SOME ASPECTS OF SEED PRODUCTION AND THE EVALUATION OF HERBICIDES FOR TUBER PRODUCTION OF THE HAMMETT 'FIGARO' SERIES SEMI-DWARF DAHLIA.

A thesis presented in partial fulfillment of the requirements for the degree of

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ABSTRACT

Seed yield and quality information was collected from 14 clones of a double flowering semi-dwarf (0.75-1m) bedding *Dahlia* series, bred by Dr Keith Hammett of Auckland, in the 1994-95 season at Palmerston North. Half-sib progeny were grown out to assess flower colour and doubleness in the 1995-96 season.

Seed yield (0.03-6.66g/plant) varied widely among the clones. Seed yield was affected more by the fertility of disc florets than by their number and so the highest seed production potential was likely to be maintained in clones of high bloom quality (degree of doubleness). Clones with yellow, orange or red flowers had greater fertility than clones with purple - magenta, white, or pale colours. This may well reflect a fertility-colour link related to the original hybridization of the garden *Dahlia* from two wild species. If such a link exists then careful manipulation of clonal ratios may be required to maintain a good overall balance of colours.

Maintaining seed quality required drying seed without delay, especially when seed was harvested under cooler conditions. Very low levels of primary dormancy were detected, but some clones produced seed which when germinated at a later date varied both in time to 50% germination (over six days) and spread of germination (over four days). This could have significant implications during plant establishment under nursery conditions, and dry storage or possibly a longer period of pre-chilling is suggested to reduce this variation. This requires further evaluation.

Oxyfluorfen, oxyfluorfen plus oryzalin, oxadiazon, and oxadiazon plus simazine herbicide treatments did not affect tuber yields and subsequent forced re-sprouting of seedling material under glasshouse conditions. Trifluralin and oryzalin reduced tuber yields, similar to the unweeded control. This was due to competition from inadequately controlled weeds, rather than any obvious toxic effects from these two herbicides. No visual phytotoxicity was observed in any of the treatments in either the initial growing season or the subsequent forced resprouting although the herbicides were not applied directly over the top of the plants.

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"To everything there is a season,
A time for every purpose under heaven:
A time to be born, And a time to die;
A time to plant,
And a time to pluck what is planted..."
Ecclesiastes 3:1-2 NKJV Bible

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1.1 INTRODUCTION

1.1.1 Botanical Background

The *Dahlia* is a member of the Compositae family, native to the mountains of Mexico and Central America, and consists of about 30 species of extremely diverse life forms. The common garden *Dahlia*, which has many forms, is a much cultivated hybrid, well known for its reliable, prolific, and extended flowering in a wide range of colours, sizes, and shapes.

The flower is actually a capitate inflorescence consisting of highly coloured ray florets ('petals') which are normally sterile, and disc florets (perfect or hermaphrodite flowers), although intermediate types do exist. Like many Compositae they are essentially self-sterile due to incompatibility mechanisms.

1.1.2 'F' Series Dahlias

In the 1950s and early 1960s, Royal Sluis Ltd, Netherlands started breeding bedding *Dahlias*, beginning with dwarf single and pompon types. The first cultivars introduced were in the 1970s with the 'Rigoletto' type, and ten years later, the 'Figaro' type was developed as an improvement (Veenstra, 1988).

Dr Keith Hammett a professional plant breeder in Auckland, New Zealand has been breeding and showing *Dahlias* for much of his life. Two of his most successful cultivars have been in the show class 'miniature decorative' up to 11.5cm (4.5in) in diameter category - 'Elizabeth Hammett' and 'Christine Hammett' which have won numerous national and international awards (Hammett, 1986a,b). In the mid-1980s, Dr Hammett began a breeding programme with Royal Sluis's Pink Figaro, which is widely regarded as being outstanding (Hobbs, 1990), together with six showpiece parents. The resultant 'F' or 'Figaro' series largely maintained a high quality double bloom on a shorter plant (up to 0.6m in height). This was mainly due to shorter internode length. A number of these, for example, 'Accolade' - a delightful white/ lilac decorative - have been selected for clonal propagation (Hooper, 1995). The 'F' series bloom shapes fall mainly into the ball, pompon, or decorative show classes (see Fig. 3).

1.1.3 Seed Production Investigations

In 1994, Dr Hammett approached the Massey University Seed Technology Centre expressing an interest in research being undertaken on the possibilities of *Dahlia* seed production. It was as a result of ensuing discussions that the work reported in this thesis was begun. Fourteen clones were used as the basis for an investigation into the seed production potential of this series, and each clone had seed yield and quality measurements detailed in the 1994-95 season. Measurements included: observations of insect visitation, seed head fertility, disc/ ray floret ratios, seed yields, germination, viability, sprouting damage, and speed and uniformity of glasshouse emergence.

Seed (half-sib lines) from ten of the 14 original clones was then grown out in the 1995-96 season to provide a measurement of the quality of plants which consumers would be growing, mainly in home gardens. The most important criteria are to maintain a high degree of inflorescence doubleness, and a good cross section of colours, as well as a dwarf and compact plant habit.

Partly as a result of this study and Han's (1996) further investigations, this series was trialled as a commercial seed line during the 1996-97 season.

Various examples of clones and seedlings are given on the next two pages as well as in Appendix 3.

Plate 1 - clone 7055/3 in mid-April showing a larger disc size due to the influence of decreasing daylengths.

Plate 2 - highly double red on a plant produced from a seedling in herbicide trial.

Plate 3 - baby pink of clone 7052/8.

Plate 4 - highly double yellow on a plant produced from a seedling in herbicide trial.

Plate 5 - clone 7075/3.

Plate 6 - clone 7052/11, since named 'Accolade'.

Plate 7 - looking across the herbicide trial - plants produced from seedlings.

Plate 8 - a general view of the clonal seed production site.

1.1.4 Herbicide Trials

As an adjunct to the seed production investigation a herbicide tolerance study was also conducted to determine whether a range of New Zealand available residual herbicides applied pre-emergence had any deleterious effects on tuber yield and subsequent resprouting ability. This work is reported in chapter two.

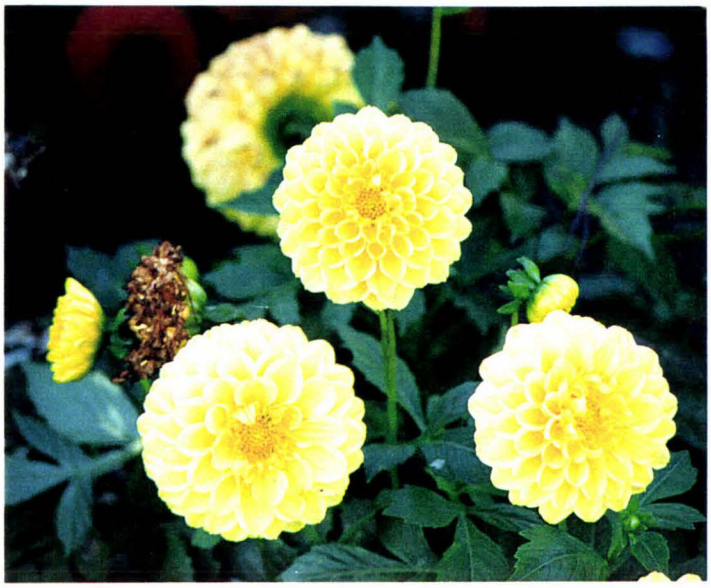


Plate 1

Plate 2

Plate 3

Plate 4

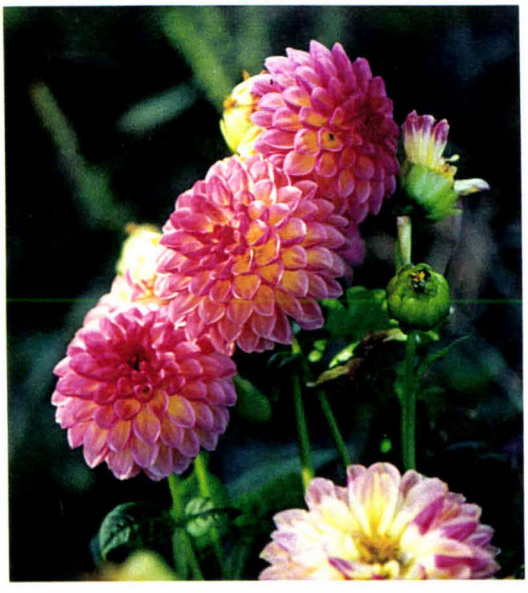


Plate 5

Plate 6

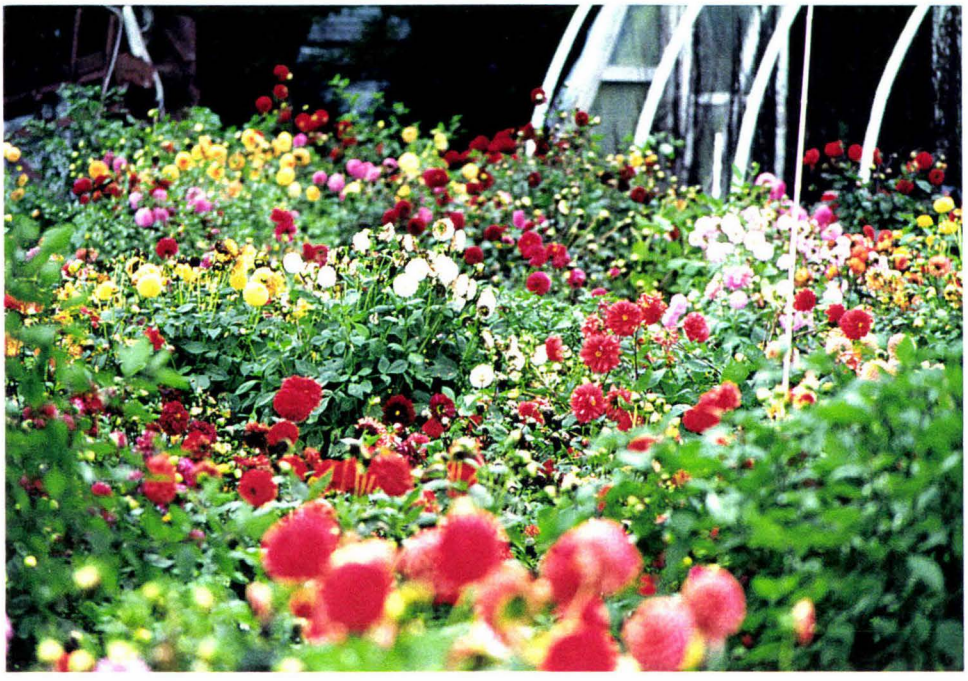


Plate 7: Seedling variation in the herbicide trial.

Plate 8: An over view of the clonal seed production site.

1.2 LITERATURE REVIEW

1.2.1 Introduction

This review will introduce the genus *Dahlia* and then expand on those aspects of seed production which are considered most relevant to the present study, e.g. pollination, flower doubleness, plant density, harvesting, processing, germination, and storage.

1.2.2 Compositae

The Compositae or Asteraceae is one of the largest families of flowering plants (Blackmore and Tootill, 1984) with about 1,100 currently accepted genera and 25,000 species. They are mainly herbaceous plants, usually with a taproot, and sometimes with tubers (Heywood, 1978). The familiar daisies, thistles and dandelions exemplify one of the most characteristic features of the Compositae, the head-like inflorescence - known as a capitulum - made up of numerous small individual flowers called florets, and surrounded by an involucre of protective bracts. The whole resembles a single flower, and is usually described as such by the layman; indeed, biologically it functions as a single flower. The central regular florets are collectively called the "disc" and the outer irregular florets are termed the "rays." The disc floret is usually bisexual (hermaphrodite) whereas the ray floret is usually pistillate or sterile (Heywood, 1978). The fruit is one-seeded, indehiscent, nearly always dry, and is termed a cypsela (a type of achene) due to its formation from an inferior ovary (Esau, 1977; Heywood, 1978; Blackmore and Tootill, 1984) and this also includes non-capillary tissue.

1.2.3 Heliantheae

Dahlia belong to one of the largest and most morphologically diverse tribes of the Composite - that of the Heliantheae (Stuessy, 1977). It includes approximately 250 genera, containing 4000 species distributed worldwide but mostly in the New World. For example *Coreopsis*, *Cosmos*, *Echinacea*, *Helianthus*, *Rudbeckia*, *Xanthium*, and *Zinnia* (Heywood, 1978).

1.2.4 Botanical Background

The genus *Dahlia* Cav. (Compositae, Heliantheae - Coreopsidinae) is composed of four sections, 27 species and four infraspecific taxa and is largely restricted to the highlands (1500-4300m elevation) of Mexico and Central America. Two species *D. coccinea* Cav.

and *D. imperialis* Roezl, are also found in some countries of South America where they are believed to have been introduced (Sorenson, 1969). The genus encompasses some extremely diverse life forms ranging from dwarfed perennial herbs scarcely over four decimetres tall (*D. scapigera* A. Dietr.), to huge arborescent plants which in some instances, grow to eight or nine metres (*D. imperialis*), to scrambling epiphytic vines which sprawl among the tree tops in rain forests (*D. macdougallii* Sheriff) . The great majority of the species have extremely restricted ranges, but one (*D. coccinea*) may be considered a roadside weed and is very wide-ranging throughout Mexico and Guatemala. A systematic treatment of the genus is given by Sorenson (1969). Some points are summarized as follows: they are perennial, herbaceous plants with a tuberous root system supporting stout, erect, branched stems (often hollow) bearing pinnate leaves in opposite pairs and terminal, brightly coloured, capitate inflorescences (Runger and Cockshull, 1985).

1.2.5 Inflorescence

The inflorescence can be loosely classified as either "single", in which an outer ring of coloured, showy florets surrounds a central disc of smaller, yellow florets; or "double", in which the coloured florets predominate (Runger and Cockshull, 1985). Each *Dahlia* "flower" is a capitate inflorescence consisting of a swollen receptacle carrying a few hundred florets, surrounded by individual bracts, the outer layer of which reflex during the later stages of flower bud development. As with other members of the Compositae, the individual inflorescence is a raceme while the flowering shoot as a whole is a cyme, with the oldest inflorescence terminating the growth of the main shoot (Runger and Cockshull, 1985).

The florets are generally of two types, though intermediate types do occur. Each floret arises in the axil of a receptacular bract. The outer ray florets are either neutral or pistillate sterile and the corolla is extended on one side to
form a coloured tongue or ligule (ray or "petal") (Runger and Cockshull, 1985). The rays are white or whitish lavender to deep purple or yellow to various shades of orange to deep blackish-scarlet (Sorenson, 1969). The central disc florets are hermaphrodite and have a symmetrical corolla divided into five teeth. The discs are normally yellow, but can be yellow with red or purple tips or the limb purple thoughout, and a range of 17-172 disc florets per head has been reported (Sorenson, 1969). The total number of

Fig. 1 Typical composite head cut vertically in half (from Porter, 1967).

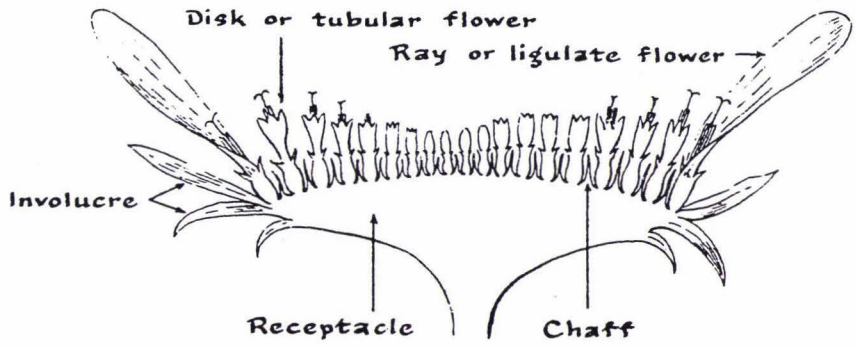
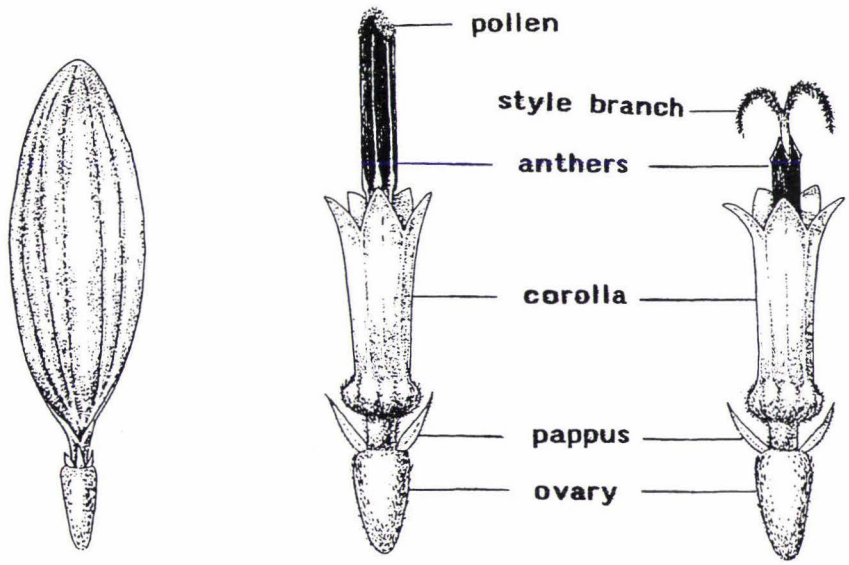


Fig. 2 Disc and Ray Florets of the Sunflower - similar to Dahlia - from Heiser, 1976. (Not to scale).



Ray Floret | Disc Floret Male Stage | Disc Floret Female Stage

florets formed on each capitulum varies among cultivars as does the proportion of ray to disc florets. Both attributes are also influenced by the environment. The total number of florets increases in long days (Maatsch and Runger, 1955; Konishi and Inaba, 1964) while the proportion of disc to ray florets increases in short days (Maatsch and Runger, 1955; Konishi and Inaba, 1964; Canham, 1969; Mastalerz, 1976; Durso and De Hertogh, 1977) which convert double inflorescences into more single or "daisy-eye" ones.

1.2.6 'Seed'

The achene (cypsela) is greyish-black to black at maturity and more or less linear to linear oblanceolate in shape (Sorenson, 1969). Pandey (1989), in describing the cypsela of a garden *Dahlia*, reported that the mature seed coat is composed of 3-4 layers of cells. The most significant feature of the pericarp is the presence of the phytomelanin layer which always develops between the hypodermis and fiber zones and acts as a protective covering around the embryo (against desiccation, insect predation, microbial attack, etc.). During seed development the endosperm is a compact tissue around the globular embryo. Soon after, the liquidation of the endosperm cells occurs and in a mature seed only the outermost layer persists. The mature embryo is straight and occupies the entire length of the seed. The hypodermal cells on the ventral side of the cotyledons elongate radially and form the palisade layer. The average size of the cypsela is 11 x 3.25mm, the average length of the embryo is 8.42mm, the hypocotyl - root axis 2.36mm and the cotyledons 6.06mm.

For the purpose of this study the cypsellas or achenes will be referred to as seeds in the remainder of this thesis.

1.2.7 Brief History

The *Dahlia* was first cultivated in Europe by Cavanilles, a senior member of the Royal Botanic Garden in Madrid. He received seed apparently of various *Dahlia* species from Vicente Cervantes, a botanist at the Mexican Botanic Gardens in Mexico City (Hammett, 1980). Cavanilles described and named *Dahlia pinnata* in 1791 honoring Andreas Dahl, a Swedish botanist and pupil of Linnaeus (the founder of modern plant classification). They had been used by the Aztecs (Huxley,1992). *Georgina* is sometimes used instead of *Dahlia*, especially in Scandinavia and the countries east of the Rhine, due to an early classification error (Sorenson, 1969).

Although some authors conclude that some hybridization had occurred before *Dahlia* introduction into Europe, Sorenson (1969), concluded from Cavanilles' description of only purple ligules (ray florets) that this had not happened. If it had occurred, ligule colours from white through light and dark purple to yellow, oranges and scarlet would have resulted. Sorenson, however, failed to consider whether any of the subsequent introductions into Europe, such as that by the famous Baron von Humboldt to Paris and

Berlin in 1804 had been hybridized. Lawrence (1970) argued convincingly on genetic grounds that the modern *Dahlia* is largely based on this second known importation. Hammett (1980) suggested the wide range of flower colour so early in the European story would be more easily explained if Humboldt's material was already hybridized.

From these various sources *Dahlias* quickly entered the horticultural trade throughout Europe (Hammett, 1980). The number of double-flowered and other forms rapidly increased. Howe (1936), as cited by Sorenson (1969) stated that in 1934 there were more than 14,000 named cultivars which had been produced in the past or were currently in the trade.

The formation of various national dahlia societies such as the American Dahlia Society in 1915 did much to stimulate interest in growing *Dahlias* and breeding new varieties, and in Europe, especially in England, Holland and France, enthusiasm remained high and skillful breeding resulted in great advancements (Everett, 1982). Huxley (1992) reported there are now 20,000 cultivars listed in the International Register of Dahlia names, in the keeping of the Royal Horticultural Society, which was appointed as the International Registration Authority (IRA) in 1966. The IRA has classified the *Dahlia* according to the morphology of the head and the flowers based on ten groups: single, anemone, collerette, waterlily or (nymphaea), decorative, ball, pompon, cactus, semi-cactus and miscellaneous. However, the American and the Central States Dahlia Societies use thirteen groups splitting the cactus and decorative divisions more finely (see Fig. 3). Further subdivisions are made on the basis of size (5) and colour (14) (see Table 1).

Today the *Dahlia* remains a popular garden plant in many parts of the world, both as a border and, increasingly, as a bedding plant. It is field grown for cut-flower production in Europe, Japan, North America (Runger and Cockshull, 1985) and Australia (Bodman and Hughes,1985) despite problems with a relatively short vase life (Roozen, 1980; Larson, 1980; Lukaszewska, 1980 and 1986; Bodman and Hughes, 1985; Swart, 1989). Recently the dwarf plants have been used as flowering pot plants (Veenstra, 1988).

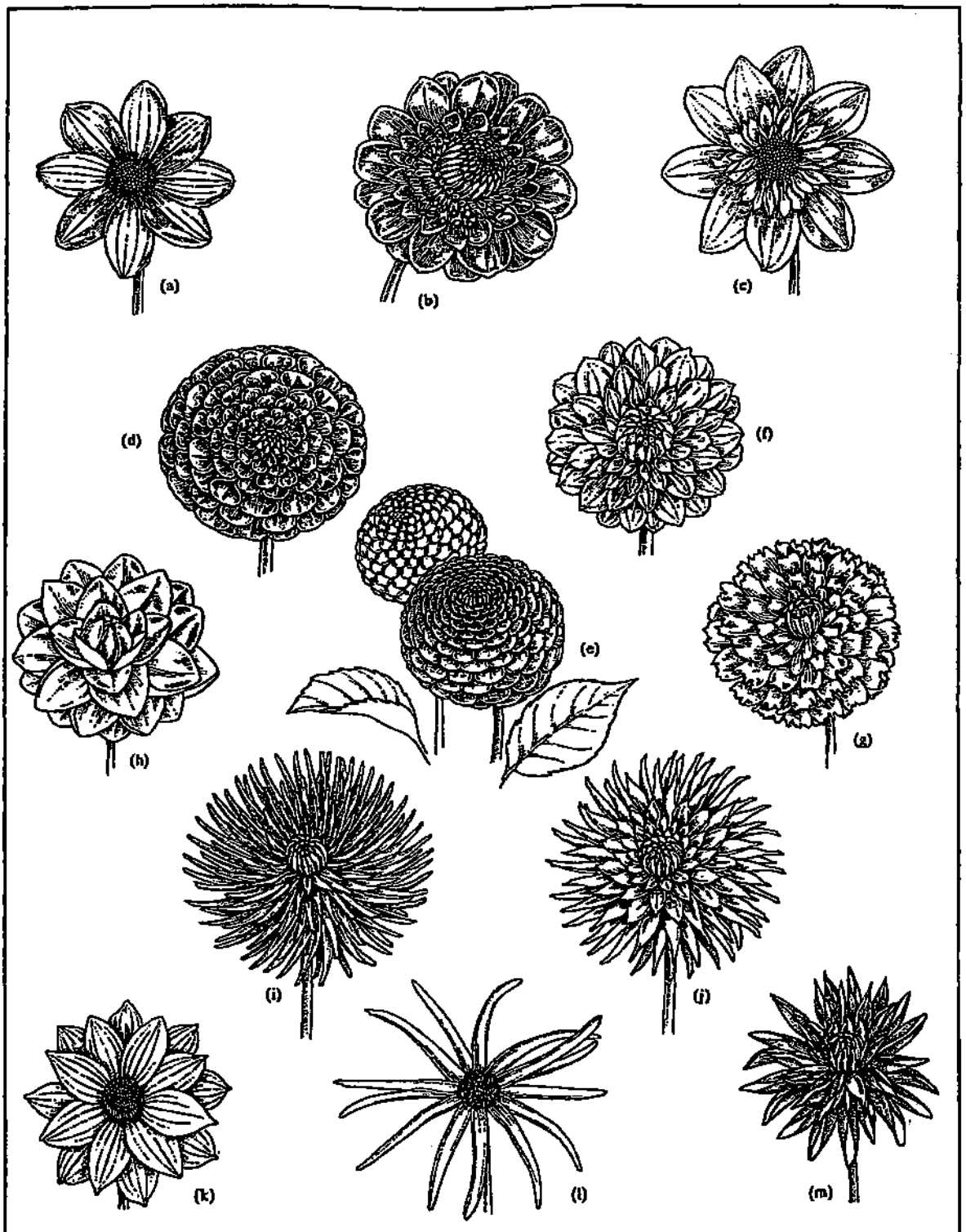


Fig. 3 Garden Dahlia forms: [a] Single [b] Anemone-centred [c] Collerette [d] Ball [e] Pompon [f] Decorative [g] Decorative (fimbriated) [h] Waterlily [i] Cactus [j] Semi-cactus [k] Peony-flowered [l] Star [m] Orchid-flowered (from Huxley, 1992).

Table 1 New Zealand colour groups compared with overseas groupings (from Hammett, 1990).

New Zealand	USA	Britain
1. White/ cream	01 White	1. White
2. Yellow	02 Yellow	2. Yellow
3. Bronze	03 Orange	3. Orange
	11 Bronze	4. Bronze
4. Pink	04 Pink	8.Light Pink
	05 Dark Pink	9. Dark Pink
5. Red	06 Red	5. Flame
	07 Dark Red	6. Red
	12 Flame	7. Dark Red
6. Lavender	08 Lavender	10. Lilac/ Lavender/ Mauve
7. Purple	09 Purple	11. Purples/ Wines/ Violets
8. Fancy	10 Light Blend	12. Blends
	13 Dark Blend	13. Bicoloured/ Variegated
	14 Variegated	
	15 Bicolour	

Blends = two or more colours intermingled.

Bicolour = ground colour tipped with another colour.

Variegated = several colours striped or splashed in one bloom (Huxley, 1992).

1.2.8 Dahlia Classification

The classification by the IRA based on the morphology of the head is not related to the botanical classification of the garden *Dahlia*. Various authors have used the names *D. pinnata*, *D. variabilis* or *D. hybrida* but the non-committal term *Dahlia* sp. (Cult.) is suggested as best (Sorenson, 1969; Hammett, 1980). The New Zealand Plant Variety Rights Journal refers to all Hammett *Dahlias* as *D. coccinea* x *D. pinnata* (Anon, 1995), but Sorenson (1969) is not in favor of this type of use as it is normally only used to designate the first generation of an interspecific cross. The development of the modern cultivars has involved repeated hybridization between existing hybrids as well as between hybrids and wild species.

Lawrence (1929) demonstrated on the basis of biochemical analysis (corroborated by Sorenson, 1969) that the so-called garden *Dahlia* (designating collectively all *Dahlia* cultivars), a fertile tetraploid, n=32, was of hybrid origin initially having come from a cross between *D. coccinea* with red or yellow ligules and one of the double purple-flowered species which by a process of elimination, almost beyond doubt, is *D. pinnata*. An allotetraploid is formed by an interspecific hybrid through the formation and fusion

of unreduced diploid gametes and will usually be fertile as its nuclei will contain pairs of homologous chromosomes (Blackmore and Tootill, 1984).
Lawrence and Scott-Moncrieff (1935), Crane and Lawrence (1947), Hammett (1980), and Watts (1980), however, report that garden *Dahlia* is an octaploid. Blackmore and Tootill (1984) recorded that an allotetraploid may cross with a diploid to form a sterile triploid hybrid, which, if it produces unreduced triploid gametes, may give rise to a fertile allohexaploid. If an allohexaploid is crossed with a diploid an allooctaploid may arise in a similar fashion.

