Influence of polliniser position and honeybee colony distance in the set and quality of deciduous fruit in the Western Cape

by

Boipelo Kgomotsego Ramongalo

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Department of Botany and Zoology

Faculty of Science

Supervisor: Prof Theresa C. Wossler
Co-Supervisor: Mr Michael H. Allsopp

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Declaration

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ABSTRACT

Most modern deciduous fruit cultivars are self-incompatible, and require polliniser trees to be planted in the orchard to provide the pollen necessary for cross-pollination, fertilization and fruit set. Polliniser trees are either non-commercial cultivars interspersed in the orchard solely to provide pollen, or cross-compatible cultivars inter-planted in the same orchard. 90% of the commercial crops dependent on bee pollination are courtesy of a single species, *Apis mellifera.* Both polliniser planting pattern and honey bee colony distance are known to influence crop production and crop quality, resulting in a rapid decrease in fruit weight, fruit set and seed number with increasing distance from the polliniser or honeybee colonies. However, the response of different crops and cultivars to polliniser and pollinator proximity on optimal crop yield is not known for deciduous fruit crops in the Western Cape, South Africa. The effect of polliniser position and honeybee colony distance on fruit set and weight was investigated in plums, apples and pears on the Lourensford Estate. The relationship between fruit set and fruit weight was investigated for deciduous fruit cultivars. In addition, fruit weight and seed number was also investigated in apples and pears. Fruit set tended to increase on sides of trees closer to the polliniser but not significantly so, except for apples. This suggests that there is probably better pollination closer to the pollinisers but this does not equate to increased yield. In fact, smaller fruit was produced on the sides of the trees closer to the polliniser for all orchards and significantly so for plum and for 'Packham's Triumph' in Hillside 1. This negative relationship between fruit set and weight may indicate 'over-set' beyond the physiological limits of the trees. Fruits closer to the polliniser had significantly more seeds for both pear and apple cultivars indicating sufficient pollination. A significant relationship was found between the seed number in any particular fruit and the weight of the fruit in all the cultivars except 'Packham's Triumph' where the relationship was negative, suggesting that 'Packham's Triumph' set parthenocarpically. Colony distance had no effect on fruit weight, fruit set and on seed number indicating that colonies were adequately distributed and that

there was no “pollination depression” in the centre of the orchards at Lourensford. In conclusion, the fact that we did not get a yield gradient with increased distance from the colonies suggested that the orchards at Lourensford Estate were sufficiently pollinated.

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CHAPTER 1

General Introduction

Pollination of flowering plants

Pollination in flowering plants occurs when viable pollen is transferred from the male part of the flowers (the anthers) to the receptive female part (the stigma) of the same or different flower of the same species (Delaplane and Mayer 2000). Transfer maybe artificial or natural; and it then results in fertilization once the pollen grain germinates on the stigma and the pollen tubes grow down the style (Faust 1989; Wertheim and Schmidt 2005). Finally, the mature embryo sac develops at the base of the style. In higher plants, double fertilization is involved. The male gametophyte, also known as the pollen grain is composed of two gametes and double fertilization occurs when the two gametes from one pollen tube produce distinctly different products: one fuses with the egg to produce the zygote and embryo and is known as the generative cell; the other fuses with the central cell to produce the endosperm; the vegetative cell (Lord and Russell 2002; Márton and Dresselhaus 2008). After successful fertilization fruit and seed development are initiated. Failure of fertilization results in either senescence of the entire flower or termination of carpel development following abscission of other floral organs (Adam and Koltunow 1999). The development of carpels is controlled by the growth hormones auxin, gibberellins and cytokinins (Luckwill and Weaver 1969; Crane 1969; Weiss and Ori 2007), which are produced in seeds to stimulate the growth of fruit tissue.

Cross-pollination

During the evolution of flowering plants, flowers developed a genetically strong breeding barrier (self- incompatibility) whereby a flower is not able to utilize its own pollen for the fertilization of its ovules (Sihag and Singh 1999). Cross-pollination (the transfer of pollen from one flower to another on the same plant or different plant but of the same species) has since ensured the survival of many plant species. Cross-pollination gave rise to genetic systems that favour out-crossing; moreover, cross-pollination is considered to be important as it avoids potential inbreeding depression (Crane *et al.* 1995; Dilcher 2000). Cross-pollination also leads to hybrid vigor that comes about as a result of the crossing of two unlike plants to produce a more vigorous one (McGregor 1976).

Pollination agents

The pollination of most plants depends on the successful transfer of pollen by wind, water, gravity or animals (Klein *et al.* 2003). Grasses and cereals are adapted to wind pollination and have features which include reduced or no petals and the absence of nectaries. The inflorescences of wind pollinated flowers have many flowers with large anthers and an abundance of pollen (to correct for the inaccuracy of delivery), as well as feathery stigmata which easily trap pollen grains (Söderstrom and Cálderon 1971). Wind pollinated species generally do not put a lot of energy or effort into producing colourful petals while animal pollinated plants allocate a large portion of their resources to attractive structures such as petals and nectar (Sakai 1993). Insects and vertebrate animals such as birds and bats play an important role in the pollination of coloured flowers. Coloured and/or scented flowers attract these pollinators so that they can distribute pollen from one flower to the other. Pollinators benefit in that they collect pollen and/or nectar when they visit the flowers. Plants benefit in that the pollinator distributes pollen from one flower to another and from one plant to another, delivering the pollen from anther to stigma, ensuring pollination and fertilization, and very often ensuring cross-fertilization.

Insect Pollination

Of all the pollinators of flowering plants, insects are by far the most important (Goulson 1999). The importance of insects as pollinators was recognized towards the end of the 18th century by Knight (1799; cited in Calzoni and Speranza 1998). The evolution of flowering plants corresponds with that of pollinating insects, especially bees (Proctor *et al.* 1996; Fenster *et al.* 2004). This evolution resulted in plants developing floral parts with specialized features to attract visiting insects which would distribute pollen grains to optimize the plant's reproductive capabilities. Simultaneously, insects underwent physiological adaptations to take advantage of benefits offered by flowering plants.

All flowering plants, including most commercial crops grown world-wide, require pollinators for fruit and seed set. About 84%, of the approximately 300 widely grown crop plants, are insect pollinated (Richards 1993; Delaplane and Mayer 2000). These essentially include fruits, vegetables, oilseed crops, legumes and fodder (Richards 2001). However, the 12 most important crop plants (rice, wheat, corn, sorghum, millet, rye, barley, potatoes, sweet potatoes, cassavas, bananas and coconuts) are self or wind-pollinated (Richards 2001). Nonetheless, approximately one third of all food produced is insect pollinated (Richards 1993). Besides pollination of commercial crops, insects also pollinate native plants which provide food for wildlife and have inherent value as part of natural ecosystems (Delaplane and Mayer 2000).

Honeybee pollination

Honeybees have a host of physical attributes that result in them being the most important pollinators of flowering plants. All honeybees have mandibles that are adapted to bite the anther, thereby dislodging pollen, which is collected in specialized pollen-collecting devices for the provisioning of their young. The body of honeybees is also covered with plumose (feather-like) hairs which result in honeybees visiting flowers becoming covered in pollen, enhancing cross pollination when another flower is visited (Skaife 1992). In addition to being specialized in both the collection and distribution of pollen, honeybees have compound, spherically shaped eyes which are sensitive to ultra-violet and polarized light, enabling them to see the sun under cloudy conditions and making it easy for them to distinguish high contrast shapes and patterns, and thereby locating food sources (Jander and Jander 2002).

A further physical attribute important in successful pollination that is particularly well developed in honeybees is the ability to detect and process floral odours. As pollination is an interaction between plants and pollinators, the floral signals produced by plants should match the sensory abilities of pollinating insects they attract. Honeybees, for example, readily use these floral cues to locate nectar and pollen rewarding flowers (Gegear and Laverty 2004; Cook *et al.* 2005). Floral odours are generally a mixture of many volatile compounds which are species specific, thereby enabling honeybees to distinguish between plant species (Sandoz *et al.* 2000; Farina *et al.* 2005; Cook *et al.* 2005). The olfactory system then forms a memory of floral odour representing nectar to a honeybee (Farina *et al.* 2005), allowing for choice. Moreover, when the ability of the honeybee to communicate, by means of the dance language, the position and value of a resource, and to recruit the number of foragers to that source that correspond with the value of the resource (Skaife 1992) is considered, it becomes clear that honeybees are adapted to utilize floral resources effectively, almost optimally. Several traits are assessed by the honeybees in determining the floral resources, including the quantity and quality of nectar or pollen, the position and nature of floral nectaries, and the plant's attractiveness to honeybees (colour, shape, odour and size) (Utelli and Roy 2000). Deciduous fruit tree species and cultivars differ greatly in the quality and quantity of nectar and pollen available, and hence in their attractiveness to honeybees (Free 1993). For the most part, all apple, pear and plum cultivars produce sufficient pollen and pollen of sufficient quality to be attractive to honeybees, while most plums and apples also produce nectar of sufficient quality and quantity to be attractive to honeybees (Free 1993).

Although honeybees are undoubtedly the most important commercial pollinators, other species of bees are also used in some parts of the world as commercial pollinators, particularly mason bees (*Osmia*) (Calzoni and Speranza 1998) and bumble bees (*Bombus*) (Calzoni and Speranza 1998). At least 90% of the commercial crops produced by bee pollination, however, are courtesy of a single species, *Apis mellifera* (McGregor 1976; Richards 1993; Mussen 2004; Cuthbertson and Brown 2006). The annual value of honeybee pollination to commercial crop production in different parts of the world has variously been calculated to be $782 million (Canada; Winston and Scott 1984), $14.6 billion (USA; Morse and Calderone 2000) and £202 million (UK; Carreck and Williams 1998). The value of honeybees in crop production in South Africa was estimated at R3.2 billion per annum (Allsopp 2004), of which approximately 30% accrues from deciduous fruit crops. In addition to the value of honeybees as the pollinators of commercial crop plants, their contribution to the pollination and survival of indigenous and non-commercial flora also needs to be considered. As South Africa has comparably the richest natural flora in the world (Johnson 2004), and the vast majority of this flora is insect pollinated (Johnson 2004), the true value of honeybees as pollinators can only be considered to be inestimable.

Plant-pollinator systems that exist in nature are now under increasing threat from anthropogenic sources, including fragmentation of habitat, changes in land use, modern agricultural practices, use of chemicals such as pesticides and herbicides, and the invasion of non-native plants and animals (Kearns *et al.* 1998; Richards 2001). The disruption in plant-pollinator interactions has led to a decline in number of natural pollinators (Kearns *et al.* 1998). Crop production therefore depends almost entirely on the introduction of honeybees during the flowering period. To this end, deciduous crop producers are completely dependent on the introduction of honeybee colonies to orchards during blossom time, if adequate fruit set and yield are to be obtained. An estimated 50 871 colonies are hired for the pollination of deciduous fruit trees in the Western Cape (Allsopp and Cherry 2004). At a recommended payment of R 261.60 per colony per pollination cycle, this represents an outlay of R13.12 million by the crop producers (2005 figures).

Deciduous fruit production

The production of a deciduous fruit crop depends on many factors such as climate, soil fertility, the inter-planting of proper selections (cultivars = cultivated variety; crop plants selected and bred by man), thinning, harmful insect control, adequate irrigation, as well as adequate pollination. Pollination is a critical factor for most deciduous fruit cultivars and in most farming practices (McGregor 1976). The need for abundant pollination can never be over-emphasized as optimum fertilization depends on the number of pollen grains delivered to the stigma which depends on the number (density) of honeybees during the flowering period (McGregor 1976; Free 1993; Delaplane and Mayer 2000). A number of studies have shown that an increased visit to flowers by honeybees improves fruit set, and fruit quality. In a study by Dedej and Delaplane (2003) on honeybee pollination of Rabbiteye blueberry, the rate of honeybee flower visits increased as honeybee density increased, and there was a corresponding increase in fruit set. Furthermore, there was an increase in seed number per berry as honeybee density increased. Similarly, a study on pollination of dessert peaches by Langridge *et al.* (1977) showed clearly that honeybees have a beneficial effect on fruit set. In this study fruit set was increased by 29% when honeybees were present in orchards, compared with when honeybees were excluded from plots. Fruit weight was found to increase by 26% in the same experiment (Langridge *et al.* 1977). These improvements resulted from better self pollination as peaches do not require cross pollination (Free 1993), but similar results may be expected in species and cultivars requiring cross pollination.

The requirement of deciduous fruit crops for cross pollination is extremely variable. The family Rosaceae (the rose family which includes plums, pears and apples) has an S-RNase-mediated gametophytic incompatibility system which promotes cross fertilization (de Nettancourt 1997; Delaplane and Mayer 2000; Yao *et al.* 2001). Self-incompatibility is the inability of fertile bisexual seed plants to form zygotes following self pollination. Self-incompatibility in flowering plants evolved to prevent self fertilization due to the close proximity of female and male reproductive organs in bisexual flowers (Kao and McCubbin 1996; de Nettancourt 1997). Self pollen may be genetically inhibited from germinating, or pollen tube growth may be blocked (as is the case in deciduous fruit crops), so that fertilization is prevented (Faust 1989). Deciduous fruit cultivars can be compatible, partially-compatible or incompatible. Many cultivars are completely self-unfruitful and can only produce fruit after cross pollination, requiring an insect vector, as wind pollination is insignificant in deciduous fruit crops (Free 1993). Other cultivars are, however, self-fruitful or partially self-fruitful, and can produce some fruit when pollinated by their own pollen. To make matters even more complicated, cultivars may vary in self-fruitfulness from year to year, and from location to location. Some cultivars are also partially parthenocarpic and can set fruit without pollination or fertilization, including a number of common South African pear cultivars (Anderson 1985). As a final problem, the pollination requirements of many cultivars have never been properly assessed (Free 1993). The variability is such that some plum cultivars are totally self-sterile, relying 100% on insect pollination, while others are 100% self-fertile (Benedek and Nyéki 1996).

As a general rule, most apples, plums and pears are relatively self-unfruitful and need insect pollinators (Langridge and Goodman 1985; Nyéki *et al.* 1994; Calzoni and Speranza 1996), with the pollen typically too heavy and sticky for wind pollination (Karmö and Vickery 1960; Free 1993). Most apricots, peaches and nectarines are self-fruitful, although insect pollination often improves fruit set and fruit quality (Langridge *et al.* 1977; Langridge and Goodman 1981). For sufficient fertilization and fruit development in deciduous fruit crops, polliniser trees (trees acting as pollen donors to the main cultivar) need to be included within the orchards, in close proximity to the main cultivar to provide enough compatible pollen for fertilization of ovules and to set fruit. Alternatively, two cross-compatible commercial cultivars are planted in the same orchard in a specific pattern promoting cross-pollination. Once foraging honeybees begin working on a specific cultivar, they exhibit a high degree of fidelity with 80-90% of returning pollen foragers having the pollen of only one cultivar (Vezvaei and Jackson 1997). This attribute of foraging fidelity is of great importance in the choosing of a polliniser (a source of pollen appropriate for cross pollination) in commercial fruit production, as is the positioning of the pollinisers within the orchard.

Fruit set, seed set and fruit weight

Seeds have been studied extensively as a component of yield. Studies conducted on pollination have revealed that fruit weight and the number of seeds in fruits increase with an increase in bee visits to flowers (McGregor 1976; Free 1993; Keulemans *et al.* 1996), to the extent that seed number has frequently been used to test the efficiency of pollination (Free 1962). The importance of optimal pollination therefore needs to be stressed. The traditional view is that more pollen grains delivered to stigmata means enhanced fertilization, better seed set and therefore better fruit set (seeds prevent fruitlet abscission and promote fruit growth by releasing gibberellins) and larger fruits with greater market value (Fig 1.1).

Most fruit abscission occurs as a result of lack of fertilization, seed growth or due to environmental cues (Marcelis and Baan Hofman-Eijer 1997; Marcelis *et al*. 2004). There are usually three waves of fruit abscission; the first which usually lasts for a month depending on fruit species and variety follows full bloom i.e. once the petals have been shed and occurs as a result of lack of fertilisation (Racsko *et al*. 2006), this phase of fruit drop is referred to as "cleaning drop" of the trees. The second phase of fruit drop may occur at the onset of hot summer and is referred to as "November drop"; this phase of fruit drop depends on the loading capacity of the trees with poorly fertilised fruit falling first (Racsko *et al*. 2006). The first prediction of yield can only be attempted after the "November drop" and is recorded as initial fruit set (Racsko *et al*. 2006). The third and final phase of fruit abscission occurs just before harvesting and is called as 'preharvest drop' the remaining fruit gives the final fruit set.

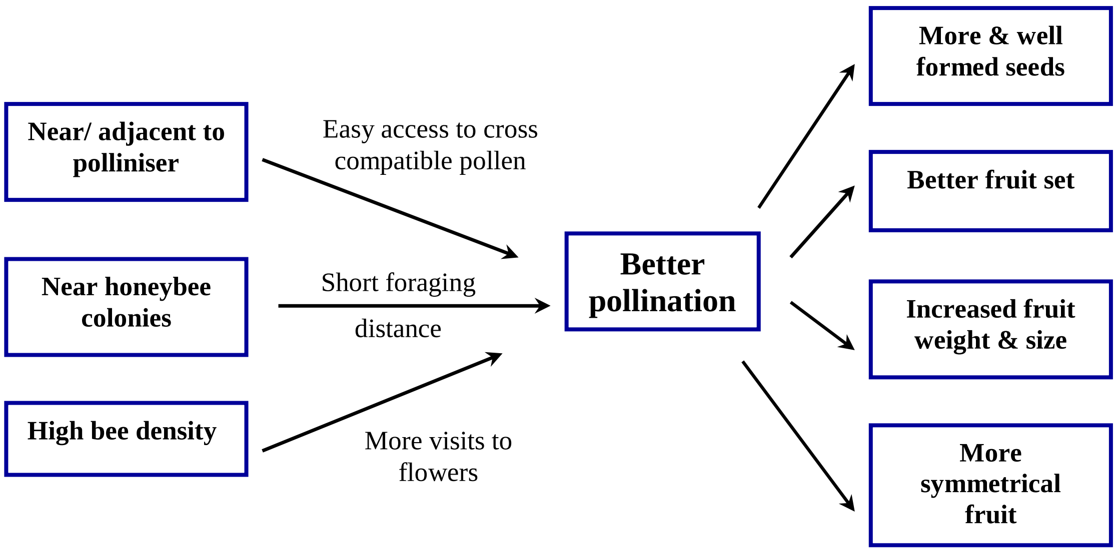

Fig 1.1: Traditional view of the importance of pollination in the production of commercial fruit crops

The seeds in fruit are a major source of phytohormones such as auxin, gibberellins and cytokinins (Crane 1969; Poovaiah 1988; Fallahi *et al*. 1997; Buccheri and Di Viao 2004; Tromp and Wertheim 2005). These hormones stimulate the growth of tissue surrounding them (Luckwill and Weaver 1969; Boselli *et al*. 1995) and facilitate the flow of mineral elements such as calcium to the fruit (Crane 1969; Buccheri and Di Vaio 2004). Young fruit are a sink into which minerals and nutrients flow; the strength of the sink is determined by the growth hormones released by the seeds (Wertheim and Schmidt 2005). Insufficient seeds due to insufficient pollination may result in low calcium levels (Bramlage *et al.* 1990; Volz *et al.* 1996; Brookfield *et al.* 1996; Buccheri and Di Viao 2004). Calcium plays a vital role in the determination of the storage life of fruit in that apples and pears with low calcium concentration resulting from low seed numbers tend to soften quickly (lose their firmness) during storage (Poovaiah 1988; Fallahi *et al.* 1987; Buccheri and Di Viao 2004). In all, seeds are believed to influence fruit in size, shape, quality, symmetry, susceptibility to drop, firmness and juiciness, russeting, vitamin-C content and storage quality (Soltész 2003). This means is that when fruit trees are planted far away from pollinisers and pollinators, they tend to have reduced pollination as less compatible pollen is delivered to stigma. Therefore less pollen grains germinate and less pollen tubes grow to the ovules and fewer seeds are formed, which results in a reduced amount of calcium and consequently fewer and smaller fruit (Brookfield *et al.* 1996; Volz *et al.* 1996; Wertheim and Schmidt 2005; Nunez-Elisea *et al*. in press).

To assess pollination efficiency parameters such as fruit set, seed number and fruit weight are often used. Fruit set is basically the phenomenon referring to blossoms initiated to grow into a fruit. Fruit set is thus calculated as the percentage of flowers in an orchard that set and mature into fruit: Fruit set (%) = (number of fruits ÷ number of flower buds) x 100. This is referred to as final fruit set which has not accounted for early fruitlet abscission. If five to ten percent of blossoms set fruit then the crop is considered to be good (Brittain 1933; Anderson 1985; Free 1993; Cuthbertson and Brown 2006). Fruit set can be used to assess if sufficient pollen was carried from the polliniser to the main cultivar. In this study, fruit set was calculated as the number of fruit that set from the initial blossom clusters counted on selected distal branches per tree.

Effective Pollination Period

An important consideration for growers is the Effective Pollination Period (EPP) of the cultivars that are grown. The ovule has a limited lifespan and degenerates with time, and for effective fertilization it must still be alive when pollen tubes enter the micropyle. EPP, the time of ovule longevity after flower opening minus the time needed for pollen tubes to grow from the stigma to the ovule (Williams 1965), is therefore a critical factor in ensuring adequate fertilization and crop yield. The EPP may vary between cultivars and seasons, and is heavily affected by factors such as temperature, nutritional levels (particularly nitrogen levels), orchard management and the previous history of the trees (Wertheim and Schmidt 2005). Most important, however, is to ensure that there is optimum supply of polliniser pollen as soon as the flowers of the target cultivar open. Any delay in pollination after flower opening will lead to reduction in fruit and seed set (Wertheim and Schmidt 2005).

Over pollination

Although fruit quality (weight) of apples and pears has generally been reported to be positively correlated with seed number, and hence with the level of pollination, the relationship between fruit weight and seed number which is around 25%-35% may vary because other factors may affect fruit weight (e.g. number of competing fruits which compete for the available assimilates) without affecting seed number (Marcelis and Baan Hofman-Eijer 1997). In essence the number of seeds alone does not determine fruit weight (quality); crop load (fruit set) is equally important, as well as many other factors. High densities of honeybee colonies introduced into the orchards may lead to too many flowers being pollinated, with this over pollination resulting in excessive crop load and a high percentage of small fruits. An additional problem is that too much pollination resulting in over-set can result in a lack of bloom in the following season (Faust 1989). Too many pollinisers or pollinators, to name but two, can result in too many fruit, at the cost of a reduction in fruit size (Wertheim and Schmidt 2005). An implication of this is that a reduction in crop load will favour bigger fruit sizes (Lötze and Bergh 2004) and that early thinning (at bloom) results in even larger fruit at harvest time. For optimal fruit production, a balance is needed between too little pollination (which will result in too little set), and too much pollination (which can result in smaller fruit). The effect of improved pollination, either through more bees, more pollinisers, closer pollinisers, or enhanced pollination, on fruit weight, fruit set and fruit quality in both deciduous fruit crops and other crops is accepted.

Pollination in Western Cape

Deciduous fruit crops are an important part of agriculture in South Africa, providing fruit for both export and local markets. Apples, plums and pears are mostly cultivated in the Western Cape but small volumes are produced in Langkloof East, Northern Province, Mpumalanga, Eastern Cape, North West, Free State, Gauteng and Lower Orange River (Deciduous Fruit Producers' Trust 2005). Currently, apple orchards occupy 20 774 hectares in South Africa with 98% of the total area in the Western Cape. Plum and prune orchards in South Africa cover 4582 hectares, 95% of which are in the Western Cape (Table 1.1). In South Africa, pears are the third most important deciduous fruit after grapes and apples. A total of 11 812 hectares of pear trees are planted in South Africa, all in the Western Cape (Table 1.1). The United Kingdom is the main apple export country for South Africa (42%); pears are mainly exported to Europe (58%), and plums also to Europe (51%) (DFPT 2005). The annual gross income of the above mentioned deciduous fruit is 2895 million (DFPT 2005).

Pollinisers and planting patterns

The pollination requirements of individual deciduous fruit cultivars are poorly known or understood (Benedek 2003) and depend on a number of factors. The positioning of the honeybee colonies, and especially the pollinisers, is essential. The orchard design has to be such that pollinators visit the polliniser before visiting the target crop. It is also necessary that the polliniser selected should bloom at the same time as the main cultivar (McGregor 1976; Anderson 1985; Free 1993) and that the flowers of the polliniser and the main cultivar should have the same level of attractiveness (McGregor 1976; Free 1993; Delaplane and Mayer 2000). Therefore, flower attributes such as flower size, flower colour and structure are important when selecting pollinisers. Pollination also depends on pollen amount and pollen viability, pollen quality and protein concentration in the pollen, as well as volume of nectar and sugar concentration in the nectar. All these are important determining characteristics and define how effective a particular cultivar is as a polliniser and hence influence the planting pattern that is required (McGregor 1976; Free 1993; Delaplane and Mayer 2000). Essentially a compromise has to be made between the cost of having pollinisers, either in terms of loss of yield for non-harvested cultivars or in terms of additional logistical and management problems when there are two cultivars pollinising each other, against the cost of having insufficient yield resulting from poor pollination. Furthermore there is a need to know as much as possible about pollination requirements of cultivars and the effect of polliniser position on fruit set and fruit quality so as to select optimal planting patterns for each cultivar.

Table 1.1: Key statistics for the deciduous fruit industry in South Africa for 2004-2005 season (DFPT 2005).

	Apples	Apricots	Peaches /nectarines	Pears	Plums	Table grapes
Production (tones/year)	658 940	82 282	184 783	328 631	55 278	351 483
Total hectares	20 774	4 302	10 492	11 812	4 582	22 755
Total hectares (W Cape)	20 311	4 224	9 551	11 808	4 370	9 818
Production hectares (age> 3 yrs)	19 303	3 667	8 466	10 647	3 543	19 211
Production hectares in W Cape (age > 3 yrs)	18 873	3 603	7 707	10 643	3 380	8 289
Total value of production (R millions)	1 438	82	360	765	250	1299
Total value of production in W Cape (R millions)	1 406	81	328	765	238	561
Crop yield (tones/ha)	55	20	25	45	25	20
Number of trees per hectare	1 650	1 250	1 600	1 650	1 425	1 667
Pollination costs per hectare[1]	653	523	653	1 308	2 092	0
Harvesting labour costs	5 670	15 912	17 025	4 635	21 657	5 279
Crop budget per hectare	111 387	84 735	110 888	95 524	101 043	125 528

[1]Pollination costs for those hectares for which remunerated pollination was paid, at R261.60 per colony, the recommended colony rate of the Western Cape Bee Industry in 2005. Note that these costs have been calculated for expected pollination requirements based on standard industry recommendations; namely 2.5 colonies per hectare for apples, 2 colonies per hectare for apricots, 2.5 colonies per hectare for peaches/nectarines, 5 colonies per hectare for pears, 8 colonies per hectare for plums and no colonies needed for grapes.

Planting patterns of commercial orchards are designed such that they facilitate farming practices such as thinning, pruning, chemical application and harvesting: However, they may greatly reduce the effect of pollination within orchards. In earlier decades, numerous cultivars were often grown in the same orchard and adequate cross-pollination was not a problem. This was due to the fact that lots of natural vegetation provided sufficient natural pollinators, there were sufficient pollinisers available, also most crops were self-compatible and could set fruit with own pollen, and there was less demand for perfect (= well-pollinated) fruit (Brittain 1933). Nowadays, to make more efficient use of land, labour and farming practices and to try to maximize pollen dispersal and cross pollination, apples and pears are seldom planted in solid blocks. Modern orchards typically have a single cultivar interspersed with pollinisers, or have cross-compatible cultivars (cultivars that set commercial crops when two or more are properly interplanted for cross-pollination) in alternating rows, or have a single cultivar with polliniser branches grafted onto trees (Kron *et al*. 2001). But for effective pollination, pollen must be dispersed between rows since honeybees are known to fly along rows rather than across rows (McGregor 1976; Free 1993). As a result, there is a concern that new planting patterns (i.e. single cultivar rows) might disperse pollen only among trees of the same cultivar, resulting in poor fruit set and fruit quality (Kron *et al.* 2001).

