 mm rainfall from the night of 24 to 27 November (Appendix 5) made seedlings recover very well. But some of them were damaged by rabbits or other animals. Although an electric rabbit fence was placed around the whole trial, it did not protect the plants very well. Damaged plants were replaced as required up until 4 December, 1995.

3.2.4.2 Tuber planting:

Dahlia tubers of 13 mixed clones of semi-dwarf dahlia ('F' series) were planted on 30 and 31, October, 1995. Some spare tubers were planted as well in order to fill some gaps later on.

Table 3.2.3 Tuber plot sizes

Treatment	Plant spacing	plants/m^2	Plot area	Plants/plot
1	0.8X0.8 m	1.56	4.0X4.8 m	42
2	0.6X0.6 m	2.78	3.0X4.2 m	48
3	0.4X0.4 m	6.25	2.4X3.2 m	54
4	0.3X0.3 m	11.1	1.8X2.1 m	56
5	0.2X0.2 m	25.0	1.4X1.6 m	72

Most tubers did not sprout. Therefore from 1 to 4 December, the tubers which had sprouted were re-planted into smaller plots, in order to keep the required densities. After transplanting, the sprouted tubers were watered immediately. The reduced tuber plot sizes are presented in Table 3.2.3

On 3 November, 1995, Mesurol (Methiocarb, 20 g/kg bait) was hand broadcast at a rate of 8 kg/ha around and within tuber plots, and on 4 December 1995, around and within all plots (tuber and seedling plots) to protect plants from slugs and snails.

Fertilizer (N:P:K=12:10:10) was broadcast at a rate of 50 kg/ha to ensure sufficient nutrition for dahlia flowering and seedhead setting on 23 January, 1996. In order to control fungal infection of the seedhead, a fungicide, (Roval WP (2g/l)) at a rate of 465 l/ha was sprayed over all plots on 27 February 1996, and this was repeated twice at 10 day intervals.

Weed control was done by push-hoeing when required.

3.2.4.3 Harvesting

Seedheads were considered ready to harvest when they had turned brown (which was before seed shattering began and when seed moisture content was around 51%; Appendix 4).

I. Selective harvest: In order to estimate the maximum possible seed yield and yield components, seedheads from three randomly chosen and labelled plants in each plot were selectively picked when they had turned brown. At the end of the trial, all the remaining seedheads were also picked regardless of whether they had turned brown or not. The picked seedheads were dried in the glass house at the Seed Technology Centre, Massey University at ambient temperature for one week, then hand-threshed.

II. Non-selective harvest: depending on plot size, four to seven plants in each plot were hand-harvested to estimate seed yield and yield components at final harvest. Because seedhead ripeness varied with the change of plant density, three different harvests were conducted when 80% of seedheads were brown as estimated by the naked-eye. The densities of 0.2X0.2 m and 0.3X0.3 m were harvested on 16 April, 1996; the density of 0.4X0.4 m was harvested on 23 April 1996; and on 7 May, 1996, the last two densities i.e. 0.6X0.6 m and 0.8X0.8 m were harvested. For the selected plants, all seedheads were harvested on their dates.

III. Machine harvesting: Because of the plot sizes and arrangements, it was not possible to directly combine harvest. After the non-selective harvest, all the remaining plants per plot (excluding the border rows) were cut at ground level, and the plants were then ambient air dried for four to six weeks, depending on harvest date. On 11 June 1996, plants were threshed by hand feeding into a combine harvester (Seedmaster Universal-hydrostatic), in which the drum speed was set at 1340 revolutions per minute and concave gap was 4-5 mm.

3.2.5 Data collection:

3.2.5.1 Vegetative growth:

Three randomly chosen plants in each plot were labelled. Plant height and branching at the early stage of plant development (from 15 January to 28 March 1996) were measured once a week. The tubers were dug out at harvest time, then they were washed, and tuber number per plant was counted and fresh tubers per plant were weighed. Aerial parts of the plant were removed at harvest and ambient air dried for two weeks in the glasshouse at the Seed Technology Centre; then they were dried for 24 hours in a 40°C oven and finally, the dry weight of plant aerial parts was recorded.

3.2.5.2 Reproductive growth:

Flower number, including wilted flowers and seedheads of the labelled plants was counted every week after the first flower appeared. The newly appeared flowers were calculated by subtracting the previous count from the current count.

3.2.5.3 Yield and yield components:

Seedheads were hand picked and recorded from labelled plants in the selective harvest and from the sampled plants in the non-selective harvest. After one to two weeks of ambient air drying in the glasshouse, seedheads were hand threshed and cleaned by blowing off chaff and removing impurities. Then seed moisture content was tested using the 103°C oven for 17 hours (ISTA, 1993). Thousand seed weight and the total seed weight from the sampled plants in each plot were recorded, and adjusted to zero percent moisture content. The average seed number was calculated from the total seed weight and thousand seed weight. The number of branches for the sampled plants was determined. Distribution of seedheads at different development stages in a plant was also examined in sampled plants for the non-selective harvest. Seed yield after hand feeding into the combine was compared with the hand harvested yield in order to estimate harvest loss.

3.3 RESULTS

3.3.1 Vegetative growth

There were no significant interactions between plant density and establishment method for above ground plant dry weight, branch number per plant or plant height.

3.3.1.1 The effect of plant density on vegetative growth

The above ground dry weight per plant, and branch number per plant at both peak flowering and harvest, differed significantly among densities (Table 3.3.1).

Above ground plant dry weight was greatest at the lowest plant density and decreased significantly as plant density increased (Table 3.3.1), although the differences between the 0.6 and 0.4 m square spacings and the 0.3 and 0.2 m square spacings were not significant.

At peak flowering, plant height did not differ with plant density (Table 3.3.1). However, at harvest, the plants in the lower densities were significantly taller than those in the higher densities (62.38 cm in the 0.8 m and 61.5 cm in the 0.6 m square spacing; 56.17, 49.58, and 47.92 cm in the 0.4, 0.3 and 0.2 m square spacings respectively (Table 3.3.1)). Branch number per plant decreased significantly as plant density increased (Table 3.3.1).

Table 3.3.1 Effect of plant density on above ground plant dry weight, branches per plant and plant height

Density (m)	Above ground plant dry weight (g)	Branches/plant		Plant height (cm)	
		PF[2]	HT[3]	PF[2]	HT[3]
0.2X0.2	16.37c[1]	5.33c	7.87d	39.9a	47.92c
0.3X0.3	27.46c	7.54c	11.46d	40.3a	49.58c
0.4X0.4	68.82b	12.70b	23.79c	38.4a	56.17b
0.6X0.6	105.92b	19.04a	41.46b	34.8a	61.5ab
0.8X0.8	172.23a	21.08a	53.12a	34.5a	62.38a

1. Values with the same letter in the same column do not differ significantly at $P \leq 0.05$.
2. PF: at the first peak flowering (8 Feb.); 3. HT: at harvest.

3.3.1.2 The effect of establishment methods on vegetative growth

Besides the effect of density on vegetative growth, there were also significant effects of establishment method on tuber weight and plant height.

***Table 3.3.2 Effect of establishment method on tuber weight and plant height**

Establishment Method	Plant height (cm)	Tuber weight (g)
Tuber	50.23b	257.96b
Transplant	60.78a	403.80a

* Values with the same letter in the same column do not differ significantly at $P \leq 0.05$.

Tuber weight was significantly heavier in transplanted plants (403.8g) than from the tuber planting (257.96 g) (Table 3.3.2). Plant height was greater in transplanted plants (60.78 cm) than from tuber planting (50.23 cm) (Table 3.3.2).

3.3.1.3 Interactions between establishment method and plant density for tuber number and fresh weight

The only significant interaction was for tuber number and fresh weight. The tuber number and fresh weight per plant was higher in lower densities than in higher densities in both tuber planting and transplanted seedlings (Table 3.3.5). For tuber planting, the significant differences in tuber number per plant occurred between the 0.8 and 0.6, and 0.4 and 0.2 m square spacings (Table 3.3.5), while in transplanted plants, the significant difference occurred between the 0.6 and 0.4 m square spacing (Table 3.3.5). At the highest density (0.2 m square), the tuber number per plant was higher in transplanted plants than for tuber planting, while for the other densities, both establishment methods had similar tuber numbers (Table 3.3.5). The tuber numbers of the low densities did not differ significantly between the two planting methods (Table 3.3.5).

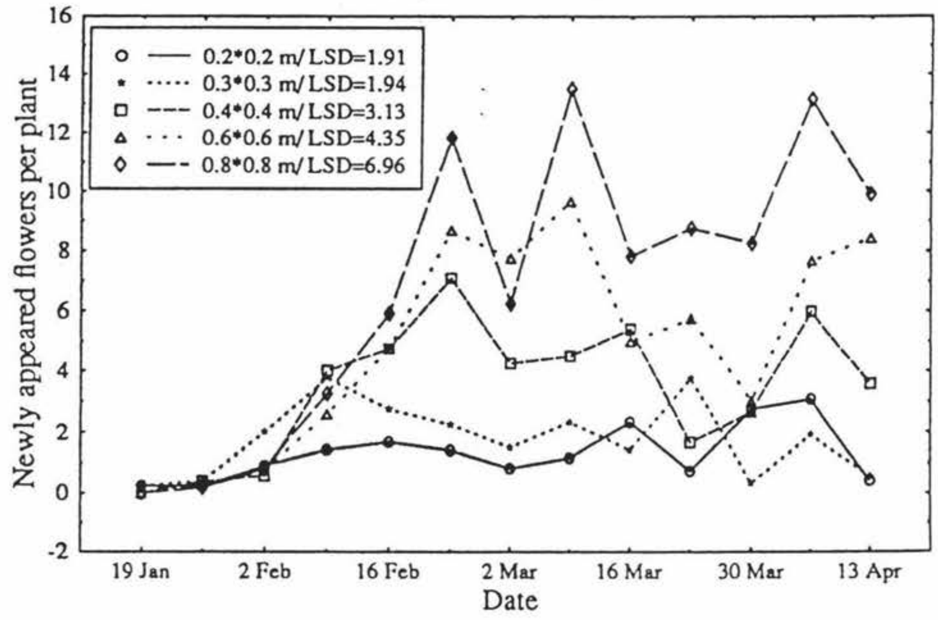
The tuber weight per plant for the lower densities (0.6 and 0.8 m square spacing) was much higher in transplanted plants than for tuber planting, while there were no differences in higher densities between two the methods (Table 3.3.5).

This result indicated that at the higher densities for transplanted plants, there were more tubers, but they were smaller in size than in tuber planting plants because the total weights for the two methods were similar.

In contrast, the tubers from the low density transplanted plants were larger in size than in the tuber planting plants, because the tuber number were similar between the two methods.

