Effect of cultural practices and selected chemicals on flowering and fruit production in some mango (*Mangifera indica* L.) cultivars.

By

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Submitted in Partial Fulfilment of the Requirements of Doctor of Philosophy: Horticulture

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In the
Faculty of Natural and Agricultural Sciences
University of Pretoria

July 2004

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"He is like a tree planted by streams of water, which yields its fruit in season and whose leaf does not wither." Psalms 1:3

I dedicate this thesis to the almighty GOD who, through his mercifulness, allowed me to reach the level I am now.

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ACKNOWLEDGEMENTS

One person never does research alone. Therefore, I would like to express my sincere gratitude and appreciation to the following persons and institutions who contributed substantially towards the completion of this thesis.

Prof. P.J. Robbertse, supervisor of this study, for his keen interest, advise, encouragement, very valuable guidance and cooperation in every aspect throughout the study period.

Prof. P.J.C. Stassen, co-supervisor of the study, for his valuable ideas, advise, discussions and encouragement.

The agricultural Research and Training Project, Alemaya University component, for their sponsoring during my study period.

Bavaria Fruit Estate, South Africa, for allowing me to conduct the experiments on their mango trees. Very special thanks to Mr. J. Fivas for his valuable ideas and his division members for helping me in different aspects while executing the experiments.

Upper Awash Agro-industry Enterprise in Ethiopia for providing me their mango trees to conduct the experiments. Higher appreciation to the General manager, Production manager, Research division and Nura Era farm staff members.

My wife, Azeb Asrat, for her loyal support, encouragement and good disposition throughout the progress of this task as well as her tremendous love for me. My son, Binyam Teferi for his patience and sacrifice throughout this study.

My brother Fisseha Yeshitela, who made a great effort to help me with launching the experiments. I also thank my brother Akalu Lentiro for all his devotions and encouragement towards my success.

Staff members Alemaya University, more especially Horticulture and Soil Science section technical assistants who helped me a lot during the lab analysis of the samples.

The University of Pretoria, especially Mr. R. Gilfillan for his technical support, Mrs. L. Adams for her support with facilities and Mr. W. Truter for reading and correcting grammar of the thesis.

Our Sunday School in Pretoria and our Church in Johannesburg, friends and colleagues for their encouragement, support and assistance throughout many difficulties encountered. Higher gratitude to Tekalign Tsegaw and Wondimu Bayu.

Mine as well as my wife's family members for their unfailing support and encouragement during my career.

Above all, Almighty God, allowing me the privilege and opportunity to fulfil my ambition.

EFFECT OF CULTURAL PRACTICES AND SELECTED CHEMICALS ON FLOWERING AND FRUIT PRODUCTION IN SOME MANGO (*Mangifera indica* L.) CULTIVARS.

BY

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ABSTRACT

Although mango (*Mangifera indica* L.) has been studied for many years, numerous problems still elude researchers. The objectives of the current trials were to study the effects of some cultural practices (fruit thinning, panicle/ bud/ renewal/ post-harvest pruning) and chemicals (Corasil.E, potassium nitrate/urea, paclobutrazol) on various vegetative, floral, yield and quality parameters. The study meant to address problems of both South African and Ethiopian mango growers. The thinning (on 'Sensation') and pruning (on 'Tommy Atkins' and 'Keitt') experiments were conducted for two seasons (2001-2003) at Bavaria Fruit Estate in South Africa. Effects of Paclobutrazol and Potassium nitrate were studied on 'Tommy Atkins' during 2002-2003 season at Upper Awash Agro-industry Enterprise in Ethiopia. Complementary effects of paclobutrazol and potassium nitrate on floral induction were studied in growth

chamber experiments at the experimental farm of University of Pretoria on 'Tommy Atkins' and 'Keitt' mango.

Where fruit on 'Sensation' were thinned to one and two fruit per panicle, a significant increase was obtained for most of the fruit quantitative parameters. The treatments where one fruit and two fruit per panicle were retained and 50% panicles removed, produced a significant increase in size of the fruit, fruit qualitative parameters and fruit retention percentage. Corasil.E produced very small sized fruit with a considerable percentage of "mules" (fruit without seed). Trees subjected to severe thinning intensities showed earlier revival of starch reserves and better vegetative growth.

Applications of paclobutrazol (1- (4-chlorophenyl) –4,4-dimethyl-2- (1,2,4- triazol-1-yl) pentan-3-ol) at rates of 5.50 and 8.25 g a.i. per tree, both as a soil drench and spray applications, on 'Tommy Atkins' mango were effective in suppressing vegetative growth as compared to the control. Consequently, the trees from these treatments had higher total non-structural carbohydrate in their shoots before flowering which led to higher results of percentages of shoots flowering, number of panicles produced, percentages of hermaphrodite flowers, yield and quality of the fruit.

Trees that received panicle pruning (during full bloom) treatment at the point of apical bud attachment, were observed to be induced for synchronized re-flowering and also attained more fruit per panicle. On the other hand, trees on which renewal pruning (early in the season) and post-harvest pruning (especially for early cultivars) treatments were applied, have been observed for the development of an adequate

number of productive inflorescences. Post-harvest pruning treatments also resulted in greater vegetative growth on both cultivars. The responses to pruning treatments were greater especially in 'Tommy Atkins' than 'Keitt'.

The trend for the interaction of duration and chemicals in Tommy Atkins and Keitt mango cultivars revealed the possible floral induction complementary effect of PBZ after the trees were induced only for 15 days at 10/15 ^{o}C temperature. Higher potassium nitrate concentrations especially in combination with urea (5 litre solution of 4% KNO_3+0.5 g urea tree^{-1} and 5 litres of 4% KNO_3+1 g urea tree^{-1}) produced higher results for most of the flowering and yield parameters in 'Tommy Atkins'.

Key words: apical bud, apical whorl of leaves, cold units, fruit per panicle, fruit quality, fruit quantity, fruit thinning, mango, paclobutrazol, potassium nitrate, total-non-structural carbohydrate, urea

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Fresh tropical fruits are still winning ground on world markets. Production has risen by 4% annually since 1997 (Anonymous, 2001), and exporters of diverse fruit have grown by more than 10% annually. The bulk of these fruit (98%) are grown in developing countries and the biggest importers are the European Union (41%) and North America (33%). Nonetheless, the traded amount is only a fraction of the total production since less than 10% of the total fresh fruits produced are shipped abroad. More than 40% of fresh fruit exporters originate from Latin America and the Caribbean. Africa, in particular Cote D'Ivoire, Cameroon, Ghana, Kenya and South Africa, account for 14% of the world trade. Among the tropical fruit, pineapple accounts for 44% of the total traded volume, followed by mangoes (27%), avocados (12%) and papayas (7%). The main reason for increase in demand of tropical fruit is the growing familiarity of consumers with tropical fruit; their taste and nutritional values.

Mangoes (*Mangifera indica*) are produced in more than 100 countries through both the tropics and the subtropics, from 36^{o} northern latitude in Spain, to 33 ^{o} southern latitude in South Africa (Galan-Sauco, 1993, 1996). The mango is the third most cultivated tropical fruit in the world and the most important producers in the world

are India (1,963,000 ha. in 1993), Thailand (235,666 ha. in 1995), Mexico (152,103 ha. in 1997) and Brazil (53, 107 ha. in 1997) (Sao Jose & Reboucas, 2000).

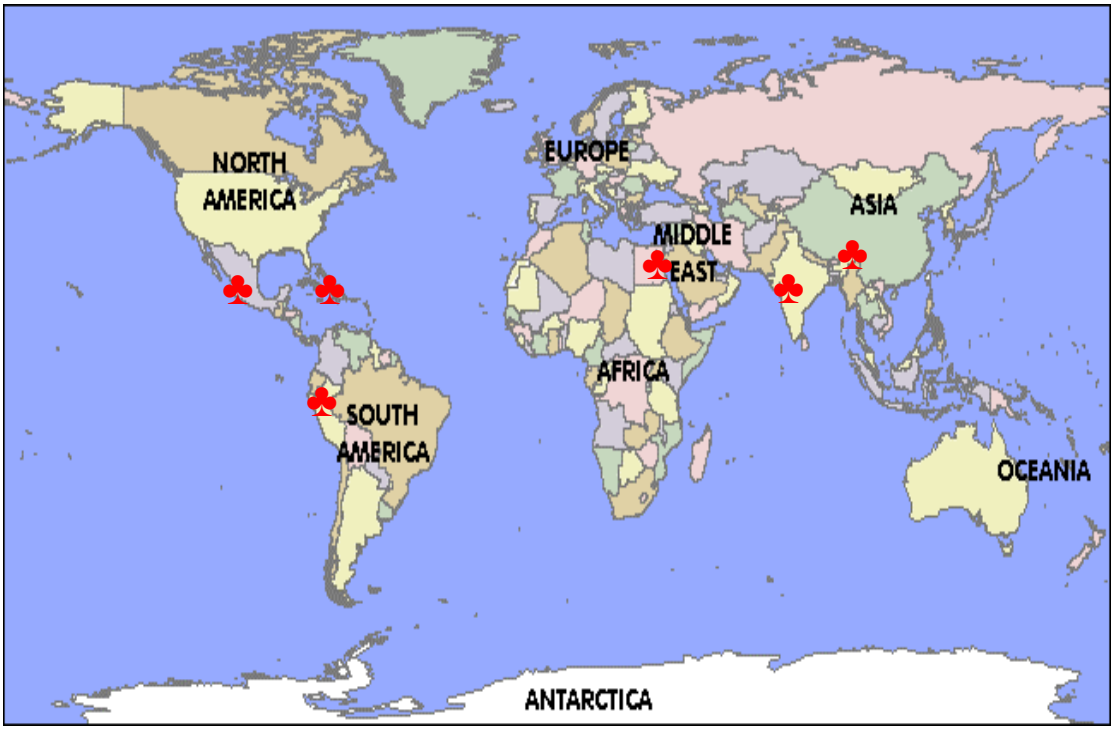

Figure 1.1 World main mango producing areas.

(Source: http://www.fao.org/inpho/compend/img/ch20/inpho@fao.org).

According to Fig. 1.1, the major mango producing areas of the world can be grouped in to six regions: A) Florida (USA), Mexico, Central America B) West Indies (Caribbean Islands) C) South America D) Africa/Arabian Peninsula E) Indian Subcontinent F) Indochina (China)/ Indonesia/ Pacific.