Distance of cultivar from polliniser

The distance of the main cultivar from the polliniser influences fruit set and fruit quality, and even relatively small distances may reflect considerable changes in fruit set and quality (Free 1993). In deciduous fruit an increasing distance from the polliniser commonly results in a decrease in set and quality (Free and Spencer-Booth 1964, Traynor 1966; Kron *et al.* 2001; Blazek 1996; Chiusoli 1966; Williams and Smith 1967; Maggs *et al.* 1971; Nyéki *et al.*1998; Westwood 1993; McLaren *et al.* 1996; Brookfield *et al.* 1996; Buccheri and Di Viao 2004). This has also been found in many other crop plants (e.g. Vassieré *et al*. 1996; Nunez-Elisea *et al.* in press). Roach (1965) found that the annual average number of trays of apples collected from trees that were: a) near the polliniser; b) in rows one removed from the polliniser; and c) in rows two removed from the pollinisers, was 313, 277, and 262 respectively. In this study yield (fruit set) decreased by 27%, 52%, 58% and 59% for trees located 2, 3, 4 and 5 trees (6.2m, 9.3m, 12.4m, and 15.5m respectively) from the polliniser in the same row. The effect of polliniser distance can be quite dramatic, and occur over relatively short distances. Vassieré *et al*. (1996) observed in kiwis a 46% fruit set in the row next to the staminate flower and only 16% one row away. Free (1962) found that plum trees adjacent to pollinisers had greater set on the sides facing pollinisers than on their far sides (10.8%: 4.3%; see Fig 1.2). Williams and

Smith (1967) also reported that sides of ‘Comice’ pear trees facing a polliniser cultivar had greater set than the distant side and Eisikovitch *et al*. (1999) found 19% more set in almonds in branches next to the polliniser as compared to branches on the same tree not adjacent to the polliniser.

All of these reports indicate a drop in fruit set as little as one tree away from the polliniser, indicating “dead spots” within the orchards. It is worth bearing in mind that a decrease of 10% in yield or quality, less than is reported in all of the above studies, could be worth as much as R500 million annually to the deciduous fruit industry in South Africa. Despite the obvious economic importance of planting patterns and pollinisers, very little data exists on the subject, and even less South African data.

Effect of distance from honeybee colony

The distance from the introduced honeybee colonies to the target crop is also a factor causing potential pollination inadequacies in commercial orchards (Free 1962). The distance over which bees transport compatible pollen depends largely on the foraging behaviour of honeybees as pollinators, which may be influenced by several factors including the flower morphology and the position of the cultivar with respect to the polliniser (Kron *et al.* 2001). A decrease in number of seeds per fruit, especially for apples and pears, is evident towards the centre of the orchard, affecting the quality of fruit (Blazek 1996). Calzoni and Speranza (1998) observed an enhanced fruit set on plum trees near honeybee colonies. A decline in yield with increasing distance from colonies has also been found in many other crop plants (e.g. Dedej and Delaplane 2003; Benedek *et al.* 2001).

Rationale

The number of fruits produced (fruit set) and their quality are principal determinants of economic returns in commercial fruit crops (Pritchard and Edwards 2006). Differences in mean fruit weight of a few grams may result in significant differences in economic returns (Lötze and Bergh 2004). Successful production of deciduous fruit depends on several factors within orchards. These factors depend on honeybee mobility during the flowering period as well as on the distance/position of the cultivar relative to the polliniser. As information concerning the effect of polliniser planting pattern on fruit set and quality for the deciduous fruit crops in the Western Cape is limited, the present study was undertaken. The main objectives were to investigate the effect of polliniser planting pattern on fruit set and quality for deciduous fruit, and to investigate the effect that honeybee colony distance has on pollination efficiency of deciduous fruit crops in the Western Cape.

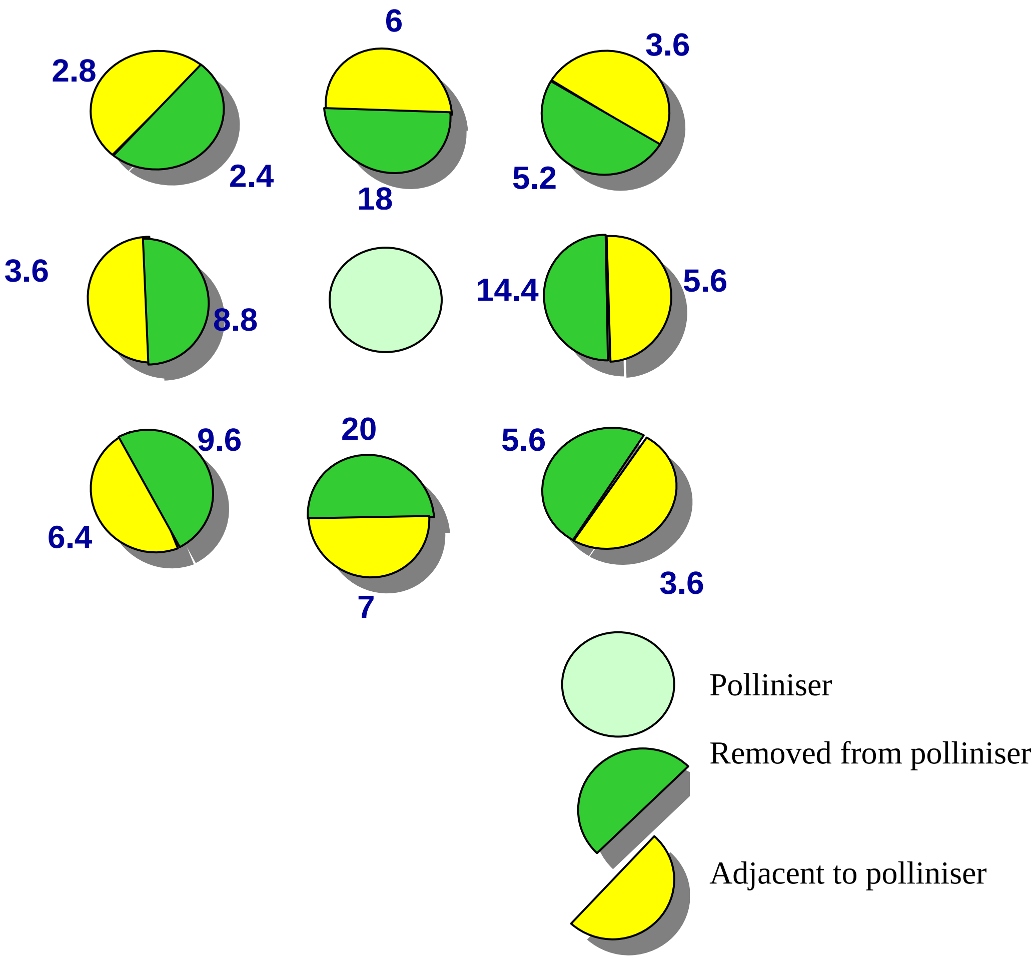

Fig 1.2: Fruit set (the percentage of flowers that set and mature into fruit) in a 1:9 planting pattern for flowers adjacent and removed from the polliniser; adapted from Free (1962).

We examined different polliniser systems commercially available to determine if polliniser planting systems do indeed result in fruit set and fruit quality problems for the growers. For all cultivars we investigated the relationship between fruit set and fruit weight. For apples and pears we further investigated the relationship between fruit weight and seed number. The other objective was to monitor honeybee activity by evaluating the effect that the number of honeybee visits to a flower has on pollination efficiency recorded as fruit set and fruit weight.

Due to the thesis layout (paper format) some repetition and consequential overlapping within the introductions and in the materials and methods may occur. The composition of this thesis is as follows:

Chapter 1 introduces the concept of pollination and the importance of honeybees as pollinators. The problems experienced by commercial deciduous fruit growers with respect to fruit set and fruit weight are discussed in relation to self incompatibility, orchard planting patterns and pollination efficiency by honeybees.

Chapter 2 deals with the pollination of plums where we examined whether 2x2 polliniser planting systems where two rows of ‘Laetitia’ are interplanted with two rows of ‘Songold’ result in fruit set and fruit quality problems for the growers in the Western Cape. We also investigated the relationship between fruit set and fruit weight of the two plum cultivars.

Chapter 3 follows the same framework as chapter two, but focuses on apple production. This chapter deals with the pollination of ‘Granny Smith’ and ‘Golden Delicious’, two apple cultivars using similar planting patterns to that of plums. For apples and pears we further investigated the relationship between fruit weight and seed number.

Chapter 4 is once again similar in structure to chapter 2 and 3, but the focus is on pear production. The planting pattern in pear orchards is different to that of plums and apples in that a polliniser tree is planted for nine trees of the main cultivars. Two of the pear orchards had 'Packham's Triumph' as the main cultivar and 'Clapps' as the polliniser, the other two had 'Abate Fetel' as the main cultivar with 'Rosemarie', 'Lily' and 'Emperor' as pollinisers.

Chapter 5 discusses the main findings in relation to pollination efficiencies within commercial orchards in the Western Cape.

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CHAPTER 2

Effect of polliniser position and honeybee colony distance in the set and weight of Japanese plum (*Prunus salicina* Lindl.) in the Western Cape.

2.1 Introduction

Plums are deciduous stone fruit of the genus *Prunus*, belonging to the subfamily Prunoideae of the Rosaceae family. There are a number of species of plum grown commercially: the Japanese plum (*P. salicina*), European plum (*P. domestica*), Asian plum (*P. simonii*), four additional North American species, as well as crosses between these species (Szabó 2003). Other than for prune production, only cultivars of the Japanese plum are grown in South Africa.

The Japanese plum carries the S-RNase-mediated gametophytic self-incompatibility (GSI) system, controlled by a single multi-allelic S-locus containing a pistil S-gene and a pollen S-gene (Sapir *et al*. 2008). Variants at the S locus are called S-haplotypes. If two cultivars share both S-haplotypes they will be incompatible with each other, if they differ in both S-haplotypes they will be fully compatible, and if they share only one of the S-haplotypes they will be semi-compatible (Sapir *et al*. 2008). Hence, plum cultivars exhibit a wide range of incompatibility traits ranging from completely self-compatible, where a full crop is set by pollen from the same cultivar, to completely self-incompatible, where there is no fruit set with pollen from the same cultivar (McGregor 1976). Most cultivars of all species are essentially self-incompatible with total incompatibility being found in 30% of Japanese plum cultivars (Langridge and Goodman 1985; Szabó 2003). There is also no parthenocarpy (fruit without fertilization) in plums (Szabó 2003). Hence, there is a significant need for cross pollination in plum production. Different cultivars also vary considerably in their effectiveness as pollinisers, especially in *P. salicina*, and orchard partners need to be selected with great care for cross compatibility and overlapping bloom period (Szabó 2003).

Although 5% fruit set is regarded to be sufficient to set a crop of Japanese plums, and 10% for European plums (Szabó 2003), pollination and yield are often considered to be a problem in commercial plum production (Calzoni and Speranza 1998), mostly because plums flower in early spring and often have poor weather conditions which limit pollinator activity. Insects are responsible for at least 62-69% set in plum production (Langridge and Goodman 1985), although they have little effect on fruit weight (Calzoni and Speranza 1998), and almost all growers introduce managed honeybee colonies to facilitate pollination, with 2 - 5 colonies of bees per hectare generally regarded as sufficient (Langridge and Goodman 1985; Free 1993). Honeybees (*Apis mellifera*) have been recognized as pollinators of most commercial cultivars of plum (Free 1993). In a study by Langridge and Goodman (1985) honeybees comprised 88.5% of all insect visitors to the flowers. Furthermore, the behaviour of other insect species was such that they had little or no effect on pollination. Calzoni and Speranza (1998) found a 30% increase in fruit quality when honeybees were used as pollinators of plums. Most Japanese plum cultivars are attractive to bees with plums having high quality nectar with sugar concentrations ranging between 16-56% (Benedek *et al.* 1994; Benedek 2003) and sufficient pollen that many foragers on plums are pollen gatherers (Free 1993).

South Africa presently produces about 0.8% of the worlds' plums and prunes, with 4582 hectares planted and an annual gross value of ZAR 250.2 million (Deciduous Fruit Producers' Trust 2005). 95% of plum production is found in the Western Cape, and plum production employs 5443 labourers with 21770 dependents (DFPT 2005). The two most commonly planted plum cultivars are Laetitia and Songold which together comprise 35% of all plums planted (DFPT 2005). 'Laetitia' originated in South Africa in 1977 from a 'Golden King' male parent, and one of 'Santa Rosa', 'Red Ace' and 'Gaviota' as the female parent, was bred by ARC-Infruitec and released in 1985 (Bester 2003). It is fully self-incompatible, usually sets very well, and thinning is normally required. This plum has a bright red colour with many white lenticels and is harvested in late January. The fruit has dark yellow flesh, weighs 70g on average and has a good storage life (Bester 2003). 'Laetitia' trees have a low chilling requirement and reach full bloom during late September. Compatible pollinisers for this cultivar are 'Songold' and 'Casselman'. 'Songold' was also bred in South Africa by ARC-Infruitec, derived from a 'Wickson' and 'Golden King' combination, first produced in 1961 and released in 1970 (Hurter 2003). 'Songold' trees have a medium chilling requirement and reach full bloom in the middle of September. Compatible pollinisers for this cultivar are 'Laetitia', 'Santa Rosa' and 'Casselman'. 'Songold' plums have an average weight of 90g and are ready for harvesting in early February (Hurter 2003). Both the skin and flesh of this plum are a golden yellow colour. 'Songold' has difficulties with set, and high honeybee densities are typically used to ensure adequate yield. As 'Songold' and 'Laetitia' are considered to be self-sterile and therefore require cross pollination with a compatible polliniser, and as they flower at the same time, these two cultivars are almost always used as orchard partners in South Africa, normally at a 1:1 ratio. 'Laetitia' and 'Songold' are commonly planted as palmette where two rows of the one cultivar alternate with two rows of the other. In this method, each "row" is actually made up of two rows, planted together at the point of the "V" and growing up each arm. Hence, there are effectively 4 rows of each cultivar interspersed with 4 rows of the other cultivar in this planting method.

Polliniser distance and position as well as honeybee colony distance can cause deficient pollination and is known to affect the yield and quality of many commercial fruit crops including plums (McGregor 1976; Free 1993). In reports on diminishing set in plums as distance from the polliniser increases, Tóth (1967) reports a decrease 3 rows away from the pollinisers and Keulemans (1980) a decrease 15m from the polliniser. Free (1962) reports a decrease in set from 7% in the row adjacent to the pollinisers to 1% set four rows away and Szabó (2003) reports a decrease in yield in the middle rows of 4-row blocks, once again in plums. As a general rule Szabó (2003) recommends 2-row blocks as the best planting pattern in Japanese plums to overcome such pollination depression.

In this study we evaluate fruit set and fruit quality of 'Songold' and 'Laetitia' adjacent to and removed from the polliniser cultivar as well as the effect of honeybee colony distance on the set and quality of 'Songold' and 'Laetitia' under the prevailing environmental and commercial conditions. Furthermore we investigate the relationship between fruit set and fruit quality (weight) in these two cultivars. Effectively the central question is to determine any polliniser-based production deficiencies in these orchards.

2.2 Materials and Method

2.2.1 Orchards

Two plum orchards (Brinksburg 1 and Brinksburg 2, both planted in 2002) were assessed from September 2004 to March 2005, and a further plum orchard (Strengmens, planted in 1993) from September 2005 to March 2006, all orchards being commercially active and on the Lourensford Estate in Somerset West (18° 54' E, 34° 03' S) in the Western Cape of South Africa. All orchards on Lourensford estate are planted with roughly north-south orientation. The Western Cape has a largely Mediterranean climate with winter rainfall and hot dry summers, and is frost free. Detailed maps were prepared for each orchard, marking the position of each tree in the orchard, as well as the position of the bee hives introduced during pollination.

2.2.2 Planting patterns

The basic orchard designs used were the 2 x 2 design. In a 2 x 2 pattern, there are two commercial cultivars, each act as the polliniser of the other. These cultivars are planted in rows, typically 2 rows of cultivar A followed by 2 rows of cultivar B, followed again by 2 rows of cultivar A, and so forth. This basic design was found in all plum orchards used (Brinksburg 1, Brinksburg 2 and Strengmens). The plum orchards were planted such that two rows of the cultivar Songold alternate with two rows of 'Laetitia'. The trees in Brinksburg 1 and Brinksburg 2 were trellised in V-shaped uprights and there were effectively 4 rows of 'Laetitia' interspersed with 4 rows of 'Songold'. There was no trellising in Strengmens, trees were singly planted, and each cultivar was planted in 2-row blocks. Strengmens was used in the second year so that a more mature orchard could be assessed, as there was concern that the relative lack of canopy development in the rows in Brinksburg 1 and Brinksburg 2, because the trees were so young, might not cause the bees to fly in rows as expected, and hence would compromise any polliniser effect. The heavy foliage along rows in Strengmens orchard would ensure that foraging bees largely stayed within a row (Free 1993). The planting distance in Brinksburg 1 and Brinksburg 2 is 3.4 m x 1.4 m. In Strengmens the planting distance is 4.3m x 1.8m.

2.2.3 Bees and farming practices

Bees were introduced into the orchards by the beekeeper servicing Lourensford Estate, the timing of which was dictated by the normal commercial operations on the farm, typically at 5% blossom. Honeybee colonies belonging to Lourensford farm, and managed by beekeepers contracted to the farm, were used for the pollination of all selected orchards. Positions for the placing of colonies were marked at the end of the rows of each orchard so that colonies would be evenly distributed around the orchards (Fig. 2.1). [Honeybee colonies are typically sited at the end of rows as bees preferably fly along rows and not across rows (Free 1993)]. The introduction of colonies into orchards was at the discretion of the farm manager and beekeeper, and colonies were introduced at normal stocking rates. In all respects, beekeeping operations were as would be practiced under normal commercial conditions. The trees were also subject to all normal farming practices such as the application of plant protection products (fungicides and insecticides) and the use of herbicides and mowing to control weeds and grass. Hand thinning was allowed in the orchards but not for the tagged clusters (see below). An attempt was made to investigate the effect of honeybee activity on fruit production by bagging clusters of flowers before pollination. Pollination bags (with fine mesh to allow light and air) were placed over a group of 7–15 flower buds per inflorescence to exclude all potential pollinators. Each bag was then removed once the flowers were open to allow pollination by bees. Some flowers were allowed a single bee visit others two and so on. After flowers had been visited 1-6 times the bags were carefully placed over the inflorescence again to prevent further visits by honeybees. We had intended to relate fruit set and fruit weight to number of bee visits. We were however unable to collect sufficient reliable data as it was difficult to replace the bags after observations without damaging the blossoms and consequently statistical analyses were not possible.

2.2.4 Experimental procedure

Effect of polliniser distance and colony distance on fruit set and fruit weight in plums

Orchards were divided into blocks, these blocks being either at the edge of the orchard and adjacent to the honeybee colonies, or in the middle of the orchard and distant from the honeybee colonies (at ± 40 trees into the orchard giving a distance of at least 50m) (Fig. 2.1). The reason for this is that any impact the polliniser might have on fruit set and fruit weight might only be apparent at relatively low bee densities (presumably the middle of the orchards) and not apparent at high bee densities (presumably on the periphery of the orchards). There were three experimental replicates per orchard (each replicate consisted of 3 experimental blocks) for each of the 3 plum orchards used (Brinksburg 1, Brinksburg 2 and Strengmens). Three blocks were on each side of the orchard, and the final 3 blocks were in the centre of the orchard.

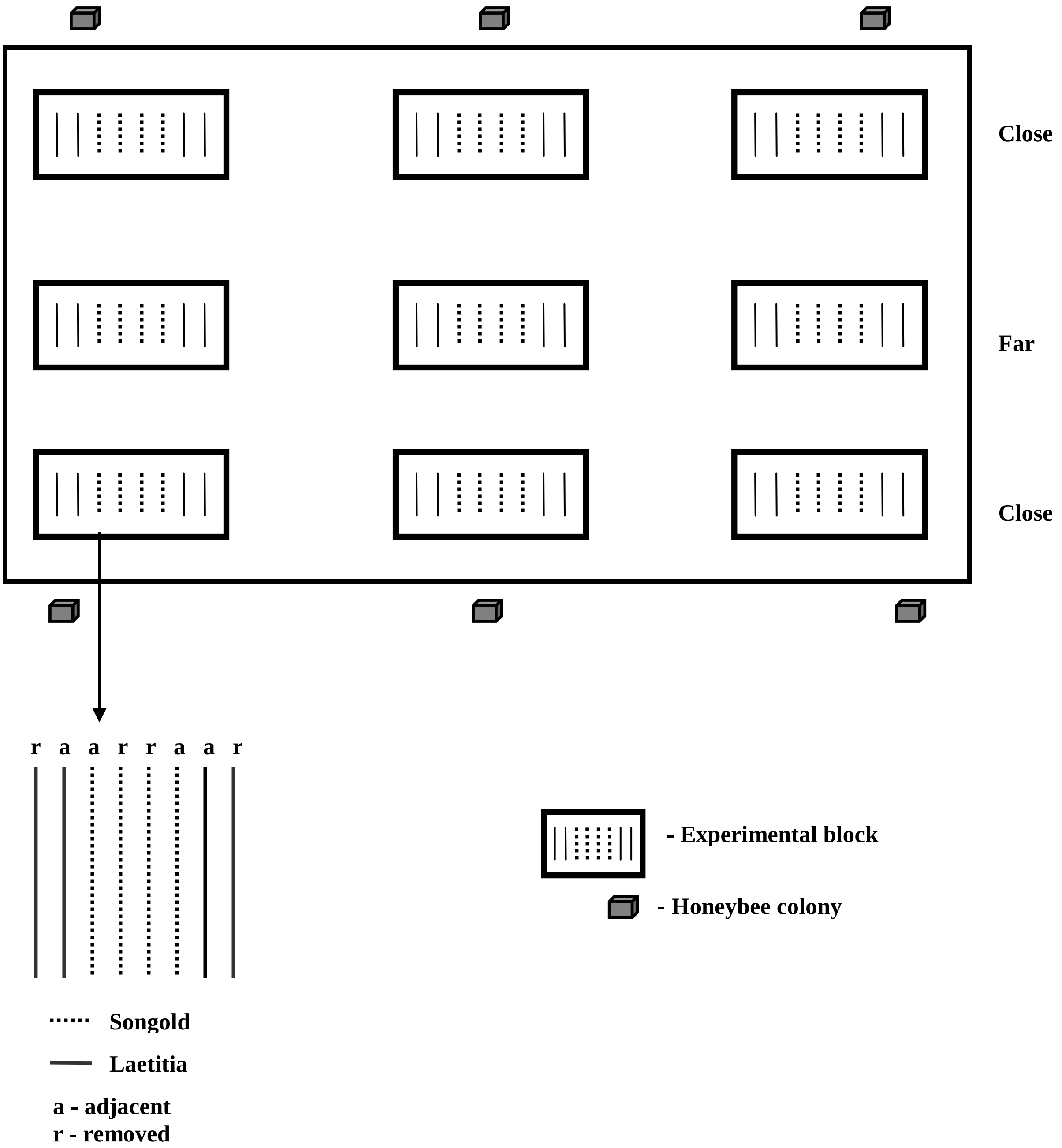

Fig 2.1: Schematic representation of an experimental plum orchard showing nine experimental blocks (= 3 replicates) and positioning of honeybee colonies. Two rows of 'Laetitia' alternate with two rows of 'Songold'. Each row is a V-shaped trellis, and hence appears as two separate rows. Six blocks are located near honeybee colonies close to the edge of the orchard and three in the middle of the orchard far from honeybee colonies.

Each block comprised of 4 rows of trees, with two rows of 'Songold' and a row of 'Laetitia' on each side. In Brinksburg 1 and Brinksburg 2 which were planted as palmette, there were effectively 8 rows in a block (see Figure 2.1). In Strengmens there were 4 rows in a block. Each block was 13-14 trees in length. Eighty horizontal 1 year old shoots were tagged in each block, typically one branch per tree for each of 10 trees in each row in Brinksburg 1 and Brinksburg 2. Branches were tagged with a durable tag tied around each branch; all flower clusters distal to the tag were counted and the total number of buds was written on the tag with a pencil. In Strengmens one branch was tagged on each side of each tree in the four rows. Branches were tagged prior to blossom, with blossom at the bud stage, for all orchards (this approach therefore excludes flower abscission). Special effort was made to select equivalent branches under all circumstances, namely one-year old shoots at approximately waist height and un-shaded. There were no windbreaks surrounding the orchards. The number of flowers per tagged branch varied between 8 and 77. A total of 720 branches were tagged (10 trees x 8 rows/sides x 9 blocks; see Fig. 2.1) per orchard. For polliniser effect the comparison made is that between branches immediately adjacent to the polliniser (a), and a branch one row removed from the polliniser (r) as shown in Fig. 2.1. In Strengmens the same effect is obtained by tagging each side of each tree. For the distance effect the comparison made is that between blocks near the honeybee colonies to those far from the colonies in the middle of the orchard. The experimental design is such that sunlight and wind direction are not factors in the comparison as, in each block and for each cultivar there is an "adjacent" row to the east of the "removed" row, and an "adjacent" row to the west of the "removed" row.

Assessing pollination efficiency for plums

Two to three days before the fruit was ready to be picked by the farmers, all fruit on tagged shoots were counted to determine fruit set and harvested. The fruit set was calculated as a percentage based on the number of flowers tagged per shoot (i.e. buds originally counted) and the number of fruit harvested (excludes flower and fruitlet abscission). Fruit weight was determined by weighing all the plums from the tagged shoots, to an accuracy of 0.01 grams, with a Sauter scale. The fruit set and fruit quality of the various sectors of the orchards with respect to the position of the polliniser and distance from the colonies was thus determined, and hence the impact of polliniser position, honeybee colony distance and planting pattern on orchard production (extrapolated from data obtained for the experimental blocks).

2.2.5 Statistical analysis

A multifactorial analysis of variance was used to analyse data with the three orchards, two colony distances, two cultivars and two polliniser positions as main effects and there were three replicates. All possible interaction effects were also determined. Degrees of freedom for sample errors were then calculated by multiplying the total degrees of freedom of the experimental design and then subtracting degrees of freedom of the model from the corrected total degrees of freedom. The effects of orchard, cultivar, polliniser position and honeybee colony distance on fruit set and fruit weight were analyzed using a Univariate Factorial Analysis of Variance (ANOVA) to explain the variation in fruit quality (weight) in relation to distance from polliniser and distance from honeybee colonies. *Post hoc* Student's test (LSD - Least Significant Difference) were performed to indicate statistical significance at $p = 0.05$. To calculate fruit set, each tagged shoot constituted a single data point and Analysis of Variance (ANOVA) was again performed to explain the variation in the number of flowers that developed into fruit with respect to the distance from polliniser and distance from honeybee colonies. *Post hoc* Student's tests (LSD- Least Significant Difference) were used to show significant variance among means at p = 0.05. Pearson correlation analyses were used to compare fruit set and fruit weight. All statistical analysis was performed using Statistical Analysis System (SAS). Data were reported as a mean ± SD.

2.3 Results

2.3.1 Orchard description

Basic information about the orchards is presented in Table 2.1. Acceptable yield was obtained for all three orchards (B. de Villiers pers. comm.). The figures in Strengmens are lower but typical of that orchard. Interestingly, the yield of 'Songold' is greater than that of 'Laetitia'. A high bee density of 5-8 colonies per hectare was used for all orchards, again typical of Lourensford's farming practices. 'Laetitia' trees were hand-thinned in all three orchards but not for the tagged shoots. Temperatures were moderately warm and constant throughout the pollination periods in both 2004 and 2005 (Figure 2.2).

Table 2.1: Orchard size, orchard production and orchard management practices in three experimental plum orchards. B1 and B2 refer to the orchards Brinksburg 1 and 2.