3.3.2 Flowering pattern

Flowering pattern per plant differed among densities and among planting methods (Figure 3.3.1). For transplanted plants, the first flowers of the two highest densities (0.2 and 0.3 m square spacings) appeared 55 days after transplanting (19 January 1996), Flowering pattern in transplanted dahlias



Flowering pattern in tuber planting dahlias

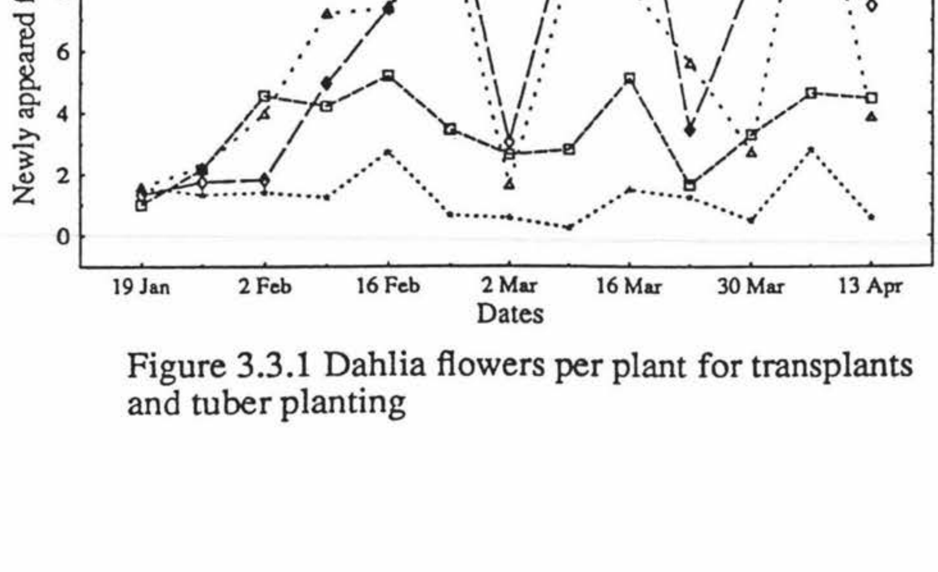
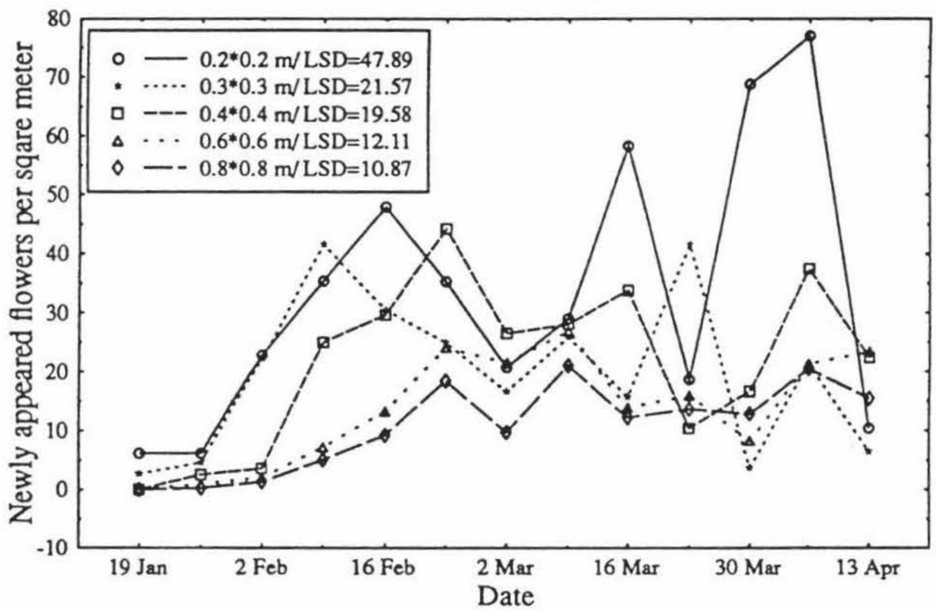


Figure 3.3.1 Dahlia flowers per plant for transplants and tuber planting

Flowering pattern in transplanted dahlias



Flowering pattern in tuber planting dahlias

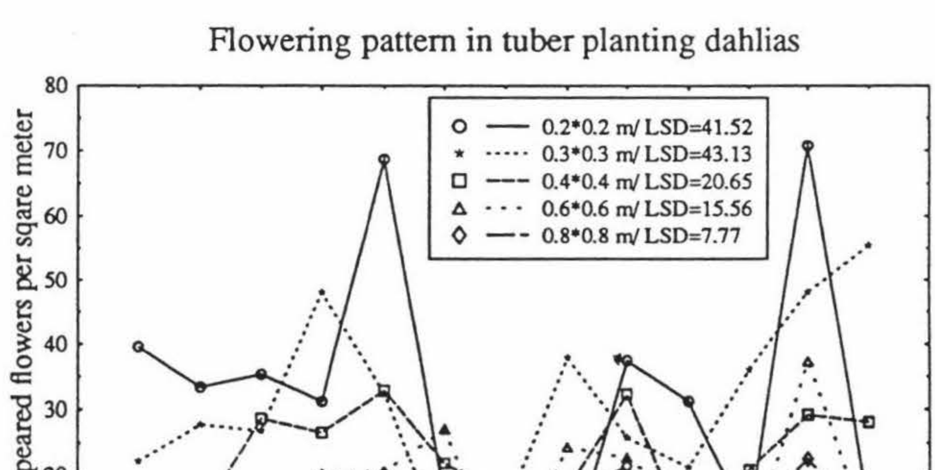


Figure 3.3.2 Dahlia flowers per square meter for transplants and tuber planting

while the first flowers of the three lower densities (0.4, 0.6 and 0.8 m square spacings) occurred one week to two weeks later. There appeared to be three flowing peaks in the lowest density (0.8 m square spacing), but they did not differ significantly. The maximum number of flowers per plant was recorded 89 days after transplanting for this spacing. There were two flowering peaks in the 0.6 m square spacing. The first started from 89 to 103 days after transplanting and the second started from 132 days after transplanting. Two flowering peaks also occurred at 89 and 132 days after transplanting in the 0.4 m square spacing. There were also two flowering peaks in the 0.3 m square spacing which occurred 75 and 118 days after transplanting. Two flowering peaks occurred 82 and 132 days after transplanting in the highest density (0.2 m square spacing).

For the tuber planting (Figure 3.3.1), the first flowers of the two highest densities (0.2, 0.3 m square spacings) appeared 72 days (12 January 1996) after planting, while the first flowers of the three lower densities (0.4, 0.6 and 0.8 m square spacings) occurred one week later than two highest density and on the same date (19 January 1996) as the two highest densities (0.2 and 0.3 m square spacings) of the transplanted dahlias. Three flowering peaks occurred in the 0.8 and 0.6 m square spacings after 114, 135 and 156 days after planting and 114, 128 and 156 days after planting respectively. There were two flowering peaks in the 0.4 m square spacing, the first of which occurred 107 days after tuber planting, and the second 156 days after planting. In the 0.3 m square spacing, the first flowering peak occurred 100 days after tuber planting and the second started from 128 days after planting. Three flowering peaks occurred in the 0.2 square spacing. They occurred 107, 135 and 156 days after tuber planting (Figure 3.3.1).

Though tubers were planted 24 days earlier and the first flower of tuber-raised plants appeared one week earlier than for transplanted seedlings , the dates of the first flowering peaks of the two planting methods were the same in the two lowest densities (23 January 1996) and in the two highest densities (9 January for 0.3 m square spacing and 16 January for 0.2 m square spacing). The first flowering peak in the 0.4 m square spacing was delayed one to two weeks in transplanted dahlias compared with tuber planting (Figure 3.3.1).

The flowering patterns per square meter were different from the flowering pattern per plant (Figure 3.3.2). Three flowering peaks for flowers per square meter of transplanted dahlias in the 0.8 m square spacing occurred 89, 103 and 132 days after transplanting, but there was no significant difference between these three points. In the 0.6 and 0.4 m square spacings, like flower pattern per plant, transplanted dahlias had two flowering peaks which occurred 103 and 132 days after transplanting (Figure 3.3.2). The 0.2 m square spacing had three flowering peaks, one of which occurred 110 days after transplanting and was a hidden peak in the flowering pattern per plant (Figure 3.3.1). For the 0.3 square spacing, flowering pattern per square meter was the same as flowering pattern per plant.

Flowering peaks per square meter for the tuber plants at all 5 densities were the same as flowering peaks per plant (Figure 3.3.1 and 3.3.2). From Figure 3.3.2, it is clear that there were many more flowers per square meter at the higher densities (0.2 and 0.3 m square spacings) than lower densities (0.4, 0.6 and 0.8 m square spacings).

3.3.3 Seed yield and yield components

3.3.3.1 The selective harvest

3.3.3.1.1 The effect of density on yield and yield components

Seed yield and yield components for the selective harvest differed significantly among densities (Table 3.3.3). Only the seed number per seedhead showed an interaction between establishment method and density (Table 3.3.5).

The yield per square meter for the 0.3 m square spacing (15.97 g/m^2) was significantly higher than three of the other four densities (Table 3.3.3), but did not differ from the 0.4 m square spacing. Yield per plant was greatest for the 0.8 m square spacing, but did not differ from the 0.6 m square spacing (4.32 and 3.32 g/plant respectively) (Table 3.3.3). The yield per plant for the other three densities did not differ significantly.

Yield components also differed with density. Branches per plant decreased as density increased, with the exception that branches did not differ between the two highest densities (Table 3.3.3). However the total seedheads per branch did not follow this pattern, as they did not differ for the 0.3, 0.6 and 0.8 m square spacings, but were greater at these spacings than at the other two densities. Effective seedheads per branch were 2.33 and 2.0 in the 0.8 and 0.6 m square spacings, and were significantly greater than the 1.44, 1.08, 0.97 in the 0.3, 0.4 and 0.2 m square spacings respectively (Table 3.3.3).

The total seedheads per plant and effective seedheads per plant also decreased as plant density increased because there were more branches per plant in low densities. The total and effective seedheads per plant for the 0.8 m square spacing were the highest at 138.7 and 123.6 respectively (Table 3.3.3) following by the 0.6 m square spacing (100.25 and 85.74 respectively); the lowest were at the 0.4, 0.3 and 0.2 m square spacings (41.45, 26.04; 26.04, 15.21; and 12.58, 7.58 respectively (Table 3.3.3)).

Thousand seed weight (TSW) also differed slightly among densities (Table 3.3.3). The lowest TSW (5.04 g) occurred at the highest density while the highest TSW (6.56 g) occurred at the 0.6 m square spacing, but this did not differ from the 0.8 or 0.3 m square spacing.

Density also affected the percentage of effective seedheads (Table 3.3.3). The 0.8 and 0.6 m square spacing had a significantly higher percentage of effective seedheads (89.3 and 81.7%) than the other three densities (60.79%, 59.8% and 59.4%) (Table 3.3.3).

3.3.3.1.2 The effect of establishment method on yield and yield components

Yield per plant and per square meter did not differ significantly between the two

Table 3.3.3 The effect of plant density on seed yield and yield components for the selective harvest

Density	[2]Yield (g/m^2)	[2]Yield/ plant (g)	Branches /plant	Seedheads /branch	[3]EFseed head/ branch	Seedheads /plant	[3]EFseed head/ plant	[3]%EFseed- head	TSW (g)
0.2X0.2	10.02b[1]	0.397c	7.9d	1.61b	0.97b	12.58d	7.6c	59.4b	4.93c
0.3X0.3	15.97a	1.435c	11.5d	2.38a	1.44b	26.04cd	15.2c	59.8b	6.4ab
0.4X0.4	11.15ab	1.782bc	23.8c	1.743b	1.08b	41.45c	26.0c	60.79b	5.59bc
0.6X0.6	9.23b	3.321ab	41.5b	2.39a	2.0a	100.25b	85.7b	81.7a	6.56a
0.8X0.8	6.74b	4.321a	53.1a	2.61a	2.33a	138.71a	123.6a	89.3a	5.93ab

1. Values with the same letter in the same column do not differ significantly at $P \leq 0.05$.
2. Yield per plant and yield per square meter were calculated from row data. Therefore, the yield per plant and per square meter calculated from means of yield components could be slightly different.
3 EFseedhead: those seedheads containing at least one seed.

stablishment methods. However, seedheads per plant, effective seedheads per plant, eedheads per branch, effective seedheads per branch and seed number per seedhead vere significantly greater from the tuber than the seedling establishment (Table 3.3.4), vhile the reverse was the case for thousand seed weight. Because the seed number per seedhead was affected by an interaction between establishment method and density, it will be presented as part of the interaction.

There were more seedheads and effective seedheads per plant from the tuber planting method (71.66, 59.96) than from transplanted plants (59.94, 43.3) (Table 3.3.4), as well as for the total seedheads and effective seedheads per branch, because there was no difference in branches per plant between them.

Table 3.3.4 The effect of establishment method on seed yield components

Establishment Method	Transplanted plants	Tuber planting
Seedheads/plant	55.94b*	71.66a
**EFseedheads/plant	43.30b	59.96a
TSW (g)	6.47a	5.30b
Seedheads/branch	1.91b	2.39a
**EFSeedheads/branch	1.33b	1.79a

* Values with the same letter in the same row do not differ significantly at $P \leq 0.05$.
** EFseedhead: those seedheads containing at least one seed.

However, the transplanted plants had bigger seeds (TSW=6.47 g) than tuber planted plants (TSW=5.30 g) (Table 3.3.4).

3.3.3.1.3 Interaction effects

There was no interaction between planting methods and density for seed yield. Of the yield components, only seeds per effective seedhead showed a significant interactive effect between planting method and density (Table 3.3.5).