The total world production in 2002 was 25,754,509 metric tons (FAOSTAT, 2003). Poor orchard yield is partly due to wide tree spacing, conventional orchards having tree spacing ranging from 10-12m (Oosthuyse, 1993a; b; c). High density planting, increased tree complexity, post-harvest pruning combined with sound irrigation and

nutrient management are currently raising sustainable yields up to the 20-30 t ha^{-1} range in the hot tropics (Wolstenholme & Whiley, 1995). Looking at the trend of world export of fresh mangoes (Anonymous, 2001), the average for 1994-97 was 371,000 tons, 469,000 tons in 1998, 498,000 tons in 1999 and 510,000 t. in 2000. The world total import was 672,204 MT in 2002 where the largest importer was USA (263,354 MT) and the next was Netherlands (71,479 MT) (FAOSTAT, 2003).

The mango is a member of the family Anacardiaceae in the genus *Mangifera*. Cytological studies indicate an allopolyploid origin for mango with a haploid number n = 20 and a diploid number 2n = 40 (Mukherjee, 1950). There are 41 *Mangifera* species distributed from India and Sri Lanka in the west to Papua New Guinea and the Philippines in the east (Mukherjee, 1953). Although at least 13 species have edible fruit, *Mangifera indica L*. is the only species widely planted and produced on a large commercial scale (Schaffer *et al.,* 1994). Well-known close relatives of mango are cashew nut *(Anacardium occidentale L.)* and pistachio nut *(Pistacia vera L.),* which also belong to the Anacardiaceae family. The primary evolutionary center of mango is reputed to be the subtropical, north-eastern Indo-Burmese region, where it is found growing in the forests (Sukonthasing *et al.,* 1991).

The mango is a medium to large (9-31 m) evergreen tree, with an open or dense symmetrical canopy (Sukonthasing *et al.,* 1991), long tap-root, and dense mass of fibrous surface roots (Purseglove, 1968). Leaves are simple, 15-40 cm long, 2-10 cm wide, lanceolate, hypostomatal, leathery in texture (Chacko, 1986; Schaffer *et al.,* 1994) and may be retained on the tree for 4-5 years if not damaged by diseases or insects (Scholefield *et al.,* 1986). The inflorescence is many branched, terminal

panicle, 10-60 cm in length bearing 300 to more than 4000 polygamous (male and hermaphrodite) flowers (Chadha & Pal, 1986). Sen (1962); Chadha & Pal (1986), on the other hand, stated that the average number of flowers per inflorescence is between 200-3000, depending on the cultivar, tree vigour, cultural practices and weather conditions. These figures were confirmed by Scholefield & Oag (1984). Both male and hermaphrodite flowers are greenish-yellow, 5-8 mm in diameter, with four or more staminodes and usually one fertile stamen. Each male flower has one abortive pistil, while each female flower has a monocarpel ovary with a lateral style and a simple stigma (Singh, 1960) containing only one pachychalazal ovule (Robbertse *et al*., 1986).

The fruit is a fleshy one-seeded drupe, variable in shape (nearly round, oval, or ovoid-oblong), from 2.5-30 cm in length, weighing 60 g to more than 2.3 kg and greenish, greenish-yellow, yellow, red, orange, or purple in colour (Sukonthasing *et al.*, 1991). The seed may be either mono-embryonic (one zygotic embryo) grouped under Indian types or poly-embryonic (2-12 nucellar embryos, one may be zygotic), enclosed in a hard endocarp, which is grouped under Indo-Chinese types (Crane & Campbell 1991; Schaffer *et al.*, 1994). A broad generalization is that cultivars of the Indian type often have highly coloured skin while those of the Indo-Chinese type are predominantly green-yellow when ripe (Schaffer *et al.*, 1994). Hybridization occurs freely between cultivars of each group (Whiley *et al.*, 1993) resulting in cultivars with wide ranging genotypic and environmental responses (Singh, 1987).

Mango trees may live for hundreds of years and some trees planted during the 16th century in India have survived to the early 20th century (Mukherjee, 1953). The tree

conforms to Scarrone's architectural model, in which tree growth and form is determined by an orthotropic, periodically active, terminal meristem which produces an indeterminate trunk bearing tiers of branches (Halle *et al.,* 1978). Schaffer *et al.* (1994) also explained that each branch-complex is orthotropic and sympodially branched as a result of terminal flowering. Tree growth is episodic and there is a temporal separation between reproductive and vegetative stages of growth (Cull, 1987).

Each period of vegetative growth, called a "flush", terminates when all new leaves (10-12 per flush) are fully expanded (Whiley *et al.,* 1989). A period of dormancy usually follows each flush (Scholefield *et al.,* 1986). The number and frequency of flushes and the amount of growth expressed as increase in shoot and leaf dry matter produced per year, depends upon cultivar, climatic conditions, tree maturity, current fruit load, and previous cropping history (Issarakraisila *et al.,* 1991).

The period between floral initiation and anthesis can be as little as four weeks under tropical conditions (Scholefield *et al.,* 1986). This rapid organogenesis demonstrates the capacity of the tree to take advantage of favourable environmental conditions. Initial fruit set in mangos can be heavy with many fruitlets developing on each panicle. However, fruit drop, particularly during the first four weeks after set, is severe with more than 80% of the initial fruit shed before maturity (Singh *et al*., 1965). Many cultivars, e.g., Kensington (syn. ‘Kensington Pride’), Tommy Atkins, and Haden usually bear one fruit per panicle through to maturity, while others like Sensation, Irwin, Lippens, and Nam Dok Mai often retain two or more fruit per panicle to maturity (Scholefield *et al.,* 1986). Mango fruit growth follows a simple

sigmoidal curve (Ram *et al.,* 1983) with fruit maturing 3-4 months after set (Sukonthasing *et al.,* 1991).

Flowering and fruit set are the most critical of all events occurring after establishment of a tree crop. Given favourable growth conditions, the timing and intensity of flowering greatly determines when and how much fruit are produced during a given season (Davenport & Nunez-Elisea, 1990). A fundamental understanding of mango flowering in the tropics and subtropics is, therefore, essential to efficiently utilize cropping management systems which comprise both the flowering and crop production seasons (Davenport & Nunez-Elisea, 1997). Several new approaches to the study of mango flowering have been made (Chacko, 1991; Davenport, 1993).

1.2 Problem statement

Mango is the most important fruit produced in most parts of eastern and southwestern Ethiopia, both in area coverage and quantities produced. There are also ample garden mango trees in different parts of the country at farmer's holdings. The livelihood of most of these farmers is highly supplemented by the selling of mango fruit. In the eastern parts of the country, where mangoes are produced, the area covered with mango reaches about 35% of the total acreage allotted for fruit production (Alemaya University staff survey, 1996). More area coverage is expected in the south western and rift valley regions of the country due to more conducive climatic and edaphic factors. Some amongst many reasons that are suggested for the low yield of mangoes in those areas include, high and bimodal production of flowers and fruit in one year and low in the other (Alemaya University staff survey, 1997). Ethiopia being situated

very close to the equator is characterized by two erratic and unreliable flowering periods due to bimodal rainy periods and low temperature (main raining season is June-August and the short one is on February-March). This situation exhausts the tree's carbohydrate reserve and usually the yield obtained is below expected, compared to the mango growing areas in the world. Subsequently, the trees usually experience an alternate bearing rhythm. Besides, excessive vegetative growth is a common characteristic of most mango cultivars resulting in unmanageable and large trees, with low fruit retention capacity. Some of the unsolved problems mentioned above, like alternate bearing and poor fruit retention are not confined to Ethiopia, and need to be addressed, particularly to the benefit of South African mango growers.

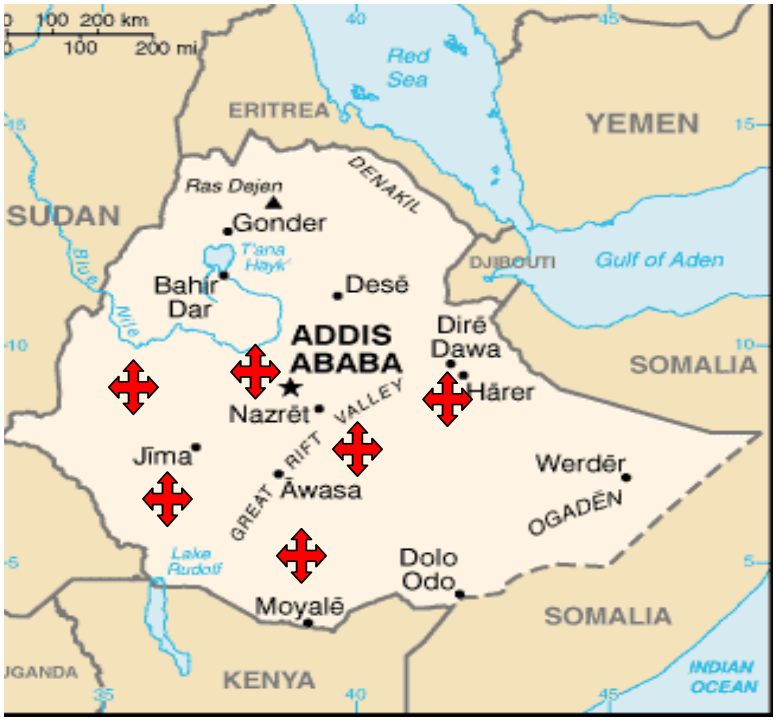

Figure 1.2 Major mango producing areas of Ethiopia (red crosses). (Original map source: http://www.1uptravel.com/worldmaps/ethiopia.html)

1.3 Main objectives of the project and hypotheses tested

In general, the yield obtained from mango trees in Ethiopia is low and irregular. The fruit quality also needs improvement. South African mango producers also encountered similar problems and the following objectives were identified for this thesis:

1) To investigate the effects of some cultural practices like specific fruit thinning mechanisms and various tree-pruning techniques. The results will show whether these practices have a beneficial effect on yield and quality components as well as starch reserve of the trees.

2) To assess the effects of potassium nitrate and paclobutrazol on various aspects of vegetative growth, flowering and fruit related developments of mango in Ethiopia. This has not been investigated previously.

3) To investigate whether the partial flower induction by suitable cold temperature can be substituted, complemented or intensified by application of some growth regulators.

The Hypotheses tested in the study were:

1. In areas like Ethiopia, where poor floral induction prevails, applications of paclobutrazol (alternative growth retardants with low toxicity and limited persistence in fruits are available) or potassium nitrate may complement the

floral induction process or increase intensity of flowering and ultimately fruiting.