Orchard	Year	Cultivar	Yield (tonnes/ hectare)	Orchard Size (ha)	Honeybee colonies introduced	Date of first introduction (= 10% blossom)	Hand thinning	Chemical thinning
B1	2004	'Laetitia'	31	2.16	15	13/09	Yes	No
		'Songold'	38				No	No
B2	2004	'Laetitia'	31	2.49	18	13/09	Yes	No
		'Songold'	32				No	No
Strengmens	2005	'Laetitia'	18	4.61	22	10/09	Yes	No
		'Songold'	18				No	No

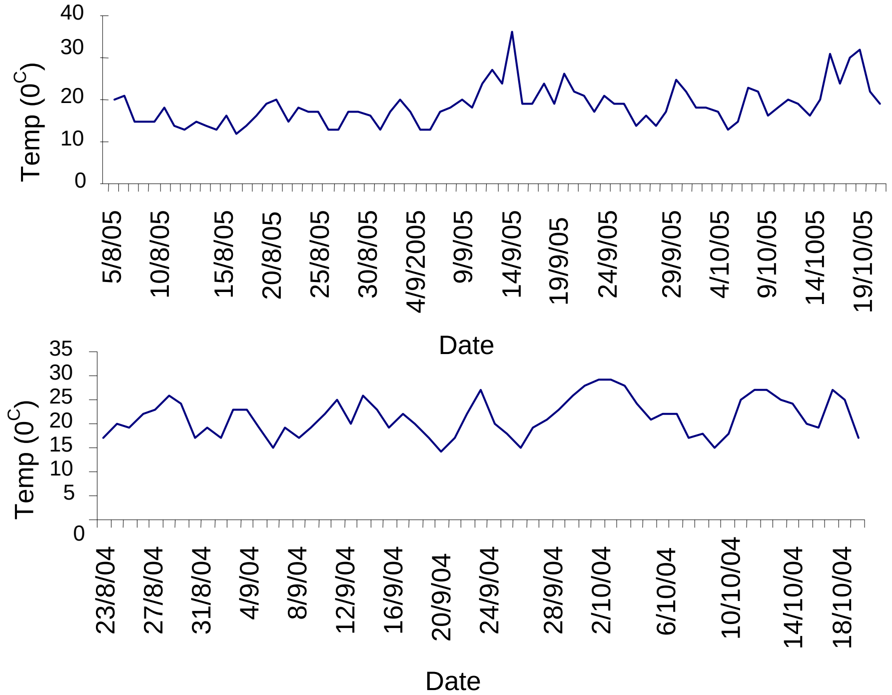

Fig 2.2: Temperature profiles at Lourensford during the pollination of plums in the years 2004 and 2005.

2.3.2 Overall orchard interactions

Fruit weight was significantly different between the three orchards (Table 2.2) as was fruit set (Table 2.3). There was a significant orchard by cultivar interaction in plum orchards for fruit weight (Table 2.2; Fig 2.3). Strengmens had the largest fruit weight for both ‘Laetitia’ and ‘Songolds’. Furthermore fruit weight for cultivar Laetitia was significantly more than that of ‘Songold’ in Strengmens. The converse was true for the Brinksburg orchards where ‘Songold’ plums are larger (Fig 2.3). ‘Songolds’ are larger (approximately 90g) than ’Laetitia’ (approximately 70g; Bester 2003; Hurter 2003) which was not the case for Strengmens with no reasonable explanation. The large fruit weight of plums in Strengmens could be related both to the low yields in Strengmens (Table 2.1) and the age of the orchard compared to the two relatively young Brinksburg orchards. Strengmens therefore produced fewer but larger fruit. Moreover, colony density was not a factor since there are fewer colonies per hectare for Strengmens than the Brinksburg orchards.

Table 2.2: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on fruit weight in plums.

Source Factor	DF	Mean Square	p
Orchard	2	39113.27	<0.001
Colony distance	1	734.27	0.2900
Orchard* Distance	2	278.15	0.6502
Cultivar	1	2791.99	0.0428
Orchard*Cultivar	2	2631.14	0.0233
Distance*Cultivar	1	1894.58	0.0926
Orchard*Distance*Cultivar	2	1363.22	0.1313
Polliniser position	1	13890.23	<.0001
Orchard*Position	2	591.13	0.4047
Distance*Position	1	559.22	0.3551
Orchard*Distance*Position	2	382.68	0.5543
Cultivar*Position	1	0.35	0.9816
Orchard*Cultivar*Position	2	568.84	0.4184
Distance*Cultivar*Position	1	1036.85	0.2099
Orchard*Distance*Cultivar*Position	2	1299.16	0.1438
Sample Error	48	639.46	

Table 2.3: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on fruit set in plums.

Source Factor	DF	Mean Square	p
Orchard	2	0.394	<.0001
Colony distance	1	0.001	0.6020
Orchard* Distance	2	0.000	0.8949
Cultivar	1	0.068	<.0001
Orchard*Cultivar	2	0.008	0.0876
Distance*Cultivar	1	0.003	0.3393
Orchard*Distance*Cultivar	2	0.002	0.5067
Polliniser position	1	0.012	0.0525
Orchard*Position	2	0.007	0.0932
Distance*Position	1	0.002	0.3740
Orchard*Distance*Position	2	0.009	0.0626
Cultivar*Position	1	0.000	0.9924
Orchard*Cultivar*Position	2	0.001	0.6138
Distance*Cultivar*Position	1	0.000	0.8117
Orchard*Distance*Cultivar*Position	2	0.002	0.4780
Sample Error	48	0.003	

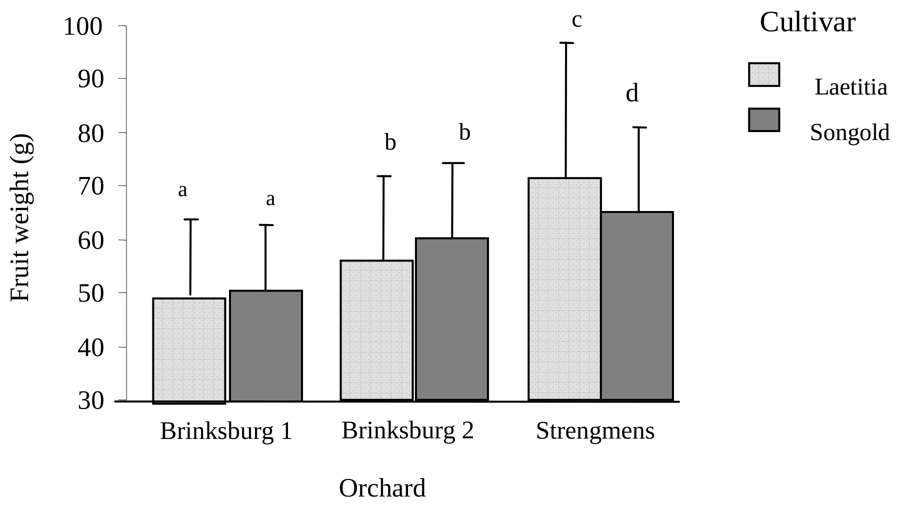

Fig 2.3 Interaction effects between orchard and cultivar in plum orchards. The values are expressed as means ± SD. Means followed by the same letter are not significantly different.

2.3.3 Effect of distance from honeybee colonies on fruit weight and fruit set

The distance from honeybee colonies did not have any significant effect on fruit weight (Table 2.2) or fruit set (Table 2.3) for plums (Table 2.4). That is, there was no decrease in fruit weight or fruit set with increasing distance from the honeybee colonies. These data are in contrast to previously published accounts which indicate a decrease in both fruit set and fruit weight with increasing distance from introduced honeybee colonies (Free 1962; Calzoni and Speranza 1998). This may suggest that there was sufficient pollinator coverage in Lourensford Estates plum orchards, that orchard size was not a limiting factor and foraging bees successfully pollinate along the lengths of the rows, and that honeybee colony numbers were sufficient.

Table 2.4: Fruit weight and fruit set in plums (mean ± SD) as influenced by honeybee colony distance. Means followed by the same letter are not significantly different.

Colony distance	Fruit Weight (g)	Fruit Set (%)
Close	55.28 ±15.73 a	4.39 ± 4.81 a
Far	54.17 ± 15.39 a	4.24 ± 4.64 a
LSD	2.02	0.51

2.3.4: Polliniser position on fruit weight and fruit set

The distance from the polliniser affected fruit weight in plum orchards (Table 2.2) where the fruit weight was significantly higher on sides of trees removed from the polliniser (Table 2.5) contrary to what would be expected in orchards (Tóth 1967; Keulemans 1980). The low fruit weight observed maybe due to the fact that initial set which was not recorded might have been higher adjacent to the polliniser and therefore reducing the final fruit size. Effects of distance from the polliniser on fruit set bordered on significance (Table 2.3). Fruit set of plum adjacent to the polliniser was slightly higher than fruit set on sides of trees removed from the polliniser (Table 2.5). This trend is similar to previous studies which illustrated a diminished fruit set in plums as distance from the polliniser increased (Free 1962, 1993; McGregor 1976; Szabó 2003).

Table 2.5: Fruit weight and fruit set of plums (mean ± SD) as influenced by polliniser position. Means followed by the same letter are not significantly different.

Colony distance	Fruit Weight (g)	Fruit Set (%)
Adjacent	53.15 ± 15.25 a	4.57 ± 4.78 a
Removed	56.88 ± 15.80 b	4.10 ± 4.72 a
LSD	1.92	0.48

2.3.5 Relationship between fruit weight and fruit set of 'Songold' and 'Laetitia' in three plum orchards over two growing seasons

Considering clusters individually, a negative and significant relationship was found between fruit weight and fruit set for 'Songold' (r = -0.114, df = 1427, P = 0.001; Table 2.6, Fig. 2.4). The relationship for 'Laetitia' was again negative, but not statistically significant. Although the relationship in 'Songold' was significant at the 99.9% level, only 1.3% of the fruit weight can be explained by the fruit set. This is likely to be of no biological significance and much too low to make claims that 'Songold' trees are at a physiological maximum in terms of production potential and hence in need of thinning to prevent a decrease in fruit weight. However, the effects of crop load on fruit growth and on final fruit weight are very well-documented (Palmer *et al*., 1997; Guardiola and García-Luis 1998) with fruit weight at harvest being inversely correlated with crop load. Fruit weight was greatest when there was minimum competition for available photo assimilates between fruit in apple orchards brought about by low crop load (Meland 2009). Unfortunately crop load was not a parameter considered in this study and therefore any trends shown in this study were not at an orchard level but relate to those shoots measured within the experimental blocks.

Table 2.6: Overall correlation between fruit weight and fruit set in 'Laetitia' and 'Songold', using Pearson's Correlation Coefficients (p = 0.05). Significant relationships are represented with an S while NS denotes non-significant relationships.

	r	P	N	
'Laetitia'	-0.014	0.591	1411	NS
'Songold'	-0.114	0.001	1428	S

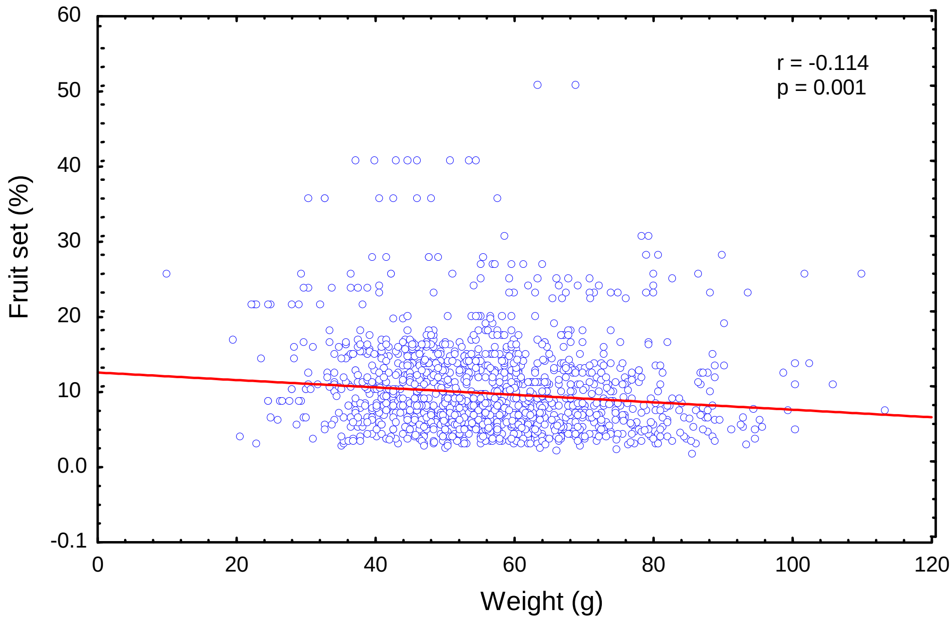

Fig 2.4: Relationship between fruit weight and fruit set for 'Songold' resulting from open pollination with 'Laetitia' as a polliniser.

2.4 Discussion

Three commercial plum orchards containing the cultivars Songold and Laetitia were used to assess the effect of polliniser distance (position) and honeybee colony distance on fruit weight and fruit set. Normal commercial conditions applied to the orchards and adequate yield was achieved in all orchards. As might be expected both fruit set and fruit weight differed between orchards, probably reflecting different soil and environmental conditions as well as differences in the age of the trees in the orchards. Surprisingly, the fruit weights of ‘Songold’ and ‘Laetitia’ were very similar in the Brinksburg orchards but ‘Songold’ was significantly smaller in Strengmens. This was in contrast to published data with the cultivar Songold weighing approximately 20g more than ‘Laetitia’ (Bester 2003; Hurter 2003). This anomaly cannot be explained. Although there was a statistically strong negative relationship (largely due to the high degrees of freedom) between fruit set and fruit weight in ‘Songold’, fruit set accounts for only 1.3% of fruit weight and it cannot be concluded that ‘Songold’ trees are being physiologically stressed by over-set. Fruit set had no significant effect on fruit weight in ‘Laetitia’.

With respect to the effect of polliniser distance and honeybee colony distance, the results are summarised in Table 2.7. Regarding the effect of polliniser distance, there are numerous reports of decreased yield in plums with increased distance from pollinisers. Tóth (1967) reported a decrease in set 3 rows away from the pollinisers, and Keulemans (1980) reported a significant difference 15 m from the pollinisers. Free (1962) reported a decrease in set from 7% in the row adjacent to the pollinisers to 1% set four rows away and Szabó (2003) reported a decrease in yield in the middle rows of 4-row blocks and for this reason recommends using 2-row blocks. Other studies, such as those on apricots by McLaren and colleagues (1996) have found that set decreased with increasing distance from the polliniser, but that fruit weight increased. They reported a fruit set of 13% and an average fruit weight of 56 g in the tree nearest the polliniser, compared to only 2% set but with a fruit weight of 67 g ten rows away. In the Lourensford plum orchards similar results were obtained. Fruit set was slightly higher closer to the polliniser but this result in smaller fruit closer to the polliniser may suggest that initial set might have been significantly higher resulting in a decrease in final fruit weight. In our orchards, however we could not use the slightly high set near the polliniser to explain the decrease in fruit size since initial fruit set was never evaluated.

Fruit weight and fruit set in plums has been found to decrease with distance from honeybee colonies (Free 1962; Calzoni and Speranza 1998). Szabó *et al.* (1999) reported similar results in apricots with intense bee pollination resulting in more fruit set and consequently in reduced average fruit size as well as reduced soluble solid content. The reduction in fruit size with improved pollination was 5-10% (Szabó *et al.* 1999).

Table 2.7: Summary of results for colony distance (comparison between trees close to bee hives and trees further away from bee hives); Polliniser effect (comparison between trees adjacent to the polliniser with trees removed from the polliniser); and fruit weight/fruit set correlations. Results are indicated as positive (+), meaning bigger fruit or more set closer to the hives or polliniser; or negative (-), meaning smaller fruit or less set closer to the hives or polliniser. If there is no difference, this is indicated with a zero (0). The significance of the difference, at the 0.05 % level (t-test - LSD) is indicated with an asterisk. The correlation results are indicated as positive (+), meaning a positive relationship, or negative (-), meaning a negative relationship. The significance of the relationship, at the 0.05 % level (Pearson's Correlation Coefficient) is indicated with an asterisk.

		Weight	Fruit Set
Colony distance		+	+
Polliniser effect		-*	+
		Weight/fruit set	
Correlations	'Laetitia'	-	
	'Songold'	-*	

In our study, colony distance did not have a significant effect on fruit weight or fruit set for plums, suggesting that adequate pollination was obtained throughout the orchard. This corresponded with the very high densities of honeybee colonies introduced into the orchards. The result for honeybee colony distance effect on set and weight of plums also indicated that there was sufficient honeybee mobility in plum orchards and therefore attempts to increase pollination by introducing additional honeybee colonies, may not necessarily result in increasing pollination effectiveness. From our data we therefore conclude that the 2x2 planting system employed in the plum orchards at Lourensford is sufficient to deliver adequate cross pollination.

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CHAPTER 3

Effect of polliniser position and honeybee colony distance in the set and quality of apples (*Malus* x *domestica* Borkh) cultivars Granny Smiths and Golden Delicious

3.1 Introduction

Apple is the pomaceous fruit of the species *Malus* x *domestica* Borkh, belonging to the subfamily Maloideae of the Rosaceae family. Apples have very good pollen production with as much as 1.7 mg/flower being produced (Free 1993; Benedek 2003), certainly more than any other deciduous fruit crop. Sugar concentration is also extremely high with an average of 36% (Benedek 2003) and a range of 20-58% (Free 1993). Pollen and nectar together make apples attractive to pollinators and therefore effective pollination is seldom a problem in apple orchards. Anderson (1985) reported that on average apple flowers receive 68 bee visits. Pollination only becomes a problem in intensive commercial production, where honeybee colonies need to be introduced to supply sufficient foragers. Typically a supply of 2-3 colonies per hectare is recommended (Anderson 1985; Free 1993).

Although apples have been grown for thousands of years, and intensively managed for about 100 years, there is an incomplete understanding of fertilization and its influence on the formation of the seeds (Sheffield *et al*. 2005). Flowers of apple cultivars consist of five carpels and each carpel usually has two ovules with the potential to form two seeds each, or ten seeds per fruit (McGregor 1976; Faust 1989; Free 1993; Brault and de Olivera 1995). Typically, at least 5-6 seeds in apples have to be formed, or else misshapen fruit will result, or fruit will be eliminated with early fruit drop (Anderson 1985; Free 1993; Delaplane and Mayer 2000; Buccheri and Di Viao 2004). The distribution of seeds in apples typically affects its shape and weight (Free 1993) with fruit that has been poorly pollinated and has few seeds dropping off soon after bloom. However, this is a generalization and in some cultivars there is no clear correlation between fruit drop and seed numbers (Ward *et al*. 2001). Seeds are sources of phytohormones such as auxin, gibberellins and cytokinins and these hormones are known to promote growth of the fruit tissue surrounding them, as well as to facilitate mineral elements such as calcium (Crane 1969; Bramlage *et al.* 1990; Brookfield *et al.* 1996; Buccheri and Di Viao 2004). Low seed numbers in apples results in small fruit with insufficient calcium (Bramlage *et al.* 1990; Volz *et al.* 1996; Brookfield *et al.* 1996; Buccheri and Di Viao 2004). Calcium plays a vital role in the determination of storage life of fruit in that apples with low calcium concentration resulting from low seed numbers tend to soften quickly (lose their firmness) during storage (Poovaiah 1988; Fallahi *et al.* 1997; Buccheri and Di Viao 2004).

In general there is a positive correlation between the extent of pollination and seed numbers (Sheffield *et al.* 2005). There is, however, no clear correlation between the extent of pollination and fruit set (Sheffield *et al.* 2005) as this seems more related to the physiological state of the tree than it is to pollination. In reports on effect of seed number on fruit weight Bramlage *et al.* (1990), Keulemans *et al.* (1996) and Buccheri and Di Vaio (2004) all found a positive correlation between the number of seeds and fruit weight in apples. De Putter *et al.* (1996), however, found no correlation between the number of seeds and fruit weight in 3 apple cultivars. Furthermore, a positive correlation between the number of seeds and fruit shape was found in apples by Brookfield *et al.* (1996) and Buccheri and Di Vaio (2004).

Most apple varieties are self sterile and therefore depend on pollen from another cultivar in order to set fruit (Free 1993). Although some apple cultivars show some degree of self fruitfulness, this is usually not enough to allow solid block planting (McGregor 1976; Free 1993; Khan and Khan 2004). Polliniser trees must be interplanted with the main cultivar to facilitate cross pollination and fertilization. Obtaining optimum yield in apple orchards depends not only on having cross compatible cultivars but also in supplying sufficient pollinators (honeybees) to orchards during the flowering period (Brittain 1933; McGregor 1976; Free 1993; Delaplane and Mayer 2000). More work has been done on the influence of pollinisers in apple pollination, and hence on the correct planting pattern, than in any other crop (Table 3.1; Soltész 2003). Many studies have shown that fruit yield increases nearer to the polliniser (Soltész 2003). Fruit set has been found to increase nearer to the polliniser in a wide variety of apple cultivars (Free 1962; Free and Spencer-Booth 1964; Traynor 1966; Maggs *et al.* 1971; Multinovic *et al.* 1996; Kron *et al.* 2001; Buccheri and Di Vaio 2004) but not in others (DeGrandi-Hoffman *et al*. 1984). Similarly, seed number in apples generally increases nearer the polliniser (Free 1962; Traynor 1966; Maggs *et al.* 1971; Brookfield *et al.* 1996; Blazek 1996; Multinovic *et al.* 1996; De Witte *et al*. 1996; Kron *et al.* 2001; Buccheri and Di Vaio 2004), but not in all circumstances (DeGrandi-Hoffman *et al*. 1984). In an orchard of 'Golden Delicious' with solid block planting Schneider *et al*. (2001) found that 'Golden Delicious' trees on the outskirts of the orchard, adjacent to 'Top red' or to 'Granny Smith', had significantly more seeds than those in the middle of the orchard. In a similar experiment Free (1962) found that in apple orchards with main varieties and polliniser trees in separate blocks, set was higher on trees adjacent to pollinisers than on trees far away. Fruit weight in apples has also been found to generally increase nearer to the polliniser (Traynor 1966; Multinovic *et al.* 1996; Brookfield *et al.* 1996) but not in all cases (De Witte *et al*. 1996; Buccheri and Di Vaio 2004).

Table 3.1 illustrates the variety of recommendations that have been made for planting patterns in apple orchards. Everything from blocks of three trees to blocks of 20 trees; from 15 m from polliniser to 90 m from polliniser; from polliniser cultivar every fifth row to polliniser trees every alternate row. According to Kron *et al.* (2001) active pollen can be transferred as far as

86 m in apple orchards, though distance is normally much less than that. Blazek (1996) recommends a maximum of 6 rows in apples between rows of pollinisers.

Apples were introduced into South Africa in the early 1650's by Jan Van Riebeeck (Davis 1928). Globally they rank fourth in terms of production after oranges, bananas and grapes. They are the second most important deciduous fruit crops after grapes and they are mostly produced in temperate regions of the world. In 2004 apples had an estimated gross value of ZAR 1 438 million in South Africa (Deciduous Fruit Producers' Trust 2005). Apple orchards form a major part of the horticultural industry in South Africa, requiring a labour force of 28540 (DFPT 2005). They are mostly grown in the Western Cape, with the 20774 hectares planted, comprising 98% of the total planted in the country (DFPT 2005). 'Granny Smith' and 'Golden Delicious' are the primary apple cultivars planted in South Africa (DFPT 2005), together making up 49% of the total hectares planted to apple. 'Golden Delicious' originated in the United States of America. They have a high chilling requirement and bloom early to mid October. The suitable polliniser cultivars for 'Golden Delicious' are 'Granny Smith', 'Starking' types, 'Hillieri' and 'Royal Gala' (Infruitec 1992). They are ready to harvest from late February to early March. On average they weigh 160g, are green-yellow in colour and have a globe-conical shape. 'Granny Smith' originated in Australia. They have a medium to low chilling requirement and bloom early to middle of October. The suitable polliniser of 'Granny Smith' are 'Golden Delicious', 'Starking' types, 'Hillieri' and 'Spur Winter Banana'(Infruitec 1992). They are ready to harvest from late March to early April. On average they weigh 150g, are green in colour and have a globe-conical shape (Infruitec 1992). More than 70% of apples produced in South Africa are aimed at export market (DFPT 2005).

Table 3.1: Recommendations made for planting patterns in apple orchards (from Soltész 2003).

Placement	Author (year)
Every 3rd in every 3rd row is a polliniser	Gardner et al. (1952)
Maximum distance from polliniser 70 to 90 m	Kobel (1954)
Every 5th row is a polliniser (intensive planting)	Kobel (1954)
Every 4th-5th row is a polliniser	Breviglieri (1960)
Few rows wide block	Maliga (1961)
Blocks 4-5 row-wide	Hoffman (1961)
Blocks 4-5 row-wide	Bayev (1967, cit. Soltész, 1982)
Blocks 4-5 rows wide	Fulford and Way (1967)
Maximum distance from polliniser 15-20m	van Lier (1967)
Blocks 3-4 row-wide, at most	Krapf (1968)
Blocks 4-row-wide, at most	Wertheim (1968)
Alternate rows	Wertheim (1968)
Alternate blocks of 3-4 rows	Grenzitshenko (1969)
Polliniser blocks of 2-3-row wide after every 5th to 6th rows	Grenzitshenko (1969)
Blocks 20-row-wide	Pethó (1969)
Blocks 4-5-row wide	Williams (1970)
At least one polliniser for every tree	Tukey (1970)
Every 3rd in every 3rd row is a polliniser	Tukey (1970)
Blocks 4-row-wide, at most, 1 to 3 polliniser in the 5th row	Tukey (1970)
Maximum distance to the polliniser 15-20 m (in intensive plantations)	Tukey (1970)
Blocks 3-5- row-wide (intensive plantations)	Williams and Wilson (1970)
Blocks 4-6- row-wide ('Cox's Orange Pippin')	Williams and Wilson (1970)
Every 3rd in every 3rd row is a polliniser	Williams and Wilson (1970)
Maximum distance to the polliniser 20-25 m	Gautier (1971)
Alternating blocks maximum 4-row-wide each	Gautier (1971)
Maximum distance to the polliniser 30 m	Way (1971)
Every 3rd in every 3rd row is a polliniser	Way (1971)
Blocks 4-row-wide at most (of the cultivar to be pollinated)	Way (1971)
Maximum distance to the polliniser 70 m	Fritzsche (1972)
Blocks 6-10- row-wide, at most (for spur cultivars)	Reichel (1972)
Maximum distance to the polliniser 15-20 m	Reichel (1972)
Blocks 30-40 m wide, at most	Reichel (1972)
Every 3rd in every 3rd row is a polliniser	Teskey and Shoemaker (1972)
Blocks 3- row-wide, at most	Teskey and Shoemaker (1972)
Maximum distance to the polliniser 25 m	Teskey and Shoemaker (1972)
Blocks 3-4 row-wide	Teskey and Shoemaker (1972)
Blocks 8-10- row-wide, at most	Blasse (1974a,b)
Alternate rows of the respective cultivar	Blasse (1974a,b)
Every 5rd in every 5rd row is a polliniser	Blasse (1974a,b)
Polliniser blocks 2-row-wide inserted after 8-10-row blocks	Blasse (1974a,b)
Blocks 6-row-wide, at most	Popelyankov (1974)
Maximum distance to the polliniser 20 m	Hilkenbäumer (1975)
Maximum distance to the polliniser 15 m	Hugard (1975)
Blocks 50 m wide, at most	Schaer and Schäfer (1975)
Maximum distance to the polliniser 20 m (triploid cultivars)	Schaer and Schäfer (1975)
Blocks 10-row-wide, at most	Blazek et al. (1977)
Maximum distance to the polliniser 100-150 m	Kurennoy (1977)
Polliniser in every row	Parry (1978)
Polliniser blocks 2-row-wide (with two diploid cultivars) after every 4th row	Way (1978b)
Every 8th -10th row is a polliniser (intensive planting)	Stösser (1980)
Blocks 4-row-wide ('Delicious')	Giulino (1982)
Every 4th -5th row is a polliniser	Lalatta (1982)
Polliniser in every row	Lalatta (1982)
Maximum distance to the polliniser 25 m	Soltėsz (1982)
Maximum distance to the polliniser 20 m	Stainer and Gasser (1982)
At least one polliniser for every tree	Mayer (1983)
Wide blocks are possible if pollination was satisfactory)	DeGrandi-Hoffmann et al. (1984)
Blocks 2-row-wide, at most (for triploid cultivars)	Soltėsz (1986 cit. Soltėsz, 1982)
Blocks 4-6- row-wide, at most	Terragrossa (1987)
Maximum distance to the polliniser 15 m	Mantinger (1997)
Maximum distance to the polliniser less than 15 m	Mantinger (1998)
Maximum distance to the polliniser 15 m(for intensive plantation)	Soltėsz (1997)

In this study we examined whether polliniser position and honeybee colony distance affect the set and quality of 'Granny Smith' and 'Golden Delicious'. Furthermore we investigated the relationship between fruit weight and fruit set, as well as seed number, in these two cultivars.