In the wild species, Sorenson (1969) reported that chromosome numbers were known for 17 taxa of the genus *Dahlia* as follows: n=16 (7spp.); n=17 (3spp.); n=18 (1sp.); n=16 & 32 (2spp.). These last 2 spp. are *D. australis* Sheriff and *D. coccinea*.

1.2.9 Self-incompatibility

Self-incompatibility (SI) is a genetically based physiological mechanism promoting out crossing (Ascher, 1976). Nearly half of the major crops and ornamental species of the world occur in genera representative of the 71 families known to possess SI (Brewbaker, 1957; DeNettancourt, 1977). The understanding of the genetic basis of the SI system in a particular crop is important, not only for a breeding program, but also to crop production (Lewis, 1954) including utilization of SI for hybrid seed production (Frankel and Galun, 1977).

Since SI is a pre-fertilization barrier, pollen tube growth in plants exhibiting SI is slowed or inhibited in such a way that fertilization does not occur when there is recognition of like specificities between pollen and pistil. Hughes and Babcock (1950) and Gerstel(1950) first described the sporophytic SI reaction in *Crepis foetida* L. and *Parthenium argentatum* Gray, both members of the Composite. Sporophytic SI is characterized by allelic interaction ranging from independence to complete dominance, and inhibition of pollen tubes occurring at the stigmatic surface. This type of SI has come to be recognized as characteristic of the Compositae, Cruciferae and Convolvulaceae families (Ronald and Ascher, 1975).
Sorenson (1969) reports that most wild species of *Dahlia* are self-incompatible (presumably saprophytic SI). Hammett (1980) also reports that garden *Dahlia* is

reproductively self-incompatible and, in addition, incompatibility also occurs between a parent and a proportion of its offspring, which makes the outcome of back crossing uncertain.

1.2.10 Hybrids

Sorenson (1969) stated that when self-incompatibility as a barrier to inbreeding prevails, a high degree of hetrozygosity is maintained in the population, and all plants of each generation are, in a sense, "hybrids". Each of the "hybrids" contains two, or the segments of two or more genomes, allowing for a tremendous amount of stored variability. Such reproductive SI in combination with a high percentage of heterozygosity provides for a full exploration of the genotypic and phenotypic potential of any given breeding population in each generation.

An F1 hybrid, in contrast, is the result of a cross between any two genetically distinct parent plants of the same species, irrespective of their state of homozygosity. Thus, in an out bred population, because self-pollination is unlikely to occur, all plants will be F1 hybrids. In the modern connotation, however, an F1 hybrid is the result of a cross between two homozygous (but genetically distinct) parents or lines, and all F1 plants resemble one another exactly due to heterozygosity. If F1 hybrids are allowed to inter-pollinate and set seed, plants of the subsequent generation (F2) will consist of a wide range of types due to genetic segregation (Watts, 1980).

Sorenson (1969) states that although the F1 is normally fairly uniform this is not the case in *Dahlia*. The great variability in *Dahlia* plants is due to the prevailing SI which maintains in all progeny a rather high degree of heterozygosity. However, the 1993 Roger Anderson and the 1993-94 Watkins Seeds catalogues list four dwarf double *Dahlia* seed lines called 'Sunny Yellow', 'Sunny White', 'Sunny Rose' (deep rose) and 'Sunny Red' (deep scarlet) which are described as F1 hybrids. The Sunny series is reportedly an outstanding variety with 7.5cm (3") blossoms on plants that grow to 50cm (20") in the garden. However, availability is not to be relied upon due to production problems over several years (Ball, 1991). Trade prices listed in New Zealand at the time range between $7.50-12.50/g which is about two to three times higher than the price of other *Dahlia* seed lines.

1.2.11 Flower Colour

Lawrence and Scott-Moncrieff (1935) state that, with one exception, *Dahlia* species may be divided into two distinct groups for flower colour, Group I with magenta or ivory flowers, and Group II with orange-scarlet or yellow flowers. The exception, the garden *Dahlia*, combines both colour series within itself and when combined with cytological examination, suggests that the garden *Dahlia* is a hybrid between members of each of the two flower-colour groups, one with magenta and the other with orange scarlet flowers. This agrees with Sorenson's (1969) suggestion of *D. pinnata* (magenta) and *D. coccinea* (yellow-orange-scarlet flowers).

Flower colour in *Dahlia* is the expression of two series of pigments, flavones and anthocyanins. In Group I these pigments are of light intensity and are the ivory flavone, apigenin and a glycoside of cyanidin respectively. In Group II the pigments are of comparatively heavy intensity and comprise a yellow flavone and an anthocyanin of the pelargonin type. All four pigments may occur in garden *Dahlia* in varying proportions and degrees of intensity, in both light and heavy forms. Only five or possibly six genes are involved (Lawrence and Scott-Moncrieff, 1935).
In summary, flower colour is determined by relatively few genes, but their integration gives rise to many colours. Crosses between single and double flowered types, however, produce a continuous range of forms, indicating that doubleness is determined by many genes (Crane and Lawrence, 1947).

1.2.12 Propagation

Commercially, *Dahlias* are produced either by seed or stem cuttings, the latter being the most widely used (Langeslag, 1989, as cited by De Hertogh and Le Nard, 1993). The division of the tuberous roots with a portion of the crown remaining attached is mainly used by hobbyists (De Hertogh and Le Nard, 1993).
Unlike many other ornamental bulb crops which require more than one season of vegetative growth, *Dahlias* will come into flower in the first season (Bryan, 1989) as well as producing a sizeable tuber clump. Han (1996) reported that for seed-raised transplanted plants, the first flowers appeared at a similar time to tuber-raised plants. The transplanted seedlings took a total of 96 days from initial sowing until first flowering. Field-sown seed, planted later in a separate experiment, flowered 93 days

from sowing but were smaller plants. Plants grown from seed are typically smaller than those grown from tubers. If the tuber which is formed from the seed is kept and grown in the following season, then the plant will be larger in the second season (K. R.W. Hammett, Auckland, NZ, pers. comm.,1994).

1.2.13 Temperature and Light Effects

Konishi and Inaba (1966c) found that with a 13 hour photoperiod, a minimum night temperature of 10°C enhanced the quality of the flowers when compared to 5 or 15°C. When plants were grown at 10°C, they required a longer photoperiod than at 5 or 15°C. Also, they found that the number of ray and disc florets increased with decreasing night temperatures.

Temperature and light effects have been extensively studied and reviewed by Runger and Cockshull (1985). The major studies (Zimmerman and Hitchcock, 1929; Maatsch and Runger, 1955; Okada and Harada, 1955; Yasuda and Yokohama, 1960; Konishi and Inaba, 1964, 1965, 1966a,b,c,d, 1967a,b; Canham, 1969; Mathur et al., 1970; Mastalerz, 1976) show a wide range of photoperiodic responses. Most cultivars flower in a 12-14h photoperiod. However, some cultivars appear to be day neutral, while others do not flower under less than a 16h photoperiod. Short days reduce the total number of florets formed and increase the proportion of disc florets (Table 2). In many studies, short days either inhibit flower formation or induce abortion, while 16 hour or greater photoperiods delay flowering (Maatsch and Runger, 1955; Konishi and Inaba, 1964, 1966a). Low light intensities not only delay flowering but also reduce the percentage of plants flowering (Konishi and Inaba, 1966b,c).

A major interaction of photoperiod with flowering is the induction of root tuberization by short days (Wasscher, 1955). Moser and Hess (1968) showed that the critical day length was 11-12h and only five inductive cycles were necessary to trigger the process. Maximum fresh weight of tuberous roots occurred at 16-21°C and was inhibited at 10 and 27°C.

Table 2 The influence of daylength on the number of disc and ray florets in each inflorescence of *Dahlia* 'Finesse Anversoise'.

Daylength (h)	Number of Florets			Percentage of
	Disc	Ray	Total	disc florets
8	67	15	82	82
10	124	37	161	77
11	142	48	190	75
12	147	86	233	63
13	127	172	299	73
14	107	223	330	32

Reference: Maatsch and Runger (1955) as cited by De Hertogh and Le Nard (1993).

1.2.14 Agronomic Requirements

1.2.14.1 Soils

Dahlias prefer well-drained, sandy soil (De Hertogh and Le Nard, 1993), but will tolerate a wide range of soil types (Shewell-Cooper, 1975; Hammett, 1980), although high levels of organic matter are recommended. They are heavy water users and the organic matter assists in maintaining a proper water balance (De Hertogh and Le Nard, 1993). Because the soil should never be allowed to dry out, two thorough irrigations per week may be required (Bodman and Hughes, 1985). The pH should be between 6-7 (Shewell-Cooper, 1976; Hammett, 1980; Bodman and Hughes, 1985; De Hertogh and Le Nard, 1993). Raising the level of the planting bed is recommended in soils susceptible to poor drainage (Hammett, 1980) and enthusiasts will even use retaining walls in this situation. Commercial growers usually have access to bed-forming, tractor-drawn equipment. A bed of 20cm or more is preferred, with inter-rows running in the direction necessary to drain water from the production area (Bodman and Hughes, 1985). If the soil type or situation in which the *Dahlias* are grown is such that water logging is a problem, then lifting is required (Bodman and Hughes, 1985; Heriteau, 1992). *Dahlias* also require a good fertilizer programme and are often described as gross feeders. They are best grown away from the competition of other plant roots in separate beds if possible (Huxley, 1992). El-Gamassy and Moustafa (1963a,b and 1964a,b as cited by De Hertogh and Le Nard, 1993) have demonstrated that nitrogen and phosphorous are the most important elements for *Dahlia*. Modest levels of potassium

and calcium are also required for optimal growth not only for the production of tuberous roots but also for the number of flowers produced. Roozen (1980) says care should be taken that not too much nitrogen is applied to *Dahlias* and recommends 4-5kg of 7:14:28 (N:P:K) per $100m^2$.

1.2.14.2 Environment

Dahlias are best grown in an open sunny situation, avoiding the shade of tall shrubs, high walls and fences, as they demand high light levels (Shewell-Cooper,1975; Bodman and Hughes, 1985; Huxley, 1992). Planting is delayed until any danger of frost has passed (Shewell-Cooper, 1975; Huxley, 1992). *Dahlias* can be left in the ground in regions that are frost-free, or almost so, but otherwise are lifted and stored over winter (Huxley, 1992).

Some protection is needed from prevailing winds (Shewell-Cooper, 1975). A wind-break of taller plants can be used for larger plantings (Bodman and Hughes, 1985). Border cultivars require staking while bedding *Dahlias* usually do not.

1.2.14.3 Weed Control

This is fully discussed in chapter two.

1.2.14.4 Diseases, Insects and other Pests

While it is not the intention to produce an exhaustive list of important pests and diseases of *Dahlia*, some are of particular importance (Saaltink and Maas Geesteranue, 1964; Bergman, 1978; Bodman and Hughes, 1985; Langeslag, 1989). These include: powdery mildew (*Sphaerotheca* spp.); grey mould (*Botrytis cinerea*), the conidial or asexual state of *Sclerotinia fuckeliana* De Bary (Dixon, 1984) which in autumn can appear as numerous small spots on ray florets, and will also infect seed heads which retain their ray florets, thus providing an ideal site for infection (K. R. W. Hammett, Auckland, NZ, pers. comm., 1994); sclerotinia wilt or stem rot (*Sclerotinia sclerotiorum* (Lib.) De Bary); and soft rot (*Erwinia chrysanthemi*).

Virus diseases of *Dahlias* probably cause more disappointment to *Dahlia* growers around the world than any other cause. The three most commonly recorded virus diseases are: Cucumber mosaic (CMV), Tomato spotted wilt (TSWV), and Dahlia mosaic (DaMV) (Hammett, 1980). Others include Tobacco stripe (TSV), Tomato fleck

(TFV) and Tomato big bud mycoplasma. Virus-like symptoms range through varying degrees of stunted growth to curled and mottled leaves. Control is achieved by growing and multiplying only healthy stock and rogueing infected plants. The motto "if in doubt, throw it out" is recommended, although broadmites can also cause virus-like symptoms (Hammett, 1980).

Slugs and snails are reported to damage plants particularly in mild, wet weather (Hawkins, 1987; Huxley, 1992). *Dahlias* can be attacked by various aphids including green peach aphid (*Myzus persicae* Sulzer) which transmits Dahlia mosaic virus. Onion thrips (*Thrips tobaci* Lindeman) cause flecking of flowers and silvering of leaves and is known to transmit the tomato spotted wilt virus (Scott, 1984). In New Zealand, tomato fruit-worm (*Heliothis armigera conferta* Walker) has been reported to cause serious damage to *Dahlia* flower heads (Scott, 1984). Broadmite (*Polyphagotarsonemus latus* Banks) can cause new leaves to expand in a distorted manner and they may be very reduced in size and of a bronzed appearance. Only a few mites per shoot tip can cause extensive damage. Because damage is done at the shoot tip, it is not visible until leaves begin to expand. As a result, a considerable number of leaves may be affected before the problem is recognized. Sometimes only some shoots on a plant are affected (Bodman and Hughes, 1985). Broadmites are not visible to the naked eye and for this reason, and because of their relatively recent introduction are not listed as a problem with *Dahlias* in New Zealand (Scott, 1984). However, personal experience has shown they can become a major problem if left unchecked. Scott (1984) and Bodman and Hughes (1985) show they can be easily controlled with acaricides (miticides) or with insecticides which have activity against mites.

1.2.15 Pollination

1.2.15.1 Pollinating Insects

Plant species of economic importance are either self-fertile and set fruit or seed with their own pollen (self-pollination), or self-infertile and need to receive pollen from other plants of the same species (cross-pollination). Most agricultural and horticultural crops that have conspicuous, coloured and scented flowers are insect pollinated (Free, 1993). Because *Dahlias* are self-incompatible insect pollination is crucial.

The most important pollinating insects are solitary bees, bumblebees and honey bees. While insects other than bees are often recorded visiting flowers of commercial crops and may be rare pollinators, they generally lack sufficient body hairs and the necessary behaviour patterns, and probably few transfer pollen from the anthers to the stigmas of the flowers they visit. Furthermore, unlike the bees which forage consistently to obtain sufficient food for their young, most other insects only forage to satisfy their own immediate needs, and feed on a variety of foods other than from flowers. Hence, it is assumed that they perform only a supplementary role in pollination, although detailed studies of their behaviour are generally lacking. Probably, the most important supplementary pollinators are various Diptera whose hairy bodies carry as much pollen as bees, but who do not work the flowers as consistently (Free, 1993).

When many hectares are occupied by a single flowering crop there may be too few wild insect pollinators, thus limiting the potential seed yields of crops. Planting of large areas of a single crop tends to provide ample forage for a limited time only, and little or no forage to pollinating insects at other times. More over, the size of the populations of wild bees and other insects varies from year to year and place to place, so their contribution to pollination cannot be relied upon. It is also evident that clean intensive cultivation of the land including the destruction of hedge rows and rough verges has destroyed many natural food sources and nesting sites of wild pollinating insects. Organophosphorous insecticides also kill pollinators while many fungicides can kill pollen as easily as they kill fungal spores, especially pollen on dehisced anthers (Free, 1993).

For most crops an insufficiency of wild pollinators can still only be compensated for by using honey bee colonies. The honeybee, indigenous to Europe and Africa and introduced to many other parts of the world, including North America (and New Zealand) is *Apis mellifera* L. Various cultural methods are used to induce bees to visit the target crop flowers including: fertilizers, presence or absence of irrigation, correct spacing of plants, use of wind breaks, managing competing crops so they do not flower at the same time and arranging for the peak flowering period to coincide with the seasonal peak in numbers of the most important wild pollinators, and even arranging to provide other food sources while their populations are increasing (Free, 1993).

1.2.15.2 Foraging Behaviour

Bees visit flowers to collect nectar and pollen. They are attracted to flowers and recognize them by their colour, shape and odour. Bees are able to distinguish only four qualities of colour: yellow, blue-green, blue and ultraviolet; and when they are working flowers of one colour only, they become conditioned to it and do not visit flowers of a different colour. However, when a species has flowers of more than one colour, bees readily change between them and so probably ignore colour as a distinguishing feature. Bees are also able to learn the general shape of flowers, and the general form of plants, but their visual acuity is small and they readily move between tall and stunted plants of the same species and between flowers at different stages of opening. Petal expansion, nectar secretion and scent production reach their maximum to coincide with anther dehiscence, so nectar foragers also pick up mature pollen on their bodies (Free, 1993).

1.2.15.3 Honey bees

Honey bees are highly social in that individuals live permanently in cooperative groups. During winter a hive consists of one fertilized queen, up to 20,000 workers and none or a few larvae (brood). By early summer the hive population will have increased to about 60,000 workers, plus several hundred to several thousand male bees (drones) and of course the queen. The number of flowering plant species visited by honey bees is probably greater than that visited by any other species. Numerous native and introduced plants are good nectar and pollen sources for honey bees but many more species may supply lesser quantities. Although apiarists in New Zealand produce 5000-8300 tonnes of honey per annum and additional products such as pollen, beeswax, etc., by far the greatest value of honey bees lies in their efficacy as pollinators. Foraging, however, is reduced below about 13°C, and usually ceases at 10°C, and winds greater than 25-30km/h adversely affect flight. If a preferred flowering plant is present in abundance, honey bees will sometimes ignore the crop to be pollinated for the more preferred crop (Scott, 1984).

The foragers of a honeybee colony usually visit many flower species during the season, but it is undoubtedly a reflection of their ability to communicate the sources of good forage that at any one time they collect most of their forage from a few plant species. Because the majority of bees do not seek forage on their own but are recruited to crops by dancing or scout bees, differences in their findings are magnified by the foraging force

as a whole. When a honey bee colony is moved to a new crop it is important that the crop is flowering sufficiently to be the predominant species in the locality. If the foragers (workers) have previously begun visiting other flower species in the locality they will not readily forsake them (Free, 1993).

1.2.15.4 Bumble bees

Four species of bumble bee have established in New Zealand being introduced from England from 1885 to 1906 viz. the Large Earth Bumble Bee (*Bombus terrestris* L.), the Large Garden Bumble Bee (*Bombus ruderatus* F.), the Small Garden Bumble Bee (*Bombus hortorum* L.), and the Short-haired Bumble Bee (*Bombus subterraneus* L.). *B. terrestris* and *B. ruderatus* are found though out the country. *B. hortorum* is found mainly in Canterbury, Otago and Southland, although it was recently introduced into Palmerston North and Marlborough, and is thought to have ranged as far north as National Park. *B. subterraneus* is found only around inland Canterbury and Otago (Dijkgraaf, 1994).

Scott (1984) reported that bumblebees have four major attributes which make them particularly useful pollinators: they will forage for extended periods under conditions which prevent flight by other bee species; their flower visiting rate is higher than that of most other bees; their large, densely hairy bodies can carry much pollen, and the long tongued species readily pollinate flowers with deep corollas which other bees do not satisfactorily pollinate.

Conversely, two characteristics limit their importance as pollinators. Firstly, populations are usually too low for effective crop pollination and bee numbers may fluctuate widely within and between seasons, and secondly, while bumblebees have recently become manageable as portable hives, these are expensive, do not last long (from 4-12 weeks), and are mainly used for pollination of greenhouse crops such as tomatoes (Dijkgraaf, 1994). Bumble bee populations can be enhanced by introducing over-wintered queens; introducing colonies from areas well beyond the crop or naturally occurring colonies can be hived and transported, or colonization by queens of introduced hives which are placed near the crop. Higher populations can be maintained by providing continuous food sources. Colonies with ample food produce about twice as many new queens and 50% more workers and males. Late winter and spring flowers help ensure that new queens remain vigorous through to colony establishment. If long term use of bumble bees is

contemplated, flowering plants in the area should be evaluated and gaps in the seasonal flowering sequence should be filled by establishing suitable plants (Scott, 1984).

1.2.16 Floral Biology and Pollination Ecology

1.2.16.1 Floral Biology

In common with other Compositae the flower-head, or capitulum, of *Dahlia* is enclosed by an involucre of green bracts which protects the unopened head. As the bracts and ligules (or ray florets) reflex, the head opens with ray florets continuing to spread over a few days. The head contains various numbers of rows of sterile ray florets, depending on genetic and daylength factors, which are highly coloured to help make the head conspicuous, followed by many concentric rings of tubular disc (hermaphrodite) florets. The corolla consists of five united petals. The single inferior ovary of each floret contains an ovule, and when this is fertilized it ripens to form a cypsela.

The opening of the peripheral ray florets is followed by the opening of two to three spirals of disc florets in the morning. Soon after, the staminal filaments elongate rapidly and the anther tube, of five united anthers, emerges out of the corolla tube. The anthers dehisce (split longitudinally inwards) and pollen grains are shed into the anther tube. Later, the style elongates and the staminate filaments contract, which together results in pollen being pushed out of the upper end of the anther tube where it forms a conical mass. Towards the end of the afternoon the tip of the stigma appears above the anther tube and brings the remaining pollen above the anther tube. Next morning the stigmatic lobes separate and curl back, exposing their formerly hidden receptive inner surfaces for pollination. Thus each floret has two stages, the first male, and the second female. Nectar is secreted at the base of the corolla tube marking the female stage.

For much of the flowering time each head has unopened florets in the centre, surrounded by circles of florets in the male and female stage, and finally withered florets extending to the periphery of the head. The pollen grains remain viable for only a short period and hence pollination must occur within that short period although the stigmas remain receptive for 1-2 days (Patil and Zingre, 1986; Free,1993).

1.2.16.2 Pollinators

Patil and Zingre (1986) observed pollen foragers operating in the morning and late afternoon restricting their visits to the male stages of *Dahlia* flowers. Honey and solitary bees and species of a wasp, *Melipona*, alight on the disc florets and move along the rows covering about 8-10 florets at a time. *Apis dorsata* Fabricius was found an active collector of pollen and worked constantly for about five minutes on the same head. It operates along with the same or other species of bees on the same floral head. *A. florea* Fabricius crawled for 30 seconds along the row of the male stages of the heads.

Nectar foraging insects and bees alight on the disc florets in the female stage and thrust the head into the base of the ovary in between the corolla and androecium to seek nectar. In the process, the legs, head, abdomen, and ventral side, already dusted with the pollen grains from the male stage of the flower, brush against the stigmatic surfaces thus accomplishing pollination. *A. florea* and *A. mellifera* work for nectar for about one to two minutes, whereas *A. dorsata* for three to five minutes and then they fly away to other heads. It must also be borne in mind that florets actually visited are not necessarily all those being pollinated, since the longer a bee spends on a flower head, the more florets it walks on and pollinates (Patil and Zingre, 1986).

Nectar production varies with cultivar in sunflower (and presumably with *Dahlia* and other Compositae) and bees are more attracted to cultivars with higher nectar yield (Free, 1993). In *Dahlia* (and other Compositae) the foraging behaviour of bees represents a rare example of nectar-gatherers being better pollinators than bees gathering pollen only. In fact, bees that scrabble for pollen may be disadvantageous as they remove pollen with which nectar gatherers might become dusted. Honey bees also visit more than one head per trip even though a single head can often satisfy their need for pollen and nectar.

Baker and Baker (1983) found that the Compositae family produced nectar which is characteristically hexose rich (or dominant). They also found that there are similarities in sugar ratio between plants with the same pollinator type, even though they may be taxonomically unrelated. Thus nectar of flowers visited by long-tongued bees is usually sucrose-rich, while those pollinated by short-tongued bees (including honeybees) is generally hexose rich.

1.2.17 Self Incompatibility Pollination Problems

When hybrid seed is produced by crossing lines that have SI there is usually no difficulty in inducing bees to visit the lines present because they both produce pollen. Sometimes, however, individual bees become conditioned to working only one of the SI lines and do not readily move to another. This problem may again be solved by judicious inter-planting of the two cultivars, but suggests it is most important that plant breeders select SI cultivars for crossing that are equally attractive to bees, have synchronized flowering periods, have floral rewards of equal value, and ensure that bees do not distinguish between the size, shape, colour and odour of their flowers. For hybrid crops a much greater bee population than usual is needed to enhance the chances of successful pollination (Free, 1993).

1.2.18 Flower Seed Production

1.2.18.1 History

The history of commercial flower seed production only goes back to the second half of the last century. It was at this time that seed companies in Western Europe (Germany, France, UK and in the Netherlands), started growing and marketing some flower seed species in addition to their production and commercialization of vegetable seeds. Expansion occurred between the wars until, following World War II the production of flower seeds was worldwide, but restricted locally to those regions with the most suitable climate and soil conditions for particular species (Vis, 1980).

1.2.18.2 Seed Production

It is paramount that the greatest care is taken over production as only seed harvested under good conditions can be expected to have a high germination and subsequently to store well. In addition, the costs and labour expended on an inferior seed lot are almost equal to those expended on a good lot. The area for commercial flower seed production typically comprises relatively small area plantings and while the income is high so too are the costs. More than 40% of the cost is in field labour, which must be of such manual skill that good work approaches a craft status. While each species of flower grown for seed has its own planting time, culture, problems of pollination, and harvesting technique (Bodger, 1961), two production systems dominate the flower growing industry (Vis, 1980):

1. Production of open pollinated crops. These can be divided into annual species (e.g. Alyssum, Aster, Tagetes, Zinnia) and biennials and perennials (e.g. Pyrethrum), and also may include inbred or pure lines, e.g. sweet peas (Salunkhe et al., 1987).
2. Production of hybrid seeds; (e.g. Petunia, Begonia, Tagetes, Impatiens, Ageratum, Cyclamen, Pelargonium). F1 hybrids are uniform and more expensive but F2 hybrid lines which are less uniform but cheaper have been developed (Salunkhe et al., 1987).
Most *Dahlia* fits into the first category but recently some F1 lines are reported (Ball, 1991).

1.2.18.3 Climate

The climate is a determining factor in the production of flower seed, and most crops require a long growing season free of late spring and early autumn frosts, although flower crops vary in the extent to which they can withstand cool temperatures and frost. In areas with such climatic conditions it is possible to sow many crops directly in the field and to mature a satisfactory crop the same season, thereby reducing the cost of production. Most flower growers prefer a location relatively free of summer and autumn precipitation but which has a sufficiently moist atmosphere to keep seed shattering to a minimum (Hawthorn and Pollard, 1954). The Lompoc Valley, which lies near the California coast about 200km northwest of Los Angeles is one area that has an ideal climate; eight frost-free months a year, constant winds to aid pollination, and morning and evening fogs for moisture. This area is the world's major flower seed growing area (De Roos, 1968). Other important areas include the area in the rain shadow of the Harz mountains of Eastern Germany and the Provence district of France. In cooler climates many of the crops require transplanting (Hawthorn and Pollard, 1954).

1.2.18.4 Soil and Fertilizers

Flower-seed crops grow best on a sandy loam soil well supplied with organic matter. Such soil conditions are especially suited to the small seed crops which are sown directly in the field. The soil should be one that can be easily handled and will not crust or bake. For transplanted crops a somewhat heavier soil may be used (Hawthorn and Pollard, 1954).
As a general rule it is advisable to provide a plentiful supply of nutrients if high yields of seed are to be obtained. For most crops 450-670kg/ha of 10-20-0 or a 10-20-10

(N:P:K) fertilizer is advisable. The material should be drilled into the soil prior to planting or used as a side dressing as soon as the first cultivation is made (Hawthorn and Pollard, 1954).

1.2.18.5 Cultivation and Weed Control

Since many flower plants are small and slow-growing, it is highly desirable to use land which is relatively free of weeds (Hawthorn and Pollard, 1954). For a discussion of weed control see chapter two.

1.2.18.6 Irrigation

The soil should be kept moist enough so that good growth can be maintained. Over irrigation, however, may result in excessive plant growth, thereby reducing the yield of seed - a similar situation to that which occurs in the production of some vegetable seed crops (Hawthorn and Pollard, 1954). All crops in California require extensive irrigation during the summer. A common practice is to withhold water at the end of the season to encourage rapid and uniform maturing of the seed crop. Ditch irrigation is generally employed. Overhead systems are seldom used (Bodger, 1961).

1.2.18.7 Isolation

Unintentional fertilization by "foreign" pollen is insidious because there is no visible mixing. Therefore, plantings must be isolated from each other. When the grower lays out two fields of different colours or of double and single flowered varieties, he must consider the result of a possible cross. All such decisions require the skill of a geneticist (Bodger, 1961). In mixed colours the results of cross pollination (as with *Dahlia*) must be predicted. One colour may out-yield the others or a cross between red and white yield all red, all white, or some of each (perhaps even inter-shades). One colour may mature earlier than another, so the harvest time needs to be chosen carefully, or one colour will dominate the mixture (Bodger, 1961).