2. Panicle and bud pruning treatments will activate dormant axillary buds. The activated axillary buds may have a better chance of flowering and fruit setting than apical buds. Applications of renewal and post harvest pruning will also have various beneficial effects on the trees with respect to better vegetative growth that can mature early and bear the coming season's crop.
3. Paclobutrazol reduces tree vigour (excess vegetative growth) that may in turn strengthen reproductive growth of the trees. Trees that are unproductive due to excess vegetative growth and crowding of branches could be improved with application of paclobutrazol.
4. Mango trees normally produce excess fruit beyond the tree's capacity of which most of them ultimately drop. Hence, fruit thinning before the occurrence of excess fruit drop is crucial. Fruit thinning, however, should be quantified to obtain sustainable production and quality.

The specific objectives and research methodologies for the experiments is presented in detail under each chapter. The chapters are arranged in the order of their priority being prepared to be submitted for publication. Chapter 3 is accepted for publication in Experimental Agriculture, Chapter 4 is accepted in New Zealand Journal of Crop and Horticultural Science, Chapter 5 has been revised and sent back for publication in Australian Journal of Experimental Agriculture, Chapter 6 is accepted in New Zealand Journal of Crop and Horticultural Science and Chapter six is submitted to Journal of Recent Research Updates in Horticulture (Research Syndicate).

CHAPTER 2

LITERATURE REVIEW

2.1 Effects of inductive temperature periods and chemicals on flowering of some mango cultivars.

Floral induction is the basis for flowering and consequently fruiting. Unless the trees are sufficiently induced, there will be a reduction in yield. Low temperatures are the main inductive factor in mangoes. In places like around the tropics, sufficient low temperatures for mango floral induction may not be attained. Some growth regulators may intensify flowering of trees which were not adequately induced. In the following review, these aspects are addressed.

2.1.1 Floral induction process in mango

The flowering mechanism in Mango (*Mangifera indica* L.) is still poorly understood, although it clearly depends on environmental factors to bring about the transition from vegetative growth to reproductive growth, after causing a check in vegetative growth (Davenport & Nunez-Elisea, 1997). This transition is known to be induced by cold weather or combination of cold weather and water stress (Whiley, 1993). Other possible inductive factors in flowering can be photoperiod, carbohydrate and nitrogen status, plant hormones, and other yet undetermined factors (Bernier *et al*., 1981).

Induction refers to the commitment of buds to evoke a particular shoot type, i.e. vegetative shoot (vegetative induction), generative shoot (floral induction) or mixed shoot (combined vegetative – floral induction) (Davenport & Nunez-Elisea, 1997). In addition, the inductive signal can be shifted from reproductive to vegetative or vegetative to reproductive by altering temperatures to which the plants are exposed during early shoot development (Batten & McConchie, 1995; Nunez-Elisea *et al*., 1996).

2.1.2 The role of temperature on mango floral induction and differentiation

Although, the flowering stimuli of fruit trees are relatively less specific than those of herbaceous plants (Jackson & Sweet, 1972), temperature has been found to be the main factor on the flower formation of several fruit trees such as apples (Tromp, 1980; 1983), citrus fruit (Moss, 1969), litchis (Nakata &Watanabe, 1966) and olives (Badr & Hartman, 1971).

Studies in mango revealed the existence of a floral stimulus, which is continuously synthesized in mango leaves during exposure to cool, inductive temperatures (Davenport & Nunez-Elisea, 1990; Nunez-Elisea & Davenport, 1992). Unlike other plants requiring vernalization for induction (Bernier *et al*., 1981) mango leaves appear to be the only site where the putative floral stimulus is produced (Davenport & Nunez-Elisea, 1992). Complete defoliation of girdled branches during inductive conditions results in vegetative shoots instead of generative shoots (Nunez-Elisea & Davenport, 1991b; Nunez-Elisea & Davenport, 1992). The putative temperature regulated floral stimulus is short-lived *in situ*; it's influence lasting only 6-10 days (Nunez-Elisea & Davenport, 1992; Nunez-Elisea *et al*., 1996).

It is therefore clear that mango growth and development are strongly influenced by the environment as temperatures of below 15 ^{o}C readily promote floral induction; whereas vegetative growth is generally promoted by warmer temperatures (Whiley *et al*., 1989; Nunez-Elisea *et al*., 1991; Nunez-Elisea & Davenport, 1991a). Ravishankar *et al.* (1979), however, found that low temperature appears to exert a depressing effect on the further development of flower buds of mango. Similarly, Shu & Sheen (1987) showed that the longest period required for flower induction was when trees were exposed to 19/13°C for more than three weeks. According to an experiment conducted by Robbertse & Manyaga (1998), there is also a difference in the number of cold units (days) required by different cultivars. Critical low temperature requirement and the minimum duration necessary for that particular temperature ("chilling period") for a certain plant is determined based on the time when floral differentiation is observed for the first time and it may be variable in different cultivars (Chaikiattiyos *et al.*, 1994). A similar variable minimum temperature requirement has been reported in other plants such as tomato, sweet pepper, eggplant and rice (Blum, 1988).

There is a general agreement on the principle that a growth check of sufficient duration is necessary for synchronous floral induction in mango (van der Meulen *et al*., 1971). It is also agreed that vegetative growth and fruiting in mango trees are largely antagonistic and that excessive vegetative growth, especially in absence of a dry period, is likely to cause poor yields (Wolstenholme & Hofmeyer, 1985).

Attainment of floral induction does not necessarily ensure initiation of floral morphogenesis (Nunez-Elisea & Davenport, 1995). That means, growth of induced buds in the presence of cool temperature is essential for floral initiation, because induced apical buds that resumed

growth after trees were transferred to warm temperatures out-doors, produced a vegetative flush instead of an inflorescence. There is a certain threshold level where the buds are sufficiently induced for flowering and after attaining that level, they cannot be reverted to vegetative growth. Therefore it is decisive that buds are induced beyond the threshold level so that floral differentiation can occur. Temperature near 30 ^{o}C apparently counteracted floral development causing induced buds to continue vegetative development instead of initiating inflorescence. This response conforms to a statement by Shu & Sheen (1987) that, axillary buds that were previously exposed to cool temperatures but resumed growth in warm temperatures (31 ^{o}C day/ 25 ^{o}C night) expressed vegetative instead of floral morphogenesis.

Floral induction in mangoes, hence, is not a once off happening, but rather a continuous process lasting during the early stages of bud differentiation. The leafiness of an inflorescence would indicate the level of induction on a tree. Leafless inflorescences are an indication of total induction, while a leafy inflorescence indicates partial induction (Joubert *et al*., 1993). Leafy inflorescences normally develop when the daily mean temperature during the induction period exceeds 15 ^{0}C. Van der Meulen *et al.* (1971) stated that leafy inflorescences reflect a lack of stress and excessive tree vigour, usually associated with high soil nitrogen. Similarly, Wolstenholme & Mullins (1982) concluded that adequately stressed trees would bear no leafy inflorescences. Stress of excessive tree vigour can probably contribute to a lesser leafy inflorescence but it cannot be a factor by its own.

Initiation of apical buds was stimulated at the start of temperature treatment by defoliating shoot tips (Nunez-Elisea *et al*., 1991). Nunez-Elisea *et al*. (1993) observed that bud initiation was characterized as the swelling and initial elongation of the apex (about 5mm in height), which assures distinct conical shape, and had tightly clasped outer bud scales. Bud break is

considered the stage at which external bud scales loosened and began to open (Nunez-Elisea, 1985).

Flower sex expression

It is also apparent that temperature plays an important role in floral sex expression. Low temperatures (10 ^{0}C –15 ^{0}C) during flowering resulted in predominantly male flowers, while high temperatures favoured a higher percentage of hermaphrodite (bisexual) flowers (Tseng & Chang, 1983). Since the post-cold treatment of 25/20 ^{0}C imitates the natural conditions, it is generally expected that the total percentage hermaphrodite flowers of different cultivars would be in the region of 50-60%. Some researchers like Majumder & Mukherjee (1961); Randhawa & Damodaran (1961); Scholefield & Oag (1984) divided the inflorescence in three equal portions. As a result, they found that the apical portion had roughly 2 to 2.5 times more hermaphrodite flowers than the basal portions, but the total number of flowers in the basal portions was much higher. Joubert *et al.,* (1993) indicated that in all cultivars that had taken cold temperature and produced inflorescences, the leafless terminal inflorescences had less hermaphrodite flowers (20.9-31.5%) than the leafy terminal inflorescences (32.7-43.7%). Shawky *et al*. (1977) found that most or all of the mature fruit were borne on the apex of the inflorescence. Male flowers compete with the hermaphrodite flowers for energy. The competition in the lower portion of the inflorescence, where at least four male flowers are competing with one hermaphrodite flower, is obviously stronger than in the apical portion where a higher fruit set could be expected (Joubert *et al.,* 1993). As in the study of Joubert *et al.* (1993), Majumder & Mukherjee (1961) reported a higher percentage of hermaphrodite flowers on lateral inflorescences than on terminal inflorescences.

2.1.3 The role of growth regulators in induction

If evidence can be supplied that growth regulators can complement the process of differentiation in the induced buds or substitute the requirement of cold temperature, a farmer may escape the risk of failure of floral morphogenesis by spraying his trees with growth regulators. That is the purpose of testing growth regulators for their effect in the process of floral induction. Chilling and warm temperature treatments together with triazole retardants, PBZ and Uniconazole (UCZ), were included in an experiment on 'Tommy Atkins' mango trees, to study vegetative and reproductive developmental responses (Nunez-Elisea *et al.*, 1993). The results of the study indicated that reproductive or vegetative morphogenesis in 'Tommy Atkins' mango can be affected by temperature (Nunez-Elisea *et al.*, 1992; 1993). PBZ or UCZ, however, did not cause floral induction because vegetative, instead of reproductive (mixed or floral) buds were formed at 30/25 ^{o}C despite PBZ or UCZ pre-treatments. PBZ and UCZ sprayed trees did, however, produce nearly 20% more floral buds than non-sprayed (91 and 93% Vs 74%) and attained earlier bud break under chilling conditions. According to them, PBZ and UCZ possibly increased flowering rate by preventing shoot elongation prior to chilling treatment. They might have also caused rapid development of reproductive buds by interfering with gibberellin metabolism.