3.2 Materials and Methods

3.2.1 Orchards

Two apple orchards (Schoemans 1 and Schoemans 8, planted in 1982 and 1983 respectively) were assessed from October 2004 to March 2005, and a further apple orchard (Schoemans 6, planted in 1983) from October 2005 to March 2006. The trees in each orchard were uniform in age and size. All orchards were commercially active and on the Lourensford Estate in Somerset West. Detailed maps were prepared for each orchard, marking the position of each tree (polliniser and commercial cultivar) in the orchard, as well as the position of the bee hives introduced during pollination.

3.2.2 Planting patterns

In Schoemans 6 and 8, two rows of 'Granny Smith' were interplanted with two rows of 'Golden Delicious'. The trees were planted at a spacing of 4.3m x 1.8m and have filled their allotted space. The other apple orchard (Schoemans 1) differed from the other two orchards in that there was only one row of 'Golden Delicious' between 2 rows of 'Granny Smith'.

3.2.3 Bees and farming practices

As described in Chapter 2, section 2.2.3

3.2.4 Experimental procedure

Effect of Polliniser Patterns and colony distance on Fruit set and Quality

Nine blocks were marked for Schoemans 1 (three blocks per replicate). There were three blocks on each side of the orchard, immediately adjacent to the bee hives, and the final 3 blocks in the centre of the orchard, away from the bee hives (Fig 3.1). As with the plums, branches were tagged and all clusters distal to the tag were counted. Only one-year old shoots were tagged, and lateral clusters were included. All tagged branches (shoots) were in a similar position with respect to height and weight. Forty shoots were tagged for each block (typically 1 per tree). In Schoemans 1, only ‘Granny Smith’ was assessed. A total of 360 branches were tagged (10 trees x 4 rows/sides x 9 blocks, see Fig. 3.1), with between 4 and 64 flowers counted on tagged branches. The 2 x 2 design apple orchards (Schoemans 6 and 8) were assessed for both ‘Granny Smith’ and ‘Golden Delicious’. In these orchards eight sides of each block were tagged (Fig. 3.2), hence each block had 80 tags. A total of 480 branches were tagged (10 trees x 8 rows/sides x 6 blocks). Prior to blossom, clusters of buds were selected and tagged as described in Chapter 2, section 2.2.4. For each block, comparisons in fruit set and fruit size were made, the experimental design was such that sunlight and wind direction were the same for the comparisons performed. In all three apple orchards the following comparisons were made for polliniser effect: a (adjacent to polliniser) versus r (removed from polliniser). For the distance effect the comparison made was that between blocks near the honey bee colonies to those far from the colonies in the middle of the orchard. Only six blocks were tagged in Schoemans 6 and 8, three blocks on the near side of the orchard and the other three in the middle, as these orchards were too small for nine independent sampling blocks.

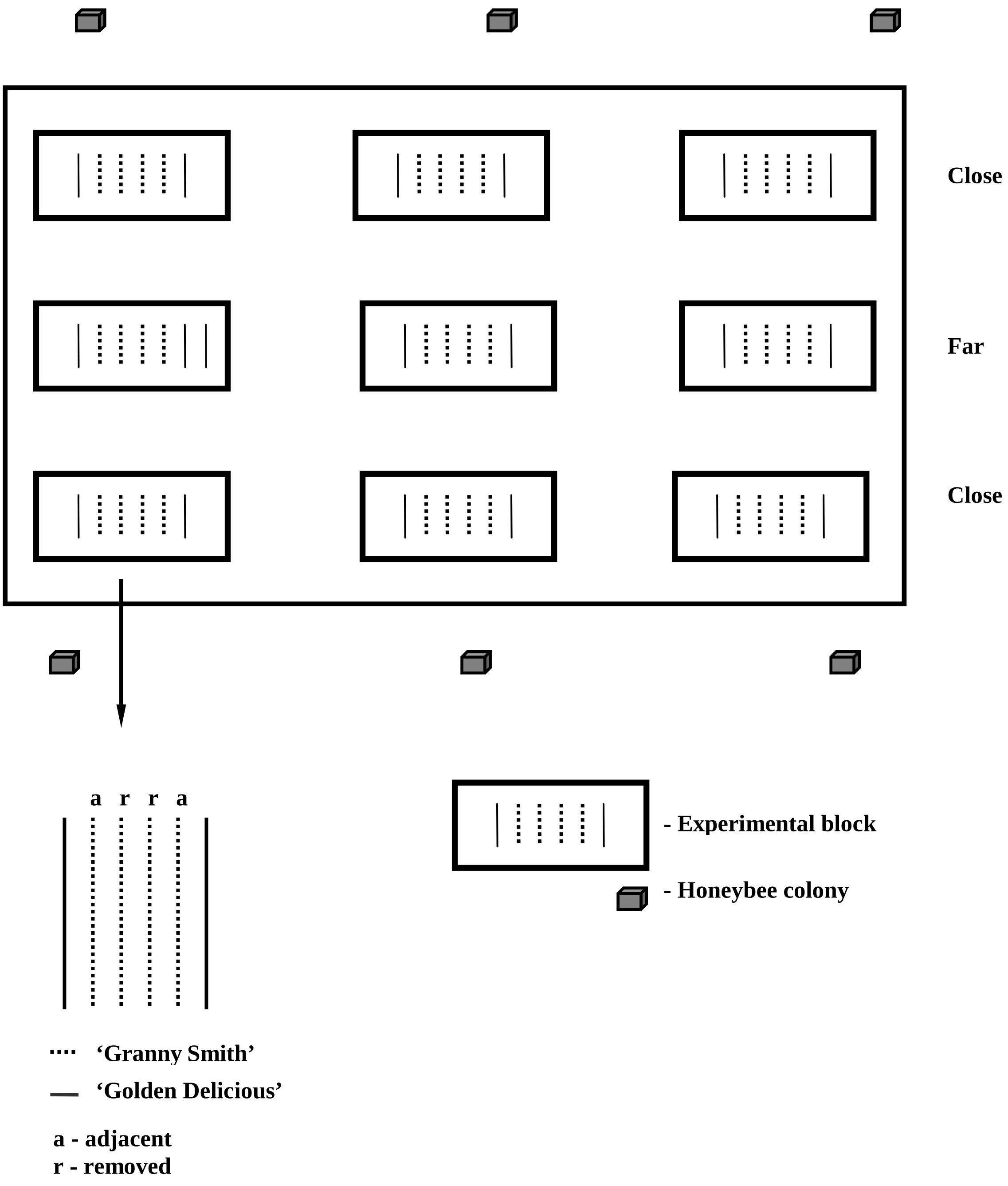

Fig. 3.1: Schematic map of an orchard with a 2x1 planting pattern and nine experimental blocks (Schoemans 1). Two rows of 'Granny Smith' are interspersed with 1 row of 'Golden Delicious'. In the diagram, each line (dotted or solid) represents one side of a row of trees. Honeybee colonies were placed at the ends of the rows as shown.

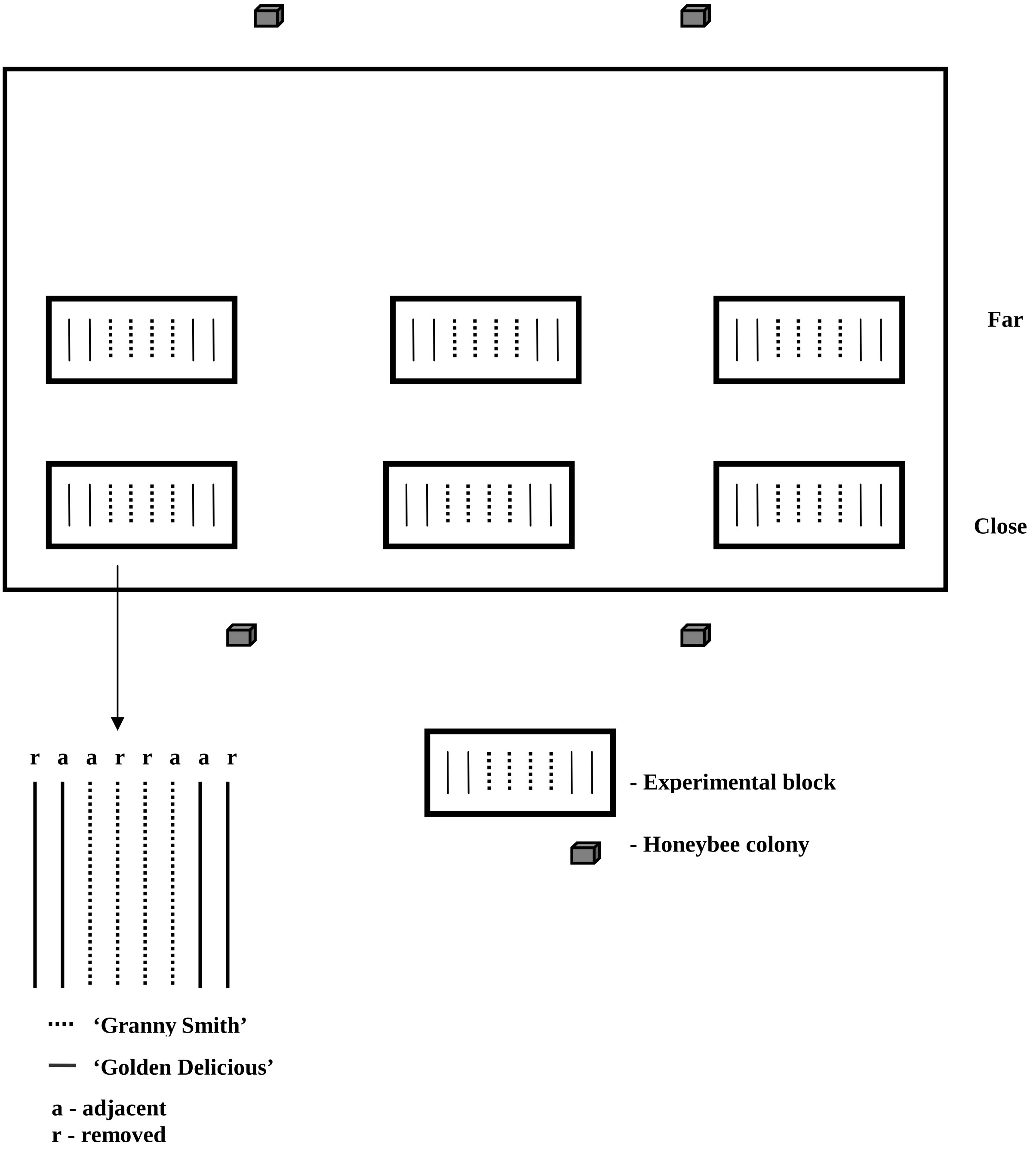

Fig. 3.2 Schematic map of an orchard with a 2 x 2 planting pattern and six experimental blocks (Schoemans 6 and 8). Two rows of 'Granny Smith' are interspersed with 1 row of 'Golden Delicious'. In the diagram, each line (dotted or solid) represents one side of a row of trees. Honeybee colonies were placed at the ends of the rows as shown (Schoemans 6 shown; Schoemans 8 had an extra honeybee colony).

Assessing pollination efficiency for apples

A few days before commercial harvest the fruit that had set and matured in each of the tagged branches was counted to determine fruit set (flower and fruit abscission were not take into account for our fruit set calculations), and then harvested. For all the apples collected individual fruit weight and the number of well developed seeds were counted. After weighing, all apples were cut in half with a knife transversally near the centre to expose the seeds without damaging them. The seeds from each fruit were removed, counted and the numbers of fertilized (plump) seeds were recorded as an indication of successful pollination. The fruit set and fruit weight of the various sectors of the orchards with respect to the position of the polliniser and distance from the colonies was determined, and hence the impact of polliniser position, honeybee colony distance and planting pattern on orchard production.

3.2.5 Statistical analysis

A multifactorial analysis of variance was used to analyse data with the three orchards, two colony distances, two cultivars and two polliniser positions as main effects. The experimental design included three replicates. All possible interaction effects were also determined. Degrees of freedom for Sample error were calculated by multiplying the total degrees of freedom of the experimental design and then subtracting the model degrees of freedom from the corrected total degrees of freedom. Data were reported as mean ± SD and were analyzed using Univariate Factorial Analysis of Variance (ANOVA) to explain the variation in fruit weight in relation to distance from polliniser and distance from colonies. *Post hoc* Student's test (LSD-Least Significant Difference) were performed to indicate statistical significance at $p = 0.05$. To calculate fruit set, each tagged branch was treated as a single data point and Analysis of Variance (ANOVA) was run to explain the variation in the number of flowers that developed into fruit with respect to distance from polliniser and distance from colonies. *Post hoc* Student's test (LSD- Least Significant Difference) were used to indicate statistical significance among means at p = 0.05. Pearson correlation analysis was used to determine the relationship between fruit weight, fruit set and seed number. All statistical analysis was performed using Statistical Analysis System (SAS).

3.3 Results

3.3.1 Orchard description

Basic information about the apple orchards is presented in Table 3.2. There was chemical thinning and hand thinning in all three apple orchards; tagged branches, however, were not hand-thinned. Temperatures were moderately warm and constant throughout the pollination periods in both 2004 and 2005 (Figure 2.2; in Chapter 2).

Table 3.2: Orchard size, orchard production and orchard management practices in three experimental apple orchards.

Orchard	Year	Cultivar	Yield (tonnes/hectare)	Orchard Size (ha)	Honeybee colonies introduced	Date of first introduction (= 10% blossom)	Hand thinning	Chemical thinning
Schoemans 6	2004	'Granny Smith'	53	2.17	6	12/10	Yes	Yes
		'Golden Delicious'	49				Yes	Yes
Schoemans 8	2004	'Granny Smith'	71	1.67	5	12/10	Yes	Yes
		'Golden Delicious'	51				Yes	Yes
Schoemans 1	2005	'Granny Smith'	30	1.62	4	13/10	Yes	Yes

3.3.2 Overall orchard interactions

The fruit weight, fruit set and the number of seeds present were assessed for the three orchards and these data are indicated in Tables 3.3., 3.4 and 3.5. Fruit weight was not significantly different (Table 3.3) while fruit set (Table 3.4) and the numbers of seeds (Table 3.5) were significantly different between the three orchards.

Fruit weight in apples has previously been found to decrease with distance from honeybee colonies (Free 1962; Calzoni and Speranza 1998). In our orchards there was a significant cultivar by colony distance interaction in apples (Table 3.3; Fig 3.3). 'Granny Smith' apples closer to honeybee colonies weighed significantly less compared to 'Granny Smith' far from honeybee colonies. However 'Golden Delicious' did not weigh more when harvested from trees close to or those further from honeybee colonies. The fact that 'Granny Smith' apples weigh more further from colonies was unexpected and currently we have no explanation for this anomaly.

Table 3.3: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on fruit weight in apples.

Source Factor	DF	Mean Square	p
Orchard	2	5645.21	0.0843
Cultivar	1	34752.11	0.0003
Orchard*Cultivar	2	2077.47	0.3278
Polliniser position	1	9.27	0.9475
Orchard*Position	2	2507.98	0.3168
Cultivar*Position	1	5554.71	0.1143
Orchard*Cultivar*Position	2	7180.64	0.0743
Colony distance	1	1287.22	0.4398
Orchard*Distance	2	3043.89	0.2506
Cultivar*Distance	1	14717.24	0.0128
Orchard*Cultivar*Distance	2	734.03	0.5588
Position*Distance	1	24.88	0.9140
Orchard*Position*Distance	2	2135.26	0.3738
Cultivar*Position*Distance	1	498.27	0.6297
Orchard*Cultivar*Position*Distance	2	742.88	0.5564
Sample Error	48	2099.58	

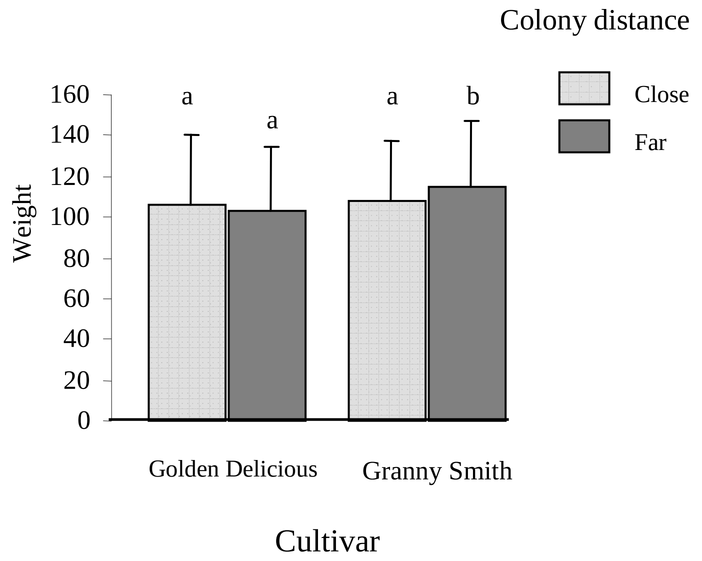

Fig 3.3 Interaction effect between cultivar and colony distance on fruit weight in apple orchards. Means followed by the same letter are not significantly different.

Table 3.4: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on fruit set in apples.

Source Factor	DF	Mean Square	p
Orchard	2	1.299	<0.0001
Cultivar	1	1.900	<0.0001
Orchard*Cultivar	2	0.588	0.0010
Polliniser position	1	0.144	0.0896
Orchard*Position	2	0.176	0.0328
Cultivar*Position	1	0.058	0.2751
Orchard*Cultivar*Position	2	0.086	0.1866
Colony distance	1	0.091	0.1751
Orchard*Distance	2	0.057	0.3172
Cultivar*Distance	1	0.013	0.6118
Orchard*Cultivar*Distance	2	0.464	0.0031
Position*Distance	1	0.004	0.7691
Orchard*Position*Distance	2	0.006	0.8842
Cultivar*Position*Distance	1	0.062	0.2623
Orchard*Cultivar*Position*Distance	2	0.043	0.3445
Sample Error	48	0.048	

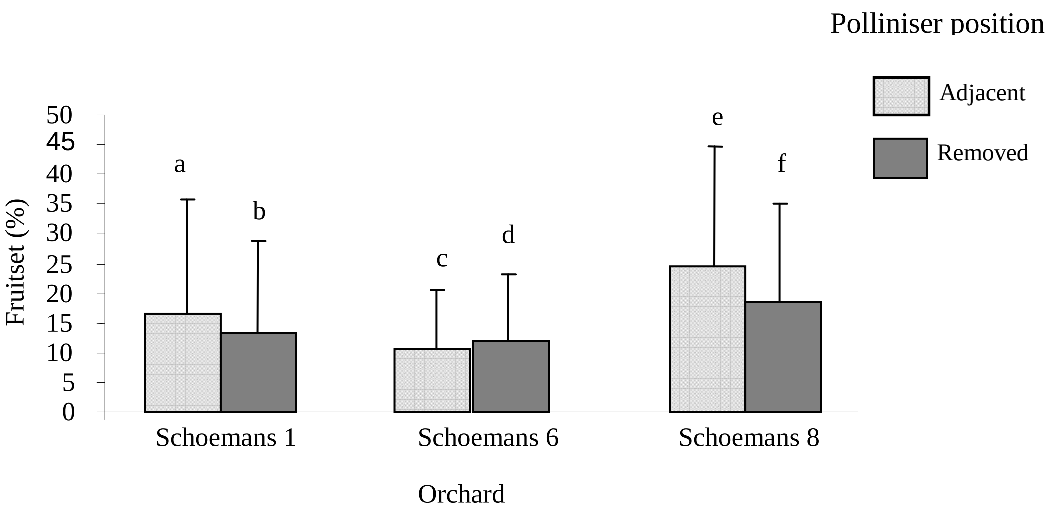

Fig 3.4 Interaction effect between orchard and polliniser position on fruit set in apple orchards. Means followed by the same letter are not significantly different. In Schoemans1 data was collected only on Granny Smith trees because of its different planting pattern where two rows of 'Granny Smith' are interspersed with 1 row of 'Golden Delicious' compared to the 2X2 planting pattern in Schoemans 6 and Schoemans 8 where two rows of 'Granny Smith' are interspersed with 1 row of 'Golden Delicious'.

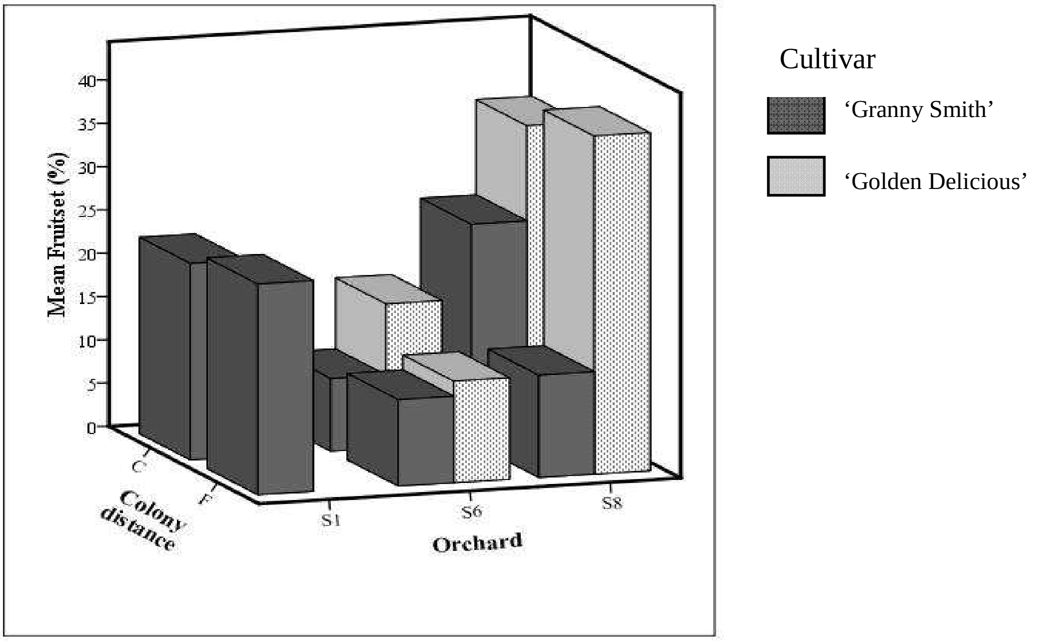

Fig 3.5 A three-way interaction effect between orchard, cultivar and colony distance on fruit set in apple orchards. Means followed by the same letter are not significantly different. In Schoeman 1 data was collected only on 'Granny Smith' trees because of its different planting pattern where two rows of 'Granny Smith' are interspersed with 1 row of 'Golden Delicious' compared to the 2X2 planting pattern in Schoeman 6 and Schoeman 8 where two rows of 'Granny Smith' are interspersed with 1 row of 'Golden Delicious'.

In the case of fruit set, a significant orchard by polliniser position interaction was observed in apple orchards (Table 3.4; Fig 3.4). There were significant differences in fruit set in all apple orchards, trees adjacent to the polliniser set more fruit compared to trees removed from the polliniser in Schoemans 1 and Schoemans 8; the opposite was true for Schoemans 6. In Schoemans 6 significantly more fruit was set on trees removed from the polliniser. Our data for Schoemans 1 and Schoemans 8 were in agreement with those of Schneider *et al*. (2001). A significant three-way orchard, cultivar and colony distance interaction was observed on fruit set in apple orchards (Table 3.4; Fig 3.5). Fruit set was significantly higher for cultivar Golden Delicious in Schoemans 8 for trees both far and near to honeybee colonies.

Table 3.5: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on the number of seeds in apples.

Source Factor	DF	Mean Square	p
Orchard	2	98.54	<0.0001
Cultivar	1	137.62	0.0002
Orchard*Cultivar	2	151.67	<0.0001
Polliniser position	1	141.16	0.0001
Orchard*Position	2	101.85	<0.0001
Cultivar*Position	1	10.69	0.2399
Orchard*Cultivar*Position	2	28.72	0.0587
Colony distance	1	2.47	0.5685
Orchard*Distance	2	13.27	0.1852
Cultivar*Distance	1	9.14	0.2763
Orchard*Cultivar*Distance	2	1.17	0.6942
Position*Distance	1	0.09	0.9118
Orchard*Position*Distance	2	2.60	0.7078
Cultivar*Position*Distance	1	2.40	0.5743
Orchard*Cultivar*Position*Distance	2	5.35	0.4029
Sample Error	48	7.44	

The number of seeds in apples was dependent on orchard, cultivar and polliniser position (Table 3.5). There was a significant orchard cultivar interaction for seed number in apple orchards (Table 3.5; Fig 3.6). Seed numbers of ‘Granny Smith’ differed significantly amongst the three orchards however number of seeds of ‘Golden Delicious’ did not differ between Schoemans 6 and Schoemans 8. In Schoemans 8 ‘Golden Delicious’ apples had significantly more seeds than ‘Granny Smith’ apples but this was not true for Schoemans 6 where the trend was for ‘Granny Smith’ to have more seeds. The two orchards with ‘Golden Delicious’ apples did not show the same trends which indicated that orchards have to be assessed independently when evaluating various aspects of pollination efficiency.

Seed number in apples was also affected by orchard x polliniser position interaction (Table 3.5; Fig 3.7). In Schoemans 1 and Schoemans 6, apples adjacent to and removed from the polliniser were not significantly different in the number of seeds produced. However the number of seeds differed significantly between the two orchards (Fig 3.7). Only in Schoemans 8 was seed number affected by polliniser position as was expected with fruit adjacent to the polliniser having significantly more seeds than fruit removed from the polliniser. Our data in Schoemans 8 are in agreement with those of Schneider *et al*. (2001). However, it is interesting to note that the number of seeds produced by apples in Schoemans 8 adjacent to the polliniser is not more than the seeds produced by those apples removed from the polliniser in Schoemans 6. This polliniser position effect in Schoemans 8 could be driven by the unusually small seed number for ‘Granny Smith’ apples in this orchard (Fig 3.6) resulting in the observed interaction. This is purely speculative with no obvious explanation for this disparity and only emphasizes that orchards behave independently and need to be evaluated as such.

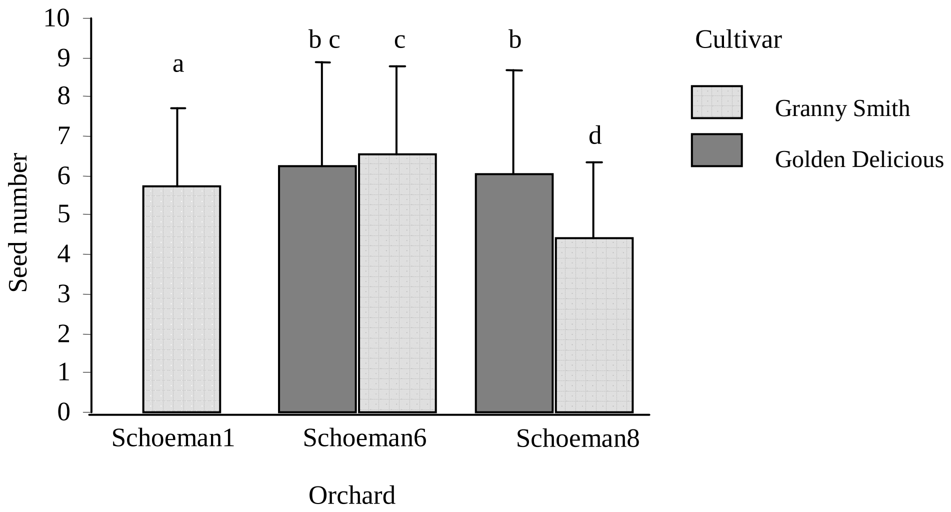

Fig 3.6 Interaction effect between orchard and cultivar on seed number in apple orchards. Means followed by the same letter are not significantly different. In Schoemans 1 data was collected only on ‘Granny Smith’ trees because of the different planting pattern where two rows of ‘Granny Smith’ are interspersed with 1 row of ‘Golden Delicious’ compared to the 2X2 planting pattern in Schoemans 6 and Schoemans 8.