Table 3.3.5 The interaction effects between establishment method and plant density on yield components and vegetative growth

Establish-ment method	Spacing (m)	Seeds /EFseedhead	Tuber wt/ plant (g)	Tubers /plant
Tuber	0.2X0.2	13.59b*	121.2e	3.25c
	0.3X0.3	9.17bc	194.9de	4.75bc
	0.4X0.4	10.17bc	194.5de	7.50b
	0.6X0.6	8.27bc	326.1cd	7.42b
	0.8X0.8	6.72c	453.2c	12.7a
Transplant	0.2X0.2	13.46b	129.1e	6.08b
	0.3X0.3	27.71a	143.7e	5.33b
	0.4X0.4	16.31b	294.2d	7.33b
	0.6X0.6	4.75c	621.6b	12.50a
	0.8X0.8	4.33c	830.3a	10.50ab
LSD $\leq$ 0.05		8.37	135.6	3.01

* Values with the same letter in the same column do not differ significantly at $P \leq 0.05$.

In tuber planting, the highest density had significantly more seeds per effective seedhead than the lowest density, while the seed numbers per effective seedhead in the densities of 0.3, 0.4, 0.5, and 0.6 m square spacings were in the middle and did not differ significantly (Table 3.3.5). In transplanted plants, the highest number of seeds per effective seedhead (27.71) was for the 0.3 m square spacing. Also, the 0.2 and 0.3 m square spacings had more seeds per seedhead than the 0.6 and 0.8 m square spacings (Table 3.3.5).

The two establishment methods had a similar trend in that the higher densities had more seeds per seedhead than the lower densities. However, the 0.3 m square spacing unusually had the highest seed number per seedhead over all densities both for the transplanted plants and tuber planting (Table 3.3.5). The lower densities had fewer seeds per seed head in both planting methods (Table 3.3.5).

3.3.3.2 The non-selective harvest

3.3.3.2.1 The effect of plant density on yield and yield components

The yield per square meter and yield per plant differed significantly among densities for the non-selective harvest, but no interaction effects between establishment method and density were detected. Unlike in the selective harvest where the 0.3 m square spacing had the greatest yield per square meter (Table 3.3.3), the highest yield per square meter (12.6 g) in the non-selective harvest occurred at the 0.4 m square spacing rather than the 0.3 m square spacing (Table 3.3.6); and the lowest yield per square meter (3.395 g) occurred at the 0.2 m square spacing. However, yield per square meter among the three lower densities (0.4, 0.6 and 0.8 m square spacings), did not differ, and yield among the two highest densities (0.2 and 0.3 m square spacings) and the lowest density (0.8 m square spacing) also did not differ significantly.

The highest yield per plant (4.49 g) occurred at the 0.8 m square spacing, but this did not differ from the 0.6 m square spacing (Table 3.3.6). The 0.2 m square spacing had the lowest yield per plant (0.153 g) but the 0.3 m square spacing yield did not significantly differ from it (Table 3.3.6).

Like the selective harvest, all yield components showed significant differences among densities. The branch number per plant, total seedheads per plant and the percentage of effective seedheads were also affected by the interaction between density and establishment method, and are presented in the section on interactions.

Seedheads per branch did not differ with density, but seedheads per plant decreased as density increased. Effective seedheads per branch and plant also declined as plant

Table 3.3.6 The effect of plant density on seed yield and yield components for the non-selective harvest

Density	[2]Yield (g/m^2)	[2]Yield/ plant (g)	Seed-heads/ branch	[3]EFseed-heads/ branch	Seed-heads /plant	[3]EFseedheads/ plant	[3]EFseedhead %	Seeds/ seedhead	TSW (g)
0.2X0.2	3.953c[1]	0.153c	11.74a	0.52c	11.49d	3.44c	39.64c	11.74a	4.69b
0.3X0.3	6.634bc	0.595c	10.31a	1.05b	28.11c	11.86c	45.33c	10.31a	5.00b
0.4X0.4	12.306a	1.966b	8.36a	2.01a	40.58c	35.65b	88.16a	8.36a	6.15a
0.6X0.6	11.294ab	4.061a	10.75a	1.7a	84.03b	60.44a	72.88b	10.75a	6.47a
0.8X0.8	7.01abc	4.492a	9.37a	1.74a	110.34a	77.56a	69.97b	9.37a	6.27a

1. Values with the same letter in the same column do not differ significantly at $P \leq 0.05$.
2. Yield per plant and yield per square meter were calculated from row data. Therefore, the yield per plant and per square meter calculated from means of yield components could be slightly different.
3. EFseedhead: those seedheads containing at least one seed.

density increased, but seeds per seedhead did not differ (Table 3.3.6). The percentage of effective seedheads was significantly greater at the 0.4 m square spacing than for all other spacings, but did not differ for the 0.6 and 0.8 m square spacings, or the 0.2 and 0.3 m square spacings.

The greater TSWs occurred at the three lower densities (6.27, 6.47 and 6.25 g in the 0.8, 0.6, and 0.4 m square spacings respectively). TSWs at the two higher densities were smaller (5.0 and 4.69 g in the 0.3 and 0.2 m square spacing) (Table 3.3.6).

3.3.2.2 The effect of establishment method on yield and yield components

Only TSW and total seedheads per branch of all the seed yield components showed significant differences between the two establishment methods for the non-selective harvest. Just like the selective harvest, TSW was greater in transplanted plants (6.195 g) than in tuber plantings (5.23 g) (Table 3.3.7). Also, there were more seedheads per branch in the tuber planting (2.51) than in transplanted plants (2.01) (Table 3.3.7), but not seedheads per plant.

Table 3.3.7 Effect of establishment method on TSW and seedheads per branch

Establishment Method	TSW (g)	Seedheads/branch
Transplant	6.195a*	2.01b
Tuber	5.231b	2.51a

* Values with the same letter in the same column do not significantly differ at $P \leq 0.05$.

3.3.2.3 The interaction between establishment method and density

In the non-selective harvest, the total seedheads per plant, the percentage of effective seedheads and branch number per plant showed a significant interactive effect between density and planting method.

Table 3.3.8 The interaction between establishment method and plant density on some yield components for the non-selective harvest

Planting method	Density	% *EFseedhead	Seedheads/plant	Branches/plant
tuber	0.2X0.2	20.82e**	15.61de	7.81e
	0.3X0.3	51.64cd	30.00cd	11.31de
	0.4X0.4	88.57a	45.75c	20.63c
	0.6X0.6	67.24bc	93.75b	35.81b
	0.8X0.8	72.74ab	95.06b	35.13b
transplant	0.2X0.2	58.46bcd	7.37e	5.41e
	0.3X0.3	39.03de	26.23cde	12.75d
	0.4X0.4	87.75a	35.4cd	15.35d
	0.6X0.6	78.51ab	74.3b	34.69b
	0.8X0.8	67.21bc	125.63a	54.5a
LSD ≤ 0.05		21.09	22.21	5.14

* EFseedhead: those seedheads containing at least one seed.
** Values with the same letter in the same column do not differ significantly at $P \leq 0.05$.

In transplanted plants or in tuber planting, the lower the density the more branches per plant there were. However, in the 0.8 m square spacing, transplanted plants had more branches per plant (54.5) than tuber planting (35.13). In the 0.4 m square spacing, tubers had more branches per plant (20.63) than in transplanted plants (15.35). In the two highest densities (0.2 and 0.3 m square spacings) and 0.6 m square spacing, the branch numbers per plant for the two establishment methods were similar (Table 3.3.8).

In transplanted plants, the 0.8 m square spacing had significantly higher branch numbers per plant (54.5) than the 0.6 m square spacing, while in the tuber planting, the 0.6 and 0.8 m square spacings had similar values (35.1 in the 0.8 m square spacing and 35.8 in the 0.6 square spacing) (Table 3.3.8).

Just like the branch number per plant, the lower the density, the more seedheads per plant there were in both establishment methods (Table 3.3.8). However, in the 0.8 m square spacing, the seedheads per plant in the transplanted plants (125.6) were significantly greater than that of the tuber planting (95.06) (Table 3.3.8), which may have resulted from more branches per plant in transplanted plants than in the plants from tubers, while the values for the rest of the densities for both establishment methods did not differ (Table 3.3.8).

Also, the lower the density, the higher the percentage of effective seedheads for the two establishment methods, with the exception that the highest number occurred at the 0.4 m square spacing (Table 3.3.8). However, there were no significant differences between the 0.4 and 0.8 m square spacings for the tuber planting, and between the 0.4 and 0.6 m square spacings for the transplanted plants. The percentage of effective seedheads for the three lower densities (0.4, 0.6 and 0.8 m square spacings) in both establishment methods were very similar (range from 67.2% to 88.6% (Table 3.3.8)), but the percentage for the highest density (0.2 m square spacing) was higher in transplanted plants (58.4%) than in the tuber planting (20.8%) (Table 3.3.8).

3.3.4 The effect of harvesting methods on seed yield

Machine harvest data should be treated with caution, because data for all treatments and replicates were not collected. The fact that only a portion of the seed threshed was being collected from the combine was not discovered until approximately two thirds of the samples had been fed into the combine, and therefore, these data had to be discarded. The machine harvest data in Table 3.3.9 are therefore not complete replicates for the treatments. The data show that selective hand harvest produced similar to or nearly double the yield of non-selective hand harvest, while major losses occurred following combine harvesting.

Table 3.3.9 Comparison of yield per plant in different harvest methods (g)

Harvesting methods	Machine*	Hand non-selective	Hand selective	Yield loss of machine comparing with non-selective
tuber 0.4X0.4 m	0.34	1.93	1.87	82%
tuber 0.3X0.3 m	0.15	0.49	1.08	69%
tuber 0.2X0.2 m	0.16	0.14	0.33	0%
transplant 0.6X0.6 m	0.76	4.35	2.33	82%
transplant 0.4X0.4	0.14	2.13	1.72	93%

* these data were calculated from only one to three replicates.

3.3.5 Maturity distribution of seedheads at harvest

Due to the different maturities among seedheads on the same plant, it was difficult to determine the overall seed moisture content (SMC) at harvest. Therefore, different colours of seedheads were collected and their seed moisture contents tested to make a SMC key to describe the profile of overall seed ripening on a plant at harvest.

Table 3.3.10 The moisture content of seedheads as presented in Appendix 4

Colours	green	striped brown	brown	dark brown	dark brown but shedding
SMC %	74.6	59.7	51.7	33.6	28.2

Five different coloured seedheads (Appendix 4) were collected and the seed moisture content tested. The seed moisture contents among the five different coloured seedheads differed significantly (Table 3.3.10).

3.3.5.1 The distribution of seedheads with different moisture content in a plant

Because the SMC of the dark brown and shedding brown seedheads were similar, they were classified together. Table 3.3.11 gives the general profile of the seedheads with different SMCs in a plant. For each treatment, the number of seedheads with different SMC within each branch position was similar (Table 3.3.11), which indicated that on the same type of branch, the ripeness of seedheads differed due to the position of each branch. While the primary branch had very young green seedheads, the secondary, tertiary, or even the quaternary branches, could have shedding brown seedheads (Table 3.3.11).

3.3.5.2 Ripeness of seedheads at harvest

Because the dark brown seedheads had nearly started shedding, the brown, dark brown and shedding brown seedheads whose SMCs were 51.7% or less were considered as ripe seedheads, while the striped brown and green seedheads whose SMC were 74.6% or higher were considered as unripe seedheads.

According to the observation of overall seedheads, it seemed that the higher densities ripened faster. Therefore, three harvests were conducted. The 0.2 and 0.3 m square spacings were harvested first on 16 April 1996; the 0.4 m square spacing was harvested one week later; and the 0.6 and 0.8 m square spacings were harvested three weeks after the first harvest.

The final results showed that plant density had an influence on the ripeness of seedheads in another way (Table 3.3.12). The lower densities had more ripe seedheads than the higher densities (Table 3.3.12 and Table 3.3.14). Establishment method did not affect the number or percentage of ripe seedheads (Table 3.3.14).

Therefore, the final results were the effect of harvest time and density. The percentage of ripe seedheads from the 0.2 and 0.3 m square spacings was slightly higher than from the 0.4 m square spacing (Table 3.3.12), although they were harvested one week earlier.