Environmental links to floral induction and evocation are generally well described (Davenport, 1993). Using such knowledge, flowering of mango can be enhanced during its normal season or manipulated to occur at other times of the year in tropical climates (Nunez-Elisea, 1985). One notable example is the use of potassium nitrate to stimulate out of season flowering of some cultivars growing at tropical latitudes (Barba, 1974); however, this treatment is not always dependable. There are a number of cultural practices (including

spraying of chemicals) that may assist in attaining of good flower development (both at on and off-seasons as well as inductive and non-inductive conditions) and consequently or directly affecting yield.

From the previous discussion in this chapter it is clear that cold temperature (below 15 ^{o}C) induces reproductive morphogenesis of buds in mango. Some growth regulators also reportedly enhance reproductive morphogenesis as a supplement to inductive temperatures even if they may not induce floral morphogenesis on their own. Under field conditions, especially in some places of the tropics, cool inductive temperatures for reproductive morphogenesis might not be attained at all or may be insufficient. These conditions only favour partial floral induction or complete vegetative morphogenesis. This is for the mere reported fact that attainment of floral induction does not necessarily ensure initiation of floral morphogenesis. Therefore, growth regulators and chemicals should be assessed for their complemental or total substitution effects (for specific cultivars) on the requirement of cold temperature for reproductive morphogenesis. The results may have special attributes to places with poor floral inductive climatic conditions or to places with frequent and sudden changes in temperature for sufficient floral induction to occur.

2.2 The impact of panicle and shoot pruning on vegetative growth, inflorescence and yield related developments in some mango cultivars.

Pruning of terminal panicles and activating axillary panicles may have advantages for better flowering and fruiting. This is basically due to a better chance of flowering in lateral buds and shifting of the flowering period to when more conducive weather conditions prevail. Post-harvest and renewal pruning of trees is also reported to be

advantageous for enabling the tree to develop new vegetative growth, that will bear the coming season's crop and removal of excess and unnecessary vegetative parts.

2.2.1 The mango inflorescence

In the mango literature, the inflorescence is called a panicle although it is in fact a thyrse. Weberling (1989) explained the difference between a panicle and a thyrse as follows: The panicle is characterized by the fact that the main axis of the inflorescence is terminated by a flower, and similarly also for all the lateral axes. The degree of branching increases more or less regularly downwards from the uppermost lateral single flower below the terminal flower, so that the complete inflorescence has a conical outline, or at least primarily so. In a panicle, or inflorescence derived from a panicle, the terminal flower assumes a dominating position. The thyrse, by contrast to the panicle, is defined as an inflorescence "with cymose partial inflorescence". By "cymose branching" is meant a branching exclusively from the axils of the prophylls, which are developed as the only leaf organs preceding the individual flowers. They usually, as in dicotyledonous plants (and in some monocots), occur in pairs and inserted in more or less transverse fashion. The branching type of the thyrse may occur either in a determinate form, where the inflorescence is provided with a terminal flower or in an indeterminate form. It is therefore clear that the mango inflorescence is a thyrse rather than a panicle. Nevertheless, since all authors refer to the mango inflorescence as a panicle, it will also be called a panicle in this thesis.

The mango inflorescence is a much-branched terminal panicle with anything from a few hundred to over 6000 flowers (Wolstenholme & Mullins, 1982). The mango is andromonoecious, which means that each inflorescence bears both hermaphrodite and

staminate flowers (Coetzer *et al*., 1995) where the staminate flowers predominate (Sedgley & Griffin, 1989). Each flower has one fertile stamen and varying numbers of staminodes, some of which are simply small thread like appendages (Coetzer *et al*., 1995). Hermaphrodite flowers have a single ovuled ovary and one functional stamen. If they are normal and pollinated, they can set into fruits. It appears, however, that many flowers containing ovaries have defective internal reproductive ovules and are therefore sterile.

Terminal inflorescences normally develop from apical buds. These inflorescences may not develop adequately due to insufficient inductive temperature or shifting of the winter periods. Diseases and insects may also affect the developed inflorescences. Growers may have the desire to shift the production to a late harvest to take advantage of off-season markets. For these reasons, panicle pruning may be advantageous.

2.2.2 Induction of axillary panicles by terminal bud removal

In mango, the removal of the apical bud or inflorescence on terminal shoots just prior to or during the flowering period results in the development of normally inhibited axillary buds proximal to the point of cutting (Reece *et al*., 1946). These buds usually develop into inflorescences, particularly if pruning is performed shortly before or after the start of normal floral bud development (Issarakraisila *et al*., 1991). If inflorescences do develop, a delay in flowering of four to eight weeks is effected (Reece *et al.*, 1946), which gives rise to a delay in harvest (Issarakraisila *et al*., 1991; Oosthuyse, 1995).

Several practical advantages have been found in the induction of axillary panicles after panicle pruning of mango (Shu, 1992). The primary advantage is to assure a good crop by escaping low winter temperatures or by compensating for the loss of panicles caused by prevailing low temperatures, frost and incessant rain (Singh *et al*., 1974). Another benefit is to substitute malformed panicles (Majumder *et al*., 1976; Pal & Chadha, 1982). Moreover, orchard owners in the central part of Taiwan have used this technique to produce off-season mango fruit (Shu & Sheen, 1987).

2.2.3 Effect of panicle pruning on flower development and cropping

Several chemicals like Cyclohexamide (Shu, 1993) have also been used in various geographical locations to de-blossom mango trees with the aim of delaying flowering to a period when conditions are more favourable for inflorescence development and fruit retention. The removal of inflorescences by chemical means was found to be useful to synchronize flowering, thereby, reducing variation in the stage of fruit growth and development prior to harvesting (Oosthuyse & Jacobs, 1996). The underlying principle in deblossoming is that the food reserves or any such substance as may induce flowering, are conserved by plucking off the inflorescence in its early stage (Singh, 1960). These reserves, according to him, are perhaps mostly depleted during later stages of fruit development. Thus the deblossomed tree, instead of developing panicles and producing fruit, puts on new vegetative growth, which flower and fruit the next year. According to Chang & Leon (1987), deblossoming of the terminal inflorescence can lead to inflorescence development from axillary buds, a 20-30 day delay in harvesting and higher yields. The yield of Mango mainly depends on the initial fruit setting and growth (Ploetz *et al.*, 1996). The large number of male flowers, a high percentage of perfect flowers which remain unpollinated and the failure of

pollen germination on the stigma are the main causes of the low percentage of set (Singh & Dhillon, 1990). Other factors reported include the failure of the gynoecium to develop properly, Thrip damage, reduction in the viability of the small quantity of pollen caused by low humidity, high temperature and bright sunlight. Despite tremendous efforts to elucidate the mechanism of this critical biological event (mango flowering) and the vast body of literature, which has resulted, many important details still elude scientists (Davenport & Nunez-Elisea, 1997).

2.2.4 Terminal shoot pruning

According to Gross (1996), pruning should maintain a good balance between growth and fruiting since a mango grower's objective is to harvest the maximum amount of marketable fruit at the lowest cost. This can be achieved, according to him, by selective pruning that will open the center of the tree, permitting air ventilation, sun for the colouring of fruit and better penetration during spraying.

Mango shoots do not flush while they are bearing fruit. In fact, fruiting appears to 'exhaust' the shoot, and it may not even flush post-harvest unless stimulated by pruning (Wolstenholme & Whiley, 1995). This is even more so in relatively cooler climates or with late harvest. Issarakraisila *et al*. (1991) found that in cool subtropical Australia only 4% of shoots that had matured a fruit, flushed after harvest. Shoots which flowered but lost their fruit had a 36% chance of flushing after harvest, while 49% of shoots which did not flower flushed after harvest.

It has been determined that the ideal time to apply terminal shoot pruning is directly after harvest (Mullins, 1986; Ram, 1993). The rationale for this inference is the allowance of maximum time for canopy recovery, shoot maturation and quiescence to maximize the likelihood of the new shoots arising after pruning to flower the next season. No direct evidence has been presented in support of this, although it has been demonstrated that older shoots are more likely to produce inflorescences than younger ones (Scholefield *et al*., 1986). The need for quiescence after flushing might be linked to the reduction of endogenous gibberellin (Chen, 1987) and the accumulation of starch reserves (Suryanarayana, 1987). New shoot development after harvest on mango cultivars like Sensation is usually delayed, occurs unevenly, or may only materialize at flowering or soon thereafter (Oosthuyse, 1994).

Pruning by enhancing post-harvest flushing to occur uniformly, may effect earlier and more complete reserve replenishment (Oosthuyse, 1994; Davie *et al*, 1995) and reduce flowering variation (Oosthuyse, 1994). The benefits of 'heading back' cuts are firstly to remove 'carbon starved, exhausted' shoots which will not fruit the next season (Wolstenholme & Whiley, 1995). Secondly, old leaves with reduced efficiency are replaced and there is a better chance to build-up carbohydrate reserves. In the prominent late cultivars like Sensation, Keitt and Kent, the time available for new shoot development after harvest and before the onset of floral inducing cool temperatures is shorter (four to ten weeks) than that for the early cultivars like Irwin, Tommy Atkins and Zill (around twelve weeks) (Oosthuyse, 1995).

As to the observations of Thimmaraju (1966) (as cited by Pandey, 1988), the absence of flushing during February, March and April followed by flushing instead of flowering during August and September resulted in crop failure. Stassen *et al*. (1999) showed that pruning a late cultivar like Sensation early after fruit set (October in South Africa) stimulated early

vegetative growth, that enabled the tree to bear a normal crop the following season. Since this also acts as a fruit thinning treatment, fruit size was significantly increased over a three-year period. On an early cultivar like Tommy Atkins, they found no significant difference in yield over a two-year period, but fruit size and external fruit colour were significantly increased.

Lack of post-harvest flush after heavy cropping may be the result of tree "exhaustion" (Narwadkar & Pandey, 1982, cited by Pandey, 1988), and can be alleviated by post-harvest pruning (Ram & Sirohi, 1991). Oosthuyse (1994) also indicated that post-harvest pruning will effect prolific and synchronous re-growth shortly after its performance, and will result in slightly delayed and more uniform flowering. The result of the latter study supports the view that the vegetative re-growth caused by pruning after harvest, elevates the level of endogenous gibberellin, and thereby effects a delay in bud development and a delay in flowering. A delay in flowering is considered to be advantageous, since inflorescence development when temperatures are higher results in an increase in the proportion of perfect as opposed to male flowers formed (Singh *et al*., 1965; Mullins, 1987), and gives rise to more effective pollination (Robbertse *et al*., 1986; Shu *et al*., 1989; Issarakraisila & Considine, 1994).