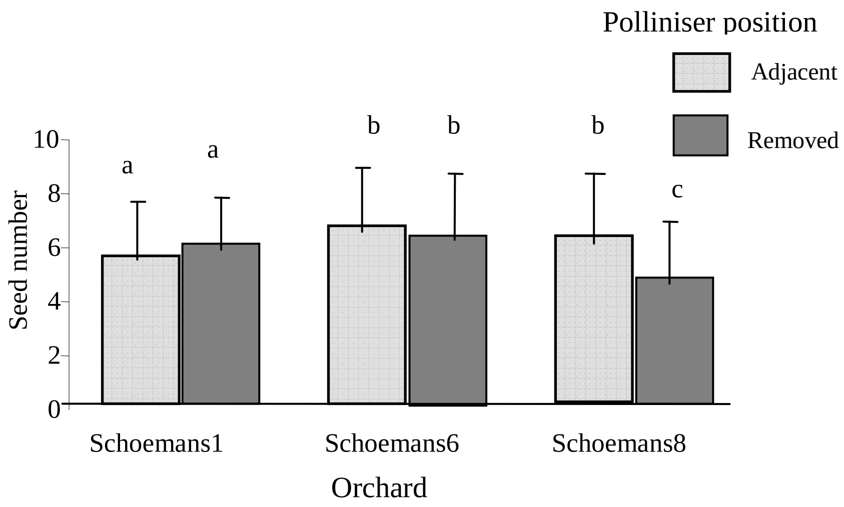

Fig 3.7 Interaction effect between orchard and polliniser position on seed number in apple orchards. Means followed by the same letter are not significantly different.

3.3.4 Polliniser position on fruit weight, fruit set and seed number of apples

As regards the effect of distance from the polliniser, it has previously been shown to affect fruit weight, fruit set, and seed number (e.g. Schneider *et al*. 2001). Our data were in agreement with those of Schneider *et al*. (2001) as there were significantly more fruit and seeds on sides of trees adjacent to the polliniser compared to sides removed from the polliniser (Table 3.6, Fig 3.4). Fruit weight, however, was not affected by distance from the polliniser. Fruit weight on sides of trees adjacent to the polliniser was not significantly different compared to sides of trees removed from the polliniser (Table 3.6). The number of seeds demonstrated the effectiveness of cross pollination in that more seeds mean sufficient pollination which should result in bigger fruit, but this was not the case in these orchards, suggesting that factors other than effective pollination were governing fruit weight and fruit yield in these orchards. We can therefore presume that there was no polliniser-related depression in the 2 x 2 ‘Granny Smith’ and ‘Golden Delicious’ orchards on Lourensford Estate.

Table 3.6: Fruit weight, fruit set and seed number (mean ± SD) of apples as influenced by polliniser position. Means followed by the same letter are not significantly different.

Polliniser Position	Fruit Weight (g)	Fruit Set (%)	Seed Number
Adjacent	107.93 ± 31.61 a	17.03 ±17.740 a	6.11± 2.42 a
Removed	108.10 ± 32.07 a	14.40 ± 14.66 b	5.56 ±2.37 b
LSD	5.27	2.44	0.31

3.3.5 Honeybee colony distance on fruit weight, fruit set and seed number of apples

Contrary to previously published data which indicated a decrease in fruit set and fruit weight with increasing distance from introduced honeybee colonies, in our apple orchards the distance from honeybee colonies does not have any significant effect on fruit set and fruit weight in apple orchards (Table 3.7). This again demonstrated clearly that pollinator coverage in Lourensford Estates apple orchards was uniform, that orchard size was not a limiting factor, that foraging bees successfully pollinated along the lengths of the rows, and that honeybee colony numbers were sufficient or more than sufficient.

Table 3.7: Fruit weight, fruit set and seed number (mean ± SD) of apples as influenced by honeybee colony distance. Means followed by the same letter are not significantly different

Colony Distance	Fruit Weight (g)	Fruit Set (%)	Number of Seeds
Close	107.45 ± 31.34 a	16.41 ± 16.33 a	5.73 ± 2.40 a
Far	108.75 ± 32.45 a	14.80 ± 16.14 a	5.99 ± 2.42 a
LSD	5.31	2.45	0.77

3.3.6 Relationship between fruit weight and fruit set/seed number of 'Granny Smith' and 'Golden Delicious' apples in three apple orchards over two growing seasons.

A significant but negative relationship was found between fruit weight and fruit set for 'Granny Smith' ($r = -0.216$, $n = 517$, $P < 0.001$; Table 3.8), but not for 'Golden Delicious'. In 'Granny Smith' fruit weight increased as fruit set decreased. A strong relationship was found between fruit weight and seed number ($r = 0.284$, $n = 567$, $P = 0.001$; Table 3.8) for 'Golden Delicious' and between fruit weight and seed number for 'Granny Smith' ($r = 0.262$, $n = 517$, $P = 0.001$; Table 3.8). This indicated that fruit weight increased significantly when number of seeds per fruit increased. The positive relationship between fruit weight and seed number for both 'Granny Smith' and 'Golden Delicious' were in accordance with previous reports, for other apple cultivars, which reported a positive correlation between seed number and fruit weight (Bramlage *et al.* 1990, Keulemans *et al.* 1996; De Putter *et al*. 1996; Buccheri and Di Vaio 2004; Blazek and Hlusickova 2006).

Table 3.8: The correlations between fruit weight and fruit set/seed number in 'Granny Smith' and 'Golden Delicious'. Significant relationships are represented with an S while NS denotes non-significant relationships.

Cultivar		r	P	N	
'Granny Smith'	Fruit set	-0.216	<0.001	517	S
	Seed number	0.262	0.001	517	S
'Golden Delicious'	Fruit set	-0.001	0.978	567	NS
	Seed number	0.284	0.001	567	S

3.4 Discussion

Three commercial apple orchards containing the cultivars Granny Smith and Golden Delicious were used to assess the effect of polliniser distance and honeybee colony distance on fruit weight, fruit set and seed number. There was a significant orchard effect (Tables 3.4 and 3.5), with fruit set and seed number differing between orchards, probably reflecting different soil and environmental conditions. Besides the orchards behaving independently, both cultivars also responded differently in the separate orchards. For example, fruit set of 'Golden Delicious' was found to be significantly higher than that of 'Granny Smith' in Schoemans 8 but not so for Schoemans 6 (Fig 3.7). Crop load, which is the number of fruits per tree, is one of the most important factors that influence the size of the fruit (Blazek and Hlusickova 2006). It is important to mention that in this study crop load was never evaluated and therefore these data cannot be discussed in relation to crop load.

Regarding polliniser position, significantly more fruit were set on sides of trees adjacent to the polliniser compared to sides removed from the polliniser also seed number was significantly higher on sides of trees adjacent to the polliniser than on the sides removed (Table 3.6, Fig 3.4). These results are in agreement with most previous studies (e.g. Buccheri and Di Viao 2004) that had reported a relationship between seed number and proximity to the polliniser. Fruit weight however was not affected by distance from polliniser (Table 3.6). Results on fruit weight are not in agreement with numerous previous observations. For example, Brookfield *et al.* (1996) and Free (1962) found an increase in fruit weight on the sides of trees adjacent to pollinisers. Final fruit set was significantly higher closer to the polliniser which may have resulted in smaller fruit closer to the polliniser. This suggests that initial set might have been significantly higher resulting in a decrease in final fruit weight regardless of the significantly high seed numbers on sides of trees adjacent to the polliniser. In our orchards, however we could not use the high set near the polliniser to explain the decrease in fruit size since initial fruit set was never evaluated, a shortcoming of the project design we are well aware of.

With respect to the effect of honeybee colony distance, the results showed that at Lourensford fruit weight, fruit set and the number of seeds of apples were not affected by the distance from colonies (Tables 3.7 and 3.9). Fruit weight and fruit set in apples has previously been found to decrease with distance from honeybee colonies (Free 1962; Calzoni and Speranza 1998). In this study, colony distance did not have a significant effect on fruit weight, fruit set or seed numbers, this might be an indication that adequate pollination was obtained throughout the orchard. This corresponded with the very high densities of honeybee colonies introduced into the orchards.

The strongly negative relationship between fruit set and fruit weight in ‘Granny Smith’ (Tables 3.8 and 3.9) indicated that, at the branch level, fruit set and fruit weight were negatively correlated. That is, in ‘Granny Smith’, more fruit on a branch resulted in smaller fruit being produced suggesting that ‘Granny Smith’ may need to be carefully hand-thinned, at the branch level, to deliver fruit of adequate size. This was not the case in ‘Golden Delicious’ where there was no significant relationship between fruit set and fruit weight at the branch level (Table 3.8). This can either mean that the fruit production was sufficiently below optimum, and hence fruit set was not limiting fruit size; or, that fruit set at the orchard level was so high that no effect could be seen at the branch level.

In commercial orchards fruit size can be increased by either chemical or hand thinning to reduce crop load. Volz *et al.* (1996) found that hand thinning in apples had little or no effect on the final fruit set, and the final fruit yield. Of importance were the initial fruit set and the initial level of pollination. Initial set was directly related to the yield of the crop, with too much set resulting in smaller fruit and lower yields. If the initial set which was not recorded in our study was extremely high, thinning could not reverse this. This is suggested to be the explanation in the ‘Golden Delicious’ orchards, and more effective early chemical thinning, or pre-blossom thinning, is required to deliver improved fruit weight. In contrast, hand-thinning may be sufficient in ‘Granny Smith’ orchards.

In contrast to the fruit set/fruit weight relationship, the fruit weight/seed numbers relationship was as expected. At the individual fruit level fruit weight increased with an increase in number of seeds in both cultivars Granny Smith and Golden Delicious, indicating that seeds have an effect on fruit weight. The positive relationship between seeds and fruit weight has been attributed to hormones such as auxin, gibberellins and cytokinin that are produced in seeds and spread throughout the fruit promoting cell division and hence fruit size (Crane 1969; Luckwill and Weaver 1969; Boselli *et al.* 1995). Evidence has indicated that these hormones stimulate growth of tissues surrounding them. Therefore a high number of seeds are likely to stimulate growth of fruit tissue as a result of great attraction of nutrients coming from other parts of the tree (Buccheri and Di Viao 2004). At least some apple cultivars exhibit ‘perfect syncarpy’, a zone of inter-carpel communication where pollen tubes have the potential to cross-over and distribute evenly among carpels (Sheffield *et al.* 2005) which mean that whatever pollen is delivered by the pollinators can be distributed evenly to ovules enhancing pollination. Consequently pollination in these apple cultivars is not as critically important as previously believed (Sheffield *et al.* 2005).

Table 3.9: Summary of results for colony distance (comparison between trees close to bee hives and trees further away from bee hives; Polliniser effect (comparison between trees close to polliniser with trees further away from the polliniser) and correlations. Results are indicated as positive (+), meaning bigger fruit or more seeds or more set closer to the hives or polliniser; or negative (-), meaning smaller fruit or less set closer to the hives or polliniser. If there is no difference, this is indicated with a zero (0). The significance of the difference, at the 0.05 % level (t-test - LSD) is indicated with an asterisk. For correlations results are indicated as positive (+), meaning a positive relationship, or negative (-), meaning a negative relationship. The significance of the relationship, at the 0.05 % level (Pearson’s Correlation Coefficient) is indicated with an asterisk.

	Weight	Seeds	Set
Colony distance	-	-	+
Polliniser effect	-	+*	+*

correlations		Weight/fruit set	Weight/seed number
	‘Granny Smith’	-*	+*
	‘Golden Delicious’	-	+*

In conclusion, in apple orchards, there was increased seed numbers nearer to the pollinisers resulting in a significant increase in final fruit set and a decrease in fruit weight (Table 3.6). The increased seed number closer to the pollinisers might be an indication of over-set in these orchards with the enhanced pollination adjacent to the pollinisers resulting in a high fruit set and decrease in fruit weight. As stated previously fruit weight is likely to be reduced by inter-fruit competition for available assimilates (Lai *et al.* 1990) therefore fruit formed will be smaller regardless of seed number. In the apple orchards, the proximity to the polliniser seems to have no effect on fruit weight. Fruit set and number of seeds were however significant suggesting that cross-pollination was effective in that the proximity to the polliniser was important; and that cross pollination and hence the position of the fruit relative to the cross pollinator were relatively important. In any event, the set in these orchards suggested that to be such that there was so much inter-fruit competition that the position of the pollinisers and pollinators has no effect on fruit weight. As with plums, increasing pollination such as by introducing additional honeybee colonies, or increasing pollination effectiveness by proximity to a polliniser, may only result in a higher initial set but concomitantly uneconomic small fruit are produced.

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CHAPTER 4

Effect of polliniser position, polliniser distance, honeybee colony distance and polliniser type in the set and quality of pears (*Pyrus communis* Linn.) cultivars Packham's Triumph and Abate Fetel

4.1 Introduction

Pears belong to the subfamily Maloideae of the Rosaceae family (Free 1993). Most cultivars of pear originate from *Pyrus communis* Linn. or *Pyrus serotina* Rahd (Westwood 1993). *Pyrus communis* Linn. (the European pear) is cultivated commercially world-wide and is derived from a large-fruited wild species. Pear pollen is heavy, very sticky and moist and is therefore well suited to being carried by insects rather than the wind (Karmo and Vickery 1960; Free 1993). Pear flowers produce lots of pollen, as much as 1.2 mg per flower (Free 1993), but have very poor nectar with the sugar concentration normally below 10% (McGregor 1976; Free 1993). Hence, bees visit pear flowers almost entirely for pollen. Honeybees are practically the only distributors of pear pollen (McGregor 1976; Nyéki and Soltész 2003), but pears are still relatively unattractive to honeybees when compared to other deciduous fruit crops and most weeds, and bees readily switch from pear flowers to other flowers (Stern *et al.* 2005). Monzón *et* al. (2004) found only 0.74 pollinators per tree per minute on 'Doyenne du Comice' pears, even when commercial honeybees and mason bees had been introduced into the orchard.

Commercial cultivars of pears are mostly self-incompatible and produce more and/or better fruit when they are cross pollinated (Free 1993). Of the 59 pear cultivars studied by Nyéki and Soltész (2003), none of them were self-fertile. Lots of bees therefore need to be introduced into pear orchards, normally at a density of five colonies per hectare, and normally in two waves so that the new bees of a second wave are attracted to the late blooming target flowers, before moving to competing flowers (Free 1993; Mayer 1994; Stern *et al*. 2005). In the Western Cape the sequential introduction of honeybee colonies in pear orchards is a standard practice; typically one wave is introduced at 10% and the second at 70% bloom. But still poor yields often occur in pear orchards, and this is often ascribed to poor pollination (Sotes Ruiz 1977).

Most pear cultivars are self-incompatible, therefore cross pollination and hence polliniser cultivars are required in orchards. As with plums and apples, the distance from pollinisers in pear orchards has an effect in the set and quality of fruit (Anderson 1985; Free 1993). For example, Free and Spencer-Booth (1964) found that 'Comice' pear trees with 'Conference' grafts (as polliniser) had a larger percentage of flowers setting fruit than 'Comice' trees without grafts. Fruit set in 'Packham's Triumph' was also found to decrease with increasing distance from the polliniser, as did seed numbers (Selimi 1969). Benedek and Nyéki (1996) found that as one moves away from the polliniser the yield decreased by 20%, and they recommended planting pollinisers in rows (not more than two of each cultivar) or in a classic 1-in-9 design. Westwood *et al.* (1966) found that there were more seeds (and presumably better pollination) in trees of 'Comice', 'Anjou' and 'Bartlett' planted adjacent to pollinisers than there were further away from the pollinisers. Seed numbers decreased up to five rows from the pollinisers but then did not decrease further.

Unlike in apples and plums, however, parthenocarpy is relatively common in pears (Nyéki and Soltész 2003). Some crops can set fruit without pollination and without fertilization of the ovule, and hence without seed set (Faust 1989; Westerkamp and Gottsberger 2000; Yao *et al*. 2001). Parthenocarpy is commonly found in some cultivars of citrus, bananas, pineapples, cucumber, raspberries, strawberries, squash, zucchini and nuts (Faust 1989). In parthenocarpy, some part of the fruit other than the seeds is capable of synthesizing the hormones necessary to ensure a flow of nutrients to the developing fruit (Nyéki and Soltész 2003). It should be noted that parthenocarpic fruit are seedless but not all seedless fruit arise parthenocarpically (McGregor 1976). Seedlessness in some cultivars is a product of post-fertilization embryo abortion. In this case fertilization and some level of embryo growth are required for fruit set (Polito 1999). Parthenocarpy can be induced in several ways, such as the spraying with various amounts of plant hormones auxin, gibberellins and cytokinin to stimulate the growth of plant tissue (Crane 1969; Calderone 2006). In some plant species parthenocarpy is induced by selection through fruit-breeding programs, by manipulating genes that control the production of plant hormones (Adam and Koltunow 1999; Pauwels *et al*. 1999; Polito 1999; Mezzetti *et al*. 2004; Calderone 2006).

In pear varieties parthenocarpic fruit set is both genetically determined and greatly influenced by environmental conditions. 'Conference', 'Packham's Triumph', 'Bergomot' and 'Early Bon Chretien' are some of the pear varieties known to set fruit parthenocarpically (Nyéki and Soltész 2003). Cultivars that are reported not to be parthenocarpic are 'Anjou', 'Bartlett', 'Doyenne du Comice' and 'Abate Fetel' (Westwood *et al*. 1966; Calzoni and Speranza 1996). Parthenocarpic fruit are typically reported to be elongated, misshapen and to be smaller than seeded fruit (Schander 1955; Luckwill 1959; Marcucci and Visser 1983; Mitra *et al*. 1991). Sharifani and Jackson (2001a), however, did not find this but rather that parthenocarpic 'Packham's Triumph' (as well as 'Lemon Bergomot') fruit were not grossly misshapen and were 30% larger than seeded fruit. In addition to poor shape, parthenocarpic fruit are reported to have poor storage abilities, resulting from a decrease in soluble solids (Sedgley and Griffin 1989), as these fruit are expected to lack calcium. Calcium plays a vital role in the determination of storage life of fruit in that fruit with low calcium concentration resulting from low seed numbers tend to soften quickly (lose their firmness) during storage (Poovaiah

1988; Fallahi *et al*. 1997; Buccheri and Di Viao 2004) and may develop bitter pit, cork sport, and are more susceptible to pathogens (Bramlage 1993).

Pears are grown in temperate and sub tropical regions, and they are the third most important deciduous fruit crop after grapes and apples. South Africa is the seventh biggest producer of pears in the world, presently producing about 2% of the worlds' pears (DFPT 2005). In Africa, South Africa is one of the main producers of pears followed by Algeria, Tunisia, Egypt and Morocco (DFPT 2005). A total of 11812 hectares are planted to pears in South Africa, all but 4 hectares being in the Western Cape, and producing 342 928 tons in 2005 with a gross value of ZAR 765.1 million (DFPT 2005). Pear production sustains 14921 labourers with 59684 dependents (DFPT 2005). The most commonly planted pear cultivar is 'Packham's Triumph' with 3331 (28%) hectares planted, followed by 'Williams Bon Chretien' and 'Forelle' cultivars (DFPT 2005). 'Abate Fetel' is a high value and more recent cultivar, with some 315 (3%) hectares planted in the Western Cape.

'Packham's Triumph' is a cultivar developed in Australia in the early 1900's from 'Bell' and 'Williams Bon Chretien' parents. 'Packham's Triumph' is 100% self-incompatible: Therefore, there is absolute need for cross pollination. There have been previous suggestions that 'Packham's Triumph' could be wind pollinated (Westwood *et al*. 1966), but clearly this is not the case, as shown by Sharifani and Jackson (2001a). In their study fruits under caged treatments had no seeds in both 'Packham's Triumph' and 'Bergomont'. Recommended pollinisers are 'Josephine', 'Winter Nelis' and 'Clapps Favourite' (Infruitec 1992). 'Packham's Triumph' has a medium to low chilling requirement and blooms mid to late September. On average they weigh 190g, have an ovate-pyriform shape and a green yellow skin colour when ripe. The harvest date for 'Packham's Triumph' is mid February. Although 'Packham's Triumph' tends to blossom regularly and profusely, yield has been regarded as mostly low (Langridge and Jenkins 1972). ‘Packham’s Triumph’ is regarded as a problem crop requiring an increase in the numbers of bees in orchards to get proper set (Mayer 1994; Stern *et a*l. 2005).

‘Abate Fetel’ is widely regarded as the most insect-dependant pear cultivar, and honeybee pollination is therefore essential for the pollination of ‘Abate Fetel’. If no bees are introduced only 1.6 tons are produced per hectare; with introduction of bees, 8 tons per hectare are produced (P. du Plooy Pers. Comm.). With introduction of bees Calzoni and Speranza (1996) found an increase in fruit weight and seed numbers in both ‘Abate Fetel’ and ‘Doyenne du Comice’; they also found a positive relationship between seeds and weight in both ‘Abate Fetel’ and ‘Doyenne du Comice’ indicating that both require insect pollination and are not parthenocarpic. Recommended pollinisers for ‘Abate Fetel’ are ‘Forelle’, ‘Flamingo’ and ‘Rosemarie’ (Infruitec 1992). The commercial weight of ‘Abate Fetel’ pears is 225g, and they have an oblong shape and smooth brown russet skin colour on a green-yellow background. ‘Abate Fetel’ blooms in mid September, has a medium chilling requirement, and is ready for harvest from late January to early February.

In this study we examined the effect of polliniser position, polliniser distance and honeybee colony distance on the set and quality of ‘Packham’s Triumph’ pears in the Western Cape. For ‘Abate Fetel’ we aimed to investigate the influence of polliniser cultivar on fruit set and fruit quality (seed number and fruit weight) when ‘Rosemarie’, ‘Lily’ and ‘Emperor’ (all of which are ARC-Infruitec bred cultivars) are used as pollinisers, as well as the effect of polliniser distance on fruit set and quality. For both ‘Packham’s Triumph’ and ‘Abate Fetel’ we further investigated the relationship between fruit weight and seed number or fruit set.

4.2 Materials and Method

4.2.1 Orchards

Two ‘Packham’s Triumph’ orchards (Hillside 1 and Hillside 11, planted in 1987 and 1975 respectively) were assessed from September 2004 to March 2005, and two ‘Abate Fetel’ orchards (Vyeboom 1 and Rooiboordvlei, both planted in 1998) from September 2005 to March 2006, all orchards being commercially active and on the Lourensford Estate in Somerset West. Detailed maps were prepared for each orchard, marking the position of each tree (polliniser and commercial cultivar) in the orchard, as well as the position of the bee hives introduced during pollination.

4.2.2 Planting patterns

The basic design examined is the 1-in-9 design, where 8 trees of a commercial cultivar are planted for 1 tree of the non-producing polliniser. This was the case in all four pear orchards examined. Two orchards had ‘Packham’s Triumph’ as the commercial cultivar and ‘Clapps Favourite’ as the polliniser, and these were used for experiments conducted during the first season. The first orchard, Hillside 11 has the typical 1-in-9 design with all the ‘Packham’s Triumph’ adjacent to a ‘Clapps Favourite’ (Figure 4.1). Trees in Hillside 1 and 11 were planted at 4.3 m x 1.8 m and have filled the allotted space. The second orchard, Hillside 1, has an atypical “1-in-9”, with the correct ratio of polliniser to commercial cultivar, but incorrect spacing of the trees in the orchards (Figure 4.2) such that a polliniser tree is planted after 9 cultivar trees. The third and fourth orchards (Vyeboom 1 and Rooiboordvlei), which were used for experiments during the second season, also have an atypical 1-in-9 planting pattern (Figure 4.3). Both of these orchards have ‘Abate Fetel’ as the commercial cultivar.

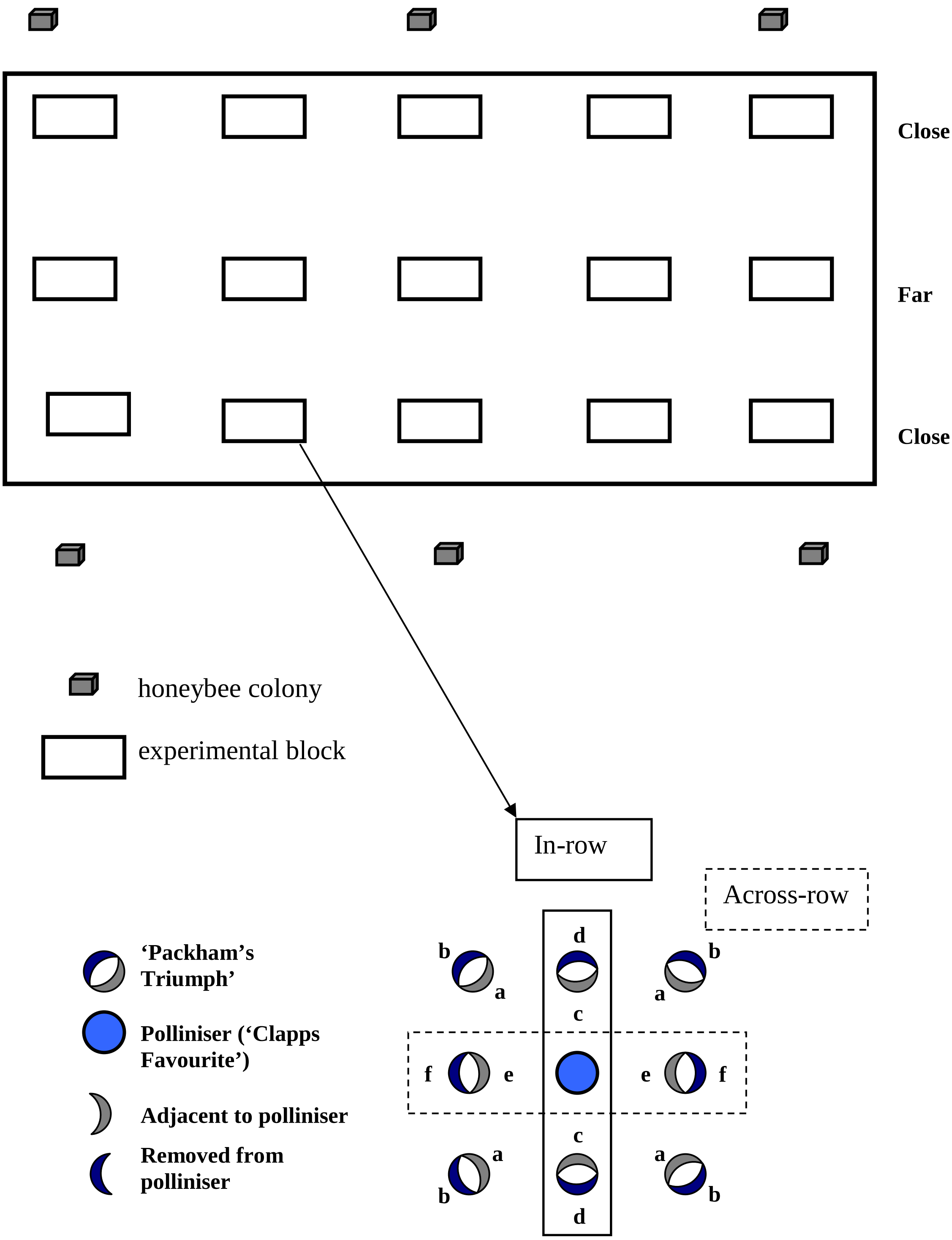

Fig 4.1: A typical 1-in-9 orchard design (Hillside 11), indicating the 15 blocks (5 replicates) used relative to the position of honeybee colonies, and the 16 positions in each block that branches are tagged, three branches per position, to measure the effect of polliniser position (adjacent vs. removed). The 'Clapps Favourite' polliniser tree is surrounded by 'Packham's Triumph' trees, the commercial cultivar.