*Table 3.3.11 The number of seedheads with different SMCs in a plant**

treatment	branch position	Seed moisture content (%)			
		≥74.6%	59.7	51.7	33.6-28.2
Tuber 0.8X0.8 m	primary	0.5a	0.4a	3.9a	5.0a
	secondary	13.0a	5.6a	6.1a	5.9a
	tertiary	16.0a	3.5b	5.1b	3.1b
	quaternary	0.5a	0.4a	0.3a	0.1a
Tuber 0.6X0.6 m	primary	1.9b	2.2b	2.3b	7.3a
	secondary	4.1b	4.8b	7.3ab	12.1a
	tertiary	7.3a	9.1a	5.1a	5.6a
	quaternary	2.8a	2.0ab	0.6ab	0.8b
Tuber 0.4X0.4 m	primary	6.6a	2.0b	1.9b	4.3ab
	secondary	12.4a	5.6b	1.0c	1.5c
	tertiary	2.8a	1.0b	0.0b	0.0b
Tuber 0.3X0.3 m	primary	4.9a	1.9b	4.3a	4.3a
	secondary	7.9a	2.8b	2.2b	0.4c
Tuber 0.2X0.2 m	primary	4.7a	0.6c	1.1c	2.2b
	secondary	2.5a	0.8b	0.3b	0.3b
Transplant 0.8X0.8 m	primary	4.9b	5.4b	5.7b	13.9a
	secondary	15.6ab	14.8b	6.1c	21.8a
	tertiary	9.1a	5.8ab	2.8b	4.2b
	quaternary	0.3a	0.2a	0.0a	0.0a
Transplant 0.6X0.6 m	primary	5.1ab	5.4ab	3.4b	10.3a
	secondary	9.6a	7.4a	6.1a	11.8a
	tertiary	3.3a	1.4a	1.1a	1.1a
Transplant 0.4X0.4 m	primary	9.0a	5.3b	3.0b	4.4b
	secondary	6.1a	2.6b	0.4c	0.9c
Transplant 0.3X0.3 m	primary	5.6a	4.5ab	2.8b	2.5bc
	secondary	3.2a	2.3ab	0.8b	0.0c
Transplant 0.2X0.2 m	primary	3.2a	0.9b	0.9b	0.7bc
	secondary	0.5a	0.0a	0.0a	0.0a

* Values with the same letter in the same row are not significantly different at $P \leq 0.05$.

Table 3.3.12 The effect of plant density on seedhead ripeness

Treatment (m square)	Seedhead number		The percentage of seedheads	
	Ripe	Unripe	Ripe	Unripe
0.2	2.7	6.6	30.2c	69.8a
0.3	8.5	16.1	33.6bc	66.4ab
0.4	8.7	26.4	24.9c	75.1a
0.6	37.2	33.1	55.3a	44.7c
0.8	41.9	51.3	48.1ab	52.bc

* Values with the same letter in the same column do not differ significantly at $P \leq 0.05$.

Table 3.3.13 The effect of establishment methods on seedhead ripeness

SMC %	ripe number	ripe(%)	unripe number	unripe(%)
Transplant	20.8a	38.7a	26.0a	61.3a
Tuber	18.8a	35.1a	27.4a	61.8a

* Values with the same letter in the same column do not differ significantly at $P \leq 0.05$.

Also, the percentage of ripe seedhead for the 0.6 m square spacing was slightly higher than for the 0.8 m square spacing, when they were harvested at the same time. However, establishment method did affect seedhead ripeness (Table 3.3.13).

Based on plant structure, the profile of seedhead ripeness in different positions on a plant is presented in table 3.3.15. On primary branches, there were mostly more ripe seedheads than unripe seedheads. However, on secondary or lower level branches, the ripe seedheads were either less than or similar to unripe seedheads.

While more ripe seedheads were found on lower class branches, the number of unripe seedheads on lower branches was not as low as expected. This suggested that although the uniformity of seedhead ripeness could be reduced by improving uniformity of branching through pinching, the seedhead position in one branch also has a great influence on the uniformity of ripeness.

Table 3.3.14 The number and percentage of ripe seedheads per plant at harvest

Treatments		Seedhead number		Percentage of seedheads which were	
		Ripe	Unripe	Ripe	Unripe
Transplant	0.2	1.62	4.66	30.62	69.37
	0.3	5.79	14.74	28.76	71.23
	0.4	8.65	22.35	27.75	72.24
	0.6	33.63	32.19	55.05	44.94
	0.8	54.3	56.06	51.16	48.84
Tuber	0.2	3.8	8.49	29.75	70.24
	0.3	11.12	17.5	38.4	61.59
	0.4	8.69	30.38	22.1	77.91
	0.6	40.81	34.06	55.56	44.44
	0.8	29.5	46.5	44.94	55.05

Table 3.3.15 The distribution of seedhead ripeness in a plant

treatment	branch position	Number of seedheads	
		ripe	unripe
tuber 0.8X0.8 m	primary	8.9	7.6
	secondary	12.0	18.6
	tertiary	8.2	19.5
	quaternary	0.4	0.9
tuber 0.6X0.6 m	primary	9.6	4.1
	secondary	19.3	8.9
	tertiary	10.8	16.4
	quaternary	4.1	4.1
tuber 0.4X0.4 m	primary	6.2	8.6
	secondary	2.5	18.0
	tertiary	0.3	3.8
tuber 0.3X0.3 m	primary	8.6	6.8
	secondary	2.6	10.7
tuber 0.2X0.2 m	primary	3.2	5.4
	secondary	0.6	3.2
transplant 0.8X0.8 m	primary	19.6	10.3
	secondary	27.8	30.4
	tertiary	6.9	14.9
	quaternary	0.8	0.5
transplant 0.6X0.6 m	primary	13.6	10.4
	secondary	17.9	17.0
	tertiary	2.1	4.8
transplant 0.4X0.4 m	primary	7.4	14.3
	secondary	1.4	8.6
	tertiary	3.0	7.8
transplant 0.3X0.3 m	primary	5.2	10.0
	secondary	0.8	5.4
transplant 0.2X0.2 m	primary	1.6	4.2
	secondary	0.0	0.5

3.4 Discussion

3.4.1 The effect of plant density

3.4.1.1 The effect of plant density on flowering

The flowering period lasted for almost three months for both establishment methods. The transplanted plants appeared to have three flowering peaks in the lowest densities, and two flowering peaks in the rest of densities, but data variation may have accounted for this. However, for both transplanted plants and tuber planting, the date of the first flowering peak was delayed one to two weeks with decreases in densities, and for tuber planting, the date the first flower opened was also delayed one week in the two lowest densities. The reduced inter-plant competition for the larger spacings would provide plants with a better nutrient situation, thus resulting in better vegetative development and delaying reproductive growth. Plants at lower densities were more variable in their branching and continued producing branches later than plants at higher densities. Therefore, the flowering peaks at the lower densities would be delayed by the later branching.

More than one flowering peak of all treatments in this study indicated non-uniformity of flowering that supports the finding by Phetpradap[1] (1992), who observed two flowering peaks.

3.4.1.2 The effect of plant density on vegetative growth

Density had not affected plant height at the first flowering peak but by final harvest, plant height had increased as density decreased. Plants at the lower densities had sufficient nutrients and space to keep developing, which resulted in taller plants and more branches per plant. Larger spacings would reduce the inter-plant competition for nutrients, water and light, and also increase ventilation. As well as plant height and branch numbers, the dry weight of above ground plant parts, tuber number and tuber weight were also greater in lower densities than in higher densities. These results are similar to those reported for many other crops, such as china aster (Phetpradap[2], 1992), and pigeonpea (Satpute and Khare, 1992). Choudhary (1989) reported that for dahlias, increasing branch number per plant increased tubers per plant.

Tuber number and tuber fresh weight per plant were also influenced by the interaction between density and establishment methods. The greater number but smaller size of tubers at the highest density in transplanted dahlias than in tuber-raised plants could have been caused by more underground room in transplanted plants than in tuber planting early in the plants' development. The tubers planted at high density were so close that there was insufficient room for them to produce more tubers, and instead, developing the existing tubers would be a priority. However, the transplanted plants in the high density had relatively more room to develop more tubers, rather than to develop individual tuber size.

Bigger tubers were developed from transplanted dahlias at the lowest density than from tuber-raised plants. This was probably associated with the better vegetative growth of transplanted dahlias than for tuber plantings at the low density as indicated by taller plants and more branches per plant. As already noted, Choudhary (1989) showed that branches pe plant exerted the greatest direct effect on tuber production per plant.

3.4.1.3 The effect of plant density on seed yield and yield components

3.4.1.3.1 The effect of plant density on seed yield per plant and yield per square meter

Yield per square meter and yield per plant had similar trends for both the selective and non-selective harvests. The highest yield per square meter occurred at intermediate densities (0.4 m square spacing for the non-selective harvest and 0.3 m square spacing for the selective harvest). There were no significant yield per square meter difference among the rest of densities except that between the 0.2 and 0.6 m square spacings for the non-selective harvest. Too low a density will always produce a low yield per square meter (Roychoudhury, 1991; Phetpradap[2], 1992; Chanda *et al,* 1994,). Likewise, too high a density will also produce a low seed yield per unit area. This yield response is very similar to studies in many other crops, in which the yield per square meter response to density is always a parabolic pattern (Bianco, 1981; Nedic, 1987). The number of seedheads was the most important seed yield component. The seedheads per branch did not differ significantly among densities and the effective seedheads per branch did not differ significantly either among the three lowest densities. The highest density of the three lowest densities would have produced more branches per square meter than other two lower densities, thus producing more seedheads per square meter and higher seed yield per square meter.

The yield per plant increased with decreasing density for both the selective and non-selective harvests. The highest yield per plant occurred at the lowest density (4.9 g/plant), but this did not significantly differ from the yield for the 0.6 m square spacing. However, at densities higher than this, yield per plant dropped significantly. The significant reduction of branches per plant and seedheads per plant at the higher densities would have caused the yield drop. This response has also been reported in china aster (Phetpradap[2], 1992) and sunflower (Almeida *et al,* 1994).

3.4.1.3.2 The effect of plant density on seedheads per plant

Plants at lower densities had more seedheads in both the selective and non-selective harvests. Seedheads per plant are the main contributor to the yield per plant of dahlia (Phetpradap[1], 1992). In crops such as mungbean (Panwar, 1987) and chinese broad bean (Graf and Rowland, 1987), the number of pods per plant was also the most sensitive yield component to plant density.

Seedheads per plant were affected by an interaction between establishment method and density in the non-selective harvest. The greater number of seedheads per plant at the lowest density (0.8 m square spacing) in transplanted plants than in the tuber planting at the same density occurred because there were more branches per plant in transplanted plants. Seedheads per plant for the other densities for both establishment methods were similar because there was little difference in branches per plant between the two establishment methods.

The higher the density was, the more empty seedheads there were. There are several possible reasons for this. First, the higher densities would have had a higher humidity, which favours fungal attack of plants (Vis, 1980, Still, 1982). Many black seedheads which were apparently fungi-infected were observed, although a fungicide was applied during anthesis. Second, a low population of bees (Leslie and Leonard, 1954) could be another reason for empty seedheads. The flowers at higher densities tended to be hidden from bees by crowded branches and other flowers. Bees could not reach these hidden flowers, and thus pollination was reduced. Therefore, individual seedheads would be either pollinated by bees, or not pollinated at all, thus resulting in some seedheads with many seeds and some empty seedheads. Third, the competition for sunlight and nutrients was probably severe at higher densities, and this may have affected seedhead fertility.

However, in the non-selective harvest, the percentage of effective seedheads at the highest density was greater in transplanted plants than in tuber-raised plants, although the reason for this is not known. The transplanted plants had fewer seedheads, but half of them contained at least one seed compared with only 20% for the tuber raised plants. Whether this was a pollination problem or a disease problem was not determined. The highest percentages of effective seedheads for both establishment methods occurred at intermediate density (0.4 m square spacing) although it was close to the values of the two lowest densities. At the 0.4 m square spacing, nearly 90% of the seedheads present contained seed, indicating that pollination at this density was not a problem.