1.2.18.8 Sowing or Transplanting

Direct sowing (as opposed to transplanting) is recommended to substantially reduce costs in producing annual flower seeds (exemplified by *China aster*) as it is one of the

two most labor intensive operations, the other being harvesting (Kobza, 1984). However, the growing district has to have a sufficiently long growing season which varies with individual species (Bodger, 1961). In addition, the quality of the seed sown has to be high otherwise poor stands will result. A good non-crusting sandy loam soil is critical if direct sowing is considered (Hawthorn and Pollard, 1954). Any delay in sowing or transplanting will have a detrimental effect on plant growth and ultimately seed yield, and may delay harvest which carries with it the risk of less favorable weather conditions and all the consequences (Vis, 1980).

Although Phetpradap (1992) used both transplants and direct-seeded *Dahlia* establishment techniques, both were by hand and the techniques were never compared. Establishment from direct sowing was not recorded, although four seeds per planting position were sown and both thinning and replacement of missing positions was necessary 14-21 days after sowing for two experiments.

Han (1996) used both methods for *Dahlia* but again they were not directly compared. Transplanted seedlings were established in the field on 24 November after initial sowing on the 14 October (41 days after sowing). Direct hand sowing of seed into the field occurred on the 7 November, 21 November, 5 December and 19 December. *Dahlias* were apparently thinned to a spacing of 25cm x 15cm. The first three sowing dates gave an average yield of 0.745g/plant. However, the transplants at 0.2 x 0.2 only gave 0.397g/plant and from personal observation it would appear border plants were included.

1.2.18.9 Method of sowing and sowing depth

Vis (1980) recommends that seed should be covered with a layer of soil not thicker than the seed itself, or at least there should be a connection between the size of the seed and sowing depth. Small seed should be sown superficially and some times on the surface. Irrigation is required immediately in this situation.

1.2.18.10 Plant Density

Vis (1980) states that it is advantageous to observe the correct sowing rate and planting distance. If plant density is too high, risk of disease is high, and plants are often thinner and weaker. If plant density is too low then weeds have more of an opportunity to enter the crop and can indeed overgrow it.

Population density studies have been completed for a number of species e.g. *Calendula* (Nordestgaard, 1988), *Chrysanthemum* (Nordestgaard, 1983), *Tagetes* (Kobza, 1993), *Zinnia* (Rajanna and Khalak, 1992), and China aster (Kobza, 1987, 1991; Phetpradap et al., 1993). Ideal density will vary with the species and/or cultivars grown. *Dahlias* have a wide range of sizes and heights with K. R. W. Hammett, Auckland, NZ, pers. comm. (1994) quoting standard showpiece hybrids of 1.75m down to 'Baby Dahl' cultivars of 0.4m in height. Standard spacing recommendation can, therefore, be anywhere between 45-90cm between plants in a row whereas distance between rows will depend on other criteria such as access for spraying (insecticides/fungicides), inter-row cultivation and harvesting. This will depend on the systems or techniques used.

Han (1996) in his density trial compared spacing and their effect on seed yield using transplanted *Dahlias*. Five densities (0.2 x 0.2, 0.3 x. 0.3, 0.4 x0.4, 0.6x 0.6, 0.8x 0.8m) were used, as well as a selective and non-selective harvest. The highest selective harvest yield of 16g/m^2 (160kg/ha) was at the spacing 0.3 x 0.3m (11 plants/m^2) although the yield from the 0.4 x 0.4m (6.3 plants/m^2) spacing was not significantly different. The highest non-selective (once over) harvest yield was 12.3g/m^2 (123kg/ha) at the 0.4 x 0.4m (6.3plants/m^2) although the yield from the 0.6 x 0.6m (2.8 plants/m^2) spacing was not significantly different.

1.2.18.11 Harvesting

This is the last stage of seed production and is one in which many mistakes can be made, leading to loss of seed quality and reduction or complete loss of yield. This is also a time when much money has already been spent. If crops are harvested too early, there may be a high percentage of immature seed which will have to be removed later by seed cleaning machines. On the other hand if crops are harvested over-ripe, some yield may be lost through shedding due to the effects of wind or rain. Experience is the best guide, and when lacking, expert knowledge should be sought (Vis, 1980).

Phetpradap (1992) recorded that continuous flowering in *Dahlia* caused seed yield to be spread over a long period. *Dahlia* seeds should be harvested as soon as the majority of the seeds reach maximum dry weight (around 42 days after peak flowering (DAPF)).

In the case of once over harvesting the rule is 'do not harvest until the plants have started to shed seed'. As harvest approaches crops should be checked regularly (daily if need be), and a careful eye kept on the weather (Vis, 1980).

The seed head of the Compositae gives a perfect environment for fungal disease if it suffers wet weather conditions for too long a period, again causing deterioration in seed quality (Vis, 1980). This is particularly the case with *Dahlia* clones which retain their ray florets (K. R. W. Hammett, Auckland, NZ pers. comm., 1994).

1.2.18.12 Harvesting techniques

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 use mechanical methods (Vis, 1980; Bodger, 1961). Mechanical harvesting usually means the single operation of mowing, threshing and pre-cleaning. The best method for cleaning flower seed is either direct harvesting with a combine harvester which is adjustable to individual requirements and judgment, or to mow (windrow) and thresh in two separate operations. In the latter case mowing can be carried out by normal tractor and reciprocating mower followed by threshing in a static machine. The cutting operation is often carried out when the morning dew is on the plants to avoid loss of the dry seeds, although species with seed heads that shatter at a touch must go on to large canvas sheets (Bodger, 1961).
Harvesting machines need to be easily adjustable and a compressor with flexible piping for thorough cleaning of the machine is an absolute necessity. Proper adjustments made to the threshing machine and not drying the crop further than an equilibrium of 50%RH, mean the crop will not be beaten into fragments, which will later be impossible to clean, but remain whole with a pure seed product and unbroken straw forming the waste. The result of this is that the seed parcel contains less mechanical impurities and fewer pieces of straw, so that it is easier to clean (Vis, 1980).
Combine harvesting of China aster after desiccation with diquat was found to be a viable technique despite 11-18% seed losses. The optimum time for mechanical harvesting occurred when inflorescence of the 1st order become completely covered by pappus and seed moisture content was about 20%. Desiccation did not lower seed quality but increased seed loss and is not recommended (Duczmal, 1989b). Dessication using diquat

also did not affect quality but also may lead to loss though spillage (Nordestgaard, 1983).

Contradicting results have been obtained with *Calendula* (Nordestgaard, 1988) and *Calendula* and *Dimorphotheca* (Bremhaar and Bouman, 1994). Nordestgaard (1988) found that cutting in swathes, allowing to dry for 12-14 days and threshing from the swathes proved better than threshing either directly after desiccation using diquat or without desiccation. Breemhaar and Bouman (1994), however, found combining several days after chemical desiccation gave the best results for both species.

1.2.18.13 Drying

Hanging over a frame (e.g. fence) and letting the wind dry the crop has traditionally been popular but the slow drying process is often interspersed with spells of rain and dew so that the crop suffers wetting and drying with a resulting deterioration in seed quality. This is especially true in periods of high humidity and high temperature.

Vis (1980) reported results of drying methods for mechanically harvested *Dahlia* seed. After being dried under glass for three days, with subsequent drying with heated air, germination was 65% compared with 85% for seed which was dried with heated air immediately after harvest. Thus this method of artificial drying results in a clear improvement in germination capacity of the seed lot.

Maximum safe drying temperatures vary with species. Large seeds are more easily damaged than small seeds. Oily seeds will lose germination if dried at temperatures above 40°C.If the safe maximum drying for a particular species is not known then the following is recommended for most species:

Seed moisture content range	Safe maximum drying temperature
30-18%	32°C
17-10%	35°C
<10%	43°C

In addition seeds should not be dried too fast or too slowly (Hill, 1993).

1.2.18.14 Seed Cleaning

Flower seed cleaning is basically the same operation as in the rest of the seed industry. Fanning mills, specific gravity separators, disk and roller separators, and occasionally

flotation are used. The difference with flower seeds lies in the multiplicity of small lots, which necessitate short machine runs and scrupulous cleaning of the machinery after each run. The high wholesale value makes for extreme care and elaborate record keeping. Suitable screens and disks to handle all shapes and sizes are essential (Bodger,1961). Burg and Hendriks (1980) give detailed instructions of seed cleaning procedures for a wide range of flower species. For *Dahlia* the following is recommended:

(1)	Thresher		
(2)	Air-screen cleaner	- top-screen	5.5mm round hole
		- middle screen	1.8mm slotted hole
		- bottom screen	1.2mm round hole
(3)	Indented Cylinder	- 8mm (round grain application)	
		- 17mm (long grain application)	

However, seed size will vary both genotypically (Hammett, 1980) and phenotypically so these instructions should be considered only as a starting point. F. Onland , Palmerston North, NZ, pers. comm. (1995) has also had good success using the gravity separator with *Dahlia*.

1.2.19 Germination Methods

The International Seed Testing Association (ISTA) Rules for Seed Testing (1996) prescribe the germination testing of *Dahlia* spp. either between or on top of paper. Temperature conditions permitted include: alternating 20°C (16h) - 30°C (8h); or constant 20°C; or 15°C. The interim count can be made between days four and seven, while the final count is after 21 days. The only dormancy-breaking method recommended is pre-chilling (normally 5-10°C for up to seven days, ISTA, 1996). This is a common method for breaking primary dormancy of recently harvested seed in a wide range of species' (K. A. Hill, Palmerston North, NZ, pers. comm., 1997).The Association of Official Seed Analysts (AOSA) test *Dahlia* spp. either on top of blotters, between blotters, or with paper towelling. The temperature recommended is 15°C with the first count after four days and the final count at 14 days. Unlike the ISTA Rules no specific dormancy-breaking method is prescribed (Wiesner, 1991). Unfilled (empty) seeds in a sample can cause wide variation in germination test results. Such variation can be eliminated by using only pure seed as is normally required for official germination testing (Bass, 1980).

The Ransom Seed Laboratory in California reported results of many years testing of flower seeds including 200 seed lots of *Dahlia* (Atwater,1980). The test temperature was 15°C for 14 days, the same as for AOSA. The mean germination of these samples was 77% and no dormancy breaking methods were used.

Phetpradap (1992) dusted *Dahlia* seed with thiram fungicide, a practice also followed when testing *Dahlia* seed by Seed Tech Services, Seed Technology Centre, Plant Science Department, Massey University (K. A. Hill, Palmerston North, NZ, pers. comm., 1995). Shroti et al. (1984), reported that complete control of seed-borne fungi associated with *Dahlia* seeds was obtained by the use of Ceresan, Dithane M-45 (mancozeb) and Aureofungin as a seed treatment.

1.2.20 Greenhouse germination

Dahlia seeds are reported to be extremely easy to grow (McDonald, 1979; Ball 1991), and at temperatures of 21.1°C usually take six to eight weeks to produce seedlings ready for transplanting (McDonald, 1979; Still, 1988). Generally, the lower the temperature the slower the germination and if the system requires any disturbance of the roots then they will take longer before they are ready to be transplanted (Heriteau, 1992). Ball (1991) recommends 25.6-26.7°C for the first three to four days followed by a drop to 20-21.1°C with 50ppm nitrogen with calcium, added once per week. Temperatures should then be lowered to 15.5-16.7°C for a further 7 days (total 24-25 days), after which they will be ready for transplanting, shipping or bedding. Covering is also recommended to reduce problems with drying out. Germination percentages decrease significantly under lighted conditions. Some colours in a mixture are reportedly 'weaker' than others, so when most seedlings are ready, it is recommended they all be transplanted. The weaker seedlings often develop into strong plants (Ball, 1991). 'Fresh' seed (seed only a few months after harvest) often shows delayed and protracted germination (F. Onland , Palmerston North, NZ, pers. comm., 1995) This, however, is not a normal feature of seed after more extended dry storage (Ball, 1991).

1.2.21 Seed Dormancy

The literature does not report any major problems with dormancy in *Dahlia*. Phetpradap (1992) records differences of only 1-5% between normal germinants and viable seeds

which includes both normal and abnormal germinants and fresh ungerminated (dormant) seeds in cv. Unwins Mixed Dwarf. Germination ranged from 70-80% and viability from 76-83% with Figaro White seed. It is not recorded whether remaining seed were dead or even possibly empty. See also section 1.4.18.

1.2.22 Seed Storage

Although seed storage research has been give much attention, flower seed storage has received only limited research focus. However, results have shown for the species studied that: temperatures below 0°C are preferable to those above 0°C; storage in sealed containers is better than storage in open containers provided moisture content is sufficiently low (4% to 7% for most species); sealing in an atmosphere other than air may or may not be beneficial depending upon the nature of the atmosphere, the kind of seed, seed moisture content and storage temperature. Storage in liquid nitrogen appears to have possibilities for long term preservation of germplasm of flower species (Bass, 1980). Of the Compositae genera mentioned by Bass (1980) all were stored between 13-16 years. Only *Callistephus chinensis* and *Helichrysum bracteatum* showed any marked reduction in viability. *Dahlia* appears to easily store for this length of time. However, the number of seed lots cited was low and no information of variation among cultivars or effect of year of production was provided.

1.2.23 Seed Yield Components

Yield is a complex character determined by several interacting components (Graf and Rowland, 1987). Classic yield component studies were developed with cereals based on the following components: plant density; number of ears/plant; number of seeds/ear and seed weight. Similar studies have included maize, soybean, peas, tomatoes, seed cotton, hops, ryegrass and subterranean clover (Holliday, 1960).

Seed yield components for *Dahlia* have been described as: plant density; number of inflorescences per plant; number of seeds per inflorescence (seed head) and seed weight (Phetpradap, 1992; Han, 1996). Seed weight, size and shape is determined by floret size and shape. Giant decorative *Dahlias* produce large broad seeds while small cactus types produce small thin seeds (Hammett, 1980). *Dahlia* seed yield and yield components obtained by Phetpradap (1992) are summarized in Table 3. Plant spacing was different in 1988 (50 x 50cm) compared with 1989 and 1990 (30 x 30cm) which explains the yield

differences. However, seed yields for 1989 and 1990 are similar and taken from control treatments.

Table 3 Seed Yield Components For Dahlia 'Unwins Dwarf Mix' and 'Figaro White'. (adapted from Phetpradap,1992).

Cultivar	Seed Yield/ m^2 (g)	Seed Yield/ plant (g)	Seed heads/ plant	Seeds per seed head	TSW(g)
UD[1] Mixed '88	75.2	18.8 (11.8)[2]	117	24.9	6.6
UD Mixed '89	100	9.0 (5.0)	37	36.0	6.7
UD Mixed '90	98.9	8.9 (7.6)	42	35.7	6.0
Figaro White	43.3	3.9 (1.75)	99.9 (28.8)[3]	6.4	6.0

UD[1] = Unwins Dwarf.

[2] = cleaned yield in brackets.

[3] = (28.8) = number of seed heads which had no seed.

1.2.24 Flower colour effects on yield and yield components

Phetpradap (1992) examined the influence of colours (only one plant of each) amongst the Unwins Dwarf Mixed cultivar (see Table 4). Highest yield recorded was for a pink flowered (15.5g) plant compared to the lowest yield for a deep red one (7.7g). Phetpradap suggested that the deep red colour was unattractive to bee pollinators. However, the number of seeds per seed head (one possible measurement of successful pollinator visits) in deep red flowers was marginally higher than in orange or yellow flowers and only slightly lower than in yellow-orange flowers. These three flower colours yielded more seed than the deep red for the whole plant, indicating that flower numbers per plant rather than pollinator activity was the reason.

Phetpradap (1992) further suggested that the lower seed yield in the Dwarf Figaro White cultivar was the result of reduced pollinator activity, due to indifference by bees to white. Certainly the number of seeds per seed head (one possible measurement of successful pollinator visits) was much lower in Figaro White (6.4) than in Unwins Mixed Dwarf (24.9 - 36). However, because the degree of dwarfness is much greater in Figaro than in Unwins Dwarf mixed (37cm for Figaro White compared with 64cm for Unwins Dwarf) there is also a similar restriction in inflorescence size. This will almost certainly reduce seed yields. This suggests that a comparison between coloured flowers of Unwins Dwarf

and white flowers of Figaro on the basis of colour alone as a means of explaining seed yield differences is potentially misleading.

Table 4 Seed Yield Components For Individual Coloured Dahlias 'Unwins Dwarf Mix' (adapted from Phetpradap,1992).

'Cultivar'	Yield/plant (g)	Seedheads/plant	Seeds per seed head	TSW(g)
UD pink	15.5	44	46.1	8.1
UD orange	13.3	58	31.6	7.0
UD yellow	10.0	33	30.5	7.2
UD deep red	7.7	40	32.8	6.4
UD bright red	11.4	35	46.0	7.7
UD yellow-orange	11.9	35	35.5	10.4

UD = Unwins Dwarf.

1.2.25 Inflorescence Disc:Ray Floret Ratios

As discussed earlier, the *Dahlia* 'flower' is an inflorescence, composed of many individual florets. The two main types are disc and ray (there are intermediate types). The ray florets are usually sterile so the disc florets determine the number of potential seeds that will be produced. Each disc floret has one ovary which, if fertilized, will produce one seed. However, the most central disc florets of many of the Compositae are frequently sterile (Reynolds and Tampion, 1984). Sheriff (1989) found that seed yield was higher in the outer portion of the capitula (43-52%) than in the middle (26-33%) or inner (22-27%) portions in four sunflower varieties. In addition, disc floret numbers vary widely for both genetic and phenologic (day length) reasons (Runger and Cockshull, 1985).

The most important factor which can decrease numbers of disc florets is doubleness. As plant breeders try to improve flower colour they also often select plants with unusually large flowers or 'double flowers'. There are two types of double flowers. Sometimes the stamens and/or the carpels of the flower may fail to develop properly and may instead take the shape and colour of the petals. A separate form of doubleness occurs in the Compositae, in plants such as *Dahlia*, *Chrysanthemum* and *Zinnia*. Composite flower heads may have disc and ray florets, both of which may be fertile. (In *Dahlia* the ray

florets are rarely fertile). Fully double versions of these flowers have heads of ray florets only. They occur naturally in the dandelion and have been produced by selective breeding in cultivated composite flowers (Proctor and Proctor, 1978).
In the Compositae it is also quite common for day length to alter the ratio of ray to disc florets so that during early to mid summer, inflorescences can appear quite if not fully double but later, as the days shorten, the ratio of ray to disc floret decreases. This is reported in *Dahlia* (Zimmerman and Hitchcock, 1929; Maatsch and Runger, 1955; Konishi and Inaba, 1964; Durso and De Hertogh, 1977; Hammett, 1980) as well as in China aster (*Callistephus chinensis*), *Chrysanthemum* spp., *Helianthus* (sunflower) *Tagetes* and *Calendula* (Reynolds and Tampion, 1983) and *Zinnia* (Okada, 1951; Stimart et al., 1987) and is likely to occur more widely.

Reynolds and Tampion (1983) defined doubleness as any flower having additional petaloid parts, while Rabiet (1992) defined it as any flower that has twice or more than twice as many petals as a normal (single) flower of the same species. Some authors described it as having no disc florets (Proctor and Procter, 1978) especially during long daylength. Hammett (1980) stated that in semi-double flowers, more than one row of ray florets occurs, although the central disc remains visible. This suggests that the term 'single', when applied correctly, refers to flowers with just a single row of ray florets surrounding the central disc. A double 'flower', however, is defined as one which has an increased number of ray florets and once it has developed to the point of exposing its central disc florets, it is said to be 'blown'. It is at this stage that the style elongates up the anther tube, and from which the pollen is swept by hairs of the style arms and presented at the apex of the anther tube to any visiting pollinator. Later, the style arms separate to expose the stigmatic surfaces (Heywood, 1978; Patil and Zingre, 1986). Because double-flowered plants have fewer ovules (and less pollen), lower seed production is the expected result. Certainly seed yields are lower in double *Dahlias* compared with singles (F. Onland, Palmerston North, NZ, pers. comm., 1995) but decreasing day lengths during autumn will markedly increase the potential number of fertile disc florets.

1.3 MATERIALS AND METHODS

1.3.1 Seed Production Trial

1.3.1.1 Experimental Site

This experiment (December 1994 - May 1995) was located on the Plant Growth Unit (PGU) field plots of the Department of Plant Science, Massey University, Palmerston North. The site was sheltered by a willow shelter belt to the west and north and partly from the east by a terrace.

1.3.1.2 Climate Information

A summary of climatic information is found in Appendices 1.1, 1.2, 1.3 and 1.4 as well as comparisons with Pukekohe and Ashburton. Pukekohe was included because it is the location of the Yates Research Station where all of the Hammett *Dahlias* are produced in New Zealand and Ashburton because the climate is more ideal for seed production and it is part of the main seed production area (mainly forage species) in New Zealand.

1.3.1.3 Soil Type and Land Preparation

The soil type was a Karapoti brown sandy loam, which is a flat, medium textured alluvial soil which occurs on higher parts of levees and river flats which are free of flooding. It is considered to have medium internal drainage and is overall well drained. This soil's natural nutrient status is low phosphorous, medium calcium and high potassium, and it is used for dairying, very intensive sheep farming, cattle farming, horticulture and cash cropping. Its main limitation is that it dries out slightly in summer (Cowie, 1974).
The land was prepared by a tractor mounted rotary hoe which produced a very fine planting-bed on the 14 December 1994.
The soil test result is given in Appendix 2. Because the information at the time suggested that the pH was too low (5.8), an attempt was made to correct this to nearer the 6.0-6.5 range. Hydrated lime ($Ca(OH)_2$) was added by hand on 10 January at a rate of 1.58t/ha, based on a recommendation to shift the pH of a loam soils by 0.5 of a pH unit by Clarke, Smith, Prasad and Cornforth (1986). This took into account the lower molecular weight of $Ca(OH)_2$ (74) compared to the normally used agricultural lime (calcium carbonate or $CaCO_3$ - (100)), N.S. Bolan, Palmerston North, pers. comm., 1995. This lime was subsequently watered in by irrigation and rainfall over the next

three to four weeks. Hydrated lime is both finer textured and more soluble and so is likely to have a much more rapid effect than calcium carbonate.
Nitrophoska® fertilizer 12:10:10:2 (N:P:K:S) was applied by hand at a rate of 100 kg/ha on 11 January.

1.3.1.4 Plant Material

This experiment was conducted using 14 'Figaro' series *Dahlia* clones supplied in August 1994 by Dr Keith Hammett a commercial plant breeder from Auckland, New Zealand (see plate 9). These tubers had been kept in sawdust outside under trees. Each clone was represented by one to three tuber clumps which were potted on the 19 August in appropriately sized pots in 5mm sieved pumice and placed in a glasshouse with heating at 16°C and venting at 22°C. About ten days later 3-5g of Osmocote® 14:16.1:11.6 (N:P:K) (3-4 months) was added to each pot.
Cuttings (typically 4-7cm in height with 3-5 nodes) were taken weekly from 7 September until 16 November. These were planted into containers (220 x 75 x 70mm) with a peat:pumice (2:1 v/v) mix with no fertilizer. No rooting hormone was used. These cuttings were transferred to a plastic house with heating at 18°C and venting at 22°C. Bottom heat (21-22°C) and fogging 15h/day (0600-2100h) for two minutes every ten minutes was provided within a plastic tent covering the bench.
Potting seedlings into planter bags (PB ¾ , dimension 64 x 64 x 150mm) using a bark:pumice (4:1 v/v) mix with 1kg agricultural lime, 3kg dolomite, and 1.5kg Osmocote® (3-4month) was done when sufficient rooting had occurred. Bags were placed back into the glasshouse for about one week and finally transferred to a shadehouse. Later, cuttings were kept in the glasshouse longer in an attempt to reduce size differences.
Transplanting into the field occurred by hand on the 20 December and plants were irrigated immediately using an aluminium pipe (internal diameter of 34mm) with needle sized holes positioned at various angles along the length of the plot. This irrigation system was capable of delivering about 4500 litres per hour which is equivalent to about 15mm of rainfall (Plate 10).

Plate 9: Dr Keith Hammett and self at the 'Figaro Series' Clonal seed production site on 13/2/95.

Plate 10: Overhead irrigation using aluminium pipes in February 1995.

1.3.1.5 Planting Design

Rooted cuttings were transplanted randomly into each of four blocks. Due to differences in original tuber clump numbers, shoot production and rooting ability the total number of plants obtained from individual clones varied. Plant spacing was 0.8 x 1.6m. Each block size was 22.4 x 9.6m giving a total area of 22.4 x 40.4 = 905m^2.

1.3.1.6 Weed Control

Weed control was achieved by inter-row spraying using a shielded sprayer containing glufosinate-ammonium (2kg/ha) on 16 January, 25 January, and paraquat (2.4kg/ha) on 28 March.

1.3.1.7 Plant Protection

The plant protection programme included an electric rabbit fence which provided between 6000-7000 volts, although it was discovered later that rabbits did not find *Dahlias* palatable!

Methiocarb (Mesurol® Snail and Slug Bait) was broadcast around the plants on 13 January at the rate of about 7kg/ha.

A regular spray programme began on 13 January (Table 5). This included an insecticide, a fungicide and sometimes a miticide and a wetter/sticker/rainproofer (Raingard™ a.i. poly-1-p-menthene, non ionic 1ml/ 3 litres). The rate of taufluvalinate (Mavrik® Aquaflow) was increased on 10 March and again from 28 March due to an increased presence of caterpillars. Spraying was done around dawn to allow spray to dry before honey bee foraging began. Taufluvalinate was used as the main insecticide due to the unavailability of other insecticides able to be used safety when flowers are likely to be visited by bees.

Table 5 Plant Protection Spraying Programme (Seed Production 1995).

Date	Days Between applications	Trade Name	Pesticide Type	a.i. Rate per litre	Active Ingredient
13/1/95	-	Attack® Benlate	Insecticide Fungicide	0.025g 0.475g 1g	permethrin + pirimiphos-methyl benomyl
4/2/95	22	Mavrik Aquaflow® Omite® 30 W Benlate	Insecticide Miticide Fungicide	0.24g 0.6g 1g	taufluvalinate propagite benomyl
25/2/95	21	Mavrik Aquaflow® Omite® 30 W Benlate	Insecticide Miticide Fungicide	0.24g 0.6g 1g	taufluvalinate propagite benomyl
10/3/95	13	Mavrik Aquaflow® Coopers mite killer Bravo® 500F	Insecticide Miticide Fungicide	0.36g 0.32g 1.5g	taufluvalinate dicofol chlorothalonil
28/3/95	18	Mavrik Aquaflow® Omite® 30 W Benlate	Insecticide Miticide Fungicide	0.48g 0.6g 1g	taufluvalinate propagite benomyl
13/4/95	16	Mavrik Aquaflow® Rovral™ WP	Insecticide Fungicide	0.48g 1g	taufluvalinate iprodione
24/4/95	11	Mavrik Aquaflow® Rovral™ WP	Insecticide Fungicide	0.48g 1g	taufluvalinate iprodione

1.3.1.8 Seed Production Measurements

1.3.1.8.1 Pollinator Visitation

Four clones were selected to observe pollinator behaviour (7055/3 - lemon; 7058/2 - white; 7072/2 - red; and 7074/3 - apricot). Three replicates (plants) per clone were chosen and the number of visits per receptive inflorescence was recorded for one minute at three times during the day (7 April: 9-10am, 2-3pm, and 6-7pm). This was repeated on the 10 April except for the dusk time. Early-mid April was the period around peak flowering.

A honeybee hive (plate 11) was introduced on 27/1/95 and removed after flowering had finished. The number of honeybees in this hive was approximately 60,000. A honeybee is shown working an inflorescence of clone 7075/3 in plate 12.

A small bumblebee hive supplied by Zonda Resources Ltd (plate 14) was introduced on 26/1/95 and when the bees had apparently died out after about eight weeks, was replaced by a new hive on the 29/3/95. The number of bees in a bumblebee hive was about 100. This supplemented the natural population, but to what degree is unknown. Plate 13 shows a bumblebee working an inflorescence of clone 7058/1.

1.3.1.8.2 Seed Fertility

Five inflorescences of each clone were randomly selected from each of the four blocks, and carefully dissected. Ray, disc and total floret numbers were counted for each inflorescence. In addition both seed numbers and position (whether ray or disc) were also recorded.

1.3.1.8.3 Seed Yield

Plants were individually harvested by hand using hedge clippers in mid-late May 1995. The cut was made sufficiently low as to include all seed heads but as high as possible to reduce the amount of vegetative matter. Various seed yield components were measured including seed weight, seed yield per plant, and yield per hectare. All weights and yields

are quoted at 10% seed moisture content. Eight replicates of 100 seeds were weighed, and expressed as an average thousand seed weight.

1.3.1.8.4 Seed Quality

Seed quality was measured by a germination test, topographical tetrazolium test, recording sprouting damage and a glasshouse emergence trial.