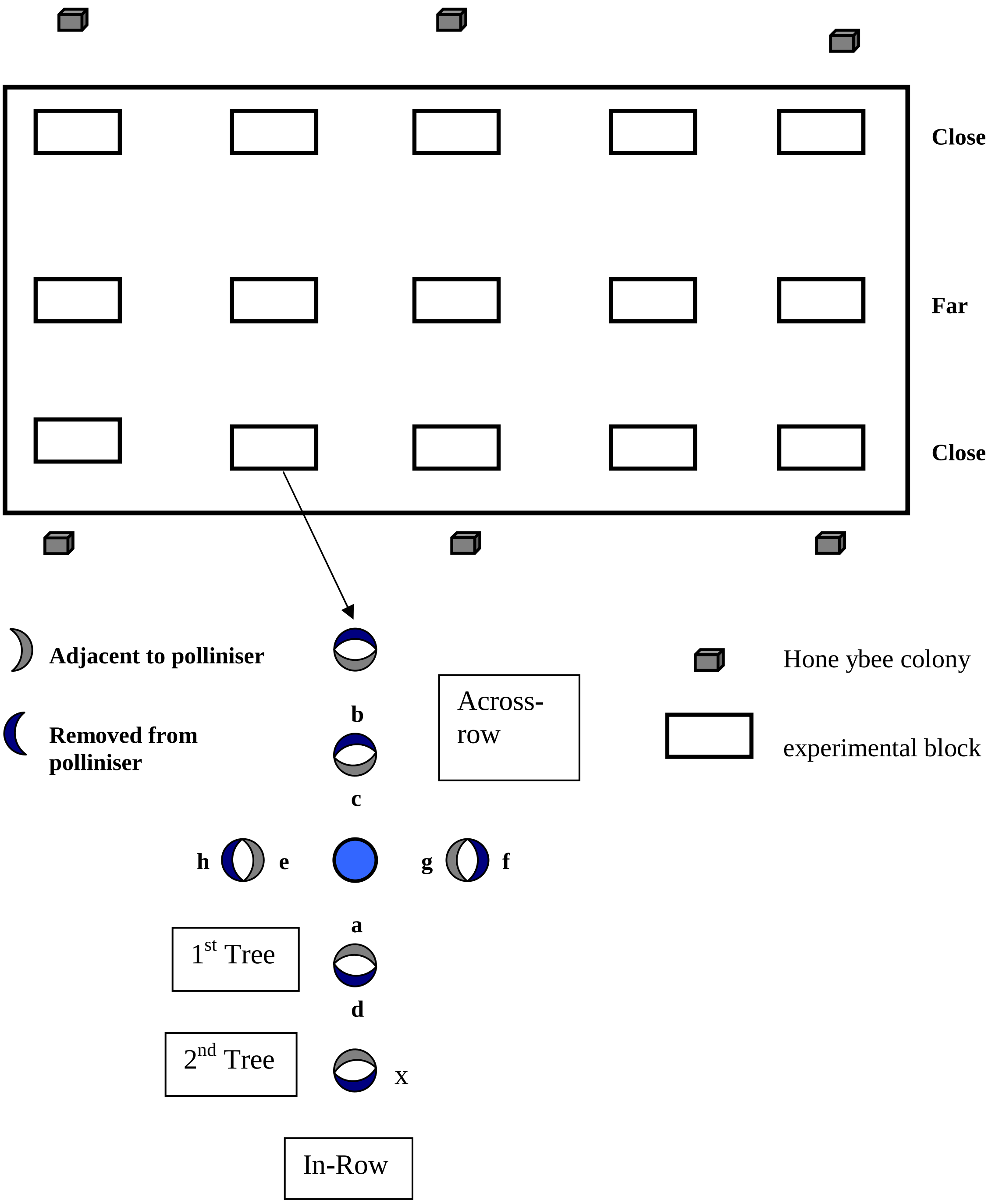

Fig 4.2: An atypical 1-in-9 orchard design (Hillside 1), indicating the 15 blocks (5 replicates) used relative to the position of honeybee colonies, and the 8 positions ('a' to 'h') in each block that branches are tagged, three branches per position, to measure the effect of polliniser position (adjacent vs. removed). Three branches are also tagged on each side on the second in-row trees ('x'), to assess the effect of polliniser distance. The 'Clapps Favourite' polliniser tree is followed by 9 'Packham's Triumph' trees, the commercial cultivar, in each row.

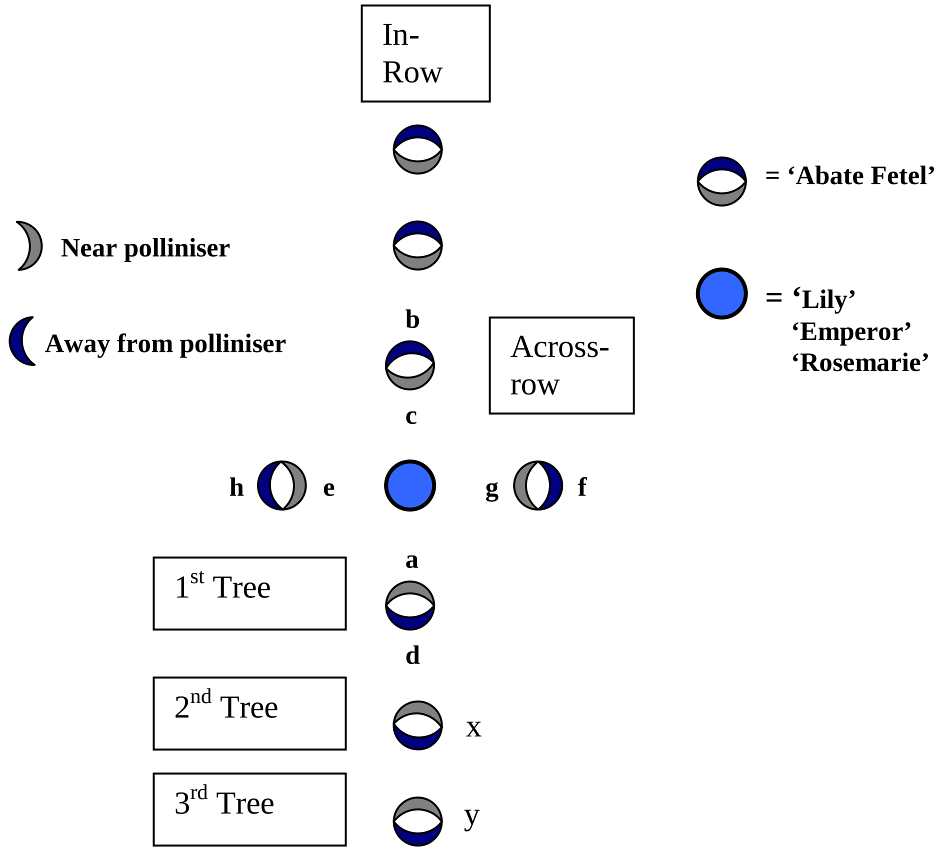

Fig 4.3: An atypical 1-in-9 planting pattern in Rooiboordvlei and Vyeboom 1 indicating the 8 positions ('a' to 'h') in each block that branches are tagged, three branches per position, to measure the effect of polliniser position (adjacent vs. removed). Three branches are also tagged on each side on the second in-row trees ('x'), and the third in-row trees ('y'), to assess the effect of polliniser distance, further away from the polliniser. The polliniser tree ('Lily', 'Emperor' or 'Rosemarie') is followed by 9 Abate Fetel' trees, the commercial cultivar, in each row. Pollinisers alternate in the row, and at least 11 blocks for each polliniser were assessed.

'Abate Fetel' was used in the second year because of concern that some 'Packham's Triumph' pears might set parthenocarpically, and hence might not be the best cultivar to study polliniser effect. 'Abate Fetel' is widely regarded as the most insect-dependant pear cultivar and therefore we expect to find polliniser effects in 'Abate Fetel'. There are three different pollinisers in the 'Abate Fetel' orchards: 'Rosemarie', 'Emperor' and 'Lily' which are planted in a repeating pattern so that the effect of each polliniser can be evaluated separately.

4.2.3 Bees and farming practices

As described in Chapter 2, section 2.2.4.

4.2.4 Experimental Procedure

Effect of Polliniser Patterns and colony distance on Fruit set and Quality of pears: 'Packham's Triumph'

Honeybees foraging in deciduous fruit orchards are expected to primarily follow the rows, rather than fly across rows (McGregor 1976; Anderson 1985; Free 1993). This row effect was investigated in the two 'Abate Fetel' orchards and the two 'Packham's Triumph' orchards, by comparing the fruit weight, number of seeds and fruit set in the across-row trees adjacent to the polliniser with the 1st in-row tree. Fifteen sampling blocks per orchard were tagged in 'Packham's Triumph' orchards (Hillside 11 and Hillside 1) during the 2004/2005 growing season. There were 15 blocks (= to 5 replicates) in each orchard with five blocks on each side of the orchard, immediately adjacent to the bee hives, and the final 5 blocks were in the centre of the orchard, away from the bee hives (Figures 4.1 and 4.2). The two pear orchards (Hillside 1 and Hillside 11) had planting patterns as shown in Figures 4.1 and 4.2 respectively. As with the plums and apples, branches were tagged and all clusters distal to the tag were counted. Only one-year old shoots were tagged, and lateral clusters were included. All tagged branches (shoots) were in a similar position with respect to height and weight. The tagging of clusters in these 2 pear orchards was different to those in the plum and apple orchards due to the 1-in - 9 design. Comparison between branches in these blocks is indicated in Fig 4.1 for a typical 1-in-9 design and Fig 4.2 for an atypical 1-in- 9 design (same proportion of polliniser to cultivar but different distances). The experimental design was such that sunlight and wind direction were not factors in the comparison as, in each block and for each cultivar there was a balanced design with each paired comparison acting as a reciprocal control. In the typical 1-in-9 orchard (Fig 4.1) the following comparisons were made for polliniser effect: a (diagonal/

inside) versus b (diagonal/outside): c (in-row/ inside) versus d (in-row/ outside): e (across-row/ inside) versus f (across-row/ outside). In this orchard three branches were tagged for each position; hence a total of 48 branches were tagged for each block and 720 branches for the orchard. There were between 5 and 48 flowers counted on tagged branches. In all cases, the comparison was between branches immediately adjacent to the polliniser and branches slightly removed from the polliniser. In the atypical 1-in-9 orchard (Fig 4.2) the following comparisons were made for polliniser effect: a (in-row/ inside) versus b (in-row/outside): c (in-row/ inside) versus d (in-row/outside): e (across-row/ inside) versus f (across-row/ outside): g (across-row/ inside) versus h (across-row/ outside) and first tree (in-row) versus second tree (in-row). In this orchard three branches were tagged for each position; hence a total of 36 branches were tagged for each block and 540 branches for the orchard. Once again, the comparison was between branches immediately adjacent to the polliniser and branches more removed from the polliniser. Between 6 and 48 flowers were counted on tagged branches. As with the previous orchard, assessment blocks were situated adjacent to the honeybee colonies as well as in the centre of the orchard. In the 2004/ 2005 season we measured fruit set, seed number and fruit weight on 'Packham's Triumph' at two distance variants from the honeybee colonies (near and far) and at various positions from the polliniser (adjacent to and removed from, diagonal to, in-row and two trees removed from). Branches of flower buds were tagged and labeled and the flower buds per branches counted as described in section 2.2.4 (Chapter 2).

'Abate Fetel'

Thirty six blocks (= 36 replicates) were tagged in the two 'Abate Fetel' orchards during the second growing season (2005/2006). The two orchards had the atypical 1-in-9 pattern described for Hillside 1. However, the sampling block differed in that 'Abate Fetel' sampling blocks had two extra in-row trees as shown in Fig 4.3, and not just the second tree assessed in Hillside 1. Furthermore, the two orchards had three different types of pollinisers; 'Rosemarie', 'Emperor' and 'Lily'. The pollinisers alternated in the rows, and sampling blocks were chosen at random throughout the orchard. Vyeboom 1 had 15 sampling blocks in total; four sampling blocks with 'Lily' as a polliniser, four with 'Rosemarie' as a polliniser and seven with 'Emperor' as a polliniser. Rooiboordvlei had 21 sampling blocks in total; seven sampling blocks with 'Lily', 'Emperor' and 'Rosemarie' as a polliniser. Comparison between branches in these blocks is indicated in Fig 4.3. Again sunlight and wind direction within a paired comparison acted as a reciprocal control. The following comparisons are made for polliniser effect: a (in-row/inside) versus b (in-row/outside): c (in-row/inside) versus d (in-row/outside): e (across-row/inside) versus f (across-row/outside), g (across-row/inside) versus h (across-row/outside), first tree versus second tree and first tree versus third tree. In this orchard three branches were tagged for each position; making a total of 48 positions tagged for each block. Once again, the comparison was between branches immediately adjacent to the polliniser and branches more removed from the polliniser. Vyeboom 1 had fifteen sampling blocks in total and therefore 720 tagged branches in the orchard. Rooiboordvlei had twenty-one sampling blocks and therefore 1008 tagged branches in the orchard. Distance effect (distance from honeybee colonies) was not tested in these two orchards. Branches of flower buds were tagged and labeled and the flower buds per branch counted as described in section 2.2.4 of Chapter 2.

Assessing pollination efficiency for pears

A few days before commercial harvest the fruits that set and matured in each tagged branch were counted to determine final fruit set, and all these pears were then harvested. All the pears collected were individually weighed, and halved to count the number of well developed seeds present. Seed set was assessed as described for apples in Chapter 3 section 3.2.4.

4.2.5 Statistical Analysis

A multifactorial analysis of variance was used to analyse data within the four orchards (two of 'Abate Fetel' and two of 'Packham's Triumph'). All possible interaction effects were also determined. Data was analyzed using Univariate Factorial Analysis of Variance (ANOVA) to explain the variation in fruit weight in relation to distance from the polliniser and distance from honeybee colonies. *Post hoc Student's* tests (LSD - Least Significant Difference) were performed to indicate statistical significance at p = 0.05. To calculate fruit set, each tagged branch constituted a single data point and Analysis of Variance (ANOVA) was run to explain the variation in the number of flowers that developed into fruit with respect to distance from polliniser and distance from colonies. *Post hoc Student's* tests (LSD - Least Significant Difference) were performed to indicate statistical significance at p = 0.05. Pearson correlation analysis was used to examine the relationship between fruit weight, fruit set and seed number. All statistical analyses were performed using Statistical Analysis System.

The data from Hillside 11 was analysed using an ANOVA that included three main effects (2 colony distances, 2 polliniser positions and 2 row effects X 5 replicates) , as well as first and second order interactions. In this orchard each data point is used only once and there is no need for separate factor interaction determinants. Consequently, sample errors were calculated by multiplying the total degrees of freedom of the experimental design and then subtracting the model degrees of freedom from the corrected total degrees of freedom.

In contrast to the analysis in apples and plums (Chapters 2 and 3), overall orchard interactions in the 'Abate Fetel' orchards and in Hillside 1 had to be assessed separately for each of the different source factors. This was because the same data points were used for multiple interactions and calculations. For example, the branches in the 1st in-row trees in the 'Abate Fetel' orchards and in Hillside 1 were used to determine three separate effects, as follows:

(a) Polliniser position: the comparison between adjacent and removed branches on trees immediately adjacent to the polliniser tree;

(b) Polliniser distance: the comparison between branches on the 1^{st}, 2^{nd} and 3^{rd} in-row trees from the polliniser tree;

(c) Row effect: the comparison between branches on the 1^{st} in-row tree and on the across-row tree from the polliniser

In Hillside 1, Rooiboordvlei and Vyeboom 1 fruit weight, fruit set and seed number were analysed in a multifactorial ANOVA with polliniser position, polliniser distance and row effect determined separately. Main effects included colony distance (2 levels) and polliniser position (2 levels) or polliniser distance (3 levels) or row effect (2 levels) or polliniser type (3 levels), as well as first order interactions in the model. No orchard X polliniser type interaction was tested since the two Hillside orchards were treated independently and moreover the effect of polliniser type was assessed without having orchards as a confounding variable. Sample errors were calculated as described for Hillside 11, with 5 replicates used in Hillside 1 and 21 (blocks) replicates used in 'Abate Fetel' orchards.

4.3 Results

4.3.1 Orchard description

Basic information about the orchards is presented in Table 4.1. There was no chemical thinning necessary in any of the orchards; however, 'Abate Fetel' orchards were hand-thinned but not for the tagged branches. Temperatures were moderately warm and constant throughout the pollination periods in both 2004 and 2005 (Figure 2.2 of Chapter 2).

Table 4.1: Orchard size, orchard yield and orchard management practices in the four experimental pear orchards.

Orchard	Year	Cultivar	Yield	Orchard	Honeybee	Date of first	Hand	Chemical

			(tonnes/ hectare)	Size (ha)	colonies introduced	introduction (= 10% blossom)	thinning	thinning
Hillside 1	2004	'Packham's Triumph'	56	2.91	15	28/09	No	No
Hillside 11	2004	'Packham's Triumph'	54	1.05	6	27/09	No	No
Rooiboordvlei	2005	'Abate Fetel'	20	6.21	31	27/09	Yes	No
Vyeboom1	2005	'Abate Fetel'	33	2.87	15	26/09	Yes	No

4.3.2 Overall orchard interactions

The main effects and interactions of the variables tested for 'Packham's Triumph', in Hillside 1 for fruit weight, fruit set and number of seeds are indicated in Tables 4.2, 4.3 and 4.4 respectively. With regards to fruit weight there was a significant polliniser position effect but no significant row effect, polliniser distance effect or colony distance effect. Strangely, the fruit weighed more on clusters removed from the polliniser. As regards to the number of seeds, there was a significant colony distance effect, polliniser position effect, polliniser distance effect and row effect. There were no significant effects for fruit set in Hillside 1, nor were there any significant interaction effects for fruit weight, number of seeds or fruit set.

Table 4. 2: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on fruit weight in 'Packham's Triumph' (Hillside 1).

Source Factor	DF	Mean Square	P
Polliniser Position			
Colony Distance	1	14867.88	0.0760
Polliniser position	1	20088.37	0.0424
Colony*Position	1	4772.78	0.2983
Sample Error	16	4130.01	
Polliniser Distance			
Colony Distance	1	3602.81	0.4683
Polliniser distance	1	1945.42	0.5927
Colony* Distance	1	3424.20	0.4794
Sample Error	16	6527.62	
Row Effect			
Colony Distance	1	14867.89	0.1799
Row Effect	1	20886.23	0.1159
Colony*Row Effect	1	0.72	0.9923
Sample Error	16	7559.14	

Table 4.3: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on fruit set in 'Packham's Triumph' (Hillside 1).

Source Factor	DF	Mean Square	P
Polliniser Position			
Colony Distance	1	0.05	0.1546
Polliniser position	1	0.00	0.7951
Colony*Position	1	0.01	0.4558
Sample Error	16	0.02	
Polliniser Distance			
Colony Distance	1	0.00	0.6905
Polliniser distance	1	0.06	0.0890
Colony* Distance	1	0.00	0.7923
Sample Error	16	0.02	
Row Effect			
Colony Distance	1	0.05	0.1774
Row Effect	1	0.04	0.2094
Colony*Row Effect	1	0.06	0.1482
Sample Error	16	0.03	

Table 4.4: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on the number of seeds in 'Packham's Triumph' (Hillside 1).

Source Factor	DF	Mean Square	P
Polliniser Position			
Colony Distance	1	79.88	0.0043
Polliniser position	1	121.81	0.0008
Colony*Position	1	5.71	0.3870
Sample Error	16	7.22	
Polliniser Distance			
Colony Distance	1	32.62	0.0319
Polliniser distance	1	69.34	0.0035
Colony* Distance	1	4.24	0.4091
Sample Error	16	5.90	
Row Effect			
Colony Distance	1	79.89	0.0055
Row Effect	1	75.67	0.0066
Colony*Row Effect	1	0.40	0.8230
Sample Error	16	7.78	

The main effects and interactions for fruit weight, fruit set and number of seeds in Hillside 11 are presented in Tables 4.5, 4.6 and 4.7 respectively. Fruit weight was significantly larger on trees closer to honeybee colonies, as well as on trees within a row compared to trees across the row from the polliniser. With regards to number of seeds in Hillside 11, there were significant polliniser position and colony distance effects. As with Hillside 1, there were no significant main effects for fruit set in Hillside 11.

Table 4.5: **M**ultifactorial ANOVA incorporating main as well as interaction factors, and their effect on fruit weight in 'Packham's Triumph' (Hillside 11).

Source Factor	DF	Mean Square	P
Colony distance	1	37413.86	0.0137
Polliniser position	1	10927.35	0.1731
Colony*Position	1	10331.07	0.1851
Row effect	1	37401.45	0.0031
Colony*Row effect	1	349.15	0.9408
Position*Row effect	1	17538.60	0.0557
Colony*Position*Row effect	1	1596.46	0.7575
Sample Error	32	5714.76	

Table 4.6: Summary of results from multifactorial ANOVA incorporating main as well as interaction factors, and their effect on fruit set in 'Packham's Triumph'(Hillside 11).

Source Factor	DF	Mean Square	P
Colony distance	1	0.05	0.1835
Polliniser position	1	0.00	0.7775
Colony*Position	1	0.02	0.3941
Row effect	1	0.01	0.6868
Colony*Row effect	1	0.04	0.2659
Position*Row effect	1	0.15	0.0057
Colony*Position*Row effect	1	0.12	0.0143
Sample Error	32	0.03	

Fruit set has been shown to decrease with increase in distance from colonies (Mayer et al. 1989; Free and Spencer-Booth 1964; Free 1993) and with increase in distance from polliniser (Selimi 1969). In Hillside 11 there was a significant three-way colony distance, polliniser position and row effect interaction for fruit set (Table 4.6; Fig: 4.4). Significantly more 'Packham's Triumph' were set on trees close to colonies and in row with the polliniser as was expected but on the sides of the trees removed from the polliniser. The expectation was that the highest fruit set would be observed on trees near colonies, in row with the polliniser and on sides of trees adjacent to (inside) the polliniser not removed from the polliniser as per our observation.

Table 4.7: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on the number of seeds in 'Packham's Triumph' (Hillside 11).

Source Factor	DF	Mean Square	P
Colony distance	1	62.84	0.0543
Polliniser position	1	140.89	0.0048
Colony*Position	1	12.64	0.3078
Row effect	1	152.68	0.0003
Colony*Row effect	1	6.79	0.6590
Position*Row effect	1	9.22	0.5687
Colony*Position*Row effect	1	7.25	0.6408
Sample Error	32	16.14	

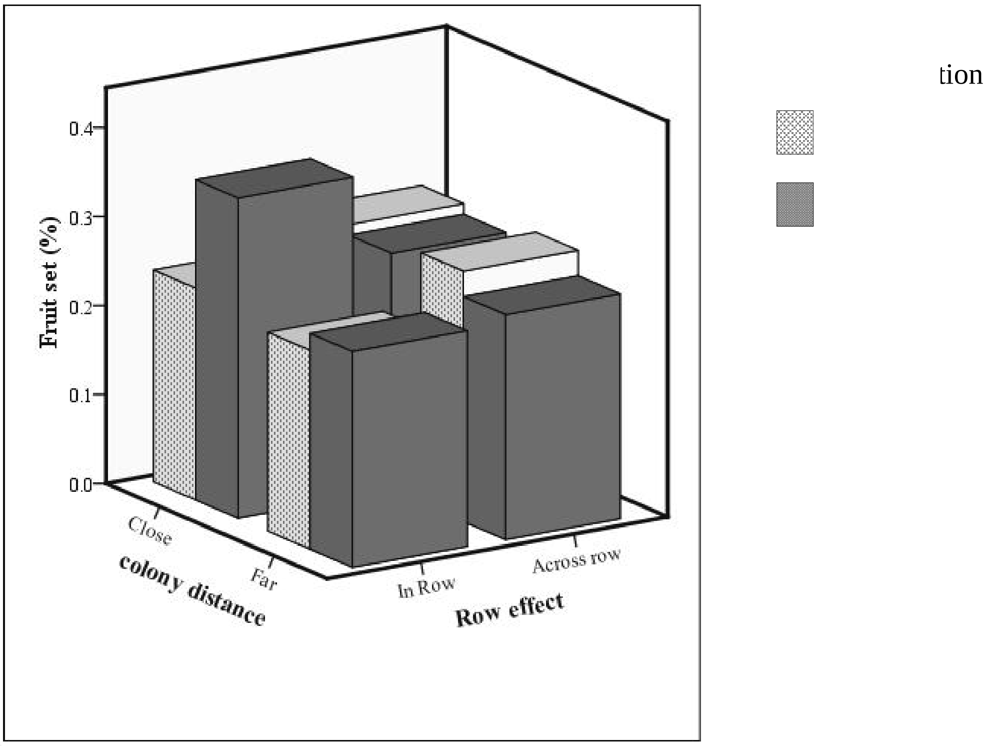

Fig 4.4 A three-way interaction effects between colony distance, polliniser position and row effect on fruit set in Hillside 11 orchard ('Packham's Triumph').

Orchard interactions for fruit weight in the 'Abate Fetel' orchards are indicated in Table 4.8. There were significant orchard and polliniser distance effects, but no significant polliniser type, polliniser position or row effects. Fruit were smaller on the tree closest to the polliniser and this effect was significant for Vyeboom 1 where the tree furthest from the polliniser tree had significantly heavier fruit than the tree closest to the polliniser tree. There were no significant interaction effects for fruit weight in 'Abate Fetel' orchards.

Table 4.8: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on fruit weight in 'Abate Fetel'.

Source Factor	DF	Mean Square	P
Polliniser Position			
Orchard	1	205743.91	<0.0001
Polliniser type	2	11832.40	0.2801
Polliniser position	1	3239.58	0.1212
Orchard*Position	1	3972.45	0.0874
Type*Position	2	490.86	0.6842
Sample Error	244	1278.01	
Polliniser Distance			
Orchard	1	271986.54	<0.0001
Polliniser type	2	20437.26	0.1715
Polliniser Distance	2	10924.05	0.0016
Orchard*Distance	2	2855.39	0.1622
Type*Distance	4	1523.85	0.4149
Sample Error	366	1525.87	
Row Effect			
Orchard	1	205743.91	<0.0001
Polliniser type	2	11832.40	0.2801
Row Effect	1	91.70	0.8191
Orchard*Row Effect	1	270.96	0.6945
Type*Row Effect	2	723.85	0.6611
Sample Error	244	1725.47	

Table 4.9: Multifactorial ANOVA incorporating main as well as interaction factors, and their effect on fruit set in 'Abate Fetel'

Source Factor	DF	Mean Square	P
Polliniser Position			
Orchard	1	0.43	<0.0001
Polliniser type	2	0.07	0.0229
Polliniser position	1	0.00	0.8056
Orchard*Position	1	0.00	0.8716
Type*Position	2	0.01	0.5888
Sample Error	244	0.01	
Polliniser Distance			
Orchard	1	0.59	<0.0001
Polliniser type	2	0.04	0.2074
Polliniser Distance	2	0.17	<0.0001
Orchard*Distance	2	0.05	0.0417
Type*Distance	4	0.01	0.6042
Sample Error	366	0.02	
Row Effect			
Orchard	1	0.43	<0.0001
Polliniser type	2	0.07	0.0229
Row Effect	1	0.25	0.0032
Orchard*Row Effect	1	0.11	0.0431
Type*Row Effect	2	0.00	0.9703
Sample Error	244	0.02	

Orchard interactions for fruit set in the 'Abate Fetel' orchards are indicated in Table 4.9. There was a significant orchard effect, row effect and polliniser distance effect, but no polliniser position effect. The polliniser type effect was significant in terms of polliniser position and row effect, but not in terms of polliniser distance. As a result of the observed significant orchard effects for almost all main effects in the 'Abate Fetel' orchards, they were treated separately in all subsequent analysis.

The interaction effect between orchard and polliniser distance on fruit set is shown in Fig 4.8. Significantly more fruit was set on the trees closest to the polliniser in both orchards (Table 4.9; Fig 4.8). Still, many more fruit set in Vyeboom 1 for trees close to as well as trees further removed from the polliniser compared to trees in Rooibootvlei. Although fruit set in

Rooibootvlei was significantly lower than that in Vyeboom 1 the decline in fruit set of Rooibootvlei follows a trend observed in Vyeboom 1 with the first tree having significantly more set followed by the second tree indicating the tendency of bees to fly down the rows in an orchard.