3.4.1.3.3 The effect of plant density on seed number per seedhead

Seed numbers per seedhead in the three higher densities were significantly higher than those in the two lower densities for the selective harvest. This result is very different from some previous studies in crops, such as China aster (Phetpradap[2], 1992), and sunflower (Rizzardi, 1993), where fewer seeds per seedhead were recorded at higher densities. However, in mungbean Panwar (1987) reported that the number of seeds per pod increased with increasing plant density, which is similar to the results in this experiment. This may be explained via several reasons. The seedheads at the higher densities had either many seeds (in the effective seedheads) or some (empty seedheads) had no seed at all, and were not therefore, considered as effective seedheads. There were very few seedheads with intermediate seed numbers. This would make the mean seed number per effective seedhead higher. When conducting the non-selective harvest, the seedhead maturity at lower densities was not as uniform as that of the higher densities. Therefore, in the low densities, there were a large number of young seedheads containing only one or two seeds, and some over-ripe seedheads which had shattered, and this would have reduced the mean seed number per seedhead. The plant structure at low density was very loose, and some horizontal and shorter branches at lower parts of the plant may have been covered by upper branches, which would also reduce the number of bees pollinating, thus reducing seed number per seedhead. Also, the flower number per square meter was much greater in the higher densities than in the lower densities, and thus plants in higher densities may have attracted more bees.

However, the seed numbers per seedhead at different densities did not significantly differ for the non-selective harvest. This may be explained as follows: at the selective harvest, all seedheads were harvested without losing seeds, whereas, in the non-selective harvest, due to the faster ripening at higher densities, seed shattering was in some cases severe, while there were few seeds shattered at the low densities because of later ripening. Also non-mature seedheads containing only one or two seeds which were found at the low density did not occur at higher densities in the non-selective harvest.

The seed number per effective seedhead was also influenced by an interaction between establishment method and density for the selective harvest. Apart from the fact that higher densities had more seeds per effective seedhead than lower densities for both establishment methods, the number of seeds per seedhead at the 0.3 m square spacing in transplanted plants was unusually higher than the other densities. This is most likely a result of sampling error, as in a hybrid population, randomly selecting only three plants might well have produced biased results.

3.4.1.3.4 The effect of plant density on TSW

The differences in TSWs among densities in the selective harvest were not as clear as in the non-selective harvest. For the selective harvest, only the highest density showed a reduction in TSW while there was no significant difference among the rest of the densities. For the non-selective harvest, the three lower densities had significantly higher TSWs than the two higher densities. The time of the non-selective harvests conducted was delayed for lower densities. Therefore, the delayed harvest time in the non-selective harvest would have enlarged the TSWs differences among densities. Also, too high a density would have resulted in smaller seeds due to severe intra-plant competition, a result also reported for china aster by Phetpradap[2] (1992).

3.4.2 The effect of establishment methods

3.4.2.1 The effect of establishment methods on vegetative growth

Although establishment method did not affect the dry weight of the plant above ground, fresh tuber weight and plant height in transplanted plants were significantly greater than those in tuber-raised plants. This result differed from the statement of Still (1982) who considered that dahlias grown from tubers were larger than those produced from seeds.

Because several shoots appear in a short space of time from tubers, they do not exhibit the main stem dominance which occurred in transplanted plants. Because they had only one main stem, the latter had more tertiary or lower classes of branches than tuber-raised plants and the highest point of the plant was usually the top of the last or the last but one class of branch. However, the greater tuber growth in transplanted plants than in tuber-raised plants seemed unusual. It is reported that tuber formation is promoted by short days, low temperature (Konishi and Inaba 1966; Brøndum and Heins, 1993), and abscisic acid (ABA), but is inhibited by gibberellin (GA) (Biran *et al*, 1974). However, no reports on the effect of establishment method on their formation were found. There was no interaction for establishment methods and branches per plant, but this may have been associated with the greater tuber number.

3.4.2.2 The effect of establishment methods on flowering

At the beginning of flowering, there were more flowers per plant on tuber-raised plants than in transplanted plants. However, the overall flowering patterns for the two establishment methods were similar, and the time of peak flowering was similar, even though tubers were planted 24 days earlier than seedlings. This is because in dahlia, daylength is the environmental signal regulating flower initiation (Mastalerz, 1976). Therefore, plant age or size was not a factor influencing flower initiation in dahlias (Mastalerz, 1976).

3.4.2.3 The effect of establishment methods on yield and yield components

Establishment method played a much less important role than density on seed yield and yield components in this experiment. It did not significantly affect the yield pe plant or yield per square meter, but did affect some yield components. Tuber-raised plants had more seedheads and effective seedheads per branch and per plant. In transplanted plants, more developed tubers could compete for nutrients with aerial parts; while in tuber-raised plants, the mother tubers could provide some nutrition and fewer tubers would reduce the competition. Thus, tuber-raised plants had a few more seedheads per plant, but a lower TSW than transplanted plants. This could be because the sink competition was more severe in tuber-raised plants due to more seedheads per branch which resulted in more seeds per branch.

3.4.3 The effect of harvest methods on seed yield

Differences in yield per plant among densities in the non-selective harvest were greater than in the selective harvest. The two lowest densities in the two harvests had similar yields while the higher densities had different yields at both harvests. This is probably because only a few seedheads were selectively harvested in the selective harvest at the low densities before conducting the non-selective harvest, and both harvests would have had similar number of seedhead per plant. For the higher densities, because of fungal infection and shattering which resulted from faster ripening, fewer seedheads per plant were present for the non-selective harvest than for the selective harvest.

3.4.4 Seedhead ripeness

Seedhead ripeness was influenced by branch position, and seedhead position, as well as because the flowering time at each position differed. Dahlia seedheads need 33 days from first flower opening to reach seed physiological maturity, and seed can usually remain in the seedhead for a further 9 days before seed shedding begins (Phetpradap[1], 1992). That means seedheads should be harvested 42 days after flower opening.

However, as the total flowering period lasted for almost three months, it is not possible to delay harvest until the last seedhead ripens. Thus, Phetpradap[1] (1992) suggested that seedheads could be harvested when 80% of the seedheads were ripe. He found that 80% of the seedheads were formed between two flowering peaks, thus indicating that around 42 days after the middle of the two flowering peaks would be the harvest time.

In this experiment, the middle of the two flowering peaks at the 0.2 and 0.3 m square spacings was around 95 days after transplanting in transplanted plants and 115 days after tuber planting. Harvest was conducted on 16 April, 1996, which was 143 days after transplanting and 167 days after tuber planting. These dates were 48 days after the middle of the two flowering peaks for transplanted plants, and 52 days for the tuber planting. The 0.4 m square spacing was harvested on 23 April 1996, 45 days after the middle of the two flowering peaks in transplanted plants and 37 days after the middle of the two flowering peaks for the tuber planting. Because there were more than two flowering peaks for the 0.6 and 0.8 m square spacings, the middle of the first and last flowering peaks was used, meaning plots were harvested on 7 May, 1996, 54 days after the middle of the flowering peak in transplanted plants, and 50 days after the middle of the flowering peaks in tuber-raised plants.

Therefore, the harvesting times were close to the recommendation of Phetpradap[1] (1992). The low percentage of ripe seedheads at the highest densities may have been because over-ripe seedheads had been shed. Because the total number sampled was so small, a very few seedheads dropping would cause a big change in the percentage.

CHAPTER 4
SOWING DATE TRIAL

4.1 Introduction

Dahlia seeds can be sown from spring to early summer (Bodman and Hughes, 1986). However, the plant's growth, flowering and seed production are greatly influenced by sowing date (Armitage, 1983; Samant and Das, 1990). For example, dahlia seedlings could be raised by seed sowing from July to October in India. Plants raised from seeds sown in July produced the tallest plants with the most leaves per plant but plants raised by sowing seeds in September produced the highest seed yield (Samant and Das, 1990). Sowing date can affect not only the temperature which will greatly influence seed germination, but also further plant development and harvest time. For example, dahlia flowering duration is shortened by later sowing (Armitage, 1983; Hong and Jeong, 1988). Many bulb seeds also require a period of cold to break dormancy (stratification) to ensure germination in the spring, producing growth and the gaining of strength after germination (Bryan, 1989).

The high temperature and low humidity from February to June in India inhibited dahlia seed germination (Samant and Das, 1990), but flower development proceeds more slowly and flowering is delayed at a lower night temperatures (below 10°C) (Rünger and Cockshull, 1985). Temperature can also influence tuber dormancy. More than 40 days at a temperature of 0°C breaks dormancy and allows sprouting to proceed when tubers are placed under warmer conditions (Rünger and Cockshull, 1985).

The objective of this experiment was to investigate the feasibility of direct sowing of dahlia seed for seed production, and to examine the effect of sowing date on seed yield.

4.2 MATERIALS AND METHODS

4.2.1 Seed and the land preparation of trial site

Seeds of clone 55/3 of the 'F' series were used (for information about the seed source, see Section 3.2.2). The field trial was conducted at the Frewen's block, Massey University. The site and land preparation have been described in Section 3.2.1

4.2.2 Pre-sowing quality assessments

Germination test:

In order to examine the quality and dormancy of the seeds which would be used in the sowing trial, a pre-sowing germination test with and without dormancy breaking was carried out using the top of paper method as prescribed in the ISTA Rules (ISTA, 1993).

Pre-sowing germination test: Four replicates of 50 seeds were placed on moist blotting paper pads in plastic boxes at 20°C. Normal seedlings (ISTA, 1993) present were removed after 4 days and then every two days until the final assessment at 21 days.

It was assumed that dahlia seeds needed to experience a period of low temperature to break dormancy, because most bulbous plants have a dormant period brought about by prevailing growing conditions, such as heat and dryness of summer (Bryan, 1989). Therefore, four replicates of 50 seeds were placed on moist blotting paper pads in plastic boxes at 5°C for 4 days, prior to transfer to 20°C for germination for up to 21 days.

Tetrazolium test:

The tetrazolium test was chosen to determine the viability of the seeds, in the event that the cold treatment did not break the dormancy. Four replicates of 50 seeds were allowed to slowly imbibe between paper at 20°C overnight. The seedcoats were then cut with a scalpel, and sliced seeds were put in 1% 2,3,5-triphenyl tetrazolium chloride solution for 12 hours at 25°C. Finally, seedcoats were removed and the seed colour and staining pattern were visually examined (ISTA, 1985) to determine seed viability.

4.2.3 Seed sowing and crop management

Four replicates of 50 seeds were sown by hand at a depth of 1-2 cm at four sowing dates, 7 November, 21 November, 5 December and 19 December, 1995. The seedlings were thinned to a density of 0.15 X 0.15 m at the two pair leaf stage. Weeding by push-hoe and hand was conducted when required. Dahlias sown on 7 and 21 November 1995 were harvested on 20 May 1996, and dahlias sown on 5 and 19 December 1995 were harvested on 25 May, 1996. At harvest, all seedheads present were hand-picked, and then dried in a glasshouse under ambient conditions at the Seed Technology Centre, Massey University for three weeks. After drying, seedheads were hand-threshed and the seeds hand-cleaned.

4.2.4 Data collection:

Morphological records were made at different plant development stages, i.e. the time to five pairs of leaves, time to first flower bud, time to first and peak flowering. Six plants were harvested for each replicate to estimate seed yield and yield components including seedheads per plant, seed number per plant and thousand seed weight. The seed yields per plant were all adjusted to 0% moisture content. Tuber number and fresh weight per plant, plant height, and branches per plant were also recorded at harvest.

4.3 Results

4.3.1 Germination

The TZ test indicated that 71% of the seeds were viable, but the highest germination obtained was only 49%. Pre-chilling did not improve germination. For three of the four sowings, field emergence was similar to the laboratory germination, but the emergence for the second sowing was significantly reduced (Table 4.3.1).

Sowing date had no great effect on seedling emergence (Table 4.3.2), with all sowings reaching 50% emergence between 11 - 14 days after sowing. The time for plants to

[1]Table 4.3.1 Initial seed quality (TZ and pre-sowing germination test) and field emergence for the different sowing dates

Initial seed quality (%)			Field emergence (%)			
TZ[2]	Pre-[3] Chill	Normal[3] Germ	7/11	22/11	5/12	19/12
71	49a	46ab	39ab	26c	41ab	35.5ab

1. Numbers with same letters in the same row are not significantly different.
2. % Viable seeds. 3. % normal seedlings with (pre-chill) and without dormancy breaking.

develop 5 pairs of true leaves was shorter in later sowings than earlier sowings (Table 4.3.2), and ranged from 56 days at the earliest sowing to 40 days at the third sowing. First flower bud formation occurred between 50 to 69 days after sowing depending on sowing date. The two middle sowing dates (21 November and 5 December, 1995) had the shortest time to bud formation after seed sowing (55 and 50 days respectively) (Table 4.3.2); while the earliest (7 November) and latest (19 December) sowings took longer to form flower buds after sowing.