Oosthuyse (1994) indicated that many of the unpruned branches that did not produce new shoots, flowered as a result of floral development from axillary buds situated behind the scar of the previous season's inflorescences. In cultivars where a small fruit size problem occurs, as happens with Sensation, a rejuvenation pruning can be carried out on the bearing tree during October/November (Fivas & Stassen, 1995). In this case bearing shoots with weak, misshaped and small fruit are cut back. On the remaining bearers the fruit is thinned to numbers the tree can cope with, in order to get marketable sized fruit while maintaining the

annual yield. Contrary to the presumption of many researchers, pruning does not adversely affect cropping, which is, apparently due to the abundance of new shoots developing after pruning and the general ability of these shoots to produce inflorescence (Oosthuyse, 1994), provided it is done at an appropriate stage. In some instances, however, the depletion of reserves by excessive fruit produced in the previous season (especially in early cultivars) has been cited as a reason for the failure of trees to flower if pruned after harvest, despite the strong vegetative re-growth after pruning (Charnvichit *et al.,* 1991). On the other hand, the quantity of carbohydrate that a tree can produce (Oosthuyse, 1995) is directly related to the number of leaves on the tree. Removing leaves, "as" by pruning, one is reducing the tree's capacity to produce carbohydrates.

The concept of leaf: fruit ratio has been widely applied to deciduous fruit, most recently to kiwifruit, where 210-315 cm^2 of leaf area is required to produce 100 g of fruit which is a high figure compared to apple and grapefruit (Snelgar & Thorp, 1988). In mango, Chacko *et al.* (1982) noted that 30 leaves were inadequate to support the growth of a single fruit to normal size. Nevertheless, certain data expressly indicate that new mango shoots play an important role in replenishing carbohydrate reserves (Davie *et al*., 1995). Pruning should not be so severe that sunburn of fruit occurs, but should rather result in a better coloured fruit (Fivas & Grove, 1998).

Cull (1991) indicated a relationship between fruit physiological problems such as 'Jelly seed' and excessive growth vigour during fruit development, caused by too much nitrogen fertilization. This is another point indicating the need for pruning to reduce excess tree vigour. Batten *et al*. (1988) also found a positive correlation between the incidence of "jelly seed" and the percentage of terminals flushing on 'Sensation' trees in subtropical Australia.

Therefore, environmental conditions that promote vegetative bias in trees, eg. high temperatures and soil moisture would reduce internal Ca allocation to fruit and increase the incidence of fruit disorders (Schaffer *et al.*, 1994).

De Jong *et al*. (1987) while studying the yield of peaches highlighted the concept of critical periods. They found that yields of early maturing peaches were considerably less than late cultivars, in spite of a longer post-harvest period to recoup reserves. The explanation was that the period of peak reproductive assimilates demand coincided with peak shoot growth in the early cultivars, but occurred after this period in the late cultivars. In other words, lower yield of the early cultivar was due to greater vegetative: reproductive competition during a critical period.

Therefore, vegetative against reproductive competition at critical periods can lead to allocation of resources away from the economic end product (Wolstenholme, 1990). This suggests that tree manipulation such as pruning needs to be considered in timely application, which should depend on certain physiological growth stages.

From the literature assessed in general and according to Oosthuyse (1992) in particular, much has still to be quantified concerning the effect of pruning on productivity; productivity being both a function of the quantity and quality of fruit produced. Intelligent pruning can open up the canopy and improve over all light relations and this is a fertile field for research (Wolstenholme & Whiley, 1995). It is of course essential that the benefit of pruning should always outweigh the additional cost incurred as a consequence of economic benefit.

2.3 Effects of Potassium Nitrate on flowering and yield promotions of mango.

Potassium nitrate can enhance flowering especially in tropical regions where cold temperature for floral induction may not be sufficient. That is due to its reported effect in supplementing nitrogen. It is also suggested that induction by potassium nitrate spray may occur as a result of ethylene synthesis. The overall effect of potassium nitrate when sprayed at different periods of plant phenological phases, concentrations and locations as well as the mechanism for its effect is reviewed.

2.3.1 Potassium nitrate stimulating flowering and factors affecting responsiveness of plants

Subsequent to the discovery and use of ethephon to replace smudging and stimulate flowering of mango, Barba (1974) reported the use of potassium nitrate (KNO_3) for the same purpose. In subtropical regions where winter conditions are usually sufficient for floral induction, flowering enhancement by KNO_3 has not been reported (Oosthuyse, 1992). KNO_3 sprays, however, have been used to stimulate off- season flowering of mango, especially in tropical regions (Bondad & Linsangan, 1979; Nunez-Elisea, 1985). Similarly, Davenport & Nunez-Elisea (1997) found that mango trees respond to KNO_3 applications when they are located in tropical conditions, but not in the subtropics. Goguey (1993) also asserted that the response of plants to different flower inducing treatments differs according to variety, climatic conditions and geographical location.

In the low- and mid- latitude tropics, receptive trees respond by initiating floral buds within two weeks after treatment and the effective spray concentration ranges from 1 to 10% KNO_3

with the optimum concentration varying with the age of the trees and climate (Davenport & Nunez-Elisea, 1997). KNO_3 concentrations of 2-4% or 1-2% NH_4NO_3 have been found to be effective for initiating floral buds (Nunez-Elisea, 1985; Nunez-Elisea & Caldeira, 1988).

Rojas & Leal (1993) stated that the concentration of KNO_3 used to induce mango flowering varies between 10-60 mg/L, while Maas (1989) found that foliar spraying with a 2% KNO_3 solution proved to be a very effective method of inducing mango trees to bloom. KNO_3 application, especially at 4% level, was slightly phytotoxic to the leaves and inflorescences that caused the distal margins of some of the leaves and the extremities of some of the inflorescence branches to become necrotic (Oosthuyse, 1996).

Astudillo & Bondad (1978) found that the results for KNO_3 sprays were influenced by the physiological age of the growth flushes, since aged vegetative flushes (5-8 months old) responded better to KNO_3 applications than young flushes. Bondad & Linsangan (1979), on the contrary, indicated a significant increase in number of panicles formed when KNO_3 treatments were applied in the initial stage of vegetative flush growth (younger flushes), in comparison with applications made at a later stage (matured flushes). They also found that trees that had low or no production in the previous season seem to respond better to the applications of KNO_3 than trees that were productive.

Recently, Davenport (2000) explained that, for successful stimulation of flowering, the nitrate salt must be applied after the resting buds of mango have reached sufficient age to overcome any inhibitory influence they may have on the flowering response

2.3.2 Mechanisms of potassium nitrate and other related factors in altering the physiology of mango trees

In line with other findings, Bondad & Linsangan (1979) elaborated that KNO_3 could modify the flowering behaviour of mango since KNO_3 makes it possible to produce fruit every year, breaking the biennial bearing habit (alternate or irregular) and can advance the flowering and fruiting periods of mango by several months. It is also shown that KNO_3 can induce flowering of trees that remain vegetative but are well beyond normal bearing age.

Accumulation of Nitrogen has also been observed before flowering (Phatak & Pandey, 1978) since it is known that nitrogen status could be affected by foliar applications of KNO_3, but whether or not this in turn influences flower induction must await further study. Protacio (2000) also discussed the need of nitrogen for flowering as follows: “From competent tissue, flower initiation can proceed. In this model nitrogen is crucial for flowering. Presumably, there is also a threshold for nitrogen concentration that if exceeded, will allow the plant to flower. Most probably, KNO_3 application triggers flowering by exceeding this threshold level.”

Singh (1987) estimated that less than 0.1% of the hermaphrodite flowers develop into mature fruit while the rest falls to the ground. Assuming there are 100,000 flowers and each flower contains 10 micro gram of nitrogen, then each time a tree flowers, it loses 1 kilogram of nitrogen. The tree will, therefore, need to have adequate nitrogen reserves for flowering and subsequent fruit formation. Increased nitrogen fertilization via the soil has also been found to affect an increase in fruit retention and tree yield of mangoes (Smith, 1994). Hence, a nutritional effect cannot be discounted. Like nitrogen (N), phosphorous (P) has also been

reported to be associated with flowering processes (El-Hinnawy, 1956). The author emphasized the enhancement of the effects of thermo-induction by inorganic phosphorus. In mango, the high level of phosphorus in bearing shoots as compared to non-bearing shoots, further supports the above hypothesis (Thimmaraju, 1966 as cited by Pandey, 1988). The presence of higher levels of other elements like calcium, magnesium & potassium along with nitrogen & phosphorous have also been reported in bearing shoots in mango (Soni, 1967 as cited by Pandey, 1988).

Aerial applications of nutrients to mango trees have been found to be ineffective in increasing leaf nutrient status (McKenzie, 1995). This is probably due to the low absorptive capacity of the leaves. On the other hand, nutrient application when inflorescences are present may be effective in increasing the nutrient status of a tree, as the inflorescences may be more capable of nutrient uptake. KNO_3 spray application to 'Tommy Atkins' mango trees whilst the inflorescences were in full-bloom, was previously found to increase fruit retention, to reduce fruit size, and to increase tree yield and tree revenue (Oosthuyse, 1996).

The mechanism responsible for KNO_3 induction appears to be hormonally mediated but the exact relationship between KNO_3 and endogenous hormones in mango is unknown (Fierro & Ulloa, 1991). Protacio (2000) explained that the classical definition of the flowering hormone is a leaf-generated photoperiodic stimulus that induces a vegetative plant to attain the flowering state. Thus, there is a transition from a juvenile vegetative plant to a mature reproductive state due to the leaf-generated flowering hormone. He mentioned that, in a mature mango tree that has already flowered or in grafted trees, KNO_3 spray is an agent that initiates flowering from tissues already competent to flower but certainly not yet determined to be flowers. Nevertheless, the exact developmental stage, which KNO_3 affects, is still

controversial. Protacio (2000) explained further that a transitional change from juvenile vegetative to flowering state is not involved because the buds from bearing trees arose from tissues that already carry with in the flowering program. It can, therefore, be stated that KNO_3 may be a stimulus for flower initiation.