Fruit set was also affected by whether pollination was within rows or across and this was further amplified by orchard (Table 4.9; Fig 4.6). More fruit was set on trees in the same row as the polliniser for both orchards, but trees in Vyeboom 1 set significantly more fruit than trees in Rooibootvlei. Once more, this demonstrates that honeybees tend to fly along rows rather than across rows delivering sufficient pollen and hence more fruit set (Free 1964; Free 1966; Mayer 1984; Mayer *et al*. 1989; Free and Spencer-Booth 1964; Free 1993). Bee densities were the same for both orchards and therefore it was not as if one of the orchards was under stocked. However the actual bee activity within the orchards was not recorded and there could have been lower foraging activity in Rooibootvlei explaining the decrease in fruit set in that orchard.

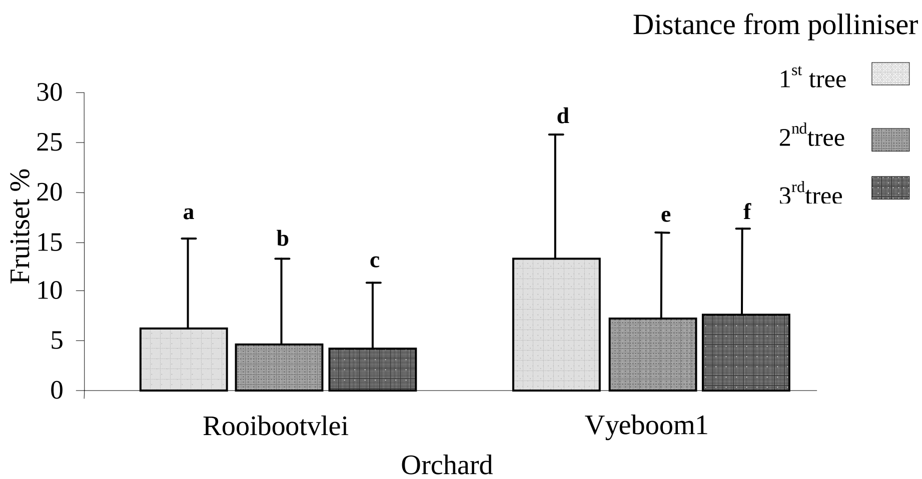

Fig 4.5 Interaction effects between orchard and polliniser distance on fruit set in 'Abate Fetel' orchards. Means followed by the same letter are not significantly different.

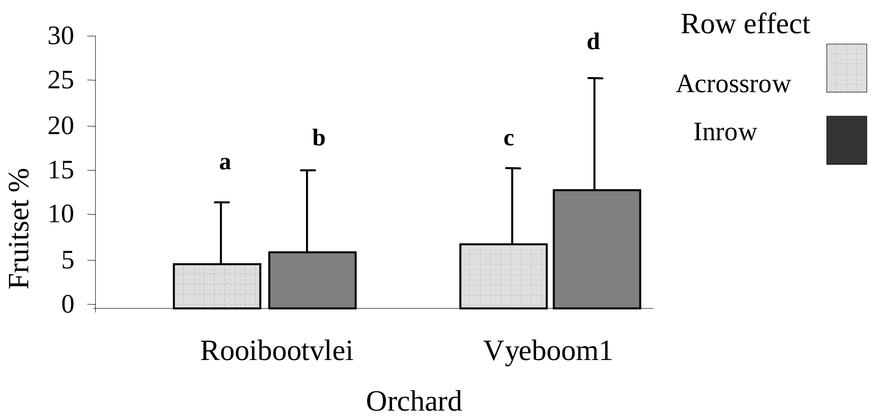

Fig 4.6 Interaction effects between orchard and row effect on fruit set in 'Abate Fetel' orchards. Means followed by the same letter are not significantly different.

Table 4.10: Summary of results from multifactorial ANOVA incorporating main as well as interaction factors, and their effect on the number of seeds in 'Abate Fetel'.

Source Factor	DF	Mean Square	P
Polliniser Position			
Orchard	1	13.96	0.2803
Polliniser type	2	57.90	0.0129
Polliniser position	1	51.98	0.0021
Orchard*Position	1	3.51	0.3915
Type*Position	2	7.05	0.2352
Sample Error	244	4.65	
Polliniser Distance			
Orchard	1	2.85	0.6399
Polliniser type	2	51.65	0.0272
Polliniser Distance	2	90.27	<0.0001
Orchard*Distance	2	1.34	0.7311
Type*Distance	4	14.85	0.0122
Sample Error	366	4.26	
Row Effect			
Orchard	1	13.96	0.2803
Polliniser type	2	57.90	0.0129
Sample Error	32	11.57	
Row Effect	1	195.24	<0.0001
Orchard*Row Effect	1	7.47	0.0401
Type*Row Effect	2	7.85	0.0149
Sample Error	244	1.63	

Orchard interactions for the number of seeds in the 'Abate Fetel' orchards are indicated in Table 4.10. There was a significant polliniser type effect, polliniser position effect, polliniser distance effect and row effect. Besides the main effects there were also significant interactions. The distance of the cultivar from the polliniser together with the type of polliniser affects seed number, with 'Rosemarie' producing the greatest effect (Table 4.10; Fig: 4.7). The 'Abate Fetel' tree closest to the 'Rosemarie' polliniser produced significantly more seeds than the trees further removed from the polliniser. This was not the case for 'Emperor' or 'Lily'. Although the differences in the number of seeds produced by pears when pollinated by 'Emperor' on the first and second trees were insignificant the decline in seed number followed a trend observed for 'Rosemarie' and 'Lily'. These observations were in agreement with those of Westwood *et al.* (1966) who found that there were more seeds in trees of 'Comice', 'Anjou' and 'Bartlett' planted adjacent to pollinisers in comparison to trees further away from the pollinisers.

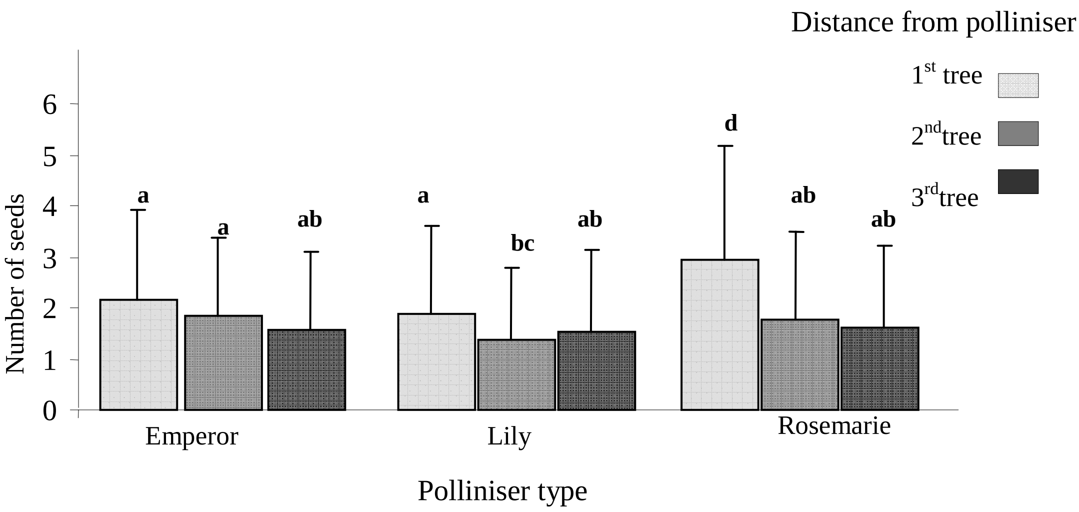

Fig 4.7 Interaction effects between polliniser type and polliniser distance on seed number in 'Abate Fetel' orchards. Means followed by the same letter are not significantly different.

Moreover, significantly more seeds were produced by trees within a row than trees across rows (Table 4.10; Fig: 4.8) from the polliniser. This was not surprising since honeybees prefer to forage down rows than fly across rows (Free 1993). Although trees within a row produced more seeds, trees in Vyeboom 1 produced significantly more seeds across rows than those in Rooibootvlei (Fig 4.8).

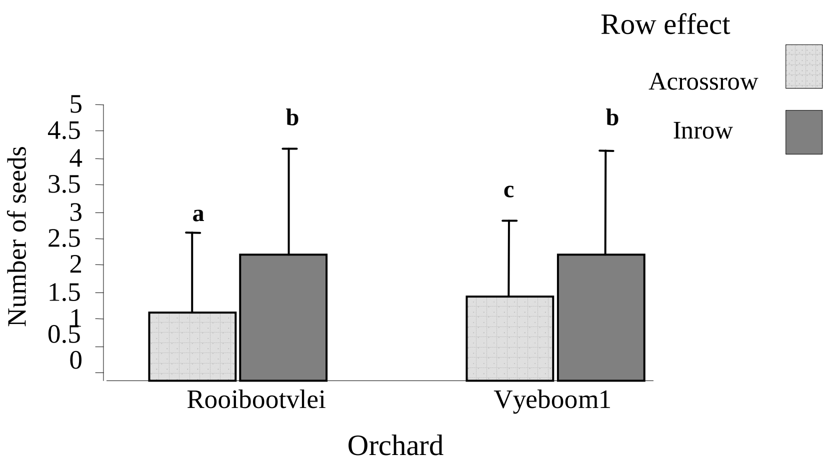

Fig 4.8 Interaction effects between orchard and row effect on seed number in 'Abate Fetel'. The values are expressed as means + SD. Means followed by the same letter are not significantly different.

The interaction effect between polliniser type and whether the trees were within or across a row from the polliniser on seed number in 'Abate Fetel' was also significant (Table 4.10; Fig 4.9). For all polliniser types the number of seeds produced by trees within a row was significantly more than the number of seeds produced by trees across the row from the polliniser with trees pollinated by 'Rosemarie' within the row producing significantly more seeds than either of the other two pollinisers (Fig 4.9). The high number of seeds on trees inrow with the polliniser could very well be explained by the fact that foraging bees tend to move along rows rather than across rows delivering sufficient pollen (Free 1964; Free 1966; Free and Spencer-Booth 1964; Mayer 1984; Mayer *et al*. 1989; Free 1993).

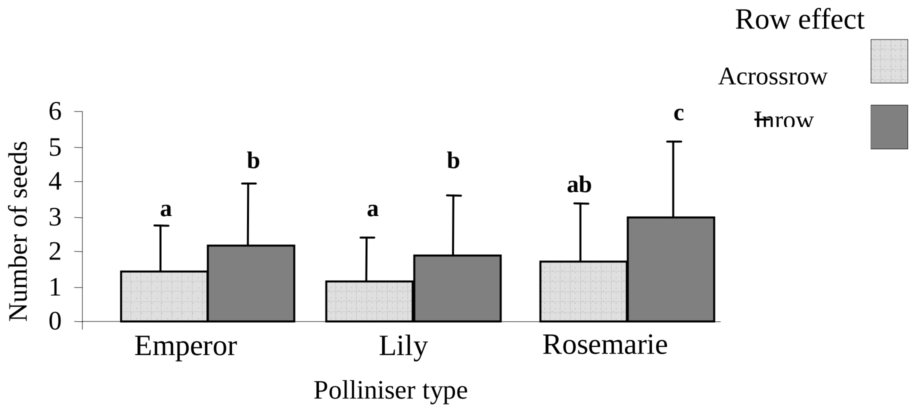

Fig 4.9 Interaction effects between polliniser type and row effect on seed number in 'Abate Fetel'. Means followed by the same letter are not significantly different

4.3.3 Distance from polliniser and polliniser position on fruit weight, fruit set and seed number in pears

The effect of distance from the polliniser was assessed by two measures in the pear orchards. Firstly, polliniser position compared the fruit weight, number of seeds and fruit set in the branches adjacent to the polliniser in trees immediately adjacent to the polliniser with branches on the same trees but removed from the polliniser (i.e. on the other sides of the trees). These data are presented in Table 4.11. In all pear orchards fruit weight was greater in the removed branches but the differences in means were not significant, except for Hillside 1. As regards the number of seeds, the orchards had significantly more seeds in the adjacent branches.

Even though 'polliniser type' was a significant factor in the overall orchard interactions in the 'Abate Fetel' orchards, the three polliniser types were not considered separately as regards their effect on polliniser position due to the complex and unpredictable planting pattern of pollinisers in these orchards.

Table 4.11: Fruit weight, seed number and fruit set (mean ± SD) of 'Packham's Triumph' in two orchards (Hillside 1 and 11) and 'Abate Fetel' orchards, as influenced by polliniser position. Means followed by the same letter are not significantly different.

Orchard	Polliniser Position	Fruit Weight(g)	Number of Seeds	Fruit Set (%)
'Abate Fetel'	Adjacent	120.13 ± 33.89 a	2.03±1.81 a	11.81 ± 11.69 a
	Removed	122.99 ± 33.21 a	1.67±1.60 b	11.39 ± 11.58 a
	LSD	3.68	0.16	2.61
'Packham's Triumph'				
Hillside 1	Adjacent	155.37 ± 43.84 a	1.91 ± 2.02 a	12.62 ± 13.36 a
	Removed	168.14 ± 52.49 b	0.92 ± 1.29 b	13.12 ± 14.97 a
	LSD	12.29	0.51	3.64
Hillside 11	Adjacent	109.53 ± 38.33 a	3.42 ± 2.14 a	19.98 ± 14.50 a
	Removed	115.04 ± 42.42 a	2.80 ± 2.01 b	20.35 ± 15.45 a
	LSD	7.93	0.42	2.46

The effect of the distance from the polliniser was also assessed in the pear orchards by means of polliniser distance. In the two 'Abate Fetel' orchards fruit weight, the number of seeds and fruit set were compared between the first, second and third in-row trees from the polliniser. As foraging bees are expected to move largely within a row on each foraging trip, carrying pollen from polliniser to main cultivar thus facilitating pollination and hence cross fertilization (Free and Spencer-Booth 1964). Consequently, there is better pollination expected on trees closer to the polliniser i.e. on the first tree. In Hillside 1 a similar comparison was made between the first and second in-row trees.

The effect of polliniser distance in the pear orchards is presented in table 4.12. In the 'Abate Fetel' orchards fruit weight was significantly smaller on the first tree i.e. next to the polliniser tree. Seed numbers in 'Abate Fetel' orchards were significantly greatest in the first tree, decreasing towards the furthest tree in the row, but with no significant difference between the second and third trees. These results were similar to those observed by Maccagnani *et al*. (2003). Interestingly, fruit set was greatest in the tree closet to the polliniser, with no difference between the second and third row trees. As regards the 'Packham's Triumph' in Hillside 1, fruit weight was also significantly less on the first tree i.e. next to the polliniser tree, while the number of seeds was significantly greater in trees nearest to the polliniser and fruit set was not affected by polliniser distance in Hillside 1. Hillside 11 was not included in polliniser distance analyses since all trees were equidistant from the polliniser in the typical 1-in-9 planting pattern reflected in Hillside 11.

Table 4.12: Fruit weight, seed number and fruit set (mean ± SD) of 'Packham's Triumph' orchard (Hillside 1) and 'Abate Fetel', as influenced by polliniser distance. Means followed by the same letter are not significantly different.

Orchard	Polliniser Distance	Fruit Weight(g)	Number of Seeds	Fruit Set (%)
'Abate Fetel'	1st Tree	116.16 ± 32.15 b	2.36 ± 1.94 a	15.73 ± 13.93 a
	2nd Tree	123.57 ± 34.11 a	1.71 ± 1.55 b	10.47 ± 10.89 b
	3rd Tree	127.30 ± 33.00 a	1.58 ± 1.56 b c	9.40 ± 9.34 b
	LSD	5.31	0.24	2.08
'Packham's Triumph'				
Hillside 1	1st Tree	155.37 ± 43.84 b	1.81 ± 1.96 a	14.06 ± 14.14 a
	2nd Tree	168.14 ± 52.49 a	1.05 ± 1.30 b	11.27 ± 13.80 a
	LSD	16.17	0.49	3.26

4.3.4 Row effect on fruit weight, fruit set and seed number of pears

In both Hillside 1 and Hillside 11 pears from trees across-row from the polliniser weighed more than pears from in-row trees (Table 4.1), significantly so in the case of Hillside 11. Similarly, fruit of 'Abate Fetel' pears also weighed significantly more on trees across-row from the polliniser (Table 4.13). One explanation could be that the fruit set was higher for trees in-row, not always significantly so though, which resulted in more yet smaller fruit.

The number of seeds present was significantly greater in the in-row trees than in the across-row trees in all orchards (Table 4.13). As seed counts are indicative of fertilization and successful pollination (Free 1993), these data clearly indicate better pollination in the in-row 1st tree in comparison with the across-row trees, and confirm the expected row effect.

Foraging bees are indeed more likely to fly down rows rather than across rows. As regards fruit set, the percentage set in all orchards was greater for in-row trees compared to across row trees, significantly so in 'Abate Fetel' orchards.

Table 4.13: Fruit weight, seed number and fruit set (mean ± SD) of 'Packham's Triumph' in two orchards (Hillside 1 and 11) and 'Abate Fetel' orchards as influenced by row effect. Means followed by the same letter are not significantly different.

Orchard	Row effect	Fruit Weight(g)	Number of Seeds	Fruit Set (%)
'Abate Fetel'	In-row	116.16 ± 32.15 a	2.36 ± 1.94 a	15.73 ± 13.93 a
	Across-row	122.06 ± 34.71 b	1.44 ± 1.45 b	9.40 ± 9.41 b
	LSD	5.31	0.24	2.08
'Packham's Triumph'				
Hillside 1	In-row	155.28 ± 45.63 a	1.81 ± 1.96 a	14.06 ± 14.14 a
	Across-row	169.17 ± 51.07 a	0.96 ± 1.40 b	11.27 ± 13.80 a
	LSD	16.69	0.53	3.85
Hillside 11	In-row	104.67 ± 37.70 a	3.86 ± 2.17 a	21.04 ± 15.02 a
	Across-row	123.29 ± 40.69 b	2.90 ± 1.91 b	19.69 ± 16.27 a
	LSD	10.20	0.54	3.17

4.3.5 Honeybee colony distance on fruit weight, fruit set and seed number

Pears close to honeybee colonies weighed more compared to pears further from honeybee colonies; the difference in means were significant in Hillside 11 (Table 4.14). The effect of distance from honeybee colonies on seed number was very interesting in that pears closer to honeybee colonies had fewer seeds compared to pears far from colonies for both Hillside 1 and 11, the difference was significant only in Hillside 1. Our results are in contrast to those of Maccagnani *et* al. (2003) as they found a decrease in seed set as distance increased from honeybee colonies in 'Abate Fetel'. As was expected fruit set for 'Packham's Triumph' in Hillside 1 and Hillside 11 was high on sides of the orchard near honeybee colonies; however, the differences in means were not significant (Table 4.14).

Table 4.14: Fruit weight, seed number and fruit set (mean ± SD) of 'Packham's Triumph' in two orchards (Hillside 1 and 11) as influenced by honeybee colony distance. Means followed by the same letter are not significantly different.

Orchard	Colony Distance	Fruit Weight(g)	Number of Seeds	Fruit Set (%)
Hillside 1	Far	154.93 ± 45.62 a	1.82 ± 1.77 a	11.35 ± 12.10 a
	Close	163.42 ± 49.17 a	1.11 ± 1.57 b	12.83 ± 14.89 a
	LSD	11.37	0.36	2.64
Hillside 11	Far	105.08 ± 38.15 a	3.41 ± 2.04 a	18.99 ± 14.65 a
	Close	115.81 ± 41.17 b	2.97 ± 2.12 a	20.75 ± 15.11 a
	LSD	8.43	0.45	2.61

4.3.6 Polliniser type on fruit weight, seed number and fruit set of 'Abate Fetel'

'Abate Fetel' pears pollinated by 'Lily' were significantly larger compared to those pollinated by 'Emperor' and 'Rosemarie' in 'Abate Fetel' orchards (Table 4.15). Fruit set, however, was significantly lower with 'Lily' as the polliniser (Table 4.15). The low fruit set of 'Abate Fetel' pollinated by 'Lily' is probably responsible for the highly significant fruit weight when pollinated by pollen from 'Lily' (producing fewer but larger fruits). Interestingly enough, seed numbers from 'Abate Fetel' pollinated by 'Lily' were also significantly low. The influence of pollinisers on fruit set, fruit weight and seed number are very well documented in apple (Keulemans *et* al. 1996; de Putter *et al.* 1996; Goldway *et* al. 1999) but less work has been done on the influence of pollinisers on fruit set, fruit weight and seed number in pears (Sharifani and Jackson 2001b).

Table 4.15: Fruit weight, seed number and fruit set (mean ± SD) of 'Abate Fetel' orchards as influenced by polliniser type. Means followed by the same letter are not significantly different.

Polliniser Type	Fruit Weight (g)	Number of Seeds	Fruit Set (%)
Emperor	116.99 ± 33.71 a	1.82 ± 1.60 a b	7.28 ± 9.06 a
Lily	132.06 ± 32.65 b	1.54 ± 1.54 b	5.12 ± 8.24 b
Rosemarie	120.73 ± 32.30 a b	2.16 ± 1.99 a	7.20 ± 9.85 a
LSD	12.96	0.43	1.58

4.3.7 Relationship among fruit weight, fruit set and seed number of 'Packham's Triumph' and 'Abate Fetel'

A negative relationship was found between fruit weight and fruit set for 'Packham's Triumph' and 'Abate Fetel' with 'Lily' and with 'Emperor' as a polliniser (Table 4.16). For 'Abate Fetel' the relationship was stronger with 'Lily' as a polliniser (Table 4.16). These data suggest that 'Packham's Triumph' and 'Abate Fetel' were at their physiological maximum in production and were unable to support all its fruit to grow to commercially desired size and quality as the increasing fruit set resulted in a decrease in fruit weight. This suggested that a decrease in fruit set would have resulted in fewer but bigger fruit. The relationship between seed number and fruit weight of 'Packham's Triumph' was significantly negative (Table 4.16). This is not surprising as Packham's Triumph is known to set parthenocarpically resulting in large fruit with few seeds per fruit. No relationship was found when fruit weight and seed number were compared for 'Abate Fetel' pollinated with 'Emperor' and 'Rosemarie'. A strong and positive relationship, however, was found between fruit weight and seed number (Table 4.16) for 'Abate Fetel' pollinated by 'Lily'. These data suggests that 'Lily' is a better polliniser of 'Abate Fetel' as 'Abate Fetel' pollinated by 'Lily' resulted in bigger fruit with high number of seeds per fruit.

Table 4.16: The correlations between fruit weight and seed number/fruit set in 'Abate Fetel' and 'Packham's Triumph'. Significant relationships are represented with an S while NS denotes non-significant relationships.

Orchard		r	p	N	
'Packham's Triumph'					
	Fruit set	-0.086	< 0.001	2156	S
	Seed number	-0.217	< 0.001	2156	S
'Abate Fetel'					
'Emperor'	Fruit set	-0.043	0.168	1021	NS
	Seed number	0.044	0.165	1021	NS
'Lily'	Fruit set	-0.113	0.01	483	S
	Seed number	0.146	0.001	483	S
'Rosemarie'	Fruit set	0.078	0.05	616	S
	Seed number	0.034	0.40	616	NS

4.4 Discussion

Bee colony distance had a significant effect on fruit weight and seed number for 'Packham's Triumph' in one of the two orchards (Table 4.14 and 4.17), but not on fruit set. Our results are dissimilar to those of Maccagnani *et* al. (2003) who found no decrease in fruit set further away from honeybee colonies in 'Abate Fetel' pears. They found that seed set decreased as distance increased from honeybee colonies in 'Abate Fetel', but not in 'Max Red Bartlett'. This together with our results highlights the inconsistencies and lack of pattern in pear pollination which may be due to the fact that 'Packham's Triumph' can set fruit parthenocarpically. Considering the effect of colony distance on fruit weight, fruit set and seed number for 'Packham's Triumph' our results did not indicate any pollination dead spots in pear orchards. These data clearly show that there was widespread pollinator coverage in Lourensford Estates pear orchards, and that orchard size was not a limiting factor. Moreover, foraging bees successfully pollinated along and across the lengths of the rows, indicating that honeybee colony numbers are sufficient. The results of colony distance in the 'Packham's Triumph' orchards suggested that there was more bee activity further away from the colonies, and that this resulted in more seed set but smaller fruit, resulting from over-set.

With respect to the effect of distance from the polliniser, Westwood *et* al. (1966) found that there were more seeds (and presumably better pollination) in trees of 'Comice', 'Anjou' and 'Bartlett' planted adjacent to pollinisers in comparison to trees further away from the pollinisers. At Lourensford fruit weight of pears was generally not affected either by polliniser position or polliniser distance for both 'Abate Fetel' and 'Packham's Triumph' (Table 4.11; Table 4.12 and Table 4.17), though fruit weight was consistently less nearer the polliniser in 'Packham's Triumph' and on the first tree/inrow in all pear orchards. The higher seed numbers of both 'Abate Fetel' and 'Packham's Triumph' on sides of trees adjacent to polliniser (polliniser position) and on in-row trees nearest the polliniser (polliniser distance)

(Table 4.11; Table 4.12 and Table 4.17) indicated that there was better pollination closer to the polliniser, but that this added pollination resulted in higher fruit set for ‘Abate Fetel’ only but not for ‘Packham’s Triumph’.

Considering row effect it is widely accepted that foraging bees move along rows rather than across rows (Free 1964; Free 1966; Mayer 1984; Mayer *et al*. 1989; Free and Spencer-Booth 1964; Free 1993) but until recently there was little empirical data. Monzón *et* al. (2004) found that 92% of honeybees in ‘Doyenne du Comice’ orchards moved to the next tree in the row; 4% moved to other trees in the same row; and only 4% to other rows. Kron *et* al. (2001) found no row effect in apple orchards; they found more pollen dispersal across rows rather than down rows. Núnez-Elisea *et* al. (2005) found a 43% increase in yield in rows in cherry orchards with polliniser trees compared to rows without polliniser trees, and Eisikovitch *et* al. (1999) found that 80% of bee movement in almond orchards was within a single tree, 15% between trees of the same row, and less than 5% across rows. Anderson’s (1985) figures on bee movement (in apples) were not so extreme. He reported that 20% of bees moved to the next tree in the row, as against 9% moving across the rows.

Table 4.17: Summary of results for Bee colony distance (comparison between trees close to bee hives and trees further away from bee hives); Polliniser effect (comparison between trees close to polliniser with trees further away from the polliniser), and correlations. Results are indicated as positive (+), meaning bigger fruit or more seeds or more set closer to close to the hives or polliniser; or negative (-), meaning less closer to the hives or polliniser. If there is no difference, this is indicated with a zero (0). The significance of the difference, at the 0.05 % level (t-test - LSD) is indicated with an asterisk. For correlations results are indicated as positive (+), meaning a positive relationship, or negative (-), meaning a negative relationship. The significance of the relationship, at the 0.05 % level (Pearson's Correlation Coefficient) is indicated with an asterisk.

		Weight	Seeds	Set
Colony effect	'Packham's Triumph'	+	-*	+
Polliniser Position	'Packham's Triumph'	0	+*	-
	'Abate Fetel'	0	+*	+
Polliniser Distance	'Packham's Triumph'	-*	+*	0
	'Abate Fetel'	-*	+*	+*
Row effect	'Packham's Triumph'	-*	+*	+
	'Abate Fetel'	-*	+*	+

			Weight/fruit set	Weight/seed number
Correlations	'Packham's Triumph'		-*	-*
	'Abate Fetel'	'Emperor'	-	+
		'Lily'	-*	+*
		'Rosemarie'	-*	+

The data collected in Hillside 1, Hillside 11 and 'Abate Fetel' orchards was strongly supportive of these results, and confirms the existence of a row effect in foraging honeybees. The trees adjacent to the pollinisers and in the same row received the most effective pollination. This resulted in the highest seed numbers in these trees (Table 4.13 and Table 4.17), but also the smallest fruit, from possible initial over-set resulting in the physiological limit of the trees being over-extended. Similar results were observed in 'Abate Fetel' orchards (Table 4.13 and Table 4.17). The organization of modern orchards into single cultivar rows is often viewed as an impediment to effective cross pollination (Kron *et al*. 2001) for, if bees fly mostly down rows, this does not result in good pollination as pollen is dispersed among trees of the same cultivar resulting in poor pollination.