Table 4.3.2 The effect of sowing date on dahlia plant development

Sowing date	7 Nov	21 Nov	5 Dec	19 Dec
days to 50% emergence	11	13	12	14
days to reach 5 pairs of true leaves	56	53	40	42
days to first flower bud appearance	69	55	50	69

4.3.2 Vegetative growth

Plant height was greatest in plots from seed sown on 5 December (72.67 cm), and was least in plots from seed sown on 21 November (52.35 cm) (Table 4.3.3). The total branch number per plant was highest in the earliest sown plants (7 November, 13.4), and lowest in plants from seeds sown on 21 November (7.71). Total branch numbers at the two latest sowing dates were intermediate (Table 4.3.3). However, the highest number of primary branches per plant (7.9) occurred on plants from the sowing on 5 December while the lowest primary branch production occurred on plants from the sowing on 21 November. Plants from the earliest sowing had the highest numbers of secondary branches per plant, which may simply reflect the longer growth period allowing more development of secondary branches.

***Table 4.3.3 The effect of sowing dates on dahlia vegetative growth**

Sowing date	Height (cm)	Branches/plant			Tuber	
		Total	Primary	Secondary	Weight/ plant(g)	number /plant
7 Nov.	59.34b	13.4a	6.1bc	6.4a	296.49a	7.48a
21 Nov.	52.35c	7.7c	5.7c	2.0b	161.95b	6.24a
5 Dec.	72.67a	11.4b	7.9a	3.6b	303.09a	7.67a
19 Dec.	62.06b	9.9b	7.7ab	2.2b	310.21a	7.29a

* Within a column, numbers with same letters are not significantly different at $P \leq 0.05$.

Although tuber numbers per plant were similar irrespective of sowing date, tuber weight from the second sowing date (21 November) was significantly lower than for the others (Table 4.3.3).

4.3.3 Flowering pattern

The interval between the appearance of the first flower among the four sowing dates was similar to or closer than the original interval of sowing dates (two weeks) (Table 4.3.4). Plants from sowings on 21 November and 5 December started flowering at the same time which was two weeks after the flowering of plants sown on 7 November (Figure 4.3.1 and Table 4.3.4). However, the onset of flowering in plants from the latest sowing (19 December) was five weeks later than the earliest sowing and three weeks later than the two middle sowings (Figure 4.3.1 and Table 4.3.4). Peak flowering was

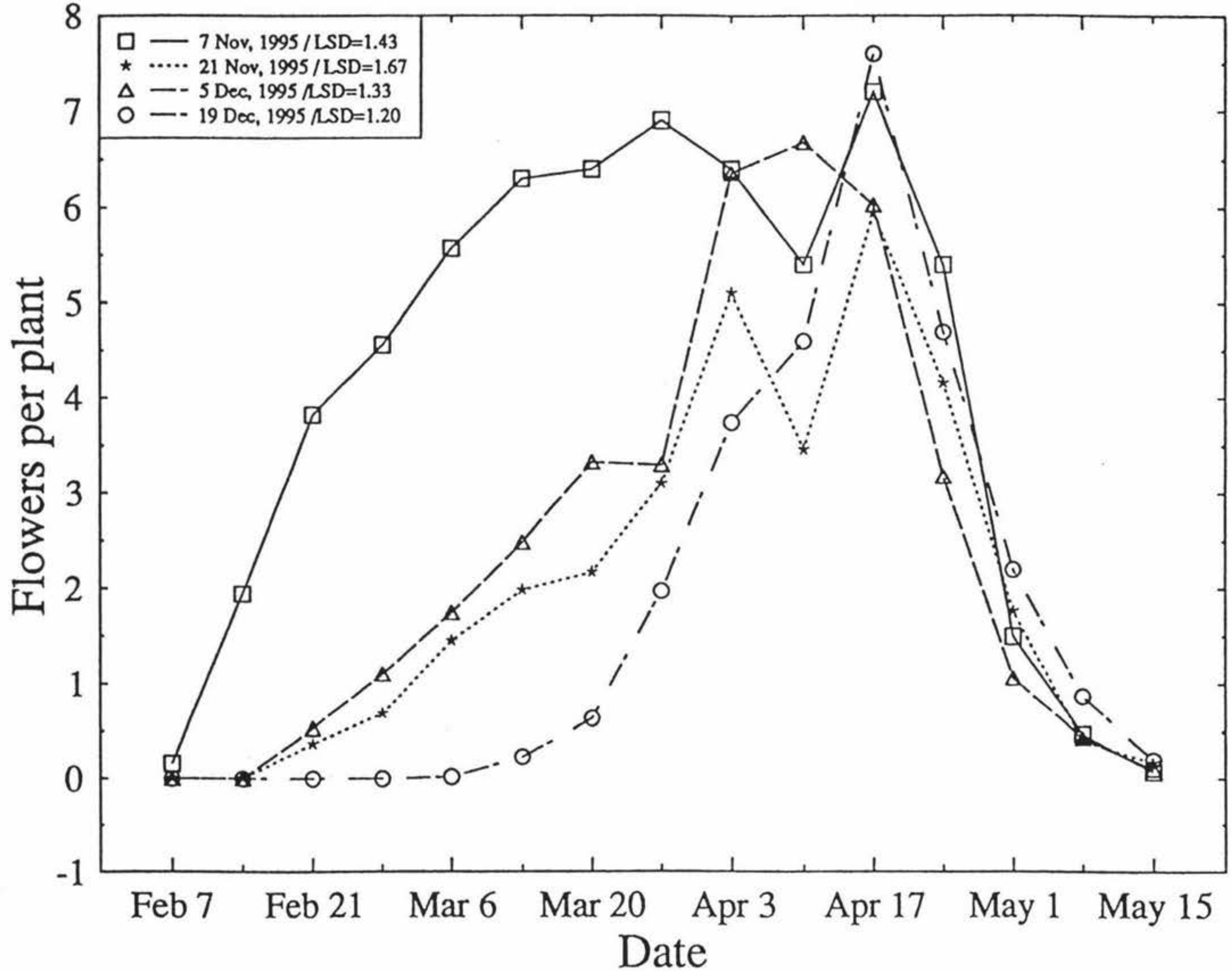


Figure 4.3.1 Flowering pattern for four sowing dates

delayed one week for each sowing date (Figure 4.3.1 and Table 4.3.4). The earlier sown dahlias (7 and 21 November) tended to have two peaks (Figure 4.3.1) which occurred at the same time (17 April). The interval of the two flowering peaks was three weeks for the 7 November sowing date, and two weeks for the 21 November sowing date (Figure 4.3.1 and Table 4.3.4).

The two latest sowings (5 and 19 Dec) had only one flowering peak (Figure 4.3.1) which occurred at the same time as the second flowering peak of the two earlier sowings (Table 4.3.4).

Flowering duration was shortened from 96 to 62 days with delayed sowing date (Figure 4.3.1 and Table 4.3.4).

Table 4.3.4 Effect of sowing date on dahlia flowering

Sowing date	Date of first flowering	Date of peak flowering	*Date of completion of flowering	Flowering duration
Nov 7	Feb 7	Mar 27, & Apr 17	May 15	96 days
Nov 21	Feb 21	Apr 3, & 17	May 15	82 days
Dec 5	Feb 21	Apr 10	May 15	82 days
Dec 19	Mar 13	Apr 17	May 15	62 days

* date of a severe frost.

4.3.4 Yield and yield components

Seed yield per plant (0.326 g) from the latest sowing (19 December) was significantly lower than that from the third sowing but did not differ from that of the first two sowing dates . No significant difference occurred in seed yield per plant between the first three sowing dates (Table 4.3.5). The total number of seedheads per plant was significantly higher for the first two sowings than from the next two sowings, with a

[1]Table 4.3.5 Effect of sowing date on dahlia seed yield and yield components

Sowing date	[2]Yield/ plant (g)	Total Seedheads /plant	[3]Effective seedheads /plant	% Effective seedheads	Seeds /effective seedhead	TSW (G)	SMC (%)
7 Nov.	0.653ab	25.34a	14.5a	57.6a	8.53b	5.4ab	59.5c
21 Nov.	0.605ab	19.17ab	10.3ab	54.7a	11.67ab	5.11ab	72.0a
5 Dec.	0.799a	16.92b	9.6ab	52.5a	15.49a	6.2a	64.75b
19 Dec.	0.326b	14.73b	7.65b	51.8a	8.53b	4.4b	74.0a
LSD $P \leq 0.05$	0.44	6.55	6.7	19.1	5.3	1.18	2.8

1. The values with the same letter in the same column mean no significant difference at $P \leq 0.05$.
2. Seed yields were all adjusted to 0 moisture content.
3. Effective seedhead: those seedheads containing at least one seed.

progressive reduction in seedheads per plant from 25 to 15 with delay in sowing date (Table 4.3.5). The number of effective seedheads per plant decreased (from 14.5 to 6.7) as sowing was delayed (Table 4.3.5). However, the effective seedheads as a percentage of total seedheads for the four sowing dates were similar, ranging from 52 to 57% (Table 4.3.5). The highest seed numbers per seedhead (15.49) occurred in the 5 December sowing, while the rest had similar numbers (Table 4.3.5). Except for the 19 December sowing, seed weight was relatively insensitive to sowing date (TSW ranged from 5.4 to 6.2 g) (Table 4.3.5). The 19 December sowing had a significantly lower TSW (4.4 g) than the 5 December sowing. Seed moisture content for the four sowing dates differed significantly at harvest (Table 4.3.5). This presumably reflected differences in the stage of seed development at harvest. Seeds from the early sowing dates (7 and 22 November) were harvested on the same day, but seed moisture content was significantly lower in plants from the 7 November sowing (59.5%) than from the 21 November sowing (72%). The same situation occurred at the second harvest, carried out 5 days later, i.e. the seed moisture content in plants sown on 5 December (64.8%) being significantly lower than from the 19 December sowing (74%) (Table 4.3.5).

4.4. Discussion

4.4.1 Germination and early growth of dahlia

The tetrazolium test indicated only 71% viability and this result confirmed that the quality of the seed lot was not high. However, the reason why 29% of the seeds were dead is not known. The difference between the TZ test and the maximum germination (46%) obtained suggested that dormancy was perhaps a problem. ISTA (1993) recommends pre-chilling as the dormancy breaking treatment for dahlia, but this treatment failed to improve germination. However, it is not possible to consider that dormancy was therefore not a problem, as other dormancy breaking methods were not applied. The fact that field emergence was generally similar to the gemination result obtained indicates that there was a factor or factors inhibiting greater germination, but exactly what this was could not be determined.

With the exception of the 21 November sowing, sowing date had no major effect on dahlia seed field emergence (Table 4.3.1). With this one exception, the results support work by Bodman and Hughes (1986), and Hong and Jeong (1988), which has shown that dahlias can be sown from spring to summer. However, the climate during seed germination has been shown to be important in affecting seedling emergence, with insufficient soil moisture, high temperature and low relative humidity resulting in poor crop establishment (Samant and Das, 1990). The rainfall and temperature conditions prevailing in the two weeks after seed sowing are shown in Appendix 5. Plants produced from seeds sown on 21 November received higher rainfall during the first two weeks after sowing than all other sowing dates but the latest one (Appendix 5), but they still had poorer establishment and poorer performance. The lower temperature from 21 November to early December (Appendix 5) may have inhibited seed germination and seedling growth, thus causing poor establishment. Very little rainfall during the period from 1 to 21 December (10 to 20 days after sowing) (Appendix 5) would had a strong negative effect on newly germinated seedlings from seeds sown on 21 November, which may also have caused poor performance.