The germination test was conducted during October-November 1995 using International Seed Testing Association (ISTA) rules (ISTA., 1996). This included a prechill treatment at 5°C for four days followed by 21 days at 20°C. Blotters were examined after 7 days, 15 days (interim counts), and 21 days (final count) and any normal seedlings were removed at the interim counts. All seeds/seedlings were classified into normal, or abnormal seedlings, fresh ungerminated, dead, or empty seeds (ISTA, 1996).

The topographical tetrazolium test was conducted using the following procedure based on the ISTA rules (ISTA, 1996). The seeds were soaked for 17h at 25°C in a 1% tetrazolium chloride solution and embryos were examined and classified as either viable or non-viable according to the staining pattern.

Sprouting damage was recorded by examining the seed used for the tetrazolium test (before soaking) for any visible evidence of germination including radicle and/or cotyledon emergence from the seed.

A glasshouse emergence trial was conducted with six clones during September-October 1995 with seed sown in Yates Blackmagic Seed Raising mix. Five replicates of 120 seeds were used. After watering, the sown trays were prechilled for five days at 5°C and transferred to a glasshouse with heating at 18°C and venting at 23°C. Emergence was recorded every two or three days for 30 days. Median time taken to germinate, spread of germination and total germination were calculated using the following equations, from Coolbear et al. (1984):

Plate 11: Honeybee hive supplied by Pohangina Valley Apiaries.

Plate 12:Honeybee working an inflorescence of clone 7075/3.

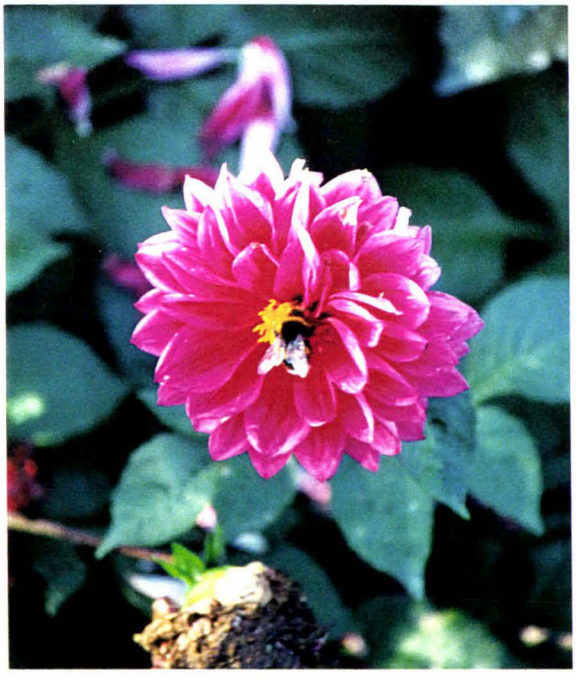


Plate 13: Bumblebee working an inflorescence of clone 7058/1.

Plate 14: Bumblebee hive supplied by Zonda Resources Ltd.

(1) Median Germination / Emergence Times (T_{50})

$$T_{50} = t_i + \frac{[(N+1)/2 - n_i]}{(n_j - n_i)} \times (t_j + t_i)$$

Where: N = final number of germinants/ emergents

n_j, n_i, = total number of germinants/ emergents by adjacent counts at t_i & t_j.

where: $n_i < (N+1)/2 < n_j$

(2) Uniformity / median spread of germination / emergence times (T_{90}-T_{10})

$$T_{10} = t_i + \frac{[(N+1)/10 - n_i]}{(n_j - n_i)} \times (t_j + t_i)$$

where: $n_i < (N+1)/10 < n_j$

$$T_{90} = t_i + \frac{[9(N+1)/10 - n_i]}{(n_j - n_i)} \times (t_j + t_i)$$

where: $n_i < 9(N+1)/10 < n_j$

1.3.2 Half-Sib Lines Trial

1.3.2.1 Experimental Site

The half-sib experiment (December 1995 - April 1996) was located about 150m south of the Seed Technology Centre in the Campus experimental plots of the Pasture and Crop Research Unit (PCRU) of Massey University, Palmerston North. The site was sheltered by a poplar shelter belt to the east. Three rows of maize were grown around the perimeter of the site in the three remaining directions.

1.3.2.2 Soil Type and Land Preparation

The soil type was an Ohakea silt loam, which is a flat soil which occurs on low terraces from old colluvium overlying stony alluvium. It is considered to have slow internal drainage and is overall imperfectly to poorly drained. The natural nutrient status is low phosphorous, medium calcium, and low potassium, and in general it is used for intensive sheep and cattle farming and some horticulture (Cowie, 1974).

The land was ploughed in mid-October and power harrowed on the 2 November 1995. Nitrophoska® fertilizer 12:10:10:2 (N:P:K:S) was applied by a fertilizer spreader mounted on a farm bike at a rate of 100kg/ha on 13 November and the land was further power harrowed on the 29 November in preparation for transplanting.

1.3.2.3 Plant Material

This experiment was conducted using half-sib lines of ten of the original 14 'F' series clones. The four clones not used had insufficient viable seed or in one case was accidentally used by Han (1996) in his density experiment. Seeds were sown in 60cell plug trays on the 19 September using a seedling mix of peat:pumice (3:2 v/v) with 3kg of dolomite, 1.5kg Osmocote® 14:16.1:11.6 (N:P:K) (3-4 months) and 0.6kg of Micromax® (trace elements) per m^3. These were watered and then placed into a 5°C room for five days before being transferred to a glasshouse with heating at 17°C and venting at 22°C. Trays were placed outside on 31 October and maintained until plants were transplanted by hand on 8 December. Irrigation occurred as described for the seed production experiment.

1.3.2.4 Planting Design

Ten plants of the half-sib lines were transplanted randomly into each of four blocks with a plant spacing of 1.3m between rows and 0.75m within rows. Each block was 18.2m x 7.5m giving a total area of approximately 18.2 x 32 = 582m^2.

1.3.2.5 Weed Control

Trifluralin (0.8kg/ha) was applied and soil incorporated with a dutch harrow within 2-3 hours prior to transplanting. Oxyfluorfen (0.96kg/ha) was applied inter-row on 13 December and plots were irrigated within a few hours of application. In addition push-hoeing of some weeds (predominantly twin cress) occurred on 27-28 March.

1.3.2.6 Plant Protection

A regular spray programme begun on 31 January included an insecticide, fungicide, miticide and a wetter/sticker/rainproofer. For details see Table 6.

1.3.2.7 Growing out half-sib lines

Ten of the original 14 clonal lines had sufficient seed for a grow out trial and plants were grown to flowering using the practices and procedures already described. Inflorescences were judged on colour and the degree of doubleness. Double flowers were classified as those in which the central disc was hidden until after it had 'blown' (Hammett, 1980).

Table 6 Plant Protection Spraying Programme (Half-sib 1996)

Date	Days Between Applications	Trade Name	Pesticide Type	a.i. Rate per litre	Active Ingredient
31/1/96	-	Mavrik Aquaflow® Omite® 30 W Benlate	Insecticide Miticide Fungicide	0.24g 0.6g 1g	taufluvalinate propagite benomyl
27/2/96	27	Mavrik Aquaflow® Kelthane® 35 Benlate	Insecticide Miticide Fungicide	0.24g 0.7g 1g	taufluvalinate dicofol benomyl
7/3/96	9	Mavrik Aquaflow® Omite® 30 W Benlate	Insecticide Miticide Fungicide	0.24g 0.6g 1g	taufluvalinate propagite benomyl
29/3/96	22	Mavrik Aquaflow® Benlate	Insecticide Fungicide	0.48g 1g	taufluvalinate benomyl

1.4 RESULTS

1.4.1 Climatic Information

A summary of climatic information is found in Appendix 1 as well as comparative data for Pukekohe and Ashburton. For the four months of the effective growing season (Jan - April) mean temperature 1995 was 1.2°C above average for Palmerston North (17.5 compared with 16.3°C) which was a little below Pukekohe at 17.9°C and above Ashburton at 14.9°C.

Palmerston North was overall wetter during these four months (358mm compared to an average of 296mm), although it was drier than normal during January and February, and wetter than normal in March and April. Ideally for seed production, this would have been better reversed. Pukekohe's average of 356mm which included a typically wet March-April is also not well suited for seed production. Ashburton's average was the driest at 255mm, with about 60% of Pukekohe's rainfall during March-April.

Sunshine was above normal for Palmerston North at 767h compared with an average of 701h. Both Pukekohe and Ashburton averaged less than Palmerston North at 693h and 667h respectively.

Mean monthly wind run was well down on average for Palmerston North at 779km/day compared with the average 997km/day. Both Pukekohe and Lincoln (no data from Ashburton) also had more wind at 1053km and 1191km/day respectively for the four months.

1.4.2 Agronomic Results

1.4.2.1 Flowering

Flowering was not specifically monitored, but regular fortnightly photos enabled overall flower numbers to be noted during the growing season. Peak flowering occurred in mid-April (see Plates 15 and 16) due to the late planting date.

1.4.2.2 Lodging

Overall wind damage was minimal because there was reasonably good site shelter (Plate 16). However, two clones - 7058/1 and 7058/2 - were affected. Clone 7058/1 was

particularly susceptible to branch breakage (Plate 17), while clone 7058/2 had a tendency to lodge (Plate 18).

1.4.2.3 Seed Development

Once fertilization had occurred ray florets began to senesce and drop off the developing seed head. The trait of dropping ray florets was dominant among the clones used in this experiment, as represented by clones 7073/2 (Plate 19) and 7055/3 (Plate 20). As the seed head continued to mature, it eventually began to open again and shed its seed (see Plates 21 and 23).

Clones 7052/11 and 7052/8, in particular, retained their ray florets. These rotting florets provided an ideal environment for botrytis (*Botrytis cinerea*, the conidial or asexual state of *Sclerotinia fuckeliana* De Bary) infection (Plate 22) which sometimes led to complete fungal disintegration of the seed head and seeds contained within. However, some seeds were observed to survive, although no actual measurements were recorded.

Plates 23 and 24 demonstrate the problems of harvest timing. As with all indeterminate crops, there was a range of developmental stages, from plants which had finished flowering but had seed heads ranging from green to brown to opening and shattering (Plate 23) to plants with most inflorescences at an immature seed head stage but still with some inflorescences flowering (Plate 24). Note also the pile of freshly dropped ray florets at the bottom left hand corner of this latter plate.

1.4.3 Pollinator activity

No differences were recorded for number of insect visitors among the four clones chosen (7056/1 - apricot, 7058/2 - white, 7055/3 - yellow, 7072/2- red). A mean of 24% of receptive inflorescences were visited over a one minute period in the morning (9-10am) and the afternoon (2-3pm) on two days, one week apart, during the peak flowering period. On the first day a dusk observation (6-7pm) revealed no pollinator visits. However, a very small number of moths were observed in the crop as a whole.

Of the pollinator visits, 89% were by honey bees (*Apis mellifera* L.), 9% by bumblebees (only *Bombus terrestris* L. was specifically identified), with the remaining visitors (2%) being flies, butterflies or moths. A number of these were caught and identified including: Dronefly (*Eristalis tenax* L.), Yellow Admiral Butterfly (*Bassaris itea* F.), Red Admiral

Plate 15: Clonal seed production site looking east during peak flowering mid-April 1997.

Plate 16: Clonal seed production site looking west during peak flowering mid-April 1997.

Plate 17: Clone 7058/1 which was susceptible to branch breakage.

Plate 18: Clone 7058/2 which was susceptible to lodging.

Plate 19: Seed heads developing on clone 7073/1.

Plate 20: Seed heads before closing

Plate 21: Seed head opening again

Plate 22: Botrytis infection on retained ray florets of clone 7052/11.

Plate 23: Plant showing seed heads from green through to shattering.

Plate 24: Plant showing inflorescences still flowering and maturing seed heads.

Butterfly (*Bassaris gonerilla* F.), Common Blue Butterfly (*Zizina otis labradus* Godt.), Common Copper Butterfly (*Chrysophanus salustius* F.), Monarch Butterfly (*Danaus plexippus* L.), White Cabbage Butterfly (*Artogeia rapae* L.), Magpie Moth (*Nyctemera annulata* Boisd.), and Tomato Fruitworm Moth (*Heliothis armiger confertus* Walk.).

1.4.4 Seed head fertility

Table 7 shows the results of what is termed seed head fertility of all 14 clones. This is the ratio of seed number to disc floret number i.e. the percentage of disc florets which were fertile. Clones are ranked in order of seed yield.

1.4.4.1 Ray Florets

Mean ray floret numbers per inflorescence ranged from 65 (7052/3) to 142 (7073/2). Although there were significant differences amongst clones no absolute pattern emerged. However, clones with more ray florets had a tendency to produce higher seed yield.

1.4.4.2 Disc Florets

Disc floret numbers per inflorescence varied from 21 (7055/8) to 58 (7072/2). Three (7052/8, 7058/2, 7075/3) of the lowest four yielding clones also had the lowest number of disc florets, but no further pattern was evident, and disc floret number among most clones was remarkably similar (9 of the 14 clones had mean disc numbers in the 40s). The number of disc florets (46) of the semi-double white clone with a clearly visible central disc(7058/2), did not vary from eight other clones which were more double in appearance. In this case, 7058/2 had a lower number of ray florets, which allowed the central disc to be visible from early unfurling of the ray florets.

1.4.4.3 Total Florets

Total floret number per inflorescence varied from 120 (7052/11) to 183 (7073/2). There was a reasonably good relationship between highest total floret numbers and highest seed yield, although this was not absolute.

Table 7: Seedhead Fertility

Clone	Ray Florets per Inflorescence	Disc Florets per Inflorescence	Total Florets per Inflorescence	Disc Florets per Inflorescence (%)	Ray/Disc Ratio per Inflorescence	Seed Number per Inflorescence	Disc Fertility[2] Per Inflorescence (%)	Disc Viable[3] Fertility Per Inflorescence (%)
7073/2	142a[1]	41cd	183a	22.5ef	3.53b	23bc	55ab	41a
7055/3	123bc	49bc	171abc	28.4de	2.55cd	27ab	56ab	40a
7073/1	112cd	44cd	156cd	28.2de	2.57cd	23bc	38cd	31b
7072/2	105cdef	58a	163bc	35.5bc	1.91de	27ab	46bc	31b
7056/1	135ab	41cd	176ab	23.3ef	3.37bc	14de	34d	26bc
7074/3	91fgh	40d	131efg	31.0bcd	2.32d	26bc	35d	26bc
7052/3	65I	55ab	120g	45.9a	1.20e	29a	53ab	20cd
7055/2	92efgh	43cd	135efg	31.7bcd	2.17d	14de	34d	18cd
7052/6	96defgh	41cd	137ef	30.0cd	2.39d	15d	36ab	13de
7058/1	82gh	47bcd	129efg	36.8b	1.84de	9ef	19e	11de
7075/3	109cde	31e	140de	21.9ef	3.82b	6fg	18e	-
7052/11	95efgh	25ef	120g	21.1f	3.81b	3fg	11ef	7e
7058/2	85gh	46cd	131efg	35.0bc	1.89de	4fg	9ef	-
7052/8	100defg	21f	121fg	17.5f	4.81a	1g	7f	-

[1] = Mean values within the same column followed by the same letter are not significantly different at P<0.05.

[2] = Percentage of disc florets which set seed per inflorescence.

[3] = Percentage of disc florets which set viable seed per inflorescence.

1.4.4.4 Percentage of Disc Florets per Inflorescence

The percentage of disc florets to total floret numbers ranged between 45.9% (7052/3) and 17.5% (7052/8). However, the percentage for the highest seed yielding clone (7073/2) was not different from three of the lowest seed yielding clones (7075/3, 7052/11, 7052/8). The remaining clones showed no relationship between seed yield and percentage of disc florets.

1.4.4.5 Ray:Disc ratio

The ratio of ray:disc florets ranged from1.20 (7052/3) to 4.81 (7052/8).
While the results were not identical to the percentage of disc florets, a number of significant differences still occurred. No ratio revealed any apparent relationship with seed yield.

1.4.4.6 Seed Number

Seed number per inflorescence varied from 29 (7052/3) to 1 (7052/8). There were three groups: those with means between 23 and 29 that comprised six of the top seven yielding clones; the middle group comprising three clones (7052/6, 7056/1, 7055/2) with means of 14 -15 seeds per inflorescence; and, apart from one clone 7058/1 (mean of 9) which was not significantly different from the middle and lowest group, the remaining four clones (7075/3, 7052/11, 7058/2, 7052/8) were also those which gave the lowest seed yields.

1.4.4.7 Disc Fertility

The percentage of disc florets which set seed seemed to correspond quite well with seed yield. A few anomalies became obvious when comparing these results with the percentage of disc florets containing a viable seed. For example, clone 7052/3 had a disc fertility of 53% but only 20% of disc florets containing a viable seed. Overall, though, the percentage of disc florets containing a viable seed gave a closer relationship to seed yield than disc fertility alone.

1.4.5 Seed Yield And Yield Components (Table 8)

1.4.5.1 Seed weight (TSW)

The four clones with the percentage of disc florets containing a viable seed also had the heaviest seed (TSW) which ranged from 8.57g to 10.90g. Most of the lighter seed was also related to clones which had low yields. One exception, 7072/2, with a TSW of only 6.98g yielded better than others of a similar TSW. The seed shape (more curved and narrower) and size appeared quite different from the rest of the series.

1.4.5.2 Seed Yield Per Plant

Clones 7073/2 (6.66g) and 7055/3 (6.63g) had the highest yields per plant, followed by clone 7073/1 (4.32g per plant). After that the mean yields declined quickly, with 8 of the 14 clones yielding a mean of less than 1g per plant. The yield of the highest clone (7073/2) was 222 times greater than that of the lowest yielding clone (7052/8).

1.4.5.3 Viable Seed Yield Per Plant

When expressed as viable seed yield per plant there were some minor differences in the relative ranking of clones and also changes in the significant differences. The most significant effect was that the top four yielding clones contributed over 80% of the total yield for the series. Three of the four lowest yielding clones (7075/3, 7058/2 and 7052/8) had insufficient seed to carry out a germination test and, therefore, no viable yield is listed.

1.4.5.4 Seed Number Per Plant

Both the seed number and viable seed number per plant gave a similar result to that described previously. Although there was no significant difference between clones 7056/1 and 7072/2 in both seed number and viable seed number, the viable yield of clone 7056/1 was nearly twice as high, due mainly to the influence of higher TSW. The seeds of clone 7056/1 were nearly 60% heavier than those of clone 7072/2.

1.4.5.5 Yield Per Hectare

Because of the constant plant spacing used in this study, clonal yields per hectare did not differ in ranking from yield per plant. Nevertheless results are given because of the more common practice of expressing yields on a per hectare basis.

Table 8: Seed Yield and Yield Components

Clone	TSWs (g)	Yield / plant (g)	Viable Yield / plant (g)	Seed No. / plant	Viable Seed No. / plant	Yield (kg/ha)	Viable Yield* (kg/ha)
7073/2	9.17bc	6.66a	5.02a	727a	541a	103.7a	78.2a
7055/3	8.57c	6.63a	4.65ab	758a	529a	103.5a	72.5ab
7073/1	9.36b	4.32b	3.46b	462b	370b	67.4b	53.9b
7056/1	10.90a	2.66c	2.08c	240c	188c	41.4c	32.5c
7072/2	6.98de	1.63cd	1.09d	234c	156c	25.4cd	17.0a
7074/3	7.62d	1.20de	0.92d	149dc	121cd	18.6de	14.4d
7055/2	7.47d	0.94defg	0.57de	125de	76de	14.7defg	8.8a
7052/3	7.56d	0.97def	0.36ef	128de	48ef	15.1def	5.7ef
7058/1	7.07de	0.47fgh	0.30ef	66ef	42ef	7.4fgh	4.7ef
7052/6	6.60ef	0.65efg	0.24ef	98def	36ef	10.1efg	3.7ef
7075/3	6.67ef	0.46gh	-	63gf	-	7.2gh	-
7052/11	7.60d	0.15hi	0.10f	20gh	13f	2.3hi	1.6f
7058/2	7.07de	0.08I	-	11h	-	1.3i	-
7052/8	6.12f	0.03I	-	5h	-	0.5i	-
Mean	7.26	1.91	1.71	220	193	29.9	26.6

* = based on a plant density of 15625 plants/ha at a spacing of 0.8 x 0.8m.

Mean values within the same column followed by the same letter are not significantly different at P<0.05.

1.4.6 Seed Quality (Table 9)

1.4.6.1 Germination Percentage

Germination ranged between 79% (7073/1) and 35% (7052/6) which is the corrected figure after all empty seeds were removed. Highest germination occurred typically in clones which gave the highest seed yields (compare with Table 8).

1.4.6.2 Fresh Ungerminated Seeds

Fresh ungerminated or dormant seeds did occur but only at very low levels (0 - 4%).

1.4.6.3 Dead Seeds

Dead seed levels varied from 19 to 57%. Abnormal seedling data are not given as they made only a minor contribution to the total and can be calculated from the tabulated.

1.4.6.4 Tetrazolium (Viability) Test

This followed a similar pattern to the germination plus fresh ungerminated test result, showing that dormancy is not an important consideration in *Dahlia* germination results. Various aspects of tetrazolium testing are shown in Plates 25, 26 and 27.

Plate 25 shows three seeds or seed parts:

(a) a whole seed which has had the top left hand corner "knicked" with a scalpel blade to allow easier penetration of the tetrazolium solution;

(b) a partly decayed embryo; and

(c) an embryo which had sprouted in the seed head before harvest.

Plate 26 shows five embryos which were judged to be non-viable because either the radical, cotyledons or both were inadequately stained.

Plate 27 shows four embryos which were judged to be viable. The third embryo from the left does have a portion of the radical tip unstained (dead) but it is quite likely secondary roots from the remaining portion of the radical would develop. The fourth embryo is more lightly stained but this is usually due to inadequate penetration of the tetrazolium solution rather than indication of a lack of viability.

Plate 25: Cut Dahlia seed and non-viable embryos.

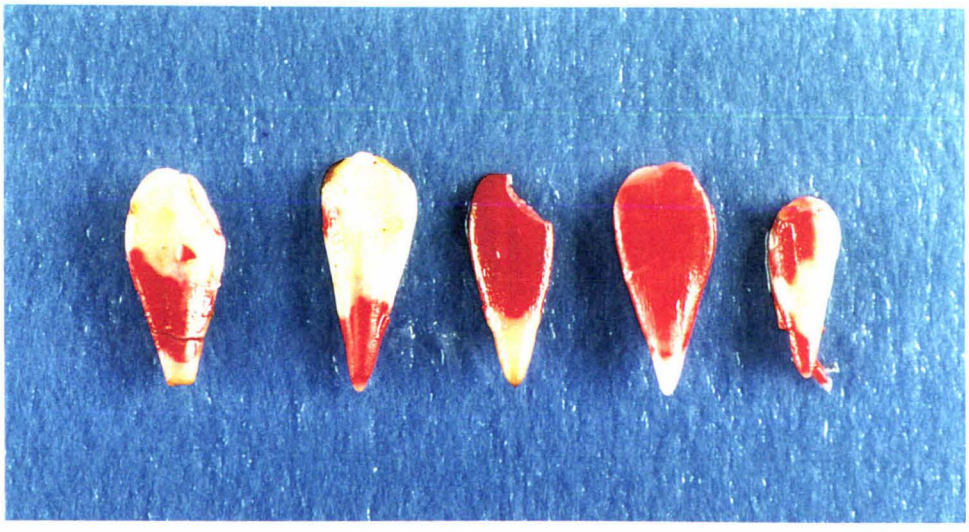


Plate 26: Examples of tetrazolium stained seeds judged to be non-viable.

Plate 27: Examples of tetrazolium stained seeds judged to be viable.

Table 9: Seed Quality

Clone	Germ (%)	Fresh Ungerm[1] (%)	Dead (%)	Germ + Fresh Ungerm[2] (%)	Tz[3] (%)	Glasshouse Emergence		
						Emergence after 30 days (%)	T50 (Days)	T90-T10 (Days)
7056/1	76ab	2cd	19c	77a	83a	40a	15.1c	10.4bcd
7073/2	73abc	2bcd	24c	75a	75ab	27bc	15.2bc	11.2abc
7073/1	79a	0d	22c	79a	71bc	30b	12.1d	9.0d
7072/2	63bcde	4abc	30bc	67abc	71bc	29bc	18.2a	13.2a
7074/3	75abc	1d	21c	75a	69bc	23cd	13.3d	9.8cd
7055/3	67abcd	2bcd	29bc	69ab	62cd	-[4]	-	-
7052/11	63cde	4a	31bc	67abc	59d	20d	16.7ab	12.6ab
7055/2	52e	4ab	39b	56c	58d	19d	15.7bc	12.3abc
7058/1	59de	2cd	38b	61bc	48e	-[5]	-	-
7052/3	37f	1d	57a	39d	36f	-[5]	-	-
7052/6	35f	1d	56a	36d	38f	-[5]	-	-

Mean values within the same column followed by the same letter are not significantly different at P<0.05.

[1] = fresh ungerminated was seed that was plump and firm, but ungerminated at the end of the germination test period.

[2] = may differ from columns 3 + 4 due to rounding.

[3] = Topographical tetrazolium test (viability test).

[4] = not tested, accidentally left out.

[5] = not tested due to insufficient seed.

1.4.6.5 Glasshouse Emergence

The time for 50% of the population to emerge varied by over six days between seed from the fastest clone (7073/1) and the slowest clone (7072/2) (Table 9). Spread of germination also varied with the same two clones showing the extremes. Clone 7073/1 had 80% (T_{90} - T_{10}) of its germination spread over 9 days, while clone 7072/2 had it spread over 13 days (Table 9).

1.4.7 Flower Colour

The half-sib progeny of 11 of the original 14 clones were broken up into the seven major flower colour groupings recognized by the New Zealand Dahlia Society (Table 1). Each colour grouping represents a range of shades, with some groupings having a broader colour range than others. Red, for example, ranges from very dark maroon to light watermelon red. By constrast lavender does not vary much. The progeny exhibited a high degree of variability of flower colour. Progeny typically expressed from 25-50% of the original maternal clone flower basic colour group. However, typically, progeny had a diverse colour range.

1.4.8 Flower Doubleness

Flower doubleness or semi-doubleness was also measured with only progeny from clone 7058/1 (a semi-double white) yielding significantly less double flowers (49.8%) than all other clones which gave a mean of nearly 80% of all progeny.

1.4.9 Population Colour Spread

All of the data were pooled to give the percentage of the population within any colour category (Table 11). This was done with the initial clones and then compared with a population called 'even seed yield' and a further population called 'actual seed yield'. The 'even seed yield' population was the result of the half-sib experiment where an even number of plants (40) were grown from seed from each of the 11original clones. This of course does not take into account uneven seed production from different clones as the same number of seeds from each clone was chosen. So a third population was theoretically calculated combining the results of the half-sib experiment with the seed production experiment ('actual seed yield').

Table 10: Percent Flower Colour and Doubleness in Half-Sib Lines

Clone	Maternal Colour[1]	White	Lav.[2]	Purple	Pink	Red	Orange	Yellow	Double
7052/3	Yellow	9.9bc	2.5bc	8.8b	0d	35.6abc	8.8bcd	34.5ab	71.0a
7052/6	Light Pink	28.8a	0c	3.1b	53.9a	5.6e	0d	8.7cd	80.0a
7052/8	White (red tipped)	23.3ab	20.5a	0b	21.3b	26.3bcde	3.6cd	5.0de	76.3a
7052/11	White (h.Lav. tipped)	26.9ab	12.5ab	2.5b	22.5b	17.5cde	7.5bcd	10.6cde	68.3a
7055/2	Yellow (l. red-tipped)	0d	12.2ab	3.1b	12.2bc	14.9cde	21.5ab	36.1ab	76.8a
7055/3	Yellow	2.5cd	5.3abc	5b	12.8bc	10.0de	13.1abc	51.4a	83.8a
7056/1	Orange	11.2bc	5.0bc	5.6b	5.0cd	24.6abcd	11.3bcd	37.4ab	83.5a
7058/1	Purple	2.8cd	0c	34.3a	15.7bc	47.2ab	0d	0e	49.8b
7072/2	Red	0d	0c	3.1b	11.2bc	34.6abc	37.7a	13.4cd	78.3a
7073/1	Yellow (l. red-tipped)	0d	3.6bc	0b	13.0bc	54.8a	10.7cd	18.0bc	78.8a
7073/2	Yellow (h. red-tipped)	2.5cd	9.7ab	0b	5.0cd	13.6cde	18.6abc	50.6a	90.5a

Mean values within the same column followed by the same letter are not significantly different at $P<0.05$.

[1] = approximate description of the maternal parent flower colour. See also Appendix.

[2] = Lavender.

l. = light secondary colouring of rays.

h. = a heavier secondary colouring of the rays.