Despite poor correlation between KNO_3 application and panicle formation, hormones may establish a metabolic gradient that enhances panicle formation and uniform distribution of panicles (Fierro & Ulloa, 1991). Panicle induction by KNO_3 sprays has been suggested to occur as a result of ethylene synthesis (Barba, 1974). Chacko *et al*. (1972) has confirmed the same idea and said that this contention seems reasonable since the ethylene-releasing chemical ethephon has shown similar effects in Haden and other monoembryonic cultivars. The results from the research work of Davenport & Nunez-Elisea (1990), however, indicated that the effect of KNO_3 on flowering is not mediated by ethylene. Application of KNO_3 to scaffold branches had no influence on ethylene production either during or after the promotive period.

Results obtained with KNO_3 treatments in relation to flower promotion and fruiting has not been consistent in places such as India (Pal *et al.*, 1979 cited by Fierro & Ulloa, 1991), and Australia (Winston & Wright, 1986) or negative as in Florida (Davenport, 1987). The same was observed in experiments involving date of application, interval between applications, concentrations or component salt effects (Fierro & Ulloa, 1991). Sargent *et al*. (1996) also indicated the results obtained with KNO_3 treatments in relation to flower promotion and fruiting to be inconsistent. Some authors attribute the above-mentioned inconsistencies to the following factors: (1) inefficient application of the product; (2) physiological maturity of the plants; (3) production in the previous harvest and (4) age of the shoots. As mentioned earlier,

Goguey (1993) also asserted that the response of plants to different flower inducing treatments differs according to cultivars, climatic conditions and geographical location. The potential to increase flower formation by means of KNO_3 applications, have been suggested by a number of studies, yet more information is needed for an adequate understanding of the process (Fierro & Ulloa, 1991).

2.4 Effect of Paclobutrazol on the control of vegetative growth, leaf nutrient content, flower development, yield and fruit quality of mango.

Due to lack of pruning and factors that reduce vegetative bias (like water stress, reduced fertilization, cold temperature), trees may become excessively vegetative. The yield obtained from those trees is very low and usually bear in alternate years. Thus, the vegetative vigour of such trees should be suppressed. One method is the use of growth regulators like PBZ. Caution should, however, be taken with the use of growth regulators because of fruit residue limitations while fruit will be exported to different countries.

2.4.1 Mechanism of action towards suppressing vegetative growth and enhancing flowering

Paclobutrazol (1- (4-chlorophenyl) –4,4-dimethyl-2- (1,2,4- triazol-1-yl) pentan-3-ol) is a broad-spectrum plant growth retardant that selectively controls tree vigour without markedly affecting the size of apple, peach and plum fruit (Quinlan, 1980; Williams, 1982; Anon, 1984; Webster & Quinlan, 1984; Swietlik & Miller, 1985; Erez, 1986).

The cropping manipulations possible with PBZ ranges from off-season or early season harvests to simply increased yields (Voon *et al*., 1991). Rademacher (1989) related flowering to the inhibition of plant gibberellin synthesis and to a lesser extent to other hormones, which interfere with the plant morphogenesis. The hormonal concept of flowering in mango implies that the cyclic synthesis of floral stimulus in the leaves and the difference between two such cycles would determine the flowering behaviour of a cultivar (Kulkarni, 1986). PBZ could promote flowering in two ways: it can speed up and increase the synthesis of the floral stimulus in an inductive cycle, or, it can plausibly affect the ratio between flower promoting and flower inhibiting factors (Kulkarni, 1988). He also explained that in young grafts, the shortage of a promoting factor (because of fewer leaves) favoured the inhibitor, and PBZ could reduce the amount of inhibitor and thereby shifting the balance in favour of flower promotion. Similarly, in the case of bearing trees, increased flowering earliness was noticed in the treated trees. In other words, the flower-inductive factor may commence earlier in the season.

In a related experiment, it was also found that the presence of GA_3 inhibits the expression of competence of mango to flower. Protacio (2000) explained that mango seedlings, even if still young, are competent to flower as early as right after grafting. Villanueva (1997) as cited by Protacio (2000) stated that mango seedlings flowered seven months after grafting in response to PBZ application, confirming that young grafted plants are competent to flower. One of the principal effects of GA_3 is to mobilize carbohydrates by stimulating their degradation to glucose (Jacobson & Chandler, 1987).

Therefore in an environment where GA levels are high, no starch accumulation can take place. Jacobson & Chandler (1987) also elaborated that; this may very well explain why GA

concentration needs to fall below a certain threshold level in order to accumulate starch within the tree. This is also true in the case of tuberization in potato (Ewing, 1987).

In mature mango trees, flowering is associated with reduced vegetative growth often induced by lower activity of gibberellins (Voon *et al.*, 1991). Exogenous application of GA as well as endogenous high levels of gibberellins has proved a major hindrance in the way of flower bud differentiation in a number of temperate as well as tropical fruits including mango (Tomer, 1984). These findings have contributed greatly towards better understanding of this phenomenon. Considering the above inhibitory role of GA for flower development in mango, PBZ, owing to its anti-gibberellin activity, (Quinlan & Richardson, 1984) could induce or intensify flowering by blocking the conversion of Kaurene to Kaurenoic acid. The latter is a precursor of gibberellins.

PBZ can considerably enhance the total phenolic content of terminal buds and alter the phloem to xylem ratio of the stem (Kurian & Iyer, 1992). Such alterations could be important in restricting vegetative growth and enhancing flowering by altering assimilate partitioning and patterns of nutrient supply for new growth.

2.4.2 Application methods of PBZ and reaction of species

PBZ can be applied to mango trees as foliar spray or by soil drenching (Tongumpai *et al.*, 1991). Davenport & Nunez-Elisea (1997) elaborated that unlike the other classes of growth retardants that are normally applied in foliar sprays, PBZ is usually applied to the soil due to its low solubility and long residual activity. It was shown that when PBZ was applied to the

soil, a portion is adsorbed onto the soil particles and is unavailable for immediate uptake; the chemical is also subjected to degradation by soil organisms (Pickard *et al.*, 1982).

Reports on PBZ in temperate tree fruit, show differences between species and locations in responses to methods of application. In England, soil treatment is generally effective in controlling shoot growth in cherry but not in apple (Quinlan, 1980; Quinlan & Richardson, 1984) whereas in the U.S.A., soil treatment was more efficient on apples (Williams, 1984). With plum, although foliar sprays were more effective than soil drenches in the season of application, soil drenching was more effective in the subsequent years (Webster & Quinlan, 1984).

In Israel, soil application was more effective than foliar sprays on peach (Erez, 1986). Failure or limited response to foliar sprays was generally attributed to reduced uptake in the dry conditions prevailing at that station, whereas higher efficacy of soil application in lighter soils and in irrigated orchards was attributed to better movement of the chemical towards the superficial roots (Anon, 1984).

PBZ is taken up through the root system and is transported primarily in the xylem through the stem and accumulated in the leaves and fruit if applied to the soil (Wang *et al.*, 1986). Voon *et al.* (1991) explained that PBZ is systemic and can be taken up by plant roots or through lenticels and bark perforations while foliar sprays uptake occurs through shoot tips, young stems and leaves. PBZ, being xylem mobile moves upwards with the transpiration stream (Lever *et al.*, 1982).

2.4.3 Application rates

A lot has been done to identify the best application rate of PBZ in different places. Factors like age of the trees, extent of vegetative growth and method of application should be considered when determining the rate of PBZ to be applied. The rates also affect the different tree parameters variously. In general, the amount of PBZ required to promote flowering and fruiting in fruit crops is very low (Browning *et al.,* 1992).

In general, rate of soil application is a function of tree size and cultivar. The rate is determined by multiplying the diameter of tree canopy in meters by 1 to 1.5 gram of active ingredients of PBZ (Tongumpai *et al.,* 1991). They indicated that other factors including soil type, irrigation system, etc. may affect PBZ activity and thus may be necessary to improve the effectiveness of the chemical. As to them, overdose may cause undesirable effects such as restricted growth, panicle malformation (too compact), and shoot deformity. They also asserted that to insure uniform flowering and reduce the detrimental side effects, the search for better application methods were investigated and one approach is to apply high volume of low PBZ concentration to improve better coverage.

2.4.4 Attributes on different tree aspects

Flowering

It is evident from the results of Burondkar & Gunjate (1993) that PBZ application increased the number of flowering shoots. In a related experiment, Tongumpai *et al.* (1991) noticed that the number of flowering shoots of all PBZ treated trees were twice as high as that of the

control. Kulkarni (1988) also observed increased flowering earliness in the treated trees. In other words, the flower-inductive factor may commence earlier in the season. Induction for an early flowering (Burondkar & Gunjate, 1993) may also advance fruit maturity and hence have another commercial advantage. Similar results were also reported in different important mango cultivars from Australia (Winston, 1992), Indonesia (Voon *et al.*, 1991), Thailand (Tongumpai *et al.*, 1991) and India (Kulkarni, 1988). It is probable that the application of PBZ caused an early reduction of endogenous gibberellins levels within the shoots (Anon, 1984), causing them to reach maturity earlier than those of untreated trees.

Vegetative growth

Excessive vegetative growth in the warm subtropical climates, like that of the South African lowveld results in large trees on most mango varieties, which promoted the evaluation of PBZ (Cultar) for growth suppression (Rowley, 1990) and PBZ has already proven to be an effective growth suppressant of stone fruit trees (Williams *et al.*, 1985). PBZ has the greatest effect on tissues, which are rapidly growing and developing (Steffens *et al.*, 1985), that could explain why PBZ predominantly affected the apical growth. Vijayalakshmi & Srinivasan (1999) found that, application of PBZ was found to be significantly superior in increasing the leaf area compared to other treatments like potassium nitrate, urea and ethrel recording an average area of 94.89 cm^2 where as the control was only 63.65 cm^2. According to them, the increase in leaf area has overcome the limitation of depletion for reserve food materials. As the reserve food materials were then plenty, the breaking up of alternate bearing cycle in the cultivars chosen has been achieved. However this was found to be contradictory to the findings of Embree & William (1987) and Kurian & Iyer (1993) who reported a decrease in leaf area with PBZ in pears and mangoes respectively.

According to the experiments of Kurian & Iyer (1993), PBZ at a concentration of 10.0 g per tree was the most effective and practically arrested tree growth but had some phytotoxic effects. In their experiment, when PBZ was applied at a rate of 2.5 or 5.0 g per tree, there was more than 50% reduction in tree volume expansion, with no phytotoxicity. While, independent of the methods (Spray or soil drench) and the concentrations, they found PBZ application to reduce size of leaves.