Plant morphological changes were similar to those described in previous studies (Armitage, 1983; Hong and Jeong, 1988), the time between sowing and 5 pairs of leaves generally decreasing with later sowing dates. However, the latest sown dahlias (19 December) needed the same length of time as the earliest sown dahlias to form the first flower bud, although plants from the two middle sowing dates formed their first flower buds more than ten days earlier. This meant that there was a relatively later flower onset in plants from the latest sowing. The daylength from late November to late January in Palmerston North, New Zealand at these times is between 14.13 and 15.6 hours (Appendix 6). It has been shown that optimum day length for inflorescence formation in dahlia is between 12 and 14 hours and should not be longer than 16 hours or shorter than 8 hours (Mastalerz, 1976; Rünger and Cockshull, 1985). This suggests that daylength was not a limiting factor influencing the time of bud formation in this study. It seems more likely that temperature may be the factor influencing the time of bud formation. The temperature was about 13.7, 17.5, 18.0, 17.4, and 14.6°C in November, December 1995, January, February, and March 1996 (Appendix 5 and 6).

Although the earliest sown dahlias (7 November) experienced the high temperature months (December and January), low temperatures in November would inhibit the early growth of the plant, as indicated by the longer time to reach 5 pairs of true leaves, thus delaying flower bud formation. The latest sown (19 December) plants had only a short period of growth time in a high temperature month (January), and did not experience sufficient high temperature before temperature fell (e.g. March). Therefore, flower bud formation was delayed. The two middle sowings avoided the earlier low temperature month (November) and had sufficient accumulated temperature to form flower buds before temperature declined in March. This supports the research of Rünger and Cockshull (1985) who showed that the date of anthesis of the first flower became later as both day and night temperature were lowered.

4.4.2 Vegetative growth

Sowing date had no major effect on vegetative growth. Only the dahlias sown on 21 November, 1995 seemed not to grow as well as others, producing fewer branches per plant, smaller tubers and shorter plants. As mentioned above, poor establishment and poor early performance caused by lower temperature and lack of rainfall could have resulted in poor branching, smaller tubers and shorter plants.

4.4.3 Effect of sowing date on anthesis

Later sowing produced a shorter flowering duration, a situation previously reported by Hong (1988). There was only one flowering peak for the two later sowings, while the early sowings had two flowering peaks which supported the research of Phetpradap[1] (1992). Although the interval to the first flower production in the four sowing dates was shorter than the sowing date intervals, the shortened extent differed for the four sowing dates. The earlier the flower buds were formed, the earlier the onset of first flowering. Therefore, the plants of the two middle sowings began flowering at the same time, which was two weeks later than the earliest sown dahlias, and three weeks earlier than the latest sown dahlias. This was caused by different temperatures experienced by plants at the different sowing dates (Rünger and Cockshull, 1985).

Flower number fell more abruptly with the later sowings. Flowering for all four sowing dates was dramatically reduced after 1 May and had virtually stopped on 15 May because of the low temperature and the onset of frosts. These indicate that the sowing dates used may have been too late to allow all flowers to develop fully. The weather became cold and first frosts occurred before the complete development of seed.

4.4.4 Yield and yield components

More seedheads per plant were obtained from earlier sown plants. This is the major contributor to seed yield per plant. Also, the latest sown dahlias had significantly smaller seeds (TSW = 4.4 g) and higher seed moisture content (74%) (Table 4.3.4) at harvest. This indicates the seeds did not mature sufficiently at harvest time, although it was necessary to harvest plants on 20 and 25 May, 1996, after the first frost. Seed yield per plant ranged from 0.605 to 0.799 g in the first three sowing dates. These yields are higher than the yield of 0.52 g per plant obtained by Samant (1988). However, the latest sown dahlias had a reduced seed yield per plant compared with the 19 December sowing due to fewer seedheads per plant and immature smaller seeds.

4.5 Conclusion:

Sowing dates from 7 November to 19 December did not affect vegetative growth with the exception of the sowing on 21 November. However, morphological development was delayed with later sowing although the time from sowing to visible bud; from sowing to first flower; and flowering duration were shortened.

Seed yield was affected by sowing date. The latest sown dahlias (19 December) had the lowest yield per plant, while the seed yield of plants from the three earlier sowing dates did not differ significantly. Lower yield per plant in the latest sown dahlias resulted from fewer seedheads per plant, and from the fact that seed had not fully matured by harvest. This was reflected in lower TSW and higher seed moisture content. In order to avoid the problems of growth curtailment by early frosts, a sowing date in this environment might profitably be carried out in October.

CHAPTER 5
GENERAL DISCUSSION AND CONCLUSION

Dahlias are now one of the most popular bedding plants in many parts of the world (Mastalerz, 1976; Phetpradap[1], 1992; De Hertogh and Le Nard, 1993), being used as garden plants, borders, for back ground exhibitions, cut flowers and potted plants because of their remarkable diversity of form, colour and size, and long flowering season (Mastalerz, 1976; Phetpradap, 1992; De Hertogh and Le Nard, 1993). Countries such as the Netherlands, Japan, France, Great Britain, Italy, South Africa, the United States, Germany and Colombia produce many dahlias (Palacios, et al, 1979; De Hertogh and Le Nard, 1993).

Dahlias can be propagated by tuberous roots, plant cuttings or seeds to grow as bedding plants, garden plants, and cut flowers (Brondum and Heins, 1993). Propagation from seeds could simply be the cheapest and easiest. Although dahlia seeds can be sown from spring to early summer (Bodman and Hughes, 1986), the plant's growth, flowering and seed production are greatly influenced by sowing date (Armitage, 1983; Samant and Das, 1990). The sowing date trial showed the feasibility of direct sowing from late spring to early summer in Palmerston North, New Zealand. Direct-sowing is, therefore, recommended for dahlia seed production, because of its low cost, but only provided a genetically pure line is not required. Sowing dates from 7 November to 5 December did not affect seed yield. Only the latest sowing (19 December) produced a significant reduction in seed yield. Sowing date had no major effect on dahlia seed field emergence, which supported the work by Bodman and Hughes (1986), and Hong and Jeong (1988). The time between sowing and the production of five pairs of leaves, sowing and the first visible flower bud, and flower duration generally decreased with later sowing dates. This also agrees with the research of Armitage (1983) and Hong and Jeong (1988).

Seedheads per plant (the major contributor to seed yield per plant (Phetpradap[1], 1992)) were the lowest at the latest sowing, thus resulting in the lowest seed yield per plant.

Flower numbers at all sowing dates fell abruptly from the peak, indicated perhaps that all the sowing dates were too late to allow later produced flowers to develop fully. Plants from seed sown on 19 December were harvested on 20 May, 33 days after peak flowering. Low temperature in April and May would have reduced the seed maturation rate, and immature seeds, as indicated by their high SMC (74%) and low seed weight (TSW = 4.4 g) were obtained from the latest sowing. However, the earliest sowing was not early enough to avoid frost before harvest. Therefore, a sowing date no later than 7 November, which would produce more seedheads thus producing a higher seed yield, and avoid frost before harvest, is suggested.

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). Inappropriate application of herbicide may damage crops. Thirteen herbicides were evaluated for their safety for use as pre or post-emergence herbicides to direct sown or transplanted seedlings of dahlia. Due to the big variation in dat for tuber and seed yield which resulted from genetic variation, crop injury scoring was mainly used to evaluate herbicide toxicity.

As pre-emergence herbicides, oxadiazon (1.52 kg a.i/ha) oxyfluorfen (0.72 kg a.i/ha), simazine (1.0 kg a.i/ha), EPTC (4.32 kg a.i/ha), terbacil (0.96 kg a.i/ha) and oryzalin (4.5 kg a.i/ha) reduced the emergence of direct sown dahlias, or caused injury to the early growth of both direct sown and transplanted plants. Simazine and oxyfluorfen killed both transplanted and direct sown plants. Terbacil killed direct sown plants, but was safe for transplanted dahlias, as transplanted seedlings avoided the foliar and had relatively older, and stronger roots (Walton and Walton, 1993).

Alachlor (1.92 kg a.i/ha) chlorpropham (3.2 kg a.i/ha), chlorthal dimethyl (7.5 kg a.i/ha), pendimethalin (1.32 kg a.i/ha), methabenzthiazuron (1.05 kg a.i/ha) and trifluralin (1.2 kg a.i/ha) were generally safe for use as pre-emergence herbicides for both direct sown and transplanted dahlias, although methabenzthiazuron caused minor injury to early growth for both direct sown and transplanted dahlias. Terbacil was safe for use as a pre-emergence herbicide for transplanted dahlias, but not for direct sown dahlias. All these safe pre-emergence herbicides have a similar weed control spectrum

(Walton and Walton, 1993).

Of the six post-emergence herbicides used in this experiment, chlorpropham (3.2 kg a.i/ha) chlorthal dimethyl (7.5 kg a.i/ha) methabenzthiazuron (1.05 kg a.i/ha) and haloxfop (0.3 kg a.i/ha) were safe for both transplanted and direct sown dahlias, while oxyfluorfen (0.72 kg a.i/ha) injured both transplanted and direct sown dahlias, even killing some direct sown dahlias, and terbacil (0.96 kg a.i/ha) killed both direct sown and transplanted plants. The four safe post-emergence herbicides all had a similar weed control spectrum, with the exception that haloxfop only controls grasses (Walton and Walton, 1993).

It is recommended that alachlor be used as a pre-emergence herbicide, because it provides 6-8 weeks residual control of weeds, and then methabenzthiazuron be used as a post-emergence herbicide to control subsequent weeds.

The optimum plant density for dahlia seed production was at a 0.4 m square spacing. Density higher or lower may result in the loss of yield per unit area. Among the yield components, seedheads per plant contributed most to yield per plant, because through plant self-compensation, more branches per plant at the lower densities resulted in more seedheads. However, the lowest density (0.8 m square spacing) did not produce a significantly higher yield per plant than the 0.6 m square spacing, which suggests a limitation for self-compensation. The highest harvested yield per square meter (non-selective harvest) was obtained from the 0.4 m square spacing while the potential highest yield per square meter (selective harvest) was obtained from the 0.3 m square spacing. Even though there were more branches per unit area at the highest density, the reduced seedhead number per plant reduced the seedhead number per unit area whereas at the lowest density, there were fewer branches per unit area, which resulted in a smaller number of seedheads per unit area. Seed was slightly bigger at the lower density, and this may be the better quality seed although this was not determined.

Like many previous studies (Graf and Rowland, 1987; Panwar, 1987; Phetpradap[1], 1992; Phetpradap[2], 1992), lower density produced bigger plants, more and bigger tubers, more branches per plant and a longer duration of new branch appearance than higher density. Therefore, there were more flowers per plant and more seedheads per plant in lower densities than in higher densities. Thus lower density plants had a higher seed yield per plant than the plants at higher densities. Both the highest harvested (non-selective harvest) and potential (selective harvest) yields per plant were obtained from the lowest density, 0.8 m square spacing (4.92 and 4.32 g per plant). This is supported by research in china aster (Phetpradap[2], 1992), mungbean (Panwar, 1987), chinese broad bean (Graf and Rowland, 1987) and maize (Tetio, 1988) which all produced similar results.

Seed number per seedhead, however, was greater in the three higher densities than that in the two lower densities. This is very different from the results of Phetpradap[1] (1992), and for other crops such as china aster (Phetpradap[2], 1992) and sunflower (Rizzardi, 1993). Only mungbean (Panwar, 1987) was reported to have more seeds/pod with increasing plant density, which is similar to the results in this experiment. Lower densities also produced bigger seeds in this experiment. This is similar to china aster (Phetpradap[2], 1992), and many other crops. Due to the high humidity in the higher densities, which allows fungi to attack plants much easier (Vis, 1980; Still, 1982), and probably the competition for sunlight and nutrient at higher densities, there was a higher percentage of empty seedheads in the higher densities.

Seedhead ripeness was influenced by densities. The seedheads at the higher densities ripened faster and were harvested earlier. However, the real harvested results showed that the three higher densities (0.2, 0.3 and 0.4 m square spacings) had about 20% more unripened seedhead than the two lower densities (0.6 and 0.8 m square spacings). Since seedheads at all densities were harvested after 42 days from the middle of peak flowering, the fewer ripe seedheads at higher densities may have been caused by over ripened seedheads being shed.

No differences in yield per plant or yield per square meter were found between the two establishment methods, which suggests that there is no seed production advantage for tubers over transplanted seedlings. The transplanted seedlings raised from seeds did not perform much differently from plants from tubers. Since the sowing date trial demonstrated the feasibility of direct sowing, it is deduced that seed sowing at 0.3 or 0.4 m square spacings would be the optimum way for dahlia seed production.