There were some changes in the proportion of colours which made up the population (Table 11). Firstly, when comparing initial clones with an even seed yield population, white and pink increased while red and orange remained the same. Yellow, purple and lavender decreased. Growing red, orange and yellow together and the remaining colours together revealed a very similar pattern of colour spread with the initial clonal population.

Secondly, when comparing an "actual seed yield" population, white, lavender and purple decreased. Pink, red, orange and yellow remained unchanged, because of a lot of variation. However, if red, orange and yellow were grouped together there was an increase from a mean of 65% to 81%, while the mean for the four remaining colours decreases from 35% to 19%.

Table 11: Percentage of Population Colour Spread

	White	Lavender	Purple	Pink	Red	Orange	Yellow
Initial Clones	5.75b	12.21a	10.58a	6.30b	15.78b	11.66a	37.72a
Even Seed Yield	9.80a	6.47b	5.96b	15.68a	25.88a	12.06a	24.14b
Actual Seed Yield	3.01c	5.03b	2.94b	8.45b	19.76ab	13.05a	47.77a

Mean values within the same column followed by the same letter are not significantly different at $P<0.05$.

1.5 DISCUSSION

The 14 clones of *Dahlia* used in this study showed a wide range of seeding characteristics. Some were susceptible to lodging and branch breakage, while others retained their ray florets following pollination, making them susceptible to disease (particularly Botrytis) infection. These types of characters, combined with varying degrees of indeterminancy, flower disc size, and floret fertility can all contribute to the general indecision about the optimum harvest time for high yields of high quality seeds. As an example ray florets ranged from 65-142; disc florets ranged from 21-58; seeds per inflorescence ranged from 1-29; and seed yield ranged from 0.5-103.7kg/ha. This all suggests that seed production of different *Dahlia* clones will need to be managed carefully to ensure a viable seed production enterprize.

In a cross-pollinated crop, such as *Dahlia*, insects are crucial for seed production. Bumblebees have been noted by casual observation to visit *Dahlia* flowers (Phetpradap, 1992; K.R.W. Hammett, Auckland, NZ, pers. comm., 1994). Patil and Zingre (1986) had observed three species of honeybee including *A. mellifera*, the only species present in New Zealand (Scott, 1984), working *Dahlia* flowers.

Honeybees (89% of the visits) visited flowers about ten times as frequently as bumblebees (9% of the visits), although bumblebees tended to forage for longer periods on individual inflorescences as well as during the day. Hireage of a honeybee hive containing about 60,000 bees costs about $90 (R. McCammon, Ashhurst, NZ, pers. comm., 1997) which equates to about 0.15c/bee. A bumblebee hive containing about 100 bees costs $200 per hive (N. Pomeroy, Hastings, NZ, pers. comm., 1995), about $2.00 per bee! On the basis of population and cost alone, seed producers should rely on honey bees as pollinators as they appear to work *Dahlia* flowers perfectly adequately. However, various techniques described by Dijkgraaf (1994) and Scott (1984) for enhancing the natural bumblebee populations (introducing: over-wintered queens, colonies, or empty hives which may be colonized by queens) could be worth consideration in some situations (such as plant breeding sites) where honeybee hives may be unwelcome or mostly unnecessary.

While bees can recognize flowers by colour (and shape and odour), they are apparently only able to distinguish four qualities of colour: yellow, blue-green, blue and ultraviolet (300-650nm) (Crane, 1990; Free, 1993). Honeybees perceive flower colours differently from the human eye (Meeuse, 1961; Crane, 1990). Meeuse (1961) reported, for example, that honeybees were not attracted to the red colour of poppies, but to the ultraviolet light they reflect, which is invisible to the human eye. In addition, he argued that a combination of all the wavelengths that a bee can see must give the impression of 'white'. Therefore, the removal of ultraviolet will leave a light that is no longer white but has a colour complementary to ultraviolet, probably blue-green. Meeuse (1961) also stated that most white flowers usually absorb ultraviolet rays and thus, bees get the impression of something coloured and are attracted. The honeybee, though, cannot communicate colour to other bees and her memory of it is poor, perhaps only two days (Crane, 1990). Although honeybees are reported to show colour preferences (Meeuse, 1961; Kay, 1978; Mogford, 1978; Crane, 1990), it is often within the context of a relatively small number of variants (often white) within a wild plant population. Pollinator discrimination of these variants may be one of the factors that prevent their widespread establishment (Mogford, 1978). In this context, honeybees that are working flowers of one colour only, become conditioned to it, and do not visit flowers of a different colour (Free, 1993). This phenomenon has been observed many times, especially when variants of the 'normal' flower colour have occurred (Kay, 1978; Mogford, 1978). However, when a species has flowers of a number of colours, as in this study, bees readily change between them, and so probably ignore colour as a distinguishing feature (Darwin, 1876, 1877; Mathur, 1947, as cited by Kevan, 1978; Free, 1993). In relation to this, although the general form of a plant or flower, and especially the colour of a flower, guides bees to it from a distance, when a bee is close to a flower, scent provides the stimulus to alight (Free, 1993). Also, all the *Dahlia* flowers in this present study had yellow discs, that may have contributed to bees ignoring the variously coloured ray florets.

Cultivars may vary in many respects, apart from flower colour. Kay (1978) cites Kauffeld and Sorenson (1971) who found that *Apis mellifera* L. discriminated between cultivars of *Medicago sativa* L. that differed in flower colour. However, there was a close correlation between the nectar yield of each cultivar and the order of preference

shown by these honeybees. Kuger (1955), as cited by Kay (1978), also reported that *Bombus* spp. which did not discriminate between red and white flowered cultivars of *Lathyrus odoratus* L., could be induced to confine their visits to the red form if syrup was placed in its flowers, or if the nectar of the white flowers was diluted.

Phetpradap (1992) considered adjacent dwarf 'Figaro White' and mixed coloured Unwins Dwarf *Dahlia* plantings and reported that bees ignored the enmass white dwarf population. He then speculated that white was not attractive to bees, although the results of the present study and Meeuse's (1961) review do not agree with this. Firstly, Phetpradap (1992) failed to consider that the separation of these two plantings may have contributed to the apparent observation that bees ignored the 'Figaro White', as flower conditioning and constancy among bees are well documented (Crane, 1990; Free, 1993). This 'conditioning effect' occurs where bees become accustomed to the general flower shape and form of the plants (Free, 1993), and hence, they may possibly have treated the 'enmass' dwarf 'Figaro White' almost as if it was another species. In addition, although a bee species may be polytrophic, most individuals keep to one flower species only during a single trip. Many observers have found this constancy to even extend to many successive trips or days, especially if a particular crop is more attractive and available (Free, 1993).

Secondly, no introduced bees were reported, suggesting that bee populations may have been quite low. This may have contributed to the observations of bee behaviour being quite different than if populations had been high.

Finally, and perhaps more importantly, he completely ignored the effect of cultivar differences, apart from flower colour. One visible difference was plant size, the 'Figaro White' being considerably more dwarf than the 'Unwins mixed' plants. Numerous other cultivar differences, including those less apparent, may occur, such as varying nectar levels in the flower. Nectar production has been reported to vary amongst cultivars of a plant species such as lucerne and sunflower, and bees are more attracted to cultivars with higher nectar yield (Kauffeld and Sorenson, 1971; Free, 1993). Variation amongst cultivars of other plant species, including *Dahlia*, may also be likely.

Although, a number of other insects (predominantly flies, butterflies and moths) were observed visiting the flowers, their low numbers (3% of visits) and lack of substantial

body hairs (Free, 1993) suggests they are likely to have only a minor role in effecting pollination in the crop as a whole.

Floret counts revealed a much more uniform disc size than was anticipated. Sorenson, (1969) reported disc floret numbers ranging between 17 and 172. Nine of the 14 clones in the 'F' series had mean disc floret numbers in the 40s, while the full range only extended between 21 and 58. It was also anticipated that the disc floret number would reflect in seed yield differences, with those clones that had a more semi-double flowering appearance having a larger disc and a corresponding larger number of seeds. Within this series, this was not the case. The relationship between disc size and yield was not consistent, except that three of the lowest four yielding clones (7075/3, 7052/11 and 7052/8) also had the smallest discs (31, 25, and 21 respectively). One of the lowest yielding clones (7058/2) had a disc size no different from the top four yielding clones.

Disc floret numbers were confirmed as the major determinant of potential seed yield within the inflorescence, as no seeds were found in the ray florets in any of the samples dissected. Seeds from ray florets have been reported in *Dahlia*, but normally ray florets are considered to be sterile (Sorenson, 1969; Heywood, 1978; Hammett, 1980; Runger and Cockshull, 1985). In addition, it is important to bear in mind that the most central disc florets of many Compositae are also frequently sterile (Reynolds and Tampion, 1984; Sheriff, 1989).

Higher total floret number, and to a lesser extent higher ray floret numbers, often, but not always, coincided with greater seed yields. It is unclear why such a relationship should exist. Often various ratios of floret types did not show any clear relationship.

Disc fertility is defined as the number of seeds set out of the total number of disc florets. Since there is one ovule per floret, the potential seed number is equivalent to the floret number. Disc fertility and especially viable disc fertility varied widely among clones and appeared to be the critical factor determining the seed yield of individual clones. This relationship suggests that if clones could be selected on the basis of higher disc fertility, then overall seed yield for a mixed population could be dramatically increased. It may be possible to select clones with greater disc fertility than those represented here. A seed increase block could then be established from a mixture of high fertility clones, so that

seed multiplication becomes more profitable. The propagation of clones for tuber multiplication and sale is already an established practice for Hammett *Dahlias* (K.R.W. Hammett, Auckland, NZ, pers. comm., 1994).

Rooting ability of cuttings may also become important in this regard, and considerable variation was recorded in cutting establishment. Hartmann et al. (1990) reported that differences in rooting ability of cuttings can exist amongst cultivars of various species. 'Difficult to root' cuttings must have optimal environmental conditions if rooting is to be successful. The percentage of cuttings which 'took' varied from 86% (clone 7056/1) to only 22% (clone 7075/3) with a mean of 52% for the series (Appendix 4). The two top seed yielding clones (7073/2 and 7055/3) had 64% and 52% cutting establishment respectively. Even if inexperience, or less than optimum conditions, could be claimed for the establishment of these cuttings, the general variation observed is still valid, and would remain an important consideration for the choice of clones.
A seed production block may be able to be kept for more than one season, to offset the extra cost of establishment by cuttings. However, removal of diseased plant material and good pest and disease control would become more critical.

Seed yield varied widely among clones, ranging from approximately 100kg/ha to less than 1kg/ha. This has a number of implications. Firstly, is it possible to achieve high seed yields without necessarily compromising bloom quality? Secondly, the contribution that each seed lot subsequently makes to the harvested mixture may vary greatly and the population may drift away from certain desirable traits. Perhaps this could be corrected by planting higher numbers of lower yielding clones and/or by selecting new clones that contribute a desired trait but have a higher and more consistent seed yield.

It is interesting that five of the lowest six yielding clones had flower colours of white, pale (soft pink, lavender) or purple-magenta, whereas the top yielding clones ranged through yellow, orange and red. This may be coincidental but will be discussed in a later section on flower colour.

Most of the *Dahlia* clones in this series shed their ray florets during fertilization or during early seed development. Clone 7052/11 and to a lesser extent clone 7052/8

tended to retain their ray florets, and these were then prone to rotting. Floret retention provides an ideal site for botrytis infection, especially under cool, moist autumn conditions (K.R.W. Hammett, Auckland, NZ, pers. comm., 1994). Benomyl and iprodione fungicides were used approximately every 14 days during autumn (Table 5), in an attempt to reduce the extent of the infection. However, observations in this study with the 'F' series, and especially in the 'Baby Dahl' series (not reported here) suggest they have little ability to help in this situation. This may be due to the widespread occurrence of this pathogen, and thus constant reinfection, together with consistently favourable environmental conditions for infection, including the senescing ray florets (Dixon, 1984). Many seed heads became completely decayed as a result of disease infection. Infection levels were observed to be almost non-existent where ray florets were not retained in both the afore mentioned series. Although retained ray florets had a detrimental effect on seed yield in these two clones (7052/11 and 7052/8), the overwhelming reason for low seed yield was still their low fertility. Nevertheless, this suggests there may be value in selecting high yielding clones that drop their ray florets completely when, or soon after, fertilization has occurred.

Rooted cuttings were not transplanted into the field until mid-December because of delays in bulking-up sufficient plants. Because of this the seed yields obtained were not considered optimum, even though the climatic conditions were considerably warmer, sunnier, less windy and wetter than normal for Palmerston North, and definitely favoured *Dahlia* growth (Appendices 1.1, 1.2, 1.3 and 1.4). If the crop had been transplanted into the field even one month earlier, yields would almost certainly have increased due to both the extended growing season and the more favourable climatic conditions of the 1994-95 season. Han (1996) reported an average yield of approximately 75.6kg/ha at 1.56 plants/m^2 (@ 10% seed moisture content) for either single or multiple harvests. This is without any selection specifically aimed at improving seed yields. He used a combination of original clones and seedlings. This is compared with the average yield, among all clones in this study, of only 29.9kg/ha at 1.56 plants/m^2 (@ 10% seed moisture content).

Seed germination in the present study was disappointing (range 35-79%), particularly since Atwater (1980) from the Ransom Seed Laboratory in California reported an

average seed germination of 77% (from 200 seed lots), and Phetpradap (1992) consistently obtained *Dahlia* seed germination of 85-95%.

Two main factors may be responsible. Firstly, flowering did not peak until mid-April. Reducing temperatures at this time of the year are likely to have slowed and may have curtailed seed development before maximum food reserve accumulation had occurred. *Dahlia* seed reaches full maturity about 42 days after peak flowering but this may be extended under cooler temperatures (Phetpradap, 1992). The presence of empty seed and high levels of dead seed (19-56%) supports this possibility.

Secondly, the system for air drying seed after harvest, in this present study, involved spreading seed out on concrete in a heated glasshouse. This may well have reduced quality. Vis (1980) reported that *Dahlia* seed, dried under glass for three days with subsequent drying with heated air, gave a germination of 65%, compared with seed dried with heated air immediately after harvest, which gave a germination of 85%. Phetpradap (1992) followed this second method and obtained high seed germination. Rapid removal of moisture from moist seed appears critical. Late harvest (May), in combination with very wet seed (some of which may have been immature, and/or diseased) is likely to have exacerbated the situation. If harvesting was completed earlier then these factors may have been less critical. The large number of samples (composed of branches, leaves and seed heads) involved in this present study prevented the use of the Kiwi minidriers used by Phetpradap (1992).

Seed that has not germinated at the end of the normal germination test period (21 days, ISTA, 1996), but remains plump (having imbibed water) and firm is classified as fresh ungerminated seed. Such seed is alive but dormant. Most clonal seed lots produced some fresh ungerminated seeds, but the levels (0-4%) were considered to be too low to have any significant implication. The tetrazolium test result, in most cases was similar to the normal germination plus fresh ungerminated seed result. These data and results by Phetpradap (1992) and Han (1996), both indicate that dormancy occurs at only very low levels and so is of no major concern in *Dahlia* seed germination. Indeed the International Seed Testing Association only prescribes a short period of prechilling (4 - 7 days) to break primary dormancy - a common practice for many species recently harvested (ISTA, 1996). Dry storage for a few months overcomes this and no other subsequent dormancy problem is mentioned for *Dahlia*.

The emergence of seedlings under glasshouse conditions was lower than expected, being typically one half to two thirds of the germination result. One possible reason for this was the seedling mix used (Yates Black Magic seed raising mix). This mix was later reported to reduce germination success in a range of flower seeds by one third, compared to alternative seed raising mixes in an independent test (Anon., 1996). Although the ingredients of the mixes were discussed, no specific reasons for the variation amongst mixes were given. It seems reasonably likely that this was the major reason for the poor emergence observed.

Despite this, however, the time to 50% emergence and the spread of emergence varied among clonal seed lots showing slightly different levels of residual dormancy, which delays, but does not prevent, germination. This variability appears to have a physiological and genetic basis.

This inter-clonal effect may be due to what Ball (1991) described as some colours being 'weaker' than others but later capable of developing into strong plants.

The emergence time difference among the clones tested (just over six days), together with the varying spread of emergence (four days) has implications in nursery situations where both even germination and emergence are important. F. Onland, Palmerston North, NZ, pers. comm. (1995) has also reported a long emergence time period, such that cell plugs could not be directly used. In this case seed had to be germinated in a seedling tray and then transplanted into cells. This technique, which involves another step (increased costs), was also used by Han (1996).

Dry storage of seeds until the following season may well overcome or reduce the variation in different seed lots, but whether this is economically feasible is unknown. Also, it is possible a longer period of pre-chilling and/or cooler pre-chilling temperatures may reduce this variability but this would need further testing. Another possibility for reducing variability may include various types of priming treatments. These priming treatments are all based on the initiation of seed germination under controlled conditions in order to maximize the potential vigour of the seed and allow it to gain a head start on susequent germination. The basic idea is to allow the seed to take up sufficient water to initiate early events in germination, but not to allow radicle emergence so that seeds can be subsequently dried down and handled conventionally (Coolbear, 1992). Some of

these treatments have been at least partially successful with other Compositae species, such as *Coreopsis* and *Echinacea* (Samfield et al., 1991; Finnerty and Zajicek, 1992; Pill et al., 1994; Wartidiningsih et al., 1994).

If all of the seed from all clones had been combined, then the clonal effect of spreading the time of germination out would have been masked. If a large amount of the late germinating seed was not used, due to its small size at the time of transplanting or selling, then one or more clones would, in effect, have not contributed to the next generation. This will have implications for colour balance and numerous other desirable traits in the next generation.

The flower colour range occurring in the half-sib lines clearly showed the high levels of self-incompatibility and heterozygosity prevalent in *Dahlia* (Sorenson, 1969; Hammett, 1980). Seed from different clones, however, showed varying levels of maternal dominance. The following brief descriptions of the maternal parents are supplemented by photographs of each clone (Appendix 4). No photographic record of each half-sib line was taken because it was difficult to record all progeny in this way. However, a video film was taken of all lines on 31 March - 1 April to provide a pictorial record.

The light 'baby' pink flowered clone (7052/6) produced over 50% of its progeny with pink flowers (almost all pale) and an additional 29% with white or off-white flowers. Nearly 80% of the progeny were, therefore, very like the maternal parent.

In contrast, the apricot/orange flowered clone (7056/1) produced only 11% orange flowers in the half-sib. This reduction appeared to be a result of there being a segregation of the red and yellow pigments in the progeny. Nearly 25% of the progeny produced flower colours that were red, and 37% produced flower colours that were yellow.

Another interesting clone was 7058/1 (purple-magenta) where the half-sib progeny produced nearly all their flowers in the purple - dark pink - medium red colour range. This was a much narrower colour range than almost all other half-sib lines.

Clones 7073/1 and 7073/2 were reasonably similar. Both were bicolours (Huxley, 1992), with a yellow ground colour tipped with red. The red tip on 7073/1, however, was more prominent than on 7073/2 (see Appendix 5). Over 50% of the 7073/1 half-sib progeny were red (18% yellow), whereas this was almost exactly reversed with the half-

sibs of clone 7073/2, where just over 50% were yellow and only 14% red. Therefore, the degree of red tipping over the common ground colour had a big influence on the proportions of flower colour of the respective half-sib progeny. Both clones 7073/1 and 7073/2 had similar levels of orange flowered half-sib progeny (10.7% and 18.6%) respectively, which was not significantly different.

Apart from one line, the degree of doubleness in the flowers among the half-sib progeny, did not differ significantly. However, there was a high degree of variation amongst replicates. Although ten plants per replicate were planted, not all flowered, due to plant death and a combination of late planting and competition from the shelter belt. It appears essential, when working with a highly varied genotypic population, that the number of plants per replicate is sufficiently high to reduce this variability.

Nearly 80% of the half-sib progeny bore double flowers at the time of observation (early April). Daylengths of less than 12 hours are occurring at this stage of the season. This would have contributed to increased disc floret number (Maatsch and Runger, 1955; Konishi and Inaba, 1964; Canham, 1969; Masterlerz, 1976; Durso and De Hertogh, 1977), and/or decreased ray floret number (unreported data from this study), and decreased total floret number (Maatsch and Runger, 1955; Konishi and Inaba, 1964). This may have suggested a less double looking inflorescence. Nevertheless, these results show that maintaining a high degree of doubleness in flowers of half-sibs is possible. The only clone that had a more semi-double flower in the maternal parent (7058/1) produced only 50% of its half-sib progeny with double flowers. To reduce the number of semi-double flowers it would be better to eliminate this clone or its progeny from seed multiplication. However, the plant breeder includes a particular clone for various reasons and needs to balance the various traits desired, and so this remains the breeder's choice.

Within the population provided: white/lavender, light pink or purple-magenta flower coloured clones produced lower seed yields, whereas red, orange or yellow flowered clones produced seed yields typically much higher. Whether or not this is a coincidence could be important in maintaining a reasonable colour range in a subsequent seed mix. Table 11 shows the tendency for the half-sib progeny to be dominated by red, orange and

yellow coloured flowers. Over 80% of the seed produced is predicted to produce subsequent plants with flower colours in this range. If a seed-to-seed multiplication system is used then the next generation of flowers might well be expected to have even fewer white, lavender, purple and pink flower shades.

As already noted (Lawrence and Scott-Moncrieff; 1935; Sorenson, 1969) the modern garden *Dahlia* is a hybrid, originally the product of a cross between a white/purple-magenta flowering species (probably *D. pinnata*) and a red, yellow flowering species (*D. coccinea*). This suggests there may be a genetic link between flower colour and disc fertility related to this original hybridization, leading to white/purple-magenta coloured flowering plants contributing a lower seed yield.

It is interesting that Sorenson (1969) also mentions that the only wild *Dahlia* species that might be described as a 'weed' is *D. coccinea*. Presumably, therefore, it must be a good seeder, as is the case with most of the yellow, orange or red flowering clones in this study. Only testing of further clones will determine if there is any truth to this suggestion.

CHAPTER 2

2.1 INTRODUCTION

2.1.1 The Weed Control Strategy

Weed control is an essential ingredient to the successful production of plants. This is especially so for many ornamental plants such as *Dahlia*, because weeds can rapidly out grow them. Although various cultural and mechanical methods have been developed for controlling such situations these may damage the crop (e.g. mechanical weeding of shallow rooting crops), may be inadequate, and/or may be very expensive. Correct use of selective herbicides offers the grower an efficient way of eliminating or controlling weeds. Essentially there are three components to the weed control programme. The first is to eliminate weeds prior to planting. The second is to prevent weed growth and the third is to eliminate weeds as they appear (Kulns, 1994). The third measure is often most difficult, especially if there is a wide weed spectrum growing in the crop. Eliminating weeds before sowing is vital, but on its own may be inadequate. As a result, preventing weed growth by using pre-emergence herbicides is usually an additional necessity. Pre-emergence herbicides rather than post-emergence herbicides are generally safer and often more effective in controlling weeds, particularly during the slow establishment stage of many crop plants.

2.1.2 Available Literature

One major problem is that very few herbicides have been developed and registered for specific use in ornamental crops such as *Dahlia*. Over the past 20 years, however, more work has been done on herbicide use in ornamental crops in situations such as bedding plantings, nurseries, cut flower, bulb and seed production. Work has been done with both overall and directed sprays. Although much of this work is 'locked up' in private companies, a reasonable amount of information can be gleaned from the published literature.

2.1.3 The Problem

One of the pressing production issues is the safe and effective use of herbicides in relation to tuber production , particularly the subsequent normal re-sprouting ability of *Dahlia* tubers produced following the use of residual herbicides (K. R. W. Hammett, Auckland, NZ, pers. comm., 1994). The purpose of the present study was to determine

Dahlia crop tolerance to selected herbicides and to assess the potential for carryover of herbicides in the tubers and their potential effect on re-sprouting ability.

2.2 LITERATURE REVIEW

2.2.1 Introduction

This review is predominantly restricted to herbicide use in *Dahlia* but also includes brief reference to herbicide use on other ornamental Compositae and bulb, corm, and tuber crops where this is considered relevant.

2.2.2 Weeds Defined

A weed has been generally defined as any plant growing where it is not wanted (Blackmore and Tootill, 1984); and more specifically to a plant or plants which 'interfere with the objectives of people' (Mortimer, 1990).

Problems caused by weeds include: competition, reduced crop quality, interference with harvesting, increase in the incidence of pests and diseases, delay and/or uneven maturity of crops. Many weeds can also become a problem in subsequent crops grown later in the rotation (Hawthorn and Pollard, 1951; Briggs, 1972; Lawson and Wiseman, 1978; Vis, 1980; Hance and Holly, 1990; De Hertogh and Le Nard, 1993).

Many people look at weed control as a fire fighting measure - "when weeds appear, kill them". It is easier, cheaper, safer and longer lasting to prevent weed growth than to kill existing weeds. This suggests the weed control programme should begin before planting and should also involve eliminating weeds in and around the growing area, preventing weed growth, and eliminating weeds as they appear. (Kulns,1994)
The following are a number of weed control strategies available to the manager.

2.2.3 Herbicides

Herbicides can be defined as any chemical that, when applied to a plant, will either destroy it or seriously inhibit its growth (Blackmore and Tootill, 1984) . Some herbicides are selective. These are chemicals which when applied to a mixed population of plants, will severely injure or kill certain species with little or no injury to others (Crafts, 1975). Non-selective herbicides, however, are those which are toxic to all plants (Kulns, 1994).

Herbicides can also be categorised as contact or translocated. Contact herbicides kill only that part of the plant with which they come into contact. Translocated herbicides move within the plant and kill all parts of it. Perennial weeds usually re-grow following contact herbicide application. Pre-emergence herbicides control weeds at the seed germination stage, with best results being achieved when they are applied to weed-free soil before weeds emerge. Post-emergence herbicides control existing weeds (Kulns, 1994).

Kulns (1994) states that many pre-emergence herbicides must be applied and activated with rainfall or irrigation prior to germination of weed seeds. Very few pre-emergence herbicides provide control of existing annual or perennial weeds growing from established vegetative parts, such as roots, rhizomes, or tubers.

Two essential considerations in choosing a herbicide are its safety at the relevant stage of crop growth and its efficacy against the weeds that are present at application or are expected to germinate subsequently (Rees, 1992). A herbicide's safety can be related to its selectivity to not affect the crop plant, the stage of growth of the crop, the method of application or any combination of these.

2.2.4 Herbicides for Compositae Crops

Various chemicals have been used over the years to control weeds in many herbaceous flowering crops. Appendix 6 lists herbicides which have been reported as safe on at least some ornamental Compositae crops. Alachlor, chlorpropham, chlorthal-dimethyl, oxadiazon, and trifluralin in particular are reported to be safe across a relatively large number of species.

2.2.5 Herbicides in Ornamental Bulb Crops

Since *Dahlia* is somewhat unique among the Compositae in that it forms a sizeable clump of tubers, the literature search was also extended to include herbicide use in ornamental bulbs. A lot of data has been published on work done on *Narcissus* and tulip (Wood et al.,1960; Wood, 1960; Turquand, 1962 and 1966; Briggs, 1972; Brosh et al., 1973a, and 1976; Brosh and Finkelstein, 1976; Brosh, 1976; Ryan and MacNaeidhe, 1978; Peabody, 1981; Smith and Treaster, 1982 and 1984, as cited by Skroch et al.,

1990; Bing and Macksel, 1984; Bing, 1985; and Skroch et al., 1988). Also gladioli is covered reasonably well (Brosh and Finkelstein, 1973a,b; Talia et al., 1986; Gilreath, 1986; Yadav and Bose, 1987; and Bing et al., 1988). Agamalian, (1987) and Ingle and Bussell (1991) also report on calla lilies (*Zantedeschia* spp.) In addition Appendix 7 includes a table reporting on nine herbicides applied four times over two years to 12 ornamental species or cultivars (Skroch et al., 1988).

2.2.6 Dahlia

2.2.6.1 Introduction

A brief discussion of herbicides used on *Dahlia* reported in the literature which are available in New Zealand, as well as having reasonably good weed control follows with a summation given in Table 12. Further details should be obtained from the original reference. All rates quoted are in kg of active ingredient per hectare.

2.2.6.2 Alachlor

Alachlor (3.4kg/ha) applied six days after transplanting gave acceptable weed control and did not produce any visual phytotoxicity on transplanted annual bedding plants including seed-raised plants of *Dahlia pinnata* cv. Early Bird Mix (Fretz, 1976). Alachlor (1.92kg/ha) applied to 'F' series *Dahlia* did not injure either direct sown or transplanted seedlings (Han, 1996).