With regards to polliniser type, some tend to induce higher fruit weight and more fruit set than others. Sharifani and Jackson (2001b) found that 'Josephine' was a more effective polliniser of 'Packham's Triumph' than 'Lemon Bergomot'. In a study by Keulemans *et* al. (1996) fruit weight and seed set of different apple cultivars was found to be affected by the polliniser in trials with different crosses (Keulemans *et* al. 1996). In their study 'Fuji' and 'Delcorf' were used as pollinisers of 'Gala', 'Golden', 'Jonagold' and 'Elstar'. Fruit weight and seed set were higher after pollination with 'Fuji' although fruit set was higher with 'Delcorf' as a polliniser. Similar observations were found by de Putter *et* al. (1996) and Goldway (*et* al. 1999). In this study the heaviest 'Abate Fetel' were produced with 'Lily' as a polliniser; fruit set and seed number were however, lowest. 'Emperor' and 'Rosemarie' gave the highest fruit set, but smaller fruit. The highest seed number was recorded when 'Rosemarie' was the polliniser. Fruit weight is an economically important factor that affects market price and therefore 'Lily' should be considered the best commercial polliniser of 'Abate Fetel' compared to 'Emperor' and 'Rosemarie' since it induced the highest fruit weight in 'Abate Fetel' orchards.

According to Faust (1989) previous authors have recognized that a tree cannot support all its fruits to grow to commercially desired size and quality, produce sufficient number of flower buds the following season, be able to support root growth, and accumulate food reserves to be strong enough to withstand the stress during unfavourable weather conditions. In order to obtain the 'perfect fruit' the only adjustable aspect among the process of fruit growth is therefore fruit number which is obtained by means of thinning. Thinning of fruit adjusts leaf to fruit ratio as the leaves will have fewer fruit to make food for. In orchards over-set problems occur if fruit set is more than 30% (Nyéki and Soltész 2003) resulting in smaller fruit, with reduced yields and also stressing trees into not yielding correctly in subsequent years (Nyéki and Soltész 2003). Nyéki *et* al. (1998) report that in 16 pear cultivars "oversetting" or "overcharge" is a problem with superabundant fruit set having undesirable economic consequences which happens when we have favorable weather conditions and too many pollinators. They suggest that there is need to consider the numbers of pollinisers and planting design to deal with over-set problems. Selimi (1971) looked at the effect of blossom thinning in 'Williams Bon Chretien' and 'Packham's Truimph'. In both he found that a reduction in yield is only obtained at 80% thinning and not at 60%, 40% or 20% thinning. What was also interesting was that he found that the size of the fruit increases with thinning as would be expected and that in 'Williams Bon Chretien' fruit developed more seeds in fruit when thinned. We think the problems in 'Packham's Triumph' are more likely due to physiological stresses, or internal limitations, than to pollination problems. Yet poor yield in 'Packham's Triumph' has been continuously ascribed to poor pollination, failure of pollen to fertilize ovule, seed abortion, competition for available assimilates and carbohydrates (Selimi 1971). Nyeki *et al.* 1994 reported that weather conditions were more important than pollinisers or pollinators in the production of pears, while Selimi (1971) strongly argued that it was the shortage of nutrients that was crucial and that if food reserves were exhausted good pollination failed to increase the crop due to insufficient nutrients. Selimi (1971) thus pointed to the prospects of blossom thinning as a measure to improve the quality and value of pears because, without proper thinning large fruit size was almost impossible in stone fruit (apples and pears) (Faust 1989). Furthermore fruit size was not positively related to seed count in 'Packham's Truimph'. All pear data in this study indicated sufficient or over-sufficient pollination, to the extent that fruit weight was significantly decreased in trees with better pollination. To increase fruit weight, fewer pollinisers, fewer pollinators or better thinning is required.

The analysis in 'Packham's Triumph' was complicated by the ability of this cultivar to set parthenocarpically. A significant increase in fruit weight of 'Packham's Truimph' was obtained by Sharifani and Jackson (2001a) in caged treatments, with no effect on fruit set being found (Table 4.18). Selimi (1971) stated that some other factors were clearly at play in fruit growth in 'Packham's Truimph' most probably parthenocarpy. Parthenocarpy is widespread in pears among temperate zone fruits (Faust 1989), and the significant and negative relationship between fruit weight and seed number found in 'Packham's Triumph' in this study clearly indicated that many of the fruit produced were produced parthenocarpically. While parthenocarpic fruit were reported to be elongated and to have poor storage abilities (Sedgley and Griffin 1989), this seemed not to be the case with Lourensford's 'Packham's Triumph' pears. Certainly, there was no practice at Lourensford Estates of eliminating or separating over-large fruit, and they are marketed as a normal part of the crop, and often the premier crop (Pers Comm B. De Villers) with the biggest fruit (>65mm) going to export.

Table 4.18: Effects of cage and non-cage treatments on fruit weight (g), seed set, fruit retained (%) and misshapen fruits (%) (from Sharifani and Jackson 2001a)

	Weight (g)	Seeds	Initial set (%)	Final set (%)	Misshapen fruit (%)
Cage	190	0.00	15.95	9.06	7.1
Open	135	3.84	15.94	8.62	3.6

As a final comment, it is interesting to look at the data that exists on the effectiveness of hand pollination in deciduous fruit trees. Table 4.19 shows that much better results from hand pollination of apples, and even apricots, were obtained than with the hand pollination of pears. Hand pollination successes in pears were only 6% (van den Eijnde 1996; Nyéki *et* al. 1994) whereas the success in apples was 50% or more. This suggested that pollination was not the limiting factor in pears. Even when the pollen was hand delivered, only 6% pollination success was achieved. We can therefore assume that reasons for poor yield in pears must be due to problems with fertilization, or the physiological condition of trees, and that it has nothing to do with pollination and therefore cannot be addressed with pollinators, or pollinisers, or planting patterns.

Table 4.19: Fruit set percentage from hand pollination of deciduous fruit crops. Previous studies using hand pollination and insect exclusion treatments were used to estimate crop specific fruit set. The percentage selected column represents the most realistic crop specific fruit set and a rationale for the particular fruit set value selected is provided (Allsopp *et al.* 2008, and references therein).

Crop	Fruit set percentage from hand pollination	Percentage selected	Rationale
Apple	50 (De Witte *et* al. 1996) 52 (Wertheim 1991) 56 (Sheffield *et* al. 2005) 63 (Volz *et al.* 1996) 15 (Rejman 1983) 51 (Keulemans *et* al. 1996) 36 (de Putter *et* al. 1996) 14 (Free 1964) 70 (Anderson 1985) 21 (Kron *et* al. 2001) 57 (Matsumoto *et* al. 2007) 37 (Griggs & Iwikiri 1960)	50	Seems to be an acceptable median, and is close to the 0.57 found by Matsumoto *et* al. (2007) which is the most comprehensive study, using 77 cultivar combinations.
Apricots	54 (McLaren & Fraser 1996) 25 (McLaren *et* al. 1996)	25	McClaren *et* al. (1996) is based on 62 cultivar combinations, and is the most comprehensive study.
Pears	4 (van den Eijnde 1996) 8 (Nyéki *et* al. 1994)	6	Averaged

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CHAPTER 5

DISCUSSION

The general expectation (Free 1964; Anderson 1985; Núnez-Elisea *et al.* 2005) was that we would find pollination depression and that insufficient pollination was resulting in sub-optimal fruit production in the Western Cape. The expectation was that we would get a yield gradient corresponding with an increase in distance from the pollinisers, and that pollination (and hence fruit weight, fruit set and the number of seeds) would get less as we move away from pollinisers. We further expected this to vary with different crops and with different planting designs. So, our intention was to evaluate this shortfall in terms of loss in yield and identify which planting design was best or 'least bad'. Since most orchards in the Western Cape comprise of a series of rows, each row with a single cultivar, commercial farmers are mostly concerned that there might be insufficient dispersal of pollen within orchards as a result of insufficient pollinisers. Kron *et al.* (2001) reported good pollen dispersal across 17 m or 3-4 rows in apple orchards, and as a result recommend solid blocks of no more than three rows.

The results obtained, however, were very different from expectations, and are summarized in Table 5.1. With respect to polliniser position, a comparison of fruit weight, seed number and fruit set immediately adjacent to the pollinisers in comparison to the far side of the tree, we expected to get bigger fruit, increased fruit set and greater seed number on sides of trees adjacent to the polliniser. Instead, there were smaller fruit produced closest to the polliniser in both pear and apple cultivars and significantly negative results in the plum cultivars. There were significantly more seeds closer to the polliniser in both pear cultivars, and in the apple cultivars (Table 5.1). Fruit set was generally greater nearer the polliniser, but was not significant except for apple. The data from polliniser distance assessment in pears yielded exactly the same results as the polliniser position assessment: namely, that closer to the polliniser meant better pollination but smaller fruit, with fruit set either greater closer to the pollinise or showing no effect.

Table 5.1: Summary of results for Row effect (comparison between trees in-row with the polliniser with those across-row from the polliniser); Bee effect (comparison between trees close to bee hives and trees further away from bee hives); and Polliniser effect (comparison between clusters on the near side of the tree to the polliniser compared to clusters on the far side of the tree). Results are indicated as positive (+), meaning bigger fruit or more seeds or more set closer to the hives or polliniser, in row with polliniser; or negative (-), meaning smaller fruit or less set closer to the hives or polliniser in row with polliniser. The significance of the difference, at the 0.05 % level (t-test - LSD) is indicated with an asterisk.

	Cultivar	Weight	Seeds	Set
Row Effect (in-row vs. across - row)	‘Abate Fetel’	-*	+*	+*
	‘Packham’s Triumph’	-	+*	+
Polliniser effect (Adjacent vs. removed)	‘Packham’s Triumph’	-	+*	-
	‘Abate Fetel’	-	+*	+
	Plum	-*		+
	Apples	-	+*	+*
Bee effect (near colonies vs. far from colonies)	‘Packham’s Triumph’	-	-*	+
	Plum	+		+
	Apples	-	+*	+*

The data on the number of seeds was unambiguous: There were more seeds and hence better pollination nearer the polliniser in apples and pears, as we had expected. There was thus better pollination closer to the polliniser. What was not expected was the effect that this improved pollination had on fruit weight. It was expected that fruit would be substantially larger closer to the polliniser, similar to the findings of Free and Spencer-Booth (1964). In their experiment ‘Comice’ trees with ‘Conference’ grafts had a significantly higher percentage of flowers setting fruit than those without grafts. At Lourensford, however, fruit weighed less close to the pollinisers, especially for pears and apples. Furthermore, fruit set was generally improved, but not convincingly so, by the proximity of the polliniser, with the exception for apples.

Our results suggested that nearer to pollinisers there was better pollination, resulting in more initial set, but that this resulted in 'over-set' beyond the physiological limit of trees, resulting in (a) the trees losing more fruit to the extent that final set was generally no higher close to the polliniser in comparison to further away; and (b) an initial additional wastage of energy on fruit that was lost close to the polliniser, resulted in less energy per fruit for the whole tree and subsequently smaller remaining fruit. Having said this however, we are aware that there were flaws in the experimental design in that we should have recorded initial set and final set, as we can only assume initial set to have been higher. Nevertheless, 'over-set' seems to be one plausible explanation. What this means is that there is no polliniser/pollination depression at Lourensford; if anything, orchards are over pollinated. There was not a gradient further from the polliniser, as expected, and as seen in Figure 5.1a, but rather we get sub-optimal fruit weight close to the polliniser because of too much pollination, and sub-optimal fruit weight too far from the polliniser because of too little pollination (Figure 5.1b). The optimal polliniser pattern is very difficult to determine, and will vary with local conditions, and needs careful assessment over a number of seasons (Soltész 2003). With fruit there will always be natural variation in the size on trees. Bigger fruit means better profitability (Lötze and Bergh 2004) and getting bigger fruit means reducing crop load. Too many fruit means too many small fruit, and lost income (Lötze and Bergh 2004). Optimum fruit load will be difficult to determine, and will differ with each cultivar, and also with the age of the trees, local conditions, and between seasons.

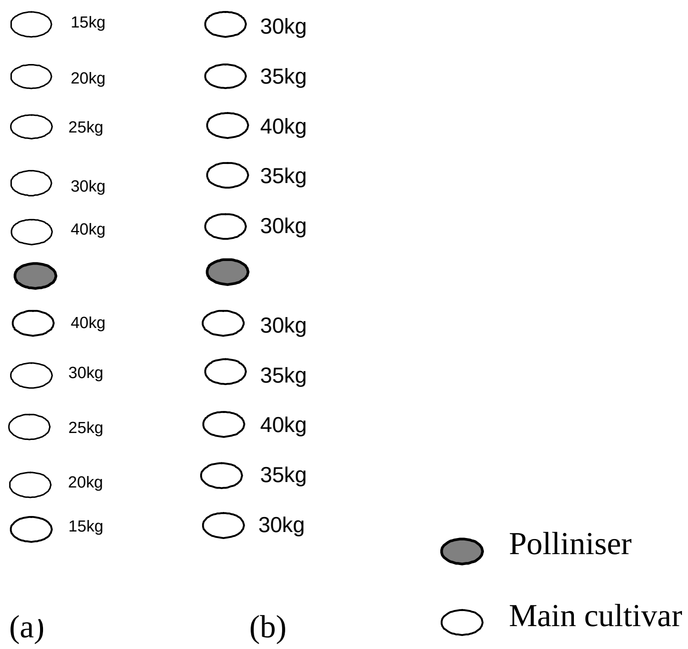

Fig 5.1: Theoretical yield of trees with increasing distance from the polliniser. (a) Expected theoretical yield gradient with an increase in distance from the polliniser. (b) Illustrative yield obtained in this study.

The implication of these data is that you can have too much pollination in deciduous fruit production. As much as you have too much water, or too much fertilizer; one can also have too much pollination which can mean too many pollinisers, or too many pollinators, or a combination of the two. It is interesting that all the pollination literature until the 1960's put emphasis on the risk of overset, and that you can have too much pollination, but this seems to be largely missing in modern literature, and contrary to conventional wisdom. Nonetheless, the same conclusion is reached in a number of publications: for example, "Bee pollination causes more fruit set and consequently reduces the average fruit size as well as the soluble solid content of fruit " (Benedek 2003), and "Excessive pollination results in over-cropping, leading to many small fruit with low commercial value" (Schneider *et al*. 2001). "Crop load is critical, and is not sufficiently understood" (Volz *et al.* 1996). While a certain degree of pollination is critical to get some seeds formed, which results in facilitating delivery of trace elements such as calcium, magnesium and potassium crucial for fruit production (Boselli *et al.* 1995; Volz *et al.* 1996; Buccheri and Di Vaio 2004), too much pollination means too many fruit with sufficient seeds, more than the energy capacity of the tree can supply. Hence, they all get less assimilates, and you get smaller fruit. What does it mean for the grower? This does not imply that the growers don’t need pollinators, or that they don’t need pollinisers. Without those, or with too little of them, a sub-optimal crop will be produced. Similarly, sub-optimal crops can also result from over-pollination as illustrated hypothetically in Figure 5.2. For any grower, for any season, for any orchard, for any crop, for any polliniser and pollinator, there will be a correct amount of pollination required and that is governed by the physiological/economic limit of the tree. There will be an economic maximum that is the best that can be returned from that tree. It might not be the highest yield (fruit set), but rather fewer fruit of higher weight and value.

For the grower with over-set problems, the easiest adjustment to make is through thinning. Thinning however, does not restore the lost energy to the tree. A tree that has aborted fruit, or had fruit thinned, has lost that energy and it cannot be directed to the remaining fruit. A tree thinned to 500 fruit does not have the same quality fruit as a tree that only had 500 fruit to begin with. To an extent, the current farming paradigm is brought into question; how much sense does it make to produce tens of thousands of flowers, and fruitlets, only to lose or remove many of them. Thinning only at the stage of fruitlets, rather than at blossom stage, is the norm as an insurance policy, but this comes at a cost. The need to thin fruit means that yield will always be sub-optimal and may also have negative influence on trees for the following season. The key in setting fruit is that trees can only afford so much set and so many fruit. There is need to determine the physiological limit of trees; what the normal fruit set rate is with optimal pollination; and then remove most or all of the excess flowers which means better pollination, better quality fruit, fewer fruit, and better yield. Growers therefore need to moderate pollination, or need to thin better and at the correct time, to avoid supra-optimal fruit set. Pre-blossom thinning is crucial in stone fruit production such as peaches and nectarines; without proper thinning large fruit size in stone fruit is almost impossible. Pre-blossom thinning, in addition to pruning, might very well be necessary to improve crop quality in pome fruit (pears and apples).

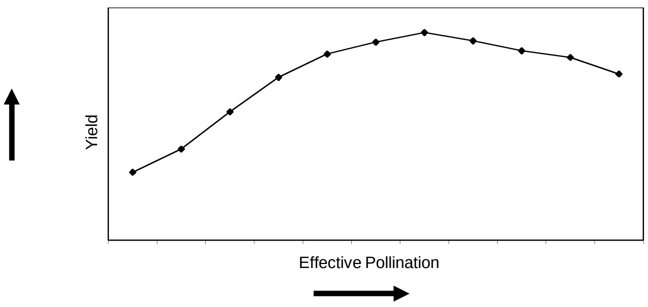

Fig 5.2: Hypothetical view of pollination effectiveness.

Over-set has often been found in kiwis (Lai *et al.* 1990; Howpage *et al*. 2001) with interfruit competition inhibiting fruit size. The effect is shown dramatically by Howpage *et al.* (2001) (Table 5.2). The data clearly demonstrate that, while bees are needed to get fruit set and fruit weight, too many results in a decrease in fruit weight and on premium quality fruit. The smaller fruit in the 30 colonies per hectare block had more seeds than either of the other blocks, clearly demonstrating over-pollination. In kiwis this can only be cured by early thinning to release more carbohydrate resources to the remaining fruit. There is a distinct disadvantage to over-pollinate a tree as it results in over-bearing with a consequent over utilization of the tree which can manifest itself for a number of seasons (MacDaniels 1930).

Table 5.2: Over-pollination in kiwis results in smaller fruit without any increase in yield (from Howpage *et al*. 2001).

Pollination intensity (hives per hectare)	Fruit set (fruit per vine)	Numbers of fruit in each weight class				
		<50g	50-69g	70-89g	90-109g	>110g
0	50	17.5	8.5	5.3	9.5	9.5
6	168	0.3	4.0	31.3	95.6	37.0
30	160	3.0	21.3	71.3	55.4	8.6

The key factors in fruit set have been given as (a) premigenic dormancy (the timing of the flower, with the first setting having dominance over others); (b) competitive vegetative growth and (c) seed effect (Bangerth 1989). The fruit on a plant compete with each other and with vegetative growth for available nutrients and trace elements (Marcelis and Baan-Hofman-Eijer 1997). Because of the nutrient sink effect, seeded fruit are expected to cause unseeded fruit to fall off the trees. The "sink strength" is the ability of fruit to attract nutrients and the presence of developing fruit can inhibit subsequent set and growth (Bangerth 1989), perhaps by dominance for auxin-transport in the earlier developed fruit or simply an over-competition for resources (Marcelis and Baan Hofman-Eijer 1997). This list should be qualified with a statement, however, that there is a limit to the fruit set that any tree in any year can energetically manage, and that fruit set beyond this limit is counter-productive. In a year with a very high set the fruit with the fewest seeds will fall because of physiological restrictions (Nyéki *et al.* 1994; Marcelis and Baan Hofman-Eijer 1997), while in a poorer year fruit with the same amount of seeds would remain.

We also expected to find that pollination and yield would be best near the bee colonies, and to find a decrease in pollination efficiency of trees moved further away from colonies and that there would be areas in orchards that perhaps were too far away and were receiving sub-economic pollination. We hoped to quantify this and hence recommend optimal orchard management practices with regards to the placing of honeybee colonies, and the numbers of colonies required for optimum pollination and production of the various fruit crops. Fruit weight and fruit set has been found to decrease with distance from honeybee colonies (Free 1993). Greater fruit set and fruit weight of 'Packham's Triumph' was observed in blocks near honeybee colonies indicating the fact that bees have a tendency to visit trees close to their hives more than those far away (Free 1962). We expect pollination intensity to decrease further away from colonies of bees, but as Table 5.1 shows that this was not the case at Lourensford. The results were inconsistent, and colony distance mostly had no effect on fruit weight, fruit set and on seed number except for apples. The conclusion that can be drawn from this is that honeybee colonies are adequately distributed, and that there is no "pollination depression" in the centre of the orchards.

With regards to row effect, we expected to find better pollination within a row in comparison to fruit across the row from the polliniser. It is generally thought that foraging bees move along rows rather than across rows (Free 1964; Free 1966; Mayer 1994; Mayer *et al*. 1989; Free and Spencer-Booth 1964; Free 1993; Monzón *et al*. 2004; Núnez-Elisea *et al.* 2005). The data collected in pear orchards are strongly supportive of these results, and confirm the existence of a row effect in foraging honeybees. The trees adjacent to the pollinisers and in the same row received the most effective pollination. This resulted in the highest seed numbers in these trees (Table 4.17 and Table 4.13), but also the smallest fruit, possibly from initial over-set resulting in the physiological limit of the trees being over-extended. The low fruit weight on trees in-row with the polliniser may have resulted from initial over-set which led to inter-fruit competition for available assimilates during early stages of fruit development forming fruit with low weight regardless of high seed numbers (Lai *et al*. 1990; Lötze and Bergh 2004).

Results on the relationship between fruit weight and fruit set or seed number are largely as expected (Table 5.3). There was always a negative relationship between fruit set and fruit weight across all orchards and for all cultivars and mostly significantly so. These results indicated once again the importance of physiological limits of trees, and may suggest that trees were at their maximum production levels since an increase in set caused a decrease in fruit weight, once again indicating over-set. Therefore a reduction in crop load/fruit set would result in the production of bigger fruit size with high market value (Lötze and Bergh 2004). Conversely, but as expected, there was a positive relationship between the number of seeds in any particular fruit and the weight of the fruit in all the cultivars except ‘Packham’s Triumph’, indicating that some other factor was at play in ‘Packham’s Triumph’ production, namely parthenocarpy. Several studies have shown that ‘Packham’s Triumph’ can set fruit parthenocarpically i.e. without pollination, fertilization of ovules and hence without seed set. Sharifani and Jackson (2001) found that ‘Packham’s Triumph’ pears formed under caged treatments (zero seed set) had significantly higher average fruit weight than non-caged (seeded) treatments. Positive relationships have been found between the number of seeds and fruit weight in many crops and cultivars, including sweet peppers, tomatoes, kiwis, grapes and squash (Marcelis and Baan-Hofman-Eijer 1997; Varga and Bruinsma 1976; Boselli *et al.* 1995; Howpage *et al*. 2001; Stephenson *et al.* 1988). Seed numbers seem to have little relationship to fruit set. A small number of seeds is needed to ensure set and thereafter more seeds have no effect on set in sweet peppers, squash or pecan (Marcelis and Baan-Hofman-Eijer 1997; Stephenson *et al.* 1988; Marquard 1992).

Table 5.3: Relationship between set and fruit weight, and number of seeds and fruit weight, for each cultivar of the three fruit types. Results are indicated as positive (+), meaning a positive relationship, or negative (-), meaning a negative relationship. The significance of the relationship, at the 0.05 % level (Pearson's Correlation Coefficient) is indicated with an asterisk.

		Set/Weight	Seeds/Weight
Apple	'Granny Smith'	-*	+*
	'Golden Delicious'	-	+*
Plum	'Songold'	-*	
	'Laetitia'	-	
Pear	'Abate Fetal' (E, L, R)	-	+
		-*	+*
		-*	+
	'Packham's Triumph'	-*	-*

It is probably unfair to state that pollination is one of the most important factors to consider when planning orchard design, but that pollination is a factor that is seldom sufficiently considered when planning an orchard is equally apparent. There is critical need to ensure adequate sites for honeybee colonies and that adequate pollinisers and pollinators are in synchrony to guarantee optimal cross pollination. As pollen dispersal is limited, the positioning of the pollen donors and the carriers is critical. From our results it is apparent that Lourensford estate was over pollinated, if anything, and there was certainly no sign of pollination depression in the orchards, and hence no need to increase numbers of pollinisers or pollinators. The planting patterns that they have in place; the 2x2 rows of different cultivars, and both forms of 1-in-9 were sufficient at delivering pollen to the target crop. The reported over-pollination did not mean that the numbers of pollinisers or even pollinators should be reduced. Planting design will directly influence pollen transfer and the effective transfer distance from a polliniser should dictate planting pattern and the abundance of the polliniser. Wertheim (1991) suggest that 7% pollinisers are sufficient; Blasse and Schrötter (1989) suggested 3%, and others have suggested as much as 20% pollinisers (Borsboom 1982). To get the maximum cross fertilization, there is a need to know the extent of pollen wastage between trees of the same cultivar, and the predicted movements of pollinators, the Effective Pollination Period (EPP) and any loss of quality of pollen with transport in order to accurately predict successful pollen transfer in the orchard. In deciduous fruit crops, improved pollination should result in increased seed numbers and increased fruit size (Bramlage *et al.* 1990) but we did not see increased fruit weight in this study or in others such as McLaren *et al.* (1996) because too much pollination in fact reduced weight.

The results obtained indicated that it would be safe, and perhaps beneficial, for Lourensford to change their planting patterns to 3x3 blocks, but other than that it is not recommended that changes be made in terms of pollinisers. Similarly, no changes should be made with the numbers of bee colonies used, or their placement. There is certainly full coverage with the bees used, penetrating throughout the orchards. Therefore we don't suggest that blocks be increased beyond 3 rows as more than that might reduce cross pollination (Kron *et al.* 2001). Keeping pollinisers and pollinators at the level that they are at present is required to compensate for possible adverse weather conditions which could reduce set and yield. But under normal weather conditions, there is need to explore the physiological limits of the trees, and the relationship between set and weight, to determine how much set is required for optimal production, and then you need to orchestrate that amount of set in the trees by careful manipulation (pruning, pre-blossom thinning). As observed too much pollination is potentially a negative thing, resulting in too many small fruit rather than large fruit. A more extensive study that investigates total yield and fruit quality, as well as average fruit weight and fruit set, is needed to accurately determine any possible cost of over-pollination. In principle, however, growers need to aim for optimal pollination levels and more is not always better.

In terms of future assessment, there is need to look into pre-blossom thinning as a method to increase fruit production and value, especially in pears, and to determine the reason for poor set in pears which seems to be the limiting factor in pear production and is obviously unrelated to pollination. A good place to start is to accurately assess the hand pollination success in all fruit cultivars. Those cultivars with low percentages of success in hand pollination will be those that have additional barriers to good yield, such as physiological limitations or other problems and these are the cultivars where yield cannot be substantially influenced by pollinisers or pollinators or planting patterns. In some crops pollination will indeed be limiting, and it is expected that enhanced pollination methods, such as hand pollination or pollen dispensers or more pollinisers and pollinators would increase fruit set and also crop yield, in comparison to current levels of insect pollination. Enhanced pollination in these crops might be a viable proposition. These are crops such as the mango or custard apples where fruit set via insect pollination is extremely low (Dag *et al.* 2001; Pritchard and Edwards 2006) and physiological limitation is not a problem in crop production. Hand pollination has already been used in a commercial setting for the production of pears in China (Yao *et al.* 2001), custard apples in Australia (Pritchard and Edwards 2006) and kiwifruit in New Zealand (Howpage *et al*. 2001). Among the deciduous fruit crops, the yield of pears could be significantly improved by hand pollination, while with other deciduous crops are probably already at their physiological maximum and hand pollination would only result in over-set and uneconomic small fruit (Yao *et al*. 2001). The economic feasibility of hand pollination will hence need to be considered on an individual crop basis, depending on the improved yield that can be obtained against the added costs of hand pollination. There is also an obvious need to assess parthenocarpy in ‘Packham’s Triumph’, and the need of this cultivar for insect pollination and pollinisers, and the value and quality of parthenocarpic fruit.

It should be noted that these results are specific to the circumstances in effect at Lourensford estate for the duration of the experiments, and specifically the numbers of honeybee colonies used for pollination at Lourensford. On other farms, or if fewer colonies were used at Lourensford, very different results might have been obtained. If too few colonies are used, it is then expected that there will be a pollinator-related (rather than polliniser-related) depression away from the pollinisers, and in the centre of the orchards away from the honeybee colonies.

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