However, some yield components were affected by the establishment method. Plants raised from tubers had more effective seedheads per branch, more total seedheads per plant and more effective seedheads per plant, but lower TSW. More seedheads per branch from tuber-raised plants produced more seeds per branch but they were smaller in size. This could be because the sink competition was more severe in tuber-raised plants than in transplanted plants.

The fresh tuber weight and plant height in transplanted plants were significantly higher than those in tuber-raised plants. Several shoots appearing in a short time in a tuber may inhibit the height of plant. It is reported that tuber formation is promoted by short days and low temperature (Konishi and Inaba, 1966; Barrett *et al*, 1978; Rünger and Cockshull, 1985), but there have been no reports on establishment method affecting tuber formation.

Dahlia is daylength sensitive, and plant age or size is not a factor influencing flower initiation in dahlias (Mastalerz, 1976). Therefore, no major effect of establishment on flower patten was seen in this experiment.

The present study showed that harvesting methods were extremely important. Hand harvesting and threshing are a relatively cheap method for small seed-lots (George, 1985). Machine harvest caused substantial seed yield loss in this experiment, although failure to check the threshing efficiency biased this result. Therefore, non-selective hand picking when 80% seedheads become brown (SMC ≈ 50%) is recommended. This is because although the selective harvest may yield more than a n-selective harvest, the increasing labour cost may not be compensated. Because there were insufficient data, the machine harvesting results are unreliable, but machine harvest would certainly cause yield loss. Moreover, the uneven ripeness of seedheads would cause a big problem for machine harvesting. The distribution of seedheads at different development stages as indicated by different SMCs at harvest was caused by the structure of plants. On the same class of branch, (i.e. primary, secondary or tertiary branch), seedheads with different SMCs ranging from 30% to 70% were almost evenly distributed. This is because the seedhead were formed at different times, although they were on the same branch. In the lower densities (0.4, 0.6 and 0.8 m square spacings), seedheads were mainly on secondary and tertiary branches, while in the higher densities (0.2, 0.3 m square spacings), seedheads were almost evenly spread on primary and secondary branches. At the two lower densities (0.6 and 0.8 m square spacings), primary branches had a few more low SMC seedheads than high SMC seedhead. This reflected in the seedhead's earlier ripeness, branches because the flowers formed earlier. In contrast, there were more higher SMC seedheads than lower SMC seedheads on primary and secondary branches at higher densities because the total unripe seedheads were greater at the higher densities. The reason for that may be as stated above, i.e. the over ripened seedhead falling. Therefore, machine harvest may not be as economic as hand-picking.

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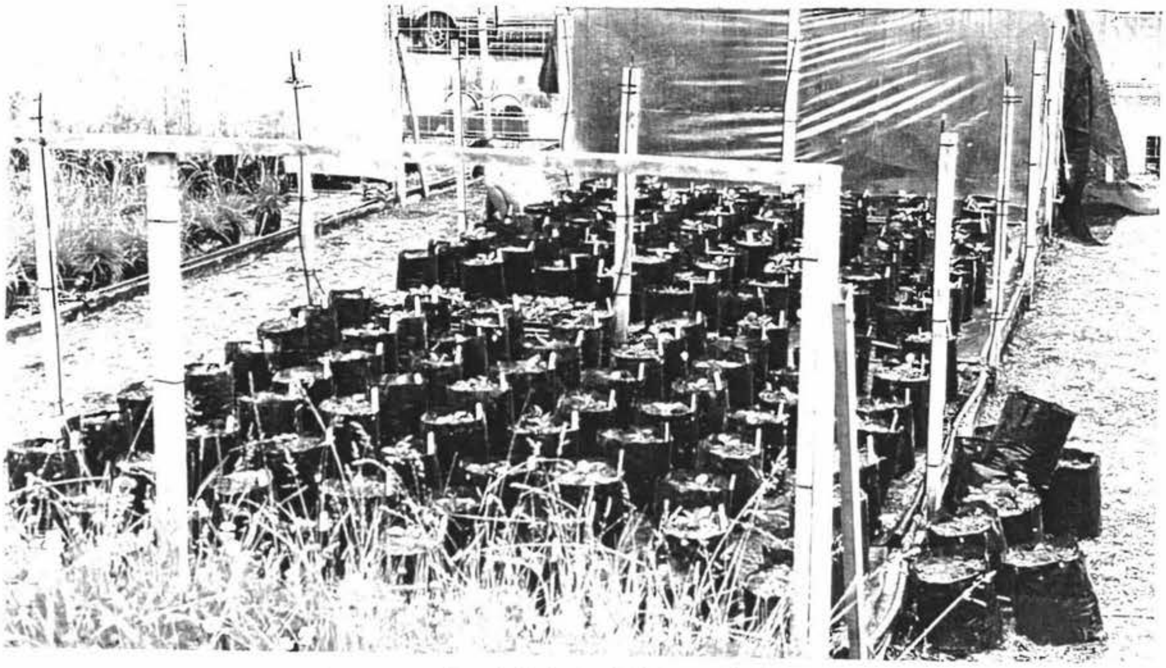
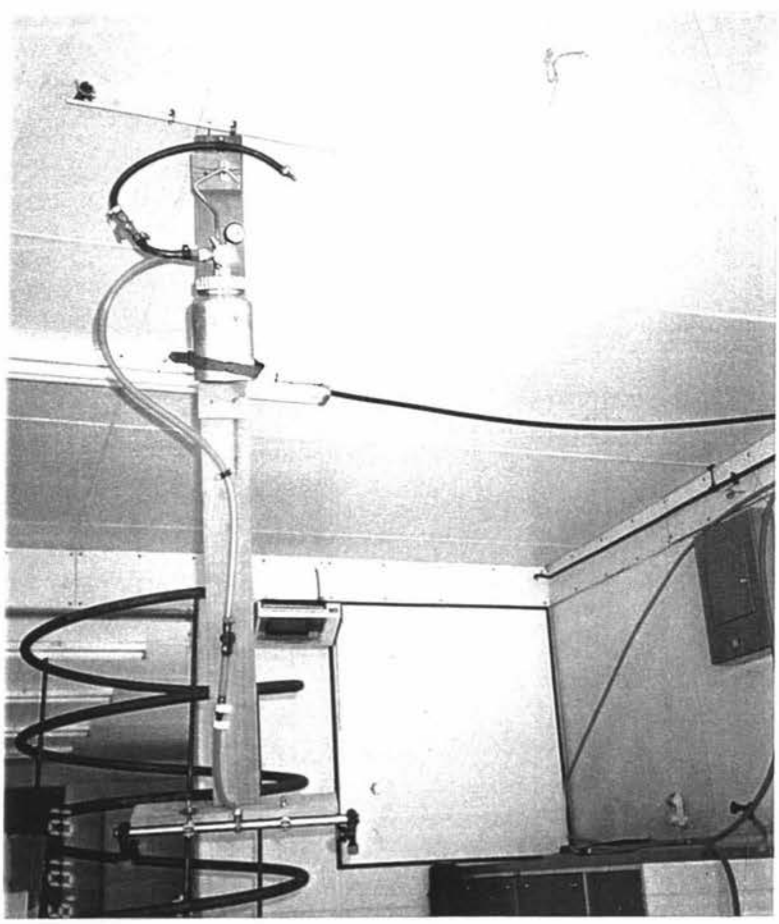
APPENDICES

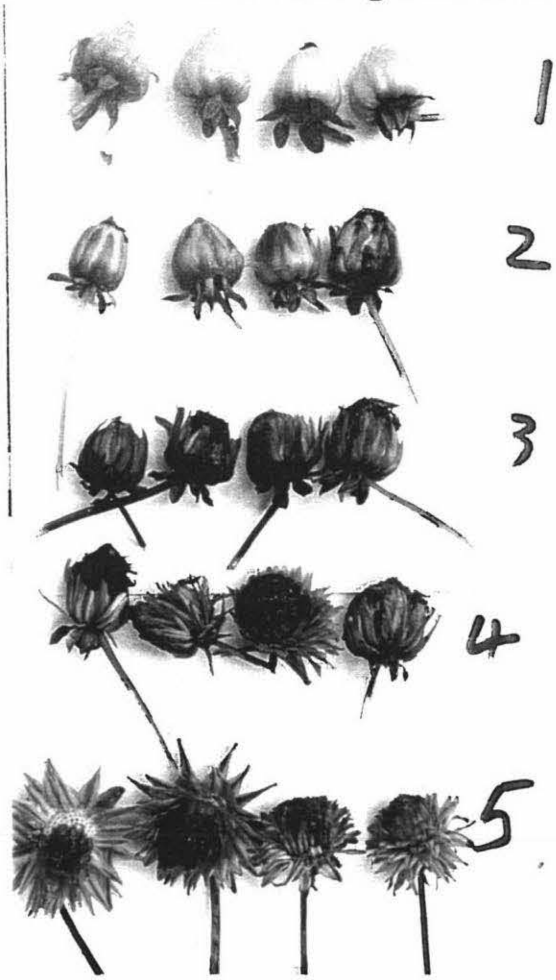


Appendix 1 Herbicide trial plots



Appendix 2 The pendulum swing sprayer

Appendix 3 The establishment method, density and sowing date trial plots



Appendix 4 Different development stages of dahlia seedheads

***Appendix 5. Rainfall and temperature records during the period of the four sowing dates**

Date	Rainfall (mm)	Temp °C			Date	Rainfall (mm)	Temp. °C		
		Mean	Max	Min			Mean	Max	Min
Nov 7	0	11.1	16	3	Dec 5	0	18.4	21	16
8	0	13.5	20	6	6	0	19.2	25	15
9	1.76	15.4	21	10	7	0	17.1	21	15
10	0.7	15.0	19	14	8	0	18.8	21	16
11	0.9	14.5	21	13	9	1.9	16.2	19	15
12	0	14.2	17	12	10	0	14.9	22	10
13	0	14.6	19	9	11	0	20.1	24	13
14	0	14.4	20	11	12	0	19.2	25	12
15	0	13.7	18	9	13	1.2	18.6	27	12
16	0	14.1	20	6	14	0.6	18.5	19	17
17	0	14.3	18	11	15	0	15.6	21	9
18	0	15.5	20	8	16	0	17.0	20	9
19	9.2	13.6	17	12	17	15.4	16.0	17	11
20	2.4	13.5	16	13	18	0	15.0	18	12
sum/ mean	14.96	14.1	18.6	9.6	sum/ mean	19.1	17.5	20.9	13
21	8.0	13.0	17	5	19	0	14.5	20	10
22	0	10.3	17	4	20	0	17.6	23	13
23	0	13.5	20	4	21	0	21.1	30	16
24	12.4	15.0	21	7	22	2.2	20.0	27	17
25	5.5	17.0	25	14	23	47	18.1	21	17
26	13.5	14.4	17	14	24	9.1	17.1	21	16
27	3.4	13.1	15	10	25	7.3	17.9	19	12
28	0	13.0	16	8	26	6.1	15.4	20	10
29	0	14.4	18	7	27	0.8	14.1	19	11
30	1.2	15.9	20	11	28	3.0	18.0	22	13
Dec.1	0	21	21	14	29	6.4	16.3	21	15
2	0	18.0	21	14	30	0	15.3	19	14
3	0	17.7	27	10	31	0	17.6	23	14
4	0	22.8	26	14	Jan.1	0	17.9	24	15
Sum/ mean	44	15.2	20.1	9.8	Sum/ mean	81.9	17.2	22.1	13.1

* Adapted from AG-RESEARCH GRASSLANDS AT 40.23° S, 175.37°E.

*Appendix 6 Climate Records

Month	Temperature °C			Day-length (hr.)	Rain-fall (mm)
	Mean	Maximum	Minimum		
1995 November	13.7	18.1	9.1	14.13	102.4
December	17.5	21.9	13.3	15.06	101.1
1996 January	18.0	23.0	14.6	14.55	50.5
February	17.4	22.8	13.8	13.54	128.7
March	14.6	20.0	10.6	12.02	79.1
April	14.8	19.0	11.6	11.13	160.4
May	10.4	15.0	7.0	10.00	114.6

* Adapted from AG-RESEARCH GRASSLANDS AT 40.23° S, 175.37° E.