2.2.6.3 Chlorthal-dimethyl (DCPA)

Clay and Ivens (1964) reported on observational trials using chlorthal-dimethyl (10lb/acre = 11.2kg/ha) on *Dahlia* which caused no apparent injury. This was confirmed by Fretz (1976), Kulns (1994) and Han (1996). Chlorthal-dimethyl controls most grasses and some broad-leaved weeds (Kulns, 1994), although some important broad-leaved weeds are not be well controlled (J. Tutaki, Pukekohe, NZ, pers. comm., 1995) and lack of persistence is a problem.

2.2.6.4 Haloxyfop

Haloxyfop selectively controls grasses in many broadleaf crops including annual poa which is not controlled by fluazifop and is reported to not harm *Dahlia* (Han, 1996).

Table 12: Summary of herbicides used on *Dahlia* plants published in the literature which are reported safe[1] or cause only minor initial damage with subsequent plant recovery.

HERBICIDES	REFERENCES[2]	WEED CONTROL[3]	NZ
alachlor	Fretz (1976), Han (1996).	Generally good.	✓[4]
bensulide	Kulns (1994).	Grasses, some broad-leaves.	×
butralin	Fretz (1976).	Unacceptable.	×
chloramben	Fretz (1976).	Unacceptable.	×
chloroxuron	Brosh et al. (1976).	Not grasses.	×
chlorpropham	Clay & Ivens (1964), Han (1996).	Limited persistence.	✓
chlorthal dimethyl (DCPA)	Clay & Ivens (1964), Fretz (1976), Kulns (1994), Han (1996).	Limited persistence.	✓
clethodim	Talbert et al. (1992).	Only grasses.	✓
diphenamid	Clay & Ivens (1964), Fretz (1976).	Reasonably good.	×
dithiopyr	Talbert et al. (1992).	Unknown.	×
EPTC	Fretz (1976), Kulns (1994).	Poor, some perennials.	✓
fluazifop	Bodman & Hughes (1985).	Grasses, not *P. annua*.	✓
haloxyfop	Han (1996).	Grasses incl. *P. annua*.	✓
lenacil	Fryer & Makepeace (1978).	Reasonably good?	×
metolachlor	Talbert et al. (1992).	Grasses.	✓
methabenzthiazuron	Han (1996).	Reasonably good.	×
napropamide	Fretz (1976), Talbert et al. (1992), Kulns (1994).	Reasonably good.	×
nitrofen	Brosh et al. (1976).	Poor.	×
oryzalin	Staats & Klett (1993), Han (1996).	Variable.	✓
oxadiazon	Brosh et al. (1976), Staats & Klett (1993) Han (1996).	Good.	✓[4]
oxyfluorfen	Staats & Klett (1993), Han (1996).	Good.	✓
pendimethalin	Talbert et al. (1992), Han (1996).	Generally good, variable.	✓
propachlor	Fryer & Makepeace (1978).	Mainly grasses.	✓
propham	Brosh et al. (1976).	Poor.	×
sethoxydim	Talbert et al. (1992), Kulns (1994).	Grasses.	✓
simazine	Clay & Ivens (1964).	Good.	✓
terbacil	Han (1996).	Good.	✓
trifluralin	Clay & Ivens (1964), Fretz (1976), Staats & Klett (1993), Kulns (1994).	Grasses, some broad-leaves.	✓
2,4 DES	Fryer & Makepeace (1978).	Poor.	×

[1] although listed as 'safe' careful reading of the reference(s) is recommended to determine the way the herbicide was applied. The timing and method of application of the herbicide; herbicide formulation, rate, efficacy and availability; type and age (or size) of propagule (tuber, rooted-cutting, seedling); soil type; climatic conditions; weed species; and cultivar/species genetic variability all influence the decision as to which herbicide is the best in any particular situation.

[2] see references in the text for more detail.

[3] this is only a brief comment. See references indicated as well as product label information and consult local growers and applicators who have used these materials.

[4] Available in New Zealand as at January 1997 but exact formulations may vary compared to the cited reference.

2.2.6.5 Oryzalin

Staats and Klett (1993) reported that in a nursery situation when oryzalin (2.8 and 4.5kg/ha) was applied to the 'soil' surface no injury to *Dahlia* resulted. However, weed control was often variable. See section 7.7.4 for further details.

Han (1996) reported that oryzalin (4.5kg/ha), while not affecting seedling emergence, did affect early growth and reduce leaf numbers per plant in direct sown plants. It also caused some injury of transplanted seedlings but these recovered quickly.

2.2.6.6 Oxadiazon

Oxadiazon (1.25-1.5kg/ha) applied pre-plant had no adverse effects on the growth of tuber-grown *Dahlia*, but when sprayed 1-2 months after planting it scorched leaves and sprouts and inhibited growth. This herbicide gave good and lasting control of *Amaranthus*, *Portulaca*, *Digitaria*, *Echinochloa*, *Notobasis*, and *Raphanus* species (Brosh et al.,1976a).

Staats and Klett (1993) reported that oxadiazon (4.5 and 9.1kg/ha) in granular form, applied to the 'soil surface' was not harmful to potted *Dahlia* and controlled all weeds in the containers.

Han (1996) reported that oxadiazon (1.52kg/ha) damaged direct sown *Dahlia* and injury to transplanted seedlings after one week of application was severe although all plants had recovered four to five weeks later.

2.2.6.7 Oxyfluorfen

Staats and Klett (1993) also reported that oxyfluorfen in granular form, applied to the 'soil surface' was not harmful to potted *Dahlia* and controlled all weeds in the containers. However, Han (1996) reported that oxyfluorfen (0.72kg/ha) damaged direct-sown *Dahlia* and also caused severe injury to transplanted seedlings after one week but plants recovered four to five weeks later. Although Han (1996) concluded that oxyfluorfen should not be used on *Dahlia* none of the final seed or tuber yield measurements differed from the control (or other treatments which caused no initial damage). This agrees with similar work by Smith et al. (1983), as cited by Skroch et al. (1990), who found that injury to shoot meristems of plants treated with napropamide and oxyfluorfen was only temporary but persisted on plants treated with trifluralin and oryzalin.

2.2.6.8 Pendimethalin

Dahlia hybrida cv. Figaro in bedding plant trials is tolerant to the pre-emergent herbicide pendimethalin (Talbert et al., 1992). In addition pendimethalin (1.32kg/ha) did not injure either direct-sown or transplanted seedlings in 'F' series *Dahlia* (Han, 1996).

2.2.6.9 Simazine

Clay and Ivens (1964) reported that in a series of field and pot trials, simazine was the most effective of a number of herbicides tested on *Dahlia* grown for flower production. A dose of 1lb/acre (1.1kg/ha) caused slight leaf injury, but did not affect flower production; 2lb/acre (2.2kg/ha) caused more serious injury. Cultivars differed in susceptibility to damage from simazine. *Dahlias* planted as divided tubers appeared to be less liable to damage than rooted cuttings.

2.2.6.10 Trifluralin

Trifluralin has been widely reported to not cause any damage to *Dahlia* plants (Clay & Ivens, 1964; Fretz, 1976; Staats & Klett, 1993; Kulns, 1994). Details of weed species controlled is given in section 2.2.7.5, and while inadequate by itself can be used in combination with another herbicide very effectively.

2.2.7 Herbicides Used: Product briefs and associated information

(from Walton and Sommerville, 1996).

2.2.7.1 Oxyfluorfen (Goal®)

In 1980 Rohm and Haas Company, USA introduced oxyfluorfen (Fletcher and Kirkwood, 1982). It is a contact herbicide which controls a wide range of broadleaf weeds and some annual grasses, and has a 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 soil layer. It is nearly insoluble in water (0.1ppm) and does not leach into the root zone of crop plants. It may be mixed with other herbicides to knock down existing vegetation and/or extend the spectrum of weeds controlled. In New Zealand it is now only available as Goal® XL which does not contain xylene and is, therefore, of lower toxicity and no longer rated as flammable.

The chemical group it belongs to is nitrophenyl ether. Oxyfluorfen is a contact herbicide with greatest activity when applied before weed emergence. In addition it has post-emergence activity but, to be effective, weeds must be very small. As a soil residual treatment, emerging weeds contact the chemical layer as they break the soil surface. 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. Weeds controlled include: bitter cress, catsear, cut-leafed geranium, field madder, field speedwell, hedge mustard, mallow spp., mouse-eared chickweed, nettle, parsley piert, pennyroyal, shepherds purse, sow thistle, storksbill and twin cress.

2.2.7.2 Oxadiazon (Foresite® 380)

In 1969 oxadiazon, an oxadiazole, was originally introduced by Rhone-Poulenc as Ronstar™ (Fletcher and Kirkwood,1982) and was available in New Zealand in 1984 under that name (O'Connor,1984). However, it was withdrawn soon after and was re-released as Foresite® by 1987 (O'Connor,1987). By 1993, the formulation had altered slightly and was trading as Foresite® 380. In addition , to add to the confusion, a new herbicide combination of oxadiazon plus simazine in a granular form, had also been released by 1990 under the trade name Ronstar™ SG (O'Connor, 1990).

Oxadiazon 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 is reduced. It is very crop-safe as is fixed to the soil surface and is almost resistant to leaching (solubility 0.7ppm). Under favourable conditions the recommended use rate will provide residual weed control for three months or more. Oxadiazon is a surface action residual herbicide which is absorbed by the emerging shoot of weeds preventing further development above the soil surface.
Weeds controlled include many grasses and broad-leaf plants except greater bindweed, scotch thistle, small flowered mallow and field pansy which will only be severely checked. Chickweed, pearlwort and most rhizomatous weeds will not be controlled.

2.2.7.3 Ronstar ™ SG (oxadiazon plus simazine)

Ronstar™ SG is a selective pre-emergence granular herbicide specifically aimed at weed control in container grown woody ornamentals, nurseries and home gardens. It controls a wide range of annual grass and broadleaf weeds. It needs to be applied to bare soil before weeds germinate. It contains both oxadiazon and simazine. Ronstar™ SG is absorbed by both emerging shoots (oxadiazon) and roots (simazine) of germinating seedlings (Walton and Sommerville, 1996).

Simazine was the first commercial triazine and was introduced by Ciba Geigy in 1956 (Fletcher and Kirkwood,1982). It is 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 grass and broadleaf weeds. The soil residual life ranges from 3-12 months depending on rate, soil type and rainfall. It is usually mixed with other herbicides to provide knockdown of existing vegetation as it has little or no activity on existing vegetation. Simazine is absorbed only through the roots of plants as they germinate, with symptoms of yellowing then death. The solubility in water is 5ppm (Walton and Sommerville, 1996).
Specific details for oxadiazon can be found under section 2.2.7.2

2.2.7.4 Oryzalin (Surflan® Flo)

Oryzalin is a selective pre-emergence surface-applied herbicide for the control of most annual grasses and certain broadleaf weeds. It belongs to the chemical group dinitroaniline. Oryzalin affects germination after being taken up by roots of germinating weed seedlings. Solubility in water is 2.5 ppm.

Susceptible weeds include: annual poa, barnyard grass, crowsfoot grass, summer grass, seedling paspalum, chickweed, fathen, field speedwell and redroot. Moderately susceptible weeds are: creeping mallow, nettle, shepherds purse, willow weed, and wire weed. The control of black nightshade and twin cress is variable.

2.2.7.5 Trifluralin (Treflan®, Tridan®, Triflur 40)

Trifluralin is a pre-plant soil-incorporated herbicide for selective weed control in many crops. It controls a wide range of annual grass and broadleaf weeds as they germinate. The chemical group it belongs to is dinitroaniline (the same as oryzalin). Trifluralin is taken up by emerging roots of susceptible species as seedlings germinate.

Weeds controlled include: *Amaranth* spp., annual poa, barnyard grass, bladder campion, bristle grass, calandrinia, catchfly, chickweed, cleavers, cornbind, fathen, red dead nettle, red root, scarlet pimpernel, spurrey, summer grass, wild portulaca, wireweed, witch grass and yellow gromwell. Resistant weeds include: black night shade, clovers, fumitory, mallows, shepherds purse, storksbill, twincress and wild turnip.

2.3 MATERIALS AND METHODS

2.3.1 Selection of Herbicides

Advice from the breeder (K. R. W. Hammett, Auckland, NZ, pers comm., 1994) and a published paper reporting herbicide use in a nursery situation (Staats and Klett, 1993) provided the basis for the 'best guess' decision on which herbicides would be used in the present study i.e.: trifluralin (Triflur 40), oxadiazon (Foresite ® 380), oxadiazon and simazine (Ronstar™ SG), oryzalin (Surflan® Flo), oxyfluorfen (Goal®), and a combined treatment of oryzalin plus oxyfluorfen (Surflan® Flo plus Goal®).

These herbicides did not significantly injure pot-grown *Dahlia* (Staats and Klett, 1993). As well, oxadiazon has been tested by the breeder (K. R. W. Hammett, Auckland, NZ, pers. comm., 1994) with good results. He had also observed that while simazine damaged plants, Ronstar™ SG which contains both oxadiazon and simazine may provide an interesting comparison with oxadiazon on its own. Clay and Ivens (1964) have also indicated that simazine was only safe at low rates. Trifluralin is registered as safe in sunflower (Walton and Sommerville,1996) in is reported safe in *Dahlia* (Clay and Ivens, 1964; Fretz, 1976; Kulns, 1994).

Oxyfluorfen has given excellent weed control (Staats and Klett, 1993) and so was also included. However, due to its formulation (emulsifiable concentrate) it was predicted to cause leaf scorch unless applied as an indirect spray (Walton and Sommerville, 1996). Although oryzalin has been found to be safe in *Dahlia* (Staats and Klett, 1993), effectiveness of weed control is often variable (Walton and Sommerville, 1996). For this reason a sixth combined treatment of oxyfluorfen and oryzalin was also included in case the oryzalin treatment failed to control weeds adequately. In addition both a hand weeded and a non-weeded control were included making a total of eight treatments. Although, all of the herbicides used have been reported safe, no measurements of tuber weights have been given in any of the studies. In addition, Dr Hammett, wanted to establish whether or not there was any subsequent effect on the re-sprouting ability of these tubers which had grown in the presence of these herbicides.

2.3.2 Experimental Site

The herbicide experiment was located on land adjacent to the Plant Growth Unit of the Department of Plant Science, Massey University, Palmerston North (Plate 28). The site

was sheltered by a poplar shelter belt to the west, a mixed shelter belt to the south and the plastic houses to the east.

2.3.3 Soil Type and Land Preparation

The soil type and land preparation, liming and fertilizer practices were the same as described for the seed production site.

2.3.4 Plant Material

Clay and Ivens (1964) reported variation to herbicide tolerance amongst the few *Dahlia* cultivars they tested. Because of this it was decided to use seedling material rather than a limited number of clones. This would then test herbicide tolerance over a potentially wider genetic range.

The experiment was conducted using 'F' series *Dahlia* seed supplied by Dr Hammett. This seed was produced in the 1992-93 and 1993-94 growing seasons in north-west Auckland. It was sown in 60 cell plug trays on 14 October 1994 using a seedling mix as described for the half-sib experiment. Cell trays were placed in a glasshouse with heating at 16°C and venting at 22°C.

On 22 November seedlings from the 1993 seed harvest (grown and supplied by Dr Hammett) were potted into PB 3/4s (dimension 64x64x150mm) using a short term mix of bark:pumice (4:1 v/v) with 1kg Agricultural Lime, 3kg Dolomite and 1.5kg of Osmocote® 14:16.1:11.6 (N.P.K) (3-4 months) /m^3.

Seedlings from the 1994 seed harvest (grown and supplied by Dr Hammett) was potted identically on 30 November. This time difference was due to residual dormancy in the 'fresh' 1994 seed (approximately six months old), compared with the older 1993 seed (approximately 18 months old) which delayed germination, and hence, subsequent growth by about one week. All seedlings were moved into a shade house one week after potting, and were transplanted into the field by hand on the 20 December and were irrigated immediately using the same method as described for the seed production experiment.

Plate 28 Herbicide Experimental Site looking approximately north-east 18 February 1995, 60 days after transplanting.

Plate 29 Re-sprouted tubers in a PGU glasshouse at the end of the recording time. Note no sign of phytotoxicity.

2.3.5 Experimental Design

The 1993 and 1994 seedlings were randomly mixed before transplanting. Each plot was 2.25m x 3.75m (= 8.44m^2) arranged in 4 lines of 8 continuous plots (Appendix 5). The plant spacing was 0.75m x 0.75m which was deemed to be non-competitive.

Treatments were allocated using a completely randomized design as it was believed there was no moisture or nutrient gradient in the field. Data were subjected to a Proc GLM procedure using SAS release 6.11 of the SAS® system. The eight treatments are described in Table 13.

2.3.6 Herbicide Application

A decision to administer an overall spray or a directed spray application procedure was required. Since the proposed herbicides included trifluralin, which had to be applied pre-planting, and Ronstar™, a granular herbicide, it was thought that an initial experiment which did not apply herbicides directly on *Dahlia* leaves would be most relevant.

Herbicides were applied using a Solo knap-sack sprayer which was calibrated to my walking speed. As an extra check, only the amount of herbicide required for the four replicates was made up, so that extra herbicide could not be applied. Trifluralin was applied on 19 December, the day before transplanting and immediately rotary hoed to an approximate depth of 20cm. All other herbicides except Ronstar™ SG were applied on 21 December, the day after transplanting. Ronstar™ SG pellets were applied by hand on 23 December. Irrigation (approx. 30mm) was applied soon after spraying. Oxyfluorfen and oryzalin in the combined treatment were applied separately. All sprays were directed to the interrow soil surface under calm conditions.

Hand weeding was done by push hoe on the 5 February, 25 February, 15 March, and 13 April when weeds were still reasonably small. Despite this, some weed competition still occurred.

Table 13 Description of the Herbicide Treatments

No.	Trade Name	Distributor	Packsize	Common Name	Recommended a.i./ha[2]	Treatment a.i./ha	Formulation	$/ha[5]
1.	Hand Weed	-	-	hard work	-	-	-	$9000[6]
2.	No herbicides + no hand weeding	-	-	-	-	-	-	$0
3.	Triflur 40	Nufarm	5 &20l	trifluralin[4]	0.6 - 1.2kg	1.2kg	emulsifiable concentrate	$48
4.	Foresite® 380	Rhone-Poulenc (NZ) Ltd.	1 &5l	oxadiazon	1.5kg	1.5kg	suspension concentrate	$272
5.	Ronstar™ SG	Rhone-Poulenc (NZ) Ltd.	20kg[3]	oxadiazon + simazine	0.4kg + 1kg	0.4kg + 1kg	pellet	$1860
6.	Goal® (now Goal® XL)	Elliot Chemicals Ltd.	5l	oxyfluorfen	0.12 - 1.44kg	1.44kg	emulsifiable concentrate	$268
7.	Surflan® Flo	Dow Elanco (NZ) Ltd.	5l	oryzalin	3 - 4.5kg	3.5kg	suspension concentrate	$314
8.	Goal® + Surflan® Flo[1]	see details above						$582

Comments from Table 13.

[1] available also as a combined product Rout® in granular form.

[2] recommended rates vary according to soil type and crop species.

[3] is also available at Garden Centres for general sale as NO WEEDS Ronstar™ SG (250g) with the a.i. at the same cost for about $13 (1997), distributed by Kiwicare Corporation Ltd., Christchurch. This works out to approximately $10400/ha.

[4] pre-plant soil-incorporated.

[5] based on prices excl. GST supplied by Morgan Laurenson Ltd., Palmerston North in January 1997.

[6] estimate based on Lamont et al. (1985) and Bannon et al. (1988).

2.3.7 Plant Protection

The plant protection programme included an electric rabbit fence, snail and slug bait and a regular spray programme which included an insecticide, a fungicide, usually a miticide and a wetter/sticker/rainproofer. Details are the same for the seed production experiment and are given in section 1.3.1.7.

2.3.8 Damage Assessments

Although initially herbicide damage assessment methods were prepared, no visible damage occurred from the treatments, so the only measurements taken during the growing season were photographs at monthly intervals.

2.3.9 Weed samples

Two quadrants (0.2x0.6m = 0.18m^2) in each plot were cut at ground level on 4 July 1995 to give a representative sample of the weed population in each plot at this time. After cutting, the weeds were categorized into the following: Black nightshade (*Solanum nigrum* L.); annual grasses (including *Echinochloa crus-galli* (L.) P. Beauv., *Setaria* spp., *Digitaria sanguinalis* (L.) Scop. and *Poa annua* L.); chickweeds (*Stellaria media* (L.) Villars and *Cerastium glomeratum* Thuill.); clovers (*Trifolium repens* L., *T. dubium* Sibth.); sow thistle (*Sonchus oleraceus* L.); and remainder. The remaining species were identified. These weeds were then oven dried for a minimum of 70h at 80 ± 3° C and then weighed.

2.3.10 Tuber Harvest and Resprouting

Tuber clumps from each treatment were dug up between the 18 and 25 July 1995. On the 29-30 July adhering soil was gently washed off and the stems were trimmed to about 10cm in length. Each tuber clump was then weighed and the number of individual tubers counted. Tubers were then put into pots appropriately the same size as the tuber clump, using the same short term mix described for potted seedlings (see section 2.3.4). These tubers were placed in a glasshouse with heating at 21°C immediately after potting. Tubers were checked every two or three days for sprouting. When a sprout had reached 1cm in length it was included in count of the total cumulative shoots which had sprouted for that tuber clump. Information was obtained on both total shoot numbers and also sprouting speed. Counts were continued for 35 days. No more shoots had emerged over the previous five days when counting was discontinued. By this stage plants were quite large. Most plants had visible buds while some plants even had the first inflorescence open (Plate 29).

2.4 RESULTS

2.4.1 Weeds

2.4.1.1 Weeds in Plots

Plates 30-37 provide examples of all treatments as they appeared 118 days after transplanting (mid-April). The oxyfluorfen plus oryzalin plot and the oxadiazon plus simazine plot had less weeds than the hand-weeded plot at sampling in July. At this time, *Dahlia* growth had effectively ceased six to eight weeks previously. Weed growth, however, was still apparent. The dominant weed was clearly black nightshade (*Solanum nigrum* L.), especially in the control and the oryzalin plots. There was no visual sign of stunting or phytotoxicity caused by any of the treatments amongst the *Dahlia* plants. This was not surprising since all herbicides were applied as a directed interplant spray.

2.4.1.2 Weed Dry Weights

The major effect on total weed dry weight was the ability or inability of individual herbicides to control black nightshade, and to a lesser extent grass and clover (Table 14). Oryzalin was ineffective in controlling nightshade but when mixed with oxyfluorfen, which is effective against black nightshade, these two chemicals reduced weed dry weight more than five fold. In fact this combination was as effective as hand weeding, oxadiazon (± simazine) and oxyfluorfen (Table 14).

Total weed dry weight was nearly five times higher in the control (unweeded) and the oryzalin treatments (combined mean of 668g/m^2)than in the hand weeded plots (137g/m^2). Only oryzalin failed to decrease weed levels compared to the unweeded control , mainly because of lack of control of black nightshade (Table 14). The trifluralin treatment produced about half the weeds (397g/m^2) of the unweeded control by the time of tuber lifting in July, primarily by reducing nightshade growth. Weed dry weight for the oxadiazon plus simazine treatment (290g/m^2) was not significantly different from that for the trifluralin treatment. The remaining three herbicide treatments all had significantly less weeds than the worse three treatments. None was significantly different from the hand weeded treatment (Table 14).

The description of weeds on a dry weight basis is perhaps misleading, since some species such as black nightshade are large dry matter plants while others like chickweed and twincress are relatively low dry matter plants. The opportunity to have described relative

species occurrence in terms of canopy structure and/or ground cover might be considered to have been more meaningful.

2.4.1.3 Weed Species Present

The most abundant weed was black nightshade (*Solanum nigrum* L.) which represented nearly 50% of the weed species present over all treatments, and between 75 and 98% of the weed dry weight in the three treatments which had the poorest weed control (Table 15). Major control of this weed was only obtained in treatments which included oxadiazon and oxyfluorfen (Table 14).

Annual grasses, the next highest weed component, comprised an average of 17% of the dry weight of the weed species over all treatments. These included barnyard grass (*Echinochloa crus-galli* (L.) P. Beauv.), bristle grasses (*Setaria* spp.), summer grass (*Digitaria sanguinalis* (L.) Scop.) and *Poa annua* L. At the time of sampling (July) the grass species represented between 10-40% of the weed dry weights in six of the eight treatments. Grasses occurred at low levels in the trifluralin (4% of the dry weight) and the oryzalin treatments (<1% of the dry weight).

Chickweeds (mainly *Stellaria media* (L.) Villars and a little *Cerastium glomeratum* Thuill.), clovers (mainly white clover *Trifolium repens* L. and a little suckling clover *T. dubium* Sibth.) and sow thistle (*Sonchus oleraceus* L.) each contributed 7-8% of the dry weight of the overall weed population. Chickweed mainly occurred in the oxyfluorfen (31% of the dry weight) and oxadiazon (24% of the dry weight) treatments. Clover occurred mainly in the trifluralin (16% of the dry weight), oxadiazon (15% of the dry weight), oxyfluorfen (15% of the dry weight) and oxyfluorfen plus oryzalin treatments (14% of the dry weight). Sow thistle made up over 40% of the dry weight of the weed population in the hand weeded control and <5% in all other treatments.

Twin cress (*Coronopsis didymus* (L.) Sm.) comprised only 3% of the dry weight of the total weed population, mainly in the unweeded control and oxyfluorfen plus oryzalin treatments, as these herbicides had mainly broken down by the time of weed harvest.

Plate 30 Treatment 1 = hand-weeded, 17 April 1995.

Plate 31 Treatment 2 = not hand-weeded + no herbicide (control), 17 April 1995, 118 days after transplanting.

Plate 32: Treatment 3 = trifluralin, 17 April 1995.

Plate 33: Treatment 4 = oxadiazon, 17 April 1995, 118 days after transplanting.

Plate 34: Treatment 5 = oxadiazon + simazine, 17 April 1995.

Plate 35: Treatment 6 = oxyfluorfen, 17 April 1995, 118 days after transplanting.

Plate 36: Treatment 7 = oryzalin, 17 April 1995.

Plate 37: Treatment 8 = oxyfluorfen plus oryzalin, 17 April 1995, 118 days after transplanting.

Table 14 Weed Dry Weights (g/m^2) Amongst Herbicide Treatments in early July shortly before Tuber Lifting

Treatment	Black Nightshade	Grass	Chickweed	Clover	Sow thistle	Twin cress	Other	Total
oryzalin	674a	3c	0b	3b	0b	0c	9b	689a
unweeded control	525a	73ab	0b	13b	11b	0c	25ab	647a
trifluralin	297b	16bc	<1b	65a	0b	7abc	13b	397b
oxadiazon + simazine	152bc	110a	1b	12b	11b	1c	3b	290bc
oxadiazon	31c	27bc	47a	30b	1b	5abc	57a	198c
oxyfluorfen	38c	29bc	49a	24b	6b	4bc	8b	158c
hand weeded	7c	30bc	12ab	<1b	59a	13a	15b	137c
oxyfluorfen + oryzalin	36c	41bc	<1b	18b	1b	10ab	22ab	129c
Mean	220	41	14	21	11	5	19	331

Mean values within the same column followed by the same letter are not significantly different at $P<0.05$.

Any small discrepencies are due to rounding errors.

Table 15 Weed Dry Weights[1] Amongst Herbicide Treatments in early July shortly before Tuber Lifting

Treatment	Black Nightshade	Grass	Chickweed	Clover	Sow thistle	Twin cress	Other
oryzalin	98	<1	0	<1	0	0	1
unweeded control	81	12	0	2	2	0	4
trifluralin	75	4	<1	16	0	2	3
oxadiazon + simazine	53	38	<1	4	4	<1	1
oxadiazon	16	14	24	15	1	2	29
oxyfluorfen	24	18	31	15	4	3	5
hand weeded	5	22	9	<1	43	10	11
oxyfluorfen + oryzalin	28	32	<1	14	1	8	17
Mean	48	18	8	8	7	3	9

[1] expressed as a percentage of the total weed dry weight.

Any small discrepencies are due to rounding errors.

The remaining weeds accounted for about 9% of the dry weight of the total weed population. Only in the oxadiazon and in oxyfluorfen plus oryzalin treatments was this category above 15% of the dry weight.

The following species were also noted: scrambling speedwell (*Veronica persica* Poiret), broadleaf fleabane (*Conyza canadensis* (L.) Cronq.), californian thistle (*Cirsium arvense* (L.) Scop.), groundsel (*Senecio vulgaris* L.), broad-leaved dock (*Rumex obtusifolius* L.), poroporo (*Solanum laciniatum* Aiton), redroot (*Amaranthus powellii* syn. *A. hybridus* and *A. retroflexus* S. Watson), scotch thistle (*Cirsium vulgare* (Savi) Ten.), yarrow (*Achillea millefolium* L.), hawksbeard (*Crepis capillaris*(L.) Wallr.), dandelion (*Taraxacum officinale* Wigg.), broad-leaved plantain (*Plantago major* L.), umbrella sedge (*Cyperus* spp.) and hairy bittercress (*Cardamine hirsuta* L.).