Leaf mineral content

Salazar-Gracia & Vazquez-Valdivia (1997) discussed that their results of an experiment with PBZ on mango trees support the work of Werner (1993) on young non-bearing trees in that soil application of PBZ decreased foliar levels of phosphorous. Leal *et al.* (2000), however, found that there was no effect of PBZ on the macronutrient content of the leaves and the statistical difference found were due to difference in tree phenological stages.

Yield

There is usually a yield increase associated with PBZ treatments, but Voon *et al.* (1991) emphasized the importance of supplying adequate nutrients, irrigation and generally good tree maintenance to maintain these high yields. In the experiments of Medonca *et al.* (2002), PBZ increased the productivity of 'Tommy Atkins'. Most other researchers also indicated that PBZ treated trees had a higher yield than non-treated.

Fruit quality

With the experiments of Medonca *et al*. (2002), there was no impact of PBZ on fruit quality parameters. On the other hand, a trial was conducted in India with 10 year old trees of Alphonso mangoes (Vijayalakshmi & Srinivasan, 2000). The trees were treated with 10 ml PBZ per tree, 1% KNO_3, 1% urea, 200 ppm Ethrel, 20 ppm NAA or 5000 ppm Mepiquat chlorode. They recorded data on ascorbic acid, carotene, total sugar and reducing sugar contents, TSS, acidity, and sugar: acid ratio in harvested fruit and concluded that applying 10 ml PBZ had the greatest effect, increasing all the parameters except for acidity. However, even if PBZ increased quality of fruits, it was ascertained that the accumulation of PBZ residues on the surface or inside mango fruit (especially due applications of higher rates) is unfriendly to human health (Singh & Ram, 2000).

The use of retardants for mangoes has not been sufficiently investigated (Werner, 1993). Whereas results for Asian and other mango varieties treated with PBZ are available and promising (Kulkarni, 1988; Voon *et al.*, 1991). Therefore, more investigation is expected to reach a final conclusion.

2.5 Effects of fruit thinning on some yield and fruit quality components as well as starch reserves of mango.

Production of excess fruit during initial fruit bearing stage is a common phenomenon in many fruit trees. The production of excess fruit beyond the tree's capacity leads to wastage of carbohydrate reserves and consequently reduces the final yield and quality of fruits as well as vegetative growth of trees.

2.5.1 Effect of excess fruit load on plant reserves and current assimilates

The mango has a worldwide reputation of being a poor yielding crop, and this poor yield may be worsened by irregular bearing (Wolstenholme & Robert, 1991). Many mango trees set a very large number of fruit that are normally nurtured to an advanced stage before abscission reduces the crop to a level the tree can handle (Davie & Stassen, 1997b). They also stated that if a tree that has set a large crop is left to its own devices, it will tend to abscise far more fruit than is necessary, thus reducing the yield to below levels the tree is in fact capable of supporting. Figures available for nine-year-old 'Haden' mangoes indicate that the maximum retention of fruit set was about five percent (Nunez-Elisea, 1985).

The delay in ridding itself of the excess fruit results in wastage of carbohydrate, which is eventually reflected in the smaller size of the remaining fruit. Commercially it is frequently desirable to have a smaller number of large fruit rather than a large number of small ones (Jackson, 1989). In general, there would appear to be an order of priority among plant sinks with developing fruit and seeds being the strongest (Wright, 1989). Janse van Vuuren *et al.* (1997) stated that as much as 65% of the starch of plants in an "on" year is finally channelled to the fruit. Fruit thinning may therefore be the answer for starch conservation. They also found that the bulk of the tree carbohydrate reserves are found in the roots, wood and to a lesser extent in the shoots. The heavy nutritional demands of fruiting distort carbon partitioning among vegetative parts including the root/shoot balance (Wolstenholme, 1990). As to the latter, the order of priority among sinks is a function of both growth rate (sink activity) and the size of the sinks. It is usually in order as follows: seeds > fleshy fruit parts as well as shoot apices and leaves > cambium > roots > storage. In other words, fruiting will firstly deplete storage reserves, then withhold assimilates from root growth (Cannell, 1985).

2.5.2 Effect of fruiting on flowering

The effects of fruiting on flower initiation are also well documented and most researches indicated heavy fruiting in one-year leads to poor flower initiation and light fruiting the following year (Wright, 1989). According to Wright (1989), developing fruit also compete with each other and the common effect of such competition is premature fruit abortion that occurs in a wide range of species.

2.5.3 Effect of fruiting on vegetative plant parts

A reduction in dry matter partitioning to shoots, leaves and roots due to fruiting has been demonstrated in a wide range of species (Wright, 1989). In apple, Heim *et al.* (1979) has shown a reduction in shoot and leaf production with increasing fruit load. He elaborated that the effects of fruiting on stem dry matter accumulation was specially severe, accounting for over 40% of the dry matter fixed in non-fruiting apple tree stems compared with just over 10% for heavily fruiting tree stems.

2.5.4 Effect of fruit thinning on fruit size and fruit quality

In thinning fruit by hand, the larger fruit are usually retained when differences in fruit size are apparent (Williams, 1979; McVeigh, 1994). In an experiment to determine the effect of fruit thinning on fruit drop and fruit size, Davie *et al.* (1995) found that the timely reduction in the number of mango fruit on the tree, to a quantity the tree can cope with, greatly reduced further fruit drop and at the same time resulted in a 15% increase in fruit size. Knight (1980) working with ‘Cox’s orange Pippin’ apple found that

thinning by removing 70% of the fruit clusters significantly increased individual fruit size and did not affect total yield compared to unthinned controls. He also found that partial tree fruit thinning was not effective as selective whole tree thinning and the best results were obtained by thinning within fruit clusters suggesting that the competitive effects are rather localized.

Fruit thinning, by reducing competition for carbohydrates between fruit (Horscroft & Sharples, 1987), also improves fruit quality in terms of firmness, soluble solids content and anthocyanin formation hence red skin colour. The effects of fruit thinning on market quality appear to result from reducing competition for assimilates; its effect on biennial bearing seems to result from reducing the supply of seed- produced hormones which inhibit flower bud formation (Jackson, 1989).

2.5.5 The phenomena of tree reserves and its implication

Many of the problems associated with mango fruit production have been ascribed to insufficient carbohydrate reserves in the tree structures. It may also be due to the inability of the tree to supply sufficient carbohydrate from current photosynthate production in order to meet the demand of a heavy fruit load (Davie *et al.,* 1999). This is because the growth of a tree and the production of fruit depend on the ability of a tree to produce and store carbohydrates (Oliveira & Priestley, 1988).

Cull (1991) mentioned that the photosynthetic capacity of the tree regulates the supply of carbohydrate, with a high percentage of the photosynthate accumulated and being utilized by the respiration processes of the tree (Kozlowski, 1992). This process provides the energy for

the morphological development of the plant. Photosynthate also has to supply the structural units for innumerable organic compounds for which the proteins, sugars, colours and flavour compounds produced in the tree and fruit (Priestley, 1963). The excess carbohydrate is then stored usually in the form of starch (Stassen, 1980; Davie & Stassen, 1997a).

Developing fruit have often been reported to increase individual leaf photosynthesis rates in tree crops, including citrus, peach and apple (Wolstenholme, 1990). De Jong (1986) attributed this to increased stomatal conductance in the presence of fruit. However, a comprehensive study on sweet cherry (Roper *et al.*, 1988) found no differences in photosynthesis between fruiting and non-fruiting plants, although the former had lower carbohydrate levels.

The starch content of fruit trees follows an annual pattern of accumulation and utilization (Davie *et al.*, 1995) and the root and wood of trees are particularly important as storage organs (Davie *et al.*, 1999). It is clearly shown from their work that the starch reserves remain at their lowest levels during the period of rapid fruit growth. Results illustrate that the roots, wood, shoots, bark and even the leaves accumulate starch during the winter and that the reserves are then drastically depleted during the spring and summer (Stassen & Janse van Vuuren, 1997a; b). Davie & Stassen (1997a) generally concluded that the phenomenon of biennial or alternate bearing in subtropical tree crops stems primarily from the depletion of the starch reserves of the tree during fruit production and development. This drain in the tree resources leaves it unable to rapidly replenish its reserves in order to meet the demand of the new cycle of vegetative growth, flowering, fruit set and fruit development.

There would seem to be two sets of situations which may cause biennial bearing: either a very low fruiting year, often caused by adverse environmental factors at flowering, or a very heavy fruit set with too little fruit drop (Wright, 1989). Monselise & Goldschmidit (1982) stated that heavy crops produced during the on-year, is the most universally recognized cause of alternation and that starch levels in an off-year are much higher than in an on-year. Davie & van der Walt (1994) found that the point in time when the 'switch' to an on- or- off- year season is determined long before the fruit development stage and it may be just before or after harvest. Stassen *et al*. (1982) concluded, it is therefore clear that the canalising of carbohydrate reserves can be redirected by means of fruit and tree manipulation as well as with other cultivation practices. In other words, the depleting effects of fruit load on starch reserves can be altered by fruit thinning and tree pruning (Davie & Stassen, 1997a; Stassen *et al.*, 1999).

Generally, sufficient reports on fruit thinning in mango are lacking (Oosthuyse & Jacobs, 1995). This might be expected since poor fruit retention is still considered to be a major problem in mango. Most of the studies conducted to date, with regard to fruit thinning and tree manipulation are basic and encourage further study.

CHAPTER 3

EFFECT OF FRUIT THINNING ON 'SENSATION' MANGO (*MANGIFERA INDICA*) TREES WITH RESPECT TO FRUIT QUALITY, QUANTITY AND TREE PHENOLOGY.

3.1 ABSTRACT

Different fruit thinning methods (various intensities in manual fruit thinning as well as a chemical thinner) were tested on 'Sensation' mango trees both as initial and cumulative effects during two seasons (2001/2002 and 2002/2003). The trial was conducted at Bavaria Estate, in the Hoedspruit area, Northern Province of South Africa. The thinning treatments were carried out in October before the occurrence of excessive natural fruit drop. The objective of the study was to select the best thinning intensity or method, based on their impacts on different parameters. Where fruit on 'Sensation' were thinned to one and two fruit per panicle, a significant increase was obtained for most of the fruit quantitative yield parameters. With the treatments where one fruit and two fruit per panicle were retained and 50% of the panicles removed, a significant increase in fruit size was noted. The same trees also produced higher figures for most of the fruit qualitative parameters as well as fruit retention percentage. However, the trend showed that bigger sized fruit were prone to a higher incidence of physiological problems, especially jelly seed. Chemical fruit thinning with Corasil.E produced very small sized fruit with a considerable percentage of "mules"

(fruit without seed). Trees subjected to severe thinning intensities showed earlier revival of starch reserves and better vegetative growth.