2.4.2 Herbicide Effects on Dahlia Tubers

2.4.2.1 Tuber Clump Fresh Weight

The unweeded control treatment gave a mean tuber clump fresh weight of 219g. Tuber clump fresh weight from the oxyfluorfen plus oryzalin treatment was nearly 1kg heavier, and for oxyfluorfen on its own nearly 0.7kg heavier. Both the treatments containing oxadiazon produced tuber clump fresh weights which were about 0.5kg heavier than the unweeded control as were tuber clumps from the hand weeded treatment. The two remaining treatments (trifluralin and oryzalin alone) had similar tuber weights to the unweeded control (Table 16).

Plates 38-45 show randomly chosen examples of tuber clumps from the eight treatments. The very large clumps of tubers in the oxyfluorfen plus oryzalin treatment (Plate 45) and the poor tuber development in the unweeded control (Plate 39) and the oryzalin treatment (Plate 44) are particularly obvious. Tuber shape appeared to be influenced by weed competition. Individual tubers from the unweeded control (Plate 39) and the oryzalin treatment (Plate 44), which was inundated by black nightshade (Plate 36), appear more rounded than tubers from the other treatments. Some variation amongst *Dahlia* tubers, though, will be undoubtedly related to genetic variation.

2.4.2.2 Tuber Number per Clump

Tuber numbers per clump for the unweeded control treatment (6.6 tubers per clump) and the oryzalin treatment (7.6 tubers per clump) were not significantly different. Plants from four other treatments: oxyfluorfen plus oryzalin, oxyfluorfen, oxadiazon, and oxadiazon plus simazine had approximately twice this number of tubers per clump (11.5 - 13.9). The hand weeded and trifluralin treatments had approximately one and a half times more tubers per clump (9.4 - 9.7, Table 16).

2.4.2.3 Average Individual Tuber Weight

Average tuber weight in the oryzalin and trifluralin treatments was not significantly different from the unweeded control. The rest of the treatments had tuber weights approximately two to three times heavier than the control (65.1 - 93.2g). Oxyfluorfen plus oryzalin treatment tubers were significantly heavier than the two treatments containing oxadiazon (Table 16).

2.4.2.4 Re-sprouted Shoot Numbers per Clump

The number of shoots produced in the trifluralin and oryzalin treatments after resprouting the tuber clumps under glasshouse conditions did not differ from the unweeded control. The remaining treatments, however, produced approximately two to two and a half times more shoots (5.78-8.13), than the unweeded control (3.15). The oxyfluorfen plus oryzalin treatment (8.13), in particular, produced significantly more shoots than the hand weeded, trifluralin and oryzalin treatments (Table 16).

2.4.2.5 Tuber weight per Shoot

This was calculated by dividing the tuber clump fresh weight by the shoot number which sprouted per clump. Tuber weight per shoot gave a similar response to shoot number per clump, except that the oxadiazon plus simazine treatment was not significantly different from the unweeded control, or the trifluralin and oryzalin treatments (Table 16).

2.4.2.6 Shoot Number per Tuber

Shoot number per tuber gave a surprisingly consistent mean of approximately 66% of shoots re-sprouted per tuber. Only the unweeded control had a lower mean of 47% although this was not significantly different to the trifluralin, oryzalin and oxadiazon treatments (Table 16).

Table 16: Herbicide Effects on Harvested *Dahlia* Tubers

Treatment	Tuber Clump Fresh Wt. (g)	Tuber No Per Clump	Average Tuber Wt. (g)	Shoot No. Per Clump	Tuber Wt. Per Shoot (g)	Shoot No. Per Tuber (%)
oxyfluorfen + oryzalin	1172a	13.9a	93.2a	8.13a	177a	69a
oxyfluorfen	905b	12.2a	85.0ab	6.80ab	153ab	66a
oxadiazon + simazine	698bc	11.8ab	65.1b	6.70ab	112bc	67a
oxadiazon	713bc	11.5abc	68.0b	6.20ab	146ab	63ab
hand weed	652c	9.4cd	75.9ab	5.78b	128b	70a
trifluralin	357d	9.7cd	40.0c	5.15bc	77c	63ab
oryzalin	335d	7.6de	40.1c	4.83bc	78c	62ab
unweeded control	219d	6.6e	33.8c	3.15c	82c	47b

Mean values within the same column followed by the same letter are not significantly different at $P<0.05$.

Plate 38

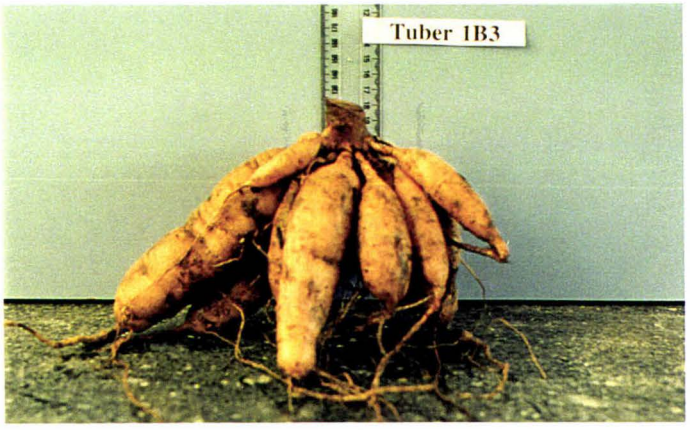


Plate 39

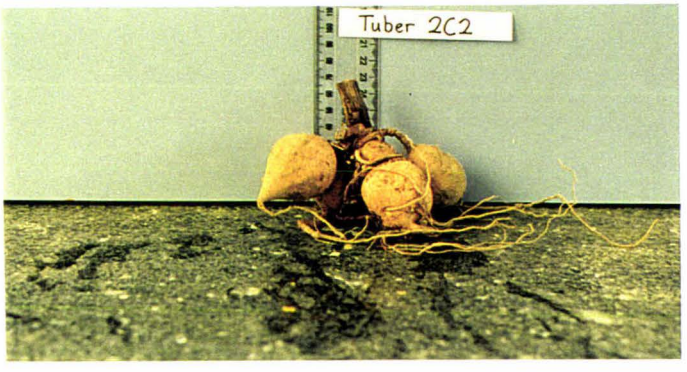


Plate 40

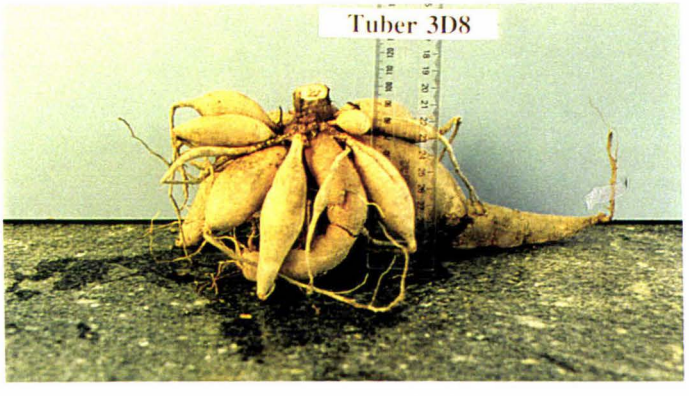
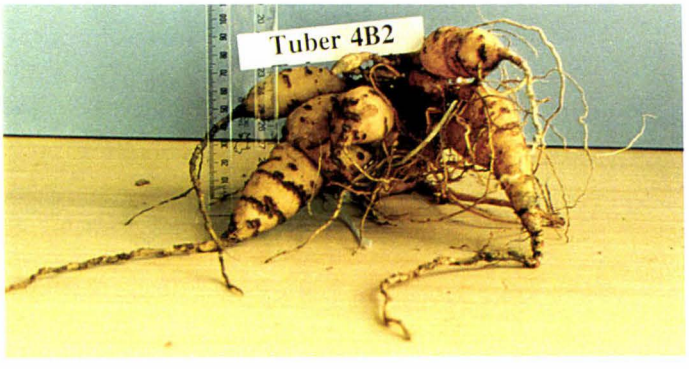


Plate 41



Plates 38-41: Examples of cleaned tuber clumps shortly before re-potting to examine re-sprouting ability from treatments 1 = hand-weeded; 2 = no hand-weeding & no herbicide; 3 = trifluralin; 4 = oxadiazon. e.g. 4B2 refers to treatment number (4), plot replicate (B), and within plot replicate (2). Note the different sized and shaped individual tubers and tuber clumps.

Plate 42

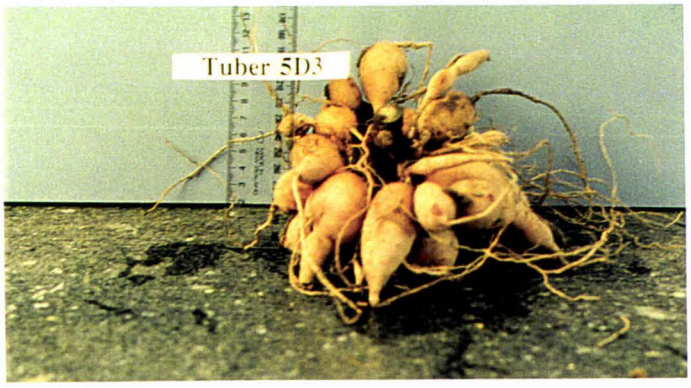


Plate 43

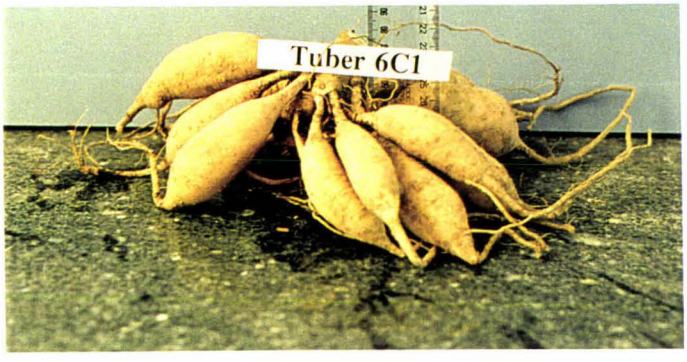


Plate 44

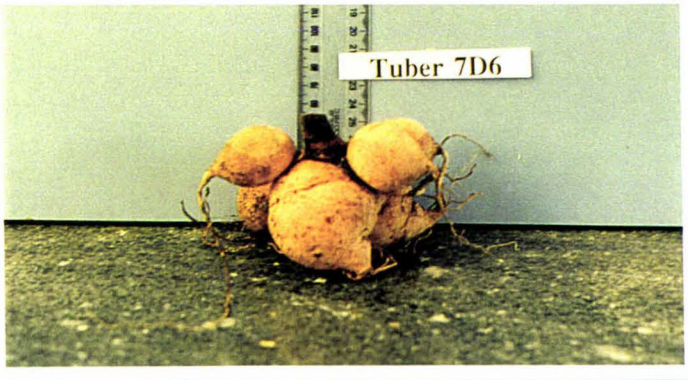
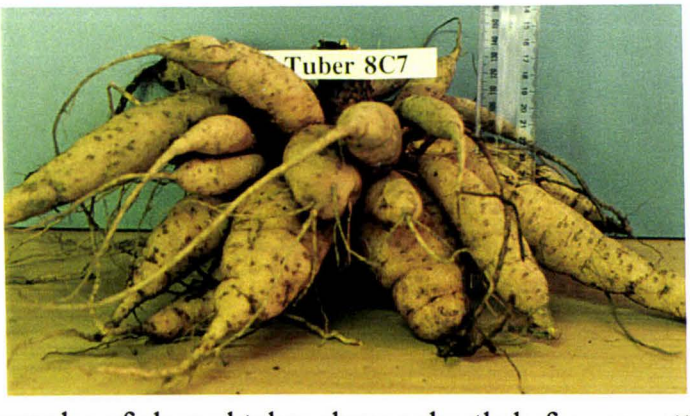


Plate 45



Plates 42-45: Examples of cleaned tuber clumps shortly before re-potting to examine re-sprouting ability from treatments 5 = oxadiazon + simazine ; 6 = oxyfluorfen; 7 = oryzalin; 8 = oxyfluorfen + oryzalin. e.g. 5D3 refers to treatment number (5), plot replicate (D), and within plot replicate (3). Note the different sized and shaped individual tubers and tuber clumps.

2.5 DISCUSSION

This herbicide trial has clearly shown the need for good weed control in the management of *Dahlia* crops. Not surprisingly, weed control by the most appropriate herbicides had a direct effect not only on the weed spectrum controlled but also on weed dry weight. This was important in directly removing weed - crop competition for moisture, light and nutrients. Just as importantly, however, good weed control allowed significantly improved tuber development and subsequent tuber resprouting ability. Since much of the commercial production of *Dahlia* in New Zealand is based on tuber shoot transplants, the results of this herbicide study are of particular relevance.

Two of the herbicide treatments (trifluralin and oryzalin), gave poor tuber yields, which were generally not significantly different from the unweeded control. This was due to weed competition rather than to any phytotoxic effect caused by the herbicide, and was clearly evident by even casual observation during the season (plates 32 and 34 compared to plate 31). Weed dry weight results also confirm this explanation (Table 13). Tables 13 and 14 should not be interpreted too literally, since they recorded measurements taken shortly before the harvest of the tubers in July. By this time the oxyfluorfen and oxadiazon treatments were breaking down, and most of the weed population in these treatments was recently germinated. This is especially true for the two oxyfluorfen treatments. Also, the three treatments that contained over 70% of the weed population as black nightshade had lost much of their leaf material (natural senescence) by July. Certainly the competition as revealed by weed dry weights would have been greater among these three treatments, compared with the other treatments, earlier in the season. In hind-sight it may have been better to have assessed weed content and spectrum a month or so earlier, coincident with the cessation of *Dahlia* growth.

Four treatments (oxyfluorfen plus oryzalin, oxyfluorfen, oxadiazon plus simazine, and oxadiazon) produced results equivalent to, or better than, the hand weeded treatment. Two of these treatments (oxyfluorfen plus oryzalin and oxyfluorfen)had higher tuber clump fresh weights. This was mainly due to clumps bearing more tubers rather than tubers being significantly heavier. K. C. Harrington, Palmerston North, NZ, pers. comm. (1996) has noted in many field-based herbicide trials, that herbicide treatments can often give better results than the hand weeded treatment. He suggests this is probably due

either to plants being injured during hand weeding, or that hand weeding was too infrequent or inefficient to prevent some weed competition. The alternative might be that the herbicide has some crop growth promoting effect, but no such effect of these herbicides has been reported in the literature. Hand weeded plots were not completely weed free (Plate 30), and therefore it is likely that some reduction in growth occurred for this reason.

Weed dry weights from the two oxadiazon treatments (oxadiazon and oxadiazon plus simazine) were slightly higher, and tuber weights lower, than the two treatments with oxyfluorfen. This is probably due to less effective weed control, particularly related to oxadiazon having less knockdown activity than oxyfluorfen (Walton and Sommerville, 1996). Since there was a seven to nine day delay between final seed bed preparation and herbicide application (except for trifluralin, which had a delay of only five days), the relatively warm December soil temperature (17.2°C) was sufficient to encourage early germinating seedlings to grow through the oxadiazon treatment. The subsequent increased levels of competition (compared to the oxyfluorfen treatments) lowered tuber yields. A delay of this length during the spring (normal time of establishment) would probably not have been as important, due to cooler soil temperatures (9.9-15.1°C) and therefore slower germination of weed seeds.

This same situation may also have contributed to the inability of oryzalin to effectively control weeds. Although Walton and Sommerville (1996) state that black nightshade is only moderately susceptible, and confirm that the control of black nightshade is variable with oryzalin. Black nightshade overwhelmingly dominated the oryzalin treated plots and indeed was a significant weed in all treatments (Tables 13 and 14). Oryzalin, though, seems to have virtually eliminated all weeds except black nightshade. This may be due to some initial activity against various weeds, and after the black nightshade had formed a dense canopy, the germination of other weeds was effectively prevented. Because of the inadequate control of black nightshade by oryzalin this herbicide might be ruled out for potential use in *Dahlia*. However, in fields where black nightshade is not present or is at very low levels, it may well do an adequate job as was reported by Phetpradap and Hampton (1991) in China aster. However, there are a number of other weeds also not well controlled by oryzalin (Walton and Sommerville, 1996). If

chickweeds are anticipated to be a problem then adding oryzalin to oxyfluorfen may be useful.

One of the major objectives of this study was to determine herbicide effects on *Dahlia* tuber yields. In addition it was important to determine any subsequent effect on the resprouting ability of the tubers. Tuber clumps are normally broken up for sale after lifting at the end of each season. This operation needs careful attention due to the anatomy of the *Dahlia* tuber and the position of the shoot (De Hertogh and Le Nard, 1993). Unlike the potato, which can shoot from a number of different 'eyes' located directly on the tuber, the *Dahlia* shoots from the base of the previous season's stem. If this tissue is knocked off or severely damaged, no sprout will eventuate (K.R.W. Hammett, Auckland, NZ, pers. comm., 1994). Because of inexperience in dividing tuber clumps and because it might introduce a confounding effect, tuber clumps remained intact for sprouting.

Shoot number per clump essentially did not vary from the hand-weeded control. Only the oxyfluorfen plus oryzalin treatment produced more shoots per clump, due mainly to the greater number of shoots formed. This is probably related to the greater number of tubers and greater individual tuber size which this treatment produced.

The unweeded control treatment had fewer shoots per tuber clump than the hand weeded control treatment. This was undoubtedly due to the weed competition that reduced both tuber number and tuber weight.

Tuber weight per shoot gives the average carbohydrate supply that is available to each subsequent shoot. A larger tuber, therefore, may result in a larger more vigorous plant that subsequently may yield a larger tuber clump. Alternatively, upon tuber clump division, heavier tubers may be more desirable and provide more of a guarantee for subsequent growers, for example home gardeners, that a healthy strong plant will result.

The mean ratio of shoot numbers sprouted as a percentage of the number of tubers per tuber clump was remarkably similar (62-70%) for seven of the eight treatments. This may suggest some dormancy mechanism in the tuber or lower stem that allows only approximately this percentage of shoots to sprout. It would have been interesting to see

if more shoots could sprout if tuber clumps were divided, but further tubers were not available.

It appears from these results and from the literature (Clay & Ivens, 1964; Brosh et al., 1976; Fryer & Makepeace, 1978; Bodman & Hughes, 1985; Talbert et al., 1992; Staats and Klett, 1993; Kulns, 1994; and Han, 1996) that *Dahlias* are resistant to a wide range of herbicides, especially if these are applied as a directed spray to the base of the plant. This means that a crop manager can select from a range of materials depending on the weed spectrum, and rotate the choice of chemicals so that weed resistance need not become an issue.

Oxyfluorfen provided excellent weed control and because of the shielding of the *Dahlia* plants during application, did not damage plants. In the subsequent half-sib experiment, seedlings from individual clonal lines of the same 'F' series were established in the field. Oxyfluorfen was applied between rows (without using a shield) of small '60 cell' *Dahlia* seedlings shortly after transplanting. Spray drift was sufficient to cause leaf scorch on most of the seedlings, although 95% of plants subsequently recovered. This agrees with Han (1996) who reported that when applied directly over *Dahlia* seedlings, oxyfluorfen scorched leaves severely. However, all plants recovered within a few weeks and both seed and tuber yields were unaffected.

One of the major reasons why oxyfluorfen was so successful, apart from the wide number of weed species it controlled, was its mode of action. Walton and Sommerville (1996) record that its residual effects in the soil are reliant on an even coverage onto the soil surface in an uninterrupted layer. Therefore, any subsequent soil disturbance would be anticipated to decrease its efficacy. However, some researchers (Yadav and Bose, 1987 with gladiolus; Mohamed, 1988 with onions; and Georgieva, 1989 with pepper), have used oxyfluorfen pre-plant, and then sown or transplanted crops into this site and still maintained acceptable weed control. Minor soil disturbance apparently does not cause significant breakage to the herbicide surface film.
Other researchers (Piang and Hussain, 1982 in cassava; Randhawa, 1985; Gautam, 1985; Thakral et al., 1985; Hooda, 1987; Bhattacharya, 1990 in potato; Singh et al., 1989 in German chamomile; and DeFrank et al., 1990 in taro) recorded even better weed control

with no phytotoxic and/or yield effects on the crop plant, when these crops were established from tubers or bulbs, or were direct-seeded, and herbicide application occurred pre-emergence.

One other important characteristic of oxyfluorfen is that it is nearly insoluble in water and does not leach into the root zone of crop plants. Emerging weeds contact the chemical as they break the soil surface. The emerging shoot absorbs the chemical which is then activated in the presence of light. This opportunity for good residual weed control obviously contributes to the successful growth of *Dahlia* tubers. Similarly, Lee (1994) has shown there was little metabolism of oxyfluorfen in the roots of rice, barnyard grass, sorghum, maize, tomato, cabbage, radish, cucumber and buckwheat.

Oxadiazon provided good weed control, and if applied immediately after transplanting in spring should give even better control than was achieved in this later planted experiment. It also is potentially less damaging to the crop than oxyfluorfen, even if there is some spray drift, as it has less activity on existing vegetation (Walton and Sommerville, 1996). Care is still required though! Oxadiazon works in a similar way to oxyfluorfen, even though they are from different chemical groups. Some researchers have even transplanted crops after spraying with oxadiazon with apparent success (in terms of maintaining good weed control) in lettuce (Paulo et al., 1990), and in sweet potatoes with oxyfluorfen (Glaze and Hall, 1986). However, Tamil-Selvan et al. (1990) reported using several rates ranging between 0.1 and 0.6 kg/ha of oxyfluorfen both pre-emergence and post-sowing. While initially the pre-emergence treatments gave better control 20 days after sowing, post-sowing treatments gave maximum weed reduction at 40 and 60 days after sowing. Presumably the soil disturbance in sowing the crop was enough to considerably shorten the effectiveness of this herbicide. Basically the comments made regarding oxyfluorfen are also valid for oxadiazon.

The oxadiazon plus simazine treatment gave very similar results to oxadiazon alone, although, again, weed control would probably have been better if application had occurred immediately after planting and sooner after final land preparation.

K.R.W. Hammett, Auckland, NZ, pers. comm. (1994) has observed some damage on *Dahlias* with simazine, but the present results indicate its safety at low rates (1kg/ha). However, the relatively large root ball (PB3/4s) may have enabled the plants to resist any detrimental effect from this herbicide. There may have been a greater detrimental effect

if '60 cell' size transplants had been used. If plants are established from tubers then this low rate of simazine would probably be safe. This study seems to agree with Clay and Ivens (1964), who also concluded that simazine rates of 1lb/acre (1.1kg/ha) were safe, even though 2lb/acre (2.2kg/ha) caused significant damage. Also, it is important to bear in mind that they reported variable damage depending on cultivar and propagation method. They also reported that the crop was enhanced by using directed sprays rather than blanket sprays. The formulation used (Table 12) was granular Ronstar™ SG. This may have contributed to crop safety, as it may have leached into the soil more slowly than a liquid spray. Ronstar™ SG is not cheap and is more suited to nursery and small bedding situations. However, mixing oxadiazon (a suspension concentrate) and simazine (available either as a water dispersible granule or a suspension concentrate) may be an option, especially if it was felt that oxadiazon could not control certain weed species which simazine could.

Oryzalin appears safe on *Dahlia* but was not particularly effective in controlling black nightshade and twin cress. This agrees with other researchers (Lamont and O'Connell, 1986; Hartley, 1993; Statts and Klett, 1993) and manufacturers claims (Fletcher and Kirkwood, 1982; Walton and Sommerville, 1996) who have reported variable weed control or significant gaps in the weed spectrum controlled. Also creeping mallow (*Modiola caroliniana* (L.) G. Don fil.), nettle (*Urtica urens* L.), shepherds purse (*Capsella bursa-pastoris* (L.) Medikus), willow weed (*Polygonum persicaria* L.) and wireweed (*Polygonum aviculare* L.) are only moderately susceptible. Groundsel (*Senecio vulgaris* L.) and oxtongue (*Picris echioides* L.) are resistant (Walton and Sommerville, 1996). These gaps in the weed control spectrum suggest oryzalin should not be used on its own. However, it does control chickweeds well and could be used when anticipating problems with this weed.

Although the trifluralin treatment yielded smaller tuber clumps than the control, this was almost certainly due to weed competition rather than to any detrimental herbicide effect. The literature records trifluralin as safe on *Dahlia* (Clay and Ivens, 1964; Fretz, 1976; Brosh et al., 1976; Fryer and Makepeace, 1978; Bodman and Hughes, 1985; Talbert et al., 1992; Kulns, 1994; and Staats and Klett, 1993) but it would need to be combined with a more species specific herbicide to control most broad-leaved weeds. Trifluralin,

in combination with oxadiazon, may be a good solution if chickweed is expected to be a problem, with oxadiazon controlling most weed species and trifluralin controlling chickweed (Walton and Sommerville, 1996).

Although the herbicides used in this study were confirmed as having no phytotoxic effect on *Dahlia* plants, their differing abilities to influence tuber size, number, and weight and to differentially affect subsequent shoot production without evidence of adverse herbicide carryover effects was of particular importance. There are, however, some crop production aspects that might be important in causing variable herbicide responses.

The *Dahlia* plants used in this study were produced from seed of the 'F' series clones bred by Dr Keith Hammett of Auckland. This should give a better indication of susceptibility to herbicides than using a handful of clones. However, there are many different types of *Dahlia* involving various species and hybrid mixes, so these results should be taken with caution and any particular use should be tested on a small scale first.

The large size of the transplants (PB3/4) used in this study meant that the plants had a reasonable root mass at the time of herbicide application. Again tests should be undertaken with the transplant size desired, as well as the method of propagation - either transplant seedling, transplant root cutting, or tuber. It is likely that tubers will have most resistance (Clay and Ivens, 1964).

The issue of directed versus a blanket spray application method is important. Some herbicides such as oxyfluorfen will damage the crop as a blanket spray (although plant recovery is excellent and final yields appear unaffected (Han, 1996)), but if directed, as demonstrated in this experiment, can provide excellent weed control with no obvious damage to *Dahlia* plants.

Time from final land preparation to herbicide application should be as short as possible so that no weed seeds have emerged prior to spraying. This is especially important if the pre-emergence herbicide has no or little knockdown activity, as was the case among most of those used in this study.

As with virtually all pre-emergence herbicides, irrigation or rainfall is required soon after herbicide application to both activate, and move, the herbicide into the soil. Also, during the growing season, if the soil drys out then a number of pre-emergence herbicides can become less effective, for example, pendimethalin (Kulns, 1994; Walton and Sommerville, 1996).

The application date employed should be sufficiently timed to ensure that residual herbicides are not beginning to lose their herbicidal effectiveness until the *Dahlia* crop has established a full canopy, preventing or reducing subsequent weed competition.

The five herbicides used in this study either alone or in combination were chosen because of their potential in controlling weeds in *Dahlia*. Despite this the herbicides chosen were not exhaustive. Other possible target herbicides available in New Zealand which have been tested and/or used on *Dahlia* (and many other ornamentals), and which might reward further evaluation (Table 12) include:

1. chlorthal dimethyl (DCPA) - despite its reported rapid breakdown and therefore shorter term weed control (Clay and Ivens, 1964; Fretz, 1976; Kulns, 1994; Han, 1996);
2. propachlor - mainly grass weeds (Fryer and Makepeace, 1978);
3. EPTC - weed control generally not acceptable but it will kill some 'tough to control' perennial weeds (Fretz, 1976; Kulns, 1994);
4. alachlor - reported safe and has given good weed control for up to four months (Fretz, 1976; Han, 1996);
5. metolachlor - grasses (Talbert et al., 1992);
6. pendimethalin - reported safe and good weed control (Talbert et al., 1992; Han, 1996);
7. sethoxydim - post-emergence for control of grasses (Talbert et al., 1992; Kulns, 1994);
8. clethodim - post emergence for grass weed control (Talbert et al., 1992);
9. haloxyfop - post emergence for grass weed control (Han, 1996); and
10. chlorpropham - residual life is quite short (Clay and Ivens, 1964; Han, 1996).

In all respects, lack of weed control dramatically reduced tuber weight, number, and subsequent shoot production. This clearly supports the need for good weed control in *Dahlia* crops where tuber production and subsequent tuber sprouting ability are important.

The consistent superiority of oxyfluorfen plus oryzalin in controlling black nightshade, sow thistle, and chickweeds, in suppressing grasses, and their promotive effect on tuber size and quality clearly suggests this herbicide combination is likely to be of particular value in *Dahlia* crop management.

CHAPTER 3

3. GENERAL DISCUSSION AND CONCLUSION

The production of high yields of high quality flower seeds requires considerable technical skill. This is because many flower crops are grown to produce more than one end product. In the case of *Dahlia*, for example, the crop may be grown for cut flower, seed or tuber production. Crop management may also be complicated by the very aspects of plant breeding that have made the crop a success. The decision as to correct harvest timing, for example, is often difficult due to the protracted blooming developed through intensive plant breeding. This character is one that has often made particular clones or series of *Dahlia* so commercially desirable.

Research into *Dahlia* seed-crop management, as with many flower species, has been generally neglected. This is presumably because the planted area and crop value are quite inadequate to support the cost of the research that is needed. Also, much flower seed research is held 'in house' by private seed companies and is unavailable to the public. The present research programme was not designed to provide a total picture of *Dahlia* seed production. However, it did attempt to concentrate some research effort on seed production, pollination, and herbicide effects on 'F' series *Dahlia*, using a range of clonal material and seed supplied by the breeder, Dr Keith Hammett of Auckland.

Seed yield of most clones was on average quite low (1.9g/plant). This was due primarily to the late field (mid-December) transplanting date that was necessary to obtain sufficient tuber sprouts for the supply of transplants. Certainly, Han (1996) reported that much higher yields (7g/plant) at the same density are possible, just by planting about four weeks earlier. *Dahlia* could be planted even earlier than this (F. Onland, Palmerston North, NZ, pers. comm., 1995), when the threat of frost is past (Shewell-Cooper, 1975; Huxley, 1992), but whether this would further improve seed yield is yet to be determined.

Early season establishment, after the danger of frost has passed, is also recommended so that peak flowering occurs at a time for the developing seed to complete food reserve accumulation. This ensures seed quality can be maximized. Phetpradap (1992) states that this typically takes about 42 days, and therefore seed crops should be established no

later than mid - late November, if the crop is estabished from transplants. The preferred range of dates will also depend on the climate of the seed production area.
A trade-off between seed yield and degree of flower doubleness was expected. This was due to an expected decrease in disc floret number (the main determinant of potential seed yield in an inflorescence) in the more desirable highly double clones. However, this was not observed within this series.
Seed yield varied widely among clones (0.01g - 6.66g/plant), with eight of the 14 clones yielding less than 1g/plant. Seed yield appeared to be more affected by floret fertility than by floret numbers or other factors.

Extrapolation of the results of this study to other series is not automatically inferred. It is quite possible that in larger or smaller *Dahlia* series, disc floret numbers may be more important in establishing actual yields. It also appears from observation in the Hammett 'Baby Dahl' series (data not given) that in the more dwarf types' floret fertility levels decrease. However, in the larger less double *Dahlias*, fertility levels may increase, producing much higher seed yields of up to 600kg/ha (F. Onland, Palmerston North, NZ, pers. comm., 1995).

This study indicates that there is potential to select higher seed yielding clones while maintaining a high degree of perceived doubleness in the inflorescences. Clones with a high rooting ability from cuttings would also be an advantage in this situation. It appears that maintaining a high degree of doubleness in parent lines is important in maintaining doubleness in successive generations. If a seed-to seed system is used, then rogueing will become an important tool for maintaining quality. Their high degree of doubleness is one of the most important components that give Hammett *Dahlias* a competitive market edge.

While the degree of doubleness is important, an unexpected complication is the fact that yellow, orange or red inflorescences typically have a much higher fertility level than white, purple-magenta, or pale flowering clones. Clones in the former colour range contribute a much higher proportion of seed and, therefore, the colour range and the percentages of any given colour in the subsequent seed-crop may change. Further work is needed to determine whether there is any basis for this observation. If true, there may

be still potential to select improved fertility levels in the white-magenta colour range and this would be recommended. If fertility levels remain low in this colour range, then increasing the proportion of plants carrying white-magenta flowers in the planted population would be necessary.

Post-harvest processing of *Dahlia* seed appears to be very important in maintaining seed quality. In particular, the immediate removal of moisture by safe drying is of importance. This is especially true if the harvest is delayed or if the weather is cool and moist. Later harvested seed is of poorer quality. This was confirmed by seed provided by Dr Hammett, that was harvested during the 1994 season (February, March, and May) and subsequently tested. The seed harvested in May was light and had a much lower viability (unreported preliminary data from this study).

'Once-over' harvesting using a combine harvester remains a possibility, but desiccation or windrowing would be necessary. Although yields may suffer, savings in labour costs would be considerable. Further work in this area is recommended.

Seed dormancy is only a minor issue, with dormancy levels recorded in germination tests ranging from 0–4% in seed about seven months old. However, there is a varied maternal influence on residual dormancy that may delay and protract germination of freshly harvested seed. Among the six clones tested, time to 50% germination of freshly harvested seed varied by over six days and the spread or eveness of germination varied by over four days. This has implications in a nursery situation, where even and rapid germination is required. How long this effect may continue is unknown but if this is considered a significant enough problem then further testing would be recommended. Prechilling moist seed for longer or at cooler temperatures may reduce residual dormancy but this would need to be tested. Alternatively, the dry storage of seed until the following season (15-16 months, e.g. April harvest, sowing in July-August in the glasshouse of the following year) may also be effective. In addition, priming treatments may be potentially useful.

The activity and value of honeybees and bumblebees as effective pollinators of *Dahlia* crops were of particular interest. Various crop management factors appeared to influence pollination efficiency. An examination of bee foraging patterns suggested that judicious inter-planting of clones (if these are used) should occur down the rows so there

is a good colour mix. Colour will then be unlikely to be a discriminating feature by pollinators. The site should also be reasonably well sheltered. If tree shelter is used then *Dahlia* should not be sited too near the shelter belt due to competition. Root pruning may be an option in some situations. In an open field situation a few rows of maize or some other tall plant may suffice.

It seems important to ensure the *Dahlia* crop is already flowering at the time the beehive(s) are introduced to the area. This allows bees to become conditioned to the crop immediately. Potential competing crops (including weed species) should be managed so that they do not flower at the same time.

Although *Dahlia* provides both pollen and nectar, exact levels compared with other species and among different cultivars of *Dahlia* are unknown. Both honeybees and bumblebees have been observed to stay "glued" to some inflorescences for considerable lengths of time, suggesting ample supplies of nectar. This suggests that any need for supplementary feeding of bees will depend on hive size, plant numbers and the number of open flowers. For this reason it seems best to manage peak flowering to coincide with warmer weather during January-February and to coincide with peak bee populations. Care must also be taken when spraying pesticides during the general pollination period. Spraying plants either close to dusk or at dawn is essential so that the pesticides have time to dry before foraging begins. In addition pesticides of low toxicity to bees should be used.

Honeybees appear to be the most economically viable species to use as pollinators, and work the flowers adequately as also suggested by Patil and Zingre (1986).

At the beginning of this study it was suggested that effective weed control in *Dahlia* was difficult and often influenced crop growth. Of the five herbicides or combinations of herbicides that were used to test this hypothesis, all except oryzalin reduced weed dry weights compared with the unweeded control. Oryzalin did not control black nightshade which was a dominant weed at the site, while trifluralin suppressed but did not prevent black nightshade growth. This suppression allowed some other weeds such as clover and twin cress to become more dominant.

The other five treatments (oxadiazon plus simazine; oxadiazon, oxyfluorfen, oxyfluorfen plus oryzalin and hand weeding) all had no significant effect on weed dry weight by the

time of weed harvesting in July. This was immediately prior to tuber lifting - about six and a half months after initial soil cultivation. By July, some weeds, especially in treatments which were not dominated by black nightshade, had begun to regrow (*Dahlia* growth had ceased by early winter). Therefore, some results may give a more inflated weed population than may have occurred during the *Dahlia* growing season.

Both trifluralin and oryzalin treatments yielded tuber clumps no heavier than the unweeded control, although trifluralin had slightly more tubers per clump than the control. The oxyfluorfen plus oryzalin treatment gave the highest tuber clump weight of 1.17kg. This was almost 1kg heavier than the unweeded control. Differences among treatments are explained by various levels of weed control. All herbicide treatments produced tuber clumps which resprouted and gave no indication of suppression by residual activity of previously applied herbicides. All treatments except trifluralin and oryzalin sprouted more shoots than the control, while the oxyfluorfen plus oryzalin treatment sprouted significantly more shoots than the hand weeded treatment. These results were related to tuber weight and number for which differences appear to be a direct result of the degree of weed competition.

The unexpectedly poor result in the hand weeding treatment perhaps suggests hand weeding was done too infrequently, or else damaged the *Dahlia* plants, thus reducing their growth compared to the best treatment oxyfluorfen plus oryzalin.

The results of this study have clearly shown the possibility for producing commercial *Dahlia* seed-crops in New Zealand. Although there is a likely compromise between seed yield and flower doubleness, there is good potential for selecting higher yielding clones while maintaining inflorescence doubleness. The results have also emphasized the wide variation in clonal seed yields, the need for adequate pollination, and the advantages of early planting and careful post harvest processing of seed. *Dahlia* plants appear to be remarkably resistant to directed application of a wide range of herbicides. Of those tested, none appeared to have any carryover in tubers or adversely affect subsequent tuber resprouting. Efficiency of weed control, however, was directly related to tuber clump weight and tuber number.

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APPENDIX 1.1 Table 17: Mean monthly minimum and maximum air temperatures (°C) at Palmerston North (sixty year average + 1994/95 + 1995/96; Pukekohe and Ashburton (sixty year averages).

	July		August		September		October		November		December		January		February		March		April		May		June		Year (av.)	
	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
PN 60yr av.	4.5	11.9	5.0	13.1	6.6	14.7	8.3	16.6	9.8	18.5	11.6	20.6	12.8	21.9	12.8	22.3	11.7	20.9	9.6	18.2	6.8	15.0	4.7	12.6	8.7	17.2
PN 1994-5	3.5	12.3	5.7	13.6	6.2	14.2	7.6	16.1	10.1	17.3	11.3	20.5	12.6	22.9	14.5	23.3	13.1	21.1	12.2	19.7	7.1	15.8	5.8	12.9	9.1	17.5
PN 1995-6	4.6	11.7	4.8	12.5	7.2	15.2	8.6	16.7	9.1	18.1	13.3	21.9	14.6	23.0	13.8	22.8	10.6	20.0	11.6	19.0	7.0	15.0	4.7	12.4	9.2	17.4
Pukekohe	6.3	13.7	7.1	14.4	8.3	15.7	9.5	17.2	11.1	19.3	12.4	21.1	14.1	23.1	14.5	23.6	13.7	22.4	11.7	19.7	9.1	16.5	7.2	14.2	10.4	18.4
Ashburton	0.0	10.2	1.3	12.0	3.6	14.7	5.7	17.5	7.4	19.6	9.5	21.3	10.5	22.6	10.5	22.4	9.0	20.4	6.3	17.2	3.1	13.5	0.5	10.7	5.6	16.8

APPENDIX 1.2 Table 18: Mean monthly rainfall (mm) at Palmerston North (sixty year average + 1994/95 + 1995/96; Pukekohe and Ashburton (sixty year averages).

	July	August	September	October	November	December	January	February	March	April	May	June	Year (Total)
PN 60yr av.	89	89	75	88	78	94	79	67	69	81	89	97	995
PN 1994-5	73.8	82.0	172.7	69.8	179.7	45.5	53.5	57.9	142.4	103.7	107.5	93.5	1182
PN 1995-6	120.8	72.8	106.4	139.6	102.4	101.0	50.5	128.7	79.1	160.4	114.6	98.5	1274.8
Pukekohe	150	124	138	90	102	114	76	66	95	119	127	148	1349
Ashburton	65	60	57	59	63	72	66	62	62	65	66	60	757

APPENDIX 1.3 Table 19: Mean monthly sunshine (hrs) at Palmerston North (sixty year average + 1994/95 + 1995/96; Pukekohe and Ashburton (sixty year averages).

	July	August	September	October	November	December	January	February	March	April	May	June	Year (Total)
PN 60yr av.	104	132	133	158	177	193	209	186	170	136	112	94	1804
PN 1994-5	100.4	110.6	112.3	184.2	167.8	199.9	258.3	185.8	188.4	134.4	122.9	79.2	1844.2
PN 1995-6	113.2	116.2	117.9	135.1	175.6	187.3	195.2	206.3	165.7	111.9	120.2	103.4	1748
Pukekohe	127	130	133	154	181	206	207	184	159	143	124	106	1854
Ashburton	123	143	155	182	189	194	198	169	158	142	122	117	1892

APPENDIX 1.4 Table 20: Mean monthly wind run (km/day) at Palmerston North (sixty year average + 1994/95 + 1995/96; Pukekohe and Lincoln (sixty year averages).

	July	August	September	October	November	December	January	February	March	April	May	June	Year (av.)
PN 60yr av.	200	270	258	270	282	275	275	260	238	224	214	201	247
PN 1994-5	164	174	190	218	311	226	197	192	236	154	131	149	195
PN 1995-6	193	195	207	176	209	217	170	189	164	136	147	146	179
Pukekohe	270	279	313	312	288	280	269	266	252	266	261	260	276
Lincoln	217	245	289	318	320	320	325	316	291	259	240	212	279

All Palm North data supplied by AgResearch Grasslands Meterological Station (E05363) at Palmerston North about 300m from the two PGU experimental sites.
Pukekohe data supplied from "Summaries of Climatological Observations to 1980" Meterological Station (C74282) but are the mean of only 12 years (1969-1980).
Ashburton data supplied from "Summaries of Climatological Observations to 1980" Meterological Station (H31971) and are the mean of between 45 and 71 years.
Lincoln data supplied from "Summaries of Climatological Observations to 1980" Meterological Station (H32641) and are the mean of 52 years.

Appendix 2 Table 21: Soil Test Results for the Two Experimental Sites

	ANALYSIS								
Soil Sample	pH	Olsen P	SO_4	Exch. K	Exch. Ca	Exch. Mg	Exch. Na	CEC	Soil volume correction factor
PGU 1	5.8	63	3.5	0.9	7.3	1.20	0.1	17	5.8
PGU 2	5.5	37	2.5	0.49	6.0	1.29	0.1	17	5.5

Comment: Phosphate and sulphate values are expressed as µg/g (air-dry). Exchangeable cations and CEC values are expressed as meq/100g (air-dry). The soil volume correction factor is a measure of the weight of air-dry soil (g) per volume (ml) and can be used to convert results to a volume basis (e.g. µg/g x soil volume correction factor = µg/ml).

PGU 1 = Clonal Seed Production Site

PGU 2 = Herbicide Trial Site

Soil test completed on the 16/12/94 from samples taken earlier in the month. Analysis performed by the: Fertilizer and Lime Research Centre
Massey University
Palmerston North

No soil test was conducted on the half-sib experiment.

Appendix 3: The following five pages contain plates of all of the clones (Plates 46-59) used in the seed production experiment taken on the 6 March 1995, 75 days after transplanting. Each clone is identified by the label on each plate and an estimate of the height of each clone at this time can be approximated from the ruler.


7052/8


7052/11


7055/2


7055/3


7056/1


7058/1


45cm
40cm
35cm
30cm
25cm
20cm
5cm
7058/2


7072/2


7073/1


7073/2

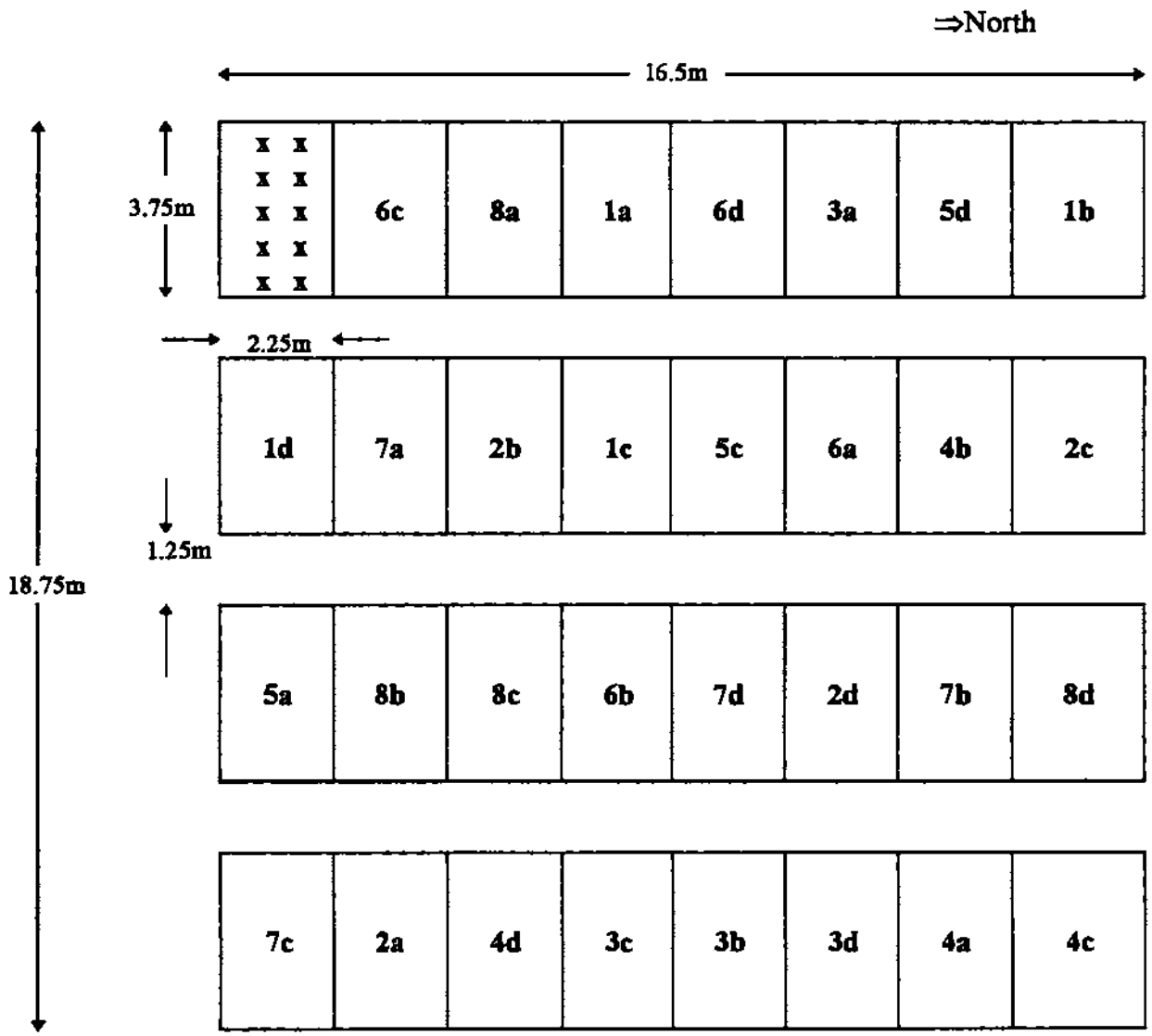

7074/3


7075/3

Appendix 4 Table 22: 'Figaro' Series Cuttings taken September-November, 1995 at the Plant Growth Unit, Department of Plant Science, Massey University, Palmerston North by Robert Southward.

Clone	% of cuttings which rooted
7052/3	41
7052/6	56
7052/8	53
7052/11	66
7055/2	31
7055/3	52
7056/1	86
7058/1	78
7058/2	76
7072/2	49
7073/1	51
7073/2	64
7074/3	38
7075/3	22
Average	52

Appendix 5 Fig 4: Layout of Herbicide Site



Plant spacing = 0.75m x 0.75m ≈ 17800 plants/ha (1.78 plants/m^2)

Treatments:
1 = hand weeded
2 = no herbicides + no hand weeding
3 = trifluralin (incorporated with rotary hoe)
4 = oxadiazon (Foresite® 380)
5 = oxadiazon + simazine (Ronstar™)
6 = oxyfluorfen (Goal®)
7 = oryzalin (Surflan® Flo)
8 = oxyfluorfen (Goal®) + oryzalin (Surflan® Flo)

a,b,c,d = replicates

Appendix 6 Herbicides in Ornamental Compositae Crops

Table 23: Summary of herbicides used on ornamental Compositae crops (except *Dahlia*) published in the literature which are reported safe or cause only minor initial damage with subsequent recovery.

HERBICIDE	CROPS	REFERENCE[1]	WEED CONTROL
alachlor	*Ageratum, Chrysanthemum, Tagetes, Zinnia.*	Fretz (1976).	Good control.
	Aster, Calendula. Chrysanthemum, Helichrysum, Zinnia.	Lamont and O'Connell (1986).	
	Callistephus.	Basavarajue et al. (1992).	
Alloxydim sodium	*Calendula.*	Pank and Ennet (1988).	?
benefin	*Achillea, Chrysanthemum, Coreopsis.*	Skroch et al. (1990).	?
bensulide	*Achillea, Chrysanthemum, Coreopsis.*	Skroch et al. (1990).	Mainly grasses, some broad-leaves.
Butralin	*Ageratum, Chrysanthemum, Tagetes, Zinnia.*	Fretz (1976).	Unacceptable.
	Tagetes, Zinnia.	Kulns (1994).	
Carbetamide	*Xeranthemum.*	Cox et al. (1990).	
Chloramben	*Calendula, Callistephus, Centaurea, Chrysanthemum.*	Ivens (1964).	Fair but short term.
Chloroxuron	*Aster.*	Brosh et al. (1973a).	Fair but short term.
	Aster, Chrysanthemum, Tagetes.	Brosh et al. (1976).	
Chlorpropham	*Calendula, Callistephus, Centaurea, Chrysanthemum, Tagetes, Zinnia.*	Ivens (1964).	Limited persistence.
	Ageratum, Tagetes, Zinnia.	Costello and Elmore (1987).	
	Calendula.	Pank and Ennet (1988).	
	Xeranthemum.	Cox et al. (1990).	
	Tanacetum, Echinacea.	Hartley (1993).	
DCPA (chlorthal-dimethyl)	*Aster.*	Brosh et al. (1973a).	Limited persistence.
	Aster, Calendula, Chrysanthemum, Tagetes.	Brosh et al. (1976).	
	Ageratum, Chrysanthemum, Tagetes, Zinnia.	Fretz (1976).	Unacceptable.
	Aster, Calendula, Chrysanthemum, Helichrysum, Zinnia.	Lamont and O'Connell (1986).	Good.
	Ageratum, Cosmos, Tagetes, Zinnia.	Costello and Elmore (1987).	
	Achillea, Chrysanthemum, Coreopsis.	Skroch et al. (1990).	
Diclofop methyl	*Calendula.*	Pank and Ennet (1988).	Grasses.
Diphenamid	*Ageratum, Chrysanthemum, Tagetes, Zinnia.*	Fretz (1976).	Good control.
Diuron	*Callistephus.*	Basavarajue et al. (1992).	
	Tanacetum, Echinacea.	Hartley (1993).	

HERBICIDE	CROPS	REFERENCE[1]	WEED CONTROL
EPTC	*Ageratum, Chrysanthemum, Tagetes, Zinnia.*	Fretz (1976).	Unacceptable.
	Ageratum, Tagetes, Zinnia.	Costello and Elmore (1987).	
Fluazifop-butyl	*Xeranthemum.*	Cox et al. (1990)	Grass killer.
Metolachlor	*Achillea, Chrysanthemum, Coreopsis.*	Skroch et al. (1990).	Grasses.
	Callistephus.	Basavarajue et al. (1992)	
Napropamide	*Ageratum, Chrysanthemum, Tagetes, Zinnia.*	Fretz (1976).	Good.
	Aster, Calendula, Chrysanthemum, Zinnia.	Lamont and O'Connell (1986).	Only 50% broadleaf weeds controlled.
	Ageratum, Tagetes, Zinnia.	Costello and Elmore (1987).	
Nitrofen	*Aster.*	Brosh et al. (1973a).	Fair but short term.
	Aster, Tagetes.	Brosh et al. (1976).	
	Calendula.	Pank and Ennet (1988).	
	Xeranthemum.	Cox et al. (1990).	
Oryzalin	*Calendula.*	Lamont and O'Connell (1986).	Only 60% broadleaves and 70% grasses.
	Tagetes, Zinnia.	Costello and Elmore (1987).	
	Callistephus.	Phetpradap and Hampton (1991).	
	Tanacetum, Echinacea.	Hartley (1993).	
Oxadiazon	*Aster.*	Brosh et al. (1973a).	Good.
	Aster, Calendula, Chrysanthemum, Tagetes.	Brosh et al. (1976).	
	Aster, Chrysanthemum, Helichrysum, Zinnia.	Lamont and O'Connell (1986).	
	Ageratum, Tagetes.	Costello and Elmore (1987).	
	Achillea, Chrysanthemum, Coreopsis.	Skroch et al. (1990).	
	Tagetes, Zinnia.	Kulns (1994).	
Oxyfluorfen	*Chrysanthemum.*	Lamont and O'Connell (1986).	Good.
	Chrysanthemum, Coreopsis.	Skroch et al. (1990).	
	Matricaria.	Singh et al. (1989).	
Napropamide	*Achillea, Chrysanthemum.*	Skroch et al. (1990). Smith et al. (1983).	Good.
Nitrofen	*Matricaria.*	Singh et al. (1989).	Poor.
Pendimethalin	*Chrysanthemum, Coreopsis.*	Skroch et al. (1990).	Generally good, variable.
	Cosmos, Tagetes.	Matsukura (1992).	
	Tanacetum, Echinacea.	Hartley (1993).	
Phenmedipham	*Calendula.*	Pank and Ennet (1988).	Reasonably good.
Pronamide	*Aster.*	Brosh et al. (1973a).	Fair but short term.
	Tagetes, Zinnia.	Agamalian (1987).	Effective on several grasses and broadleaves.
Propham	*Calendula, Callistephus, Centaurea, Chrysanthemum, Tagetes, Zinnia.*	Ivens (1964).	Fair but short term.
	Aster, Calendula. Chrysanthemum, Tagetes.	Brosh et al. (1976).	

HERBICIDE	CROPS	REFERENCE[1]	WEED CONTROL
simazine	*Callistephus.*	Basavarajue et al. (1992).	Good.
Terbacil	*Tanacetum, Echinacea.*	Hartley (1993).	Reasonably good.
Thiobencarb	*Matricaria.*	Skroch et al. (1990).	
Trifluralin	*Aster.*	Brosh et al. (1973a).	Inadequate for broadleaves.
	Aster, Calendula, Chrysanthemum, Tagetes.	Brosh et al. (1976).	
	Ageratum, Chrysanthemum, Tagetes, Zinnia.	Fretz (1976).	Less than acceptable
	Ageratum, Cosmos, Tagetes, Zinnia.	Costello and Elmore (1987).	
	Calendula.	Pank and Ennet (1988).	
	Callistephus, Zinnia.	Duczmal (1989b).	
	Callistephus.	Phetpradap and Hampton (1991).	
	Cosmos, Tagetes.	Matsukura (1992).	

[1] It is recommended that a careful reading of the reference is made before using any particular herbicide on a crop to ascertain details of application timing, herbicide formulation, rate, likely weed species to be controlled, etc.

Appendix 7 Table 24: Phytotoxicity of Herbicides to Spring Flowering Bulbs (after Skroch et al., 1988).

Bulb Species	Leaf Damage[1]	Flower Injury[1]	Bulb No.s Reduced[2]
Allium sphaerocephalon			
Anemone blanda 'Rosea'	2,5,7		
Crocus chrysanthus 'Cream Beauty'	7,9	7	7,9
C. vernus 'Remembrance'	9	7,9	7,9
Endymion hispanicus chouard 'Blue'	6,7,9		
Hyacinthus albulus orientalis 'Ostara'	1,7,9	7,9	7,9
Iris reticulata 'Harmony'	7,9	7,9	7,9
Iris germanica		7,9	
Muscari armeniacum	1,3,4,6,7,8,9	7	3,7,8
Narcissus spp. 'Carlton'			
N. spp. 'Geranium'	7,9		
N. spp. 'Unsurpassable'		7,9	
Ornithogalum umbellatum	7,9	7,9	
Scilla siberica 'Spring Beauty'	7,9	7,9	
Triteleia laxa 'Queen Fabiola'	7,9	7,9	7,9
Tulipa spp. 'Golden Apeldoorn'	7,9	7	
T. spp 'Paul Richter'	4,7,9	7,9	7
T. spp. 'Purissima'	7,9	7,9	7

[1] Leaf and flower damage recorded only in the second year.

[2] Bulb numbers harvested after the second flowering season considered to be of adequate size to produce a flower when replanted.

Herbicides Used

1 = benefin
2 = bensulide
3 = chlorthal dimethyl (DCPA)
4 = napropamide
5 = metolachlor
6 = fluazifop
7 = oxyfluorfen + pendimethalin
8 = sethoxydim
9 = oxadiazon