Key words: fruit per panicle, fruit quantity, fruit quality

- **Published in *Experimental Agriculture*, vol 40(4), pp. 1-12. (Cambridge University Press)**

3.2 INTRODUCTION

Within a reproductive cycle, it is apparent that many plants produce far more flowers than they could possibly support as fruit. Many mango cultivars in general, and 'Sensation' in particular, set a huge number of fruit of which more than half are abscised from the tree prior to harvest. Consequently, with no human interference, a tree that has set a large crop will tend to abscise far more fruit, than if the fruit on the trees were thinned beforehand, thus reducing the yield to below levels the tree is capable of supporting (Davie & Stassen, 1997b). Therefore, the delay in ridding itself of the excess fruit results in wastage of carbohydrate, which is eventually reflected in the smaller size of the remaining fruit. Commercially, it is frequently desirable to have a smaller number of large fruits rather than a large number of small ones (Jackson, 1989). Janse Van Vuuren *et al.* (1997) indicated that as much as 65% of the starch of plants in an "on" year is finally channelled to the fruit. Hence, heavy fruiting in one-year, leads to poor flower initiation and light fruiting the following year (Wright, 1989). Generally, the tree size and its carbohydrate storage capacity is one of the most important factors that determine the number of fruit the tree can nurture to maturity (Davie *et al*., 1995). Fruit thinning may therefore be the answer for starch conservation and regular bearing.

Manual or chemical thinning of blossoms or fruit to enhance fruit size is practiced in a number of fruit crops. Knight (1980) working with 'Cox's Orange Pippin' apple found that 'part tree' fruit thinning was not as effective as selective 'whole tree' thinning. The best results were obtained by thinning within fruit clusters, suggesting that the competitive

effects are rather localised. This indicates that, if accurate fruit thinning is required, the number of individual fruit per cluster should be reduced rather than removing all the fruit on a portion of the cluster (Knight & Jackson, 1980). Corasil.E is an emulsifiable concentrate plant growth regulator basically used for improving the fruit size of mandarin and orange. Its effect on mango fruit size was studied in the current study. It is generally recognised that the effect of thinning is most pronounced when performed early, i.e., at or soon after full bloom or at or soon after initial fruit set (Richardson & Dawson, 1994). In an experiment to determine the effect of fruit thinning on fruit drop and fruit size, Davie *et al.* (1995) found that the timely reduction in the number of mango fruits on the tree, to a quantity the tree can cope with, greatly reduced further fruit drop and at the same time resulted in a 15% increase in fruit size. Fruit thinning, by reducing competition for carbohydrates between fruits (Horscroft & Sharples, 1987), also improves fruit quality in terms of firmness, soluble solids content and anthocyanin formation, hence red skin colour. The effects of fruit thinning on market quality appear to result from reducing competition for assimilates. Its effect on biennial bearing seems to result from reducing the supply of seed-produced hormones which inhibit fruit bud formation (Jackson, 1989). Even if the effect of thinning has been evaluated, there was no investigation as to how and how many fruit to be thinned. Mango cultivars like Sensation produces small and poor export quality fruit that can be improved by applying suitable fruit thinning intensity. Nevertheless, there is no information about the effects of specific thinning intensities on mango production and fruit quality. Thinning spontaneously may affect tree reserves as well as may lead to unnecessary loss of crop. This necessitated conducting an experiment on different fruit thinning methods and intensities. This study reports on fruit thinning experiments done on 'Sensation' mango trees from which South Africa is getting considerable export income.

3.3 MATERIALS AND METHODS

3.3.1 Area description

The trial was conducted at Bavaria Estate, in Hoedspruit area, Northern Province of South Africa (latitude: 24^0 25'S; longitude: 30^0 54'E; elevation: 600 m.a.s.l.) during 2001/2002 and 2002/2003 seasons.

3.3.2 Plant material

After flowering, seventy-two (8-year-old) and sixty-three (9-year-old) 'Sensation' mango trees of uniform size and vigour were selected to study the initial as well as cumulative effects of treatments. All treatment trees were subjected to the standard orchard management practices as applied at the Fruit Estate.

3.3.3 Treatments applied

The total number of fruit on each tree was counted during early October 2001 and 2002 before applying the treatments. The average number of fruit per tree at that time was more than 250 fruit of varying size (each fruit being approximately 15 mm. in diameter). Various treatments were applied in different seasons and experimental groups (1a, 1b and 2) (Table 3.1). Since experiment 1b was the continuation of 1a during the subsequent season, the results of only experiments 1b and 2 were compared with each other in order to determine

season-by-treatment interactions in the result and discussion. The details of the three separate experiments are presented in Table 3.1 below.

Table 3.1 Details of treatments applied and their treatment codes according to the seasons and various experiments conducted

Treatments	Experiments/Seasons		
	1a (2001-2002)	1b (2002-2003)	2 (2002-2003)
1	†Removing all fruit (No result for first harvest)	‡All fruit retained	Spraying trees with Corasil.E as a chemical fruit thinner
2	Thinning fruit to one fruit per panicle	Thinning fruit to one fruit per panicle	Thinning fruit to one fruit per panicle
3	Thinning fruit to one fruit per panicle and removing 50% of the panicles	Thinning fruit to one fruit per panicle and removing 50% of the panicles	Thinning fruit to one fruit per panicle and removing 50% of the panicles
4	Thinning fruit to two fruit per panicle	Thinning fruit to two fruit per panicle	Thinning fruit to two fruit per panicle
5	Thinning fruit to two fruit per panicle and removing 50% of the panicles	Thinning fruit to two fruit per panicle and removing 50% of the panicles	Thinning fruit to two fruit per panicle and removing 50% of the panicles
6	Control (No thinning)	Control (No thinning)	Retain average sized fruit
7	----------	----------	Control (No hand or chemical thinning)

† There was no result for treatment 1 in 2001-2002 season due to removal of all fruit

‡ A continuation of experiment 1a where all fruit in treatment 1 was retained to evaluate effects for treatment 1 of experiment 1a

NB: During launching experiment 2, trees were sprayed with Corasil.E as one treatment that has an active ingredient of Dichlorprop (as 2-butoxyethyl ester) 50g/l.

3.3.4 Parameters studied and design used

In experiment 2, the trees were sprayed with Corasil.E (treatment 1). It has Dichlorprop (as 2-butoxyethyl ester) as an active ingredient. Quantitative as well as qualitative parameters were measured in all the three trials, but due to cost implications, only experiment 1a was considered for starch analysis and measurement of vegetative growth parameters. Accordingly, the following parameters were evaluated:

Yield

The fruit left on each tree was counted after applying the treatments. During harvesting, on 6 February 2002 and 1 February 2003, for the first and second season experiments respectively, the number of fruit retained on each of the trial trees were counted to calculate fruit retention percentage and then weighed to calculate yield based on tree spacing, and was finally presented as t ha^{-1}.

Fruit quality

Different fruit quality parameters were also measured after shipping simulation by storing the fruit for 28 days at 10 ^{0}C and ripening them at room temperature for two days. All the sampled fruit passed through the commercial pack house procedures. For this purpose, two representative fruit from three size groups (small≈30mm, medium≈50mm, large≈70mm in diameter) of each tree were taken for recording specific parameters: The total soluble solids (TSS) was measured using a EUROMEX handheld digital refractometer. The titratable acid (TA) was measured after preparing the sample by mixing the pulp of the six sampled fruits per tree and mixing them together with a juicer. The samples were centrifuged for ten

minutes at 1000-rpm intensity. The floating fluid on top of the sedimented pulp from the centrifuge was then diluted to 1:4 with deionised water and titrated using a METTLER TOLEDO DL 25 (Mettler-Toledo Inc., USA) Titrator, using 0.1 N sodium hydroxide solution. The titratable acid is expressed in m eq l^{-1}. The fruit firmness was measured using 8 mm diameter Penetrometer probe, after peeling a portion of the exocarp and expressed as kg cm^{-2}. Presence of any physiological defects in the fruit, particularly jelly seed, was assessed using Fivas's (1997) guidelines.

Vegetative growth

Vegetative growth data was taken on May 2002, once new shoot development had ceased. The total number of new flushes developed, the length of twenty randomly selected new flushes, number of leaves per new flush and the length as well as width of forty newly developed leaves randomly selected from the whole tree canopy was measured. The leaf area of each of the forty leaves measured was calculated using the formula:

$$Y= -0.146+0.706X \ (r^2=0.995)$$

where Y= leaf area (cm^2) and X = leaf length (cm) × leaf width (cm) (Nii *et al.*, 1995). It is expressed in cm^2.

3.3.5 Starch analysis

Wood, bark, leaf and fruit samples were also taken from each of the trial trees for starch analysis. Wood samples for analysis were collected immediately before applying the treatments (24 October 2001), during peak fruit development stage (10 January 2002), soon

after harvest (8 March 2002), during rest period (3 May 2002) as well as during bud maturation and burst period (10 July 2002). Due to cost implications, bark, leaf and fruit samples for analysis were collected during October 24-2001 and January 10-2002 representing starch status of the samples before treatment application and during peak fruit development stage, respectively. In all stages, fresh and disease free samples were collected. The sampled plant parts were oven dried at 70 ^{o}C before the starch analysis. The starch analysis was conducted according to the AOAC (1980) procedure, but the enzyme chromogen reagent was prepared with 4-amino-antipyrine instead of orthodianisidine as recommended by Karkalas (1985). In addition a further modification was introduced in order to remove any interfering substances (phenolics) as per the method used by Davie & Stassen (1997a). The periods when samples were collected represent different tree phenological phases and the reason for this was to identify possible relationships between starch content and tree phenological phases as influenced by the treatments. The starch results are expressed as mg g^{-1} dry matter.

A randomised complete block design was used with three blocks and four trees (experiment 1a and 1b) and three trees (experiment 2) per plot. The trees on the outermost rows of all the blocks were not used as treatment trees to avoid border effects. Besides, a movable canvas shield was used to cover a tree when it was being sprayed with Corasil.E, to prevent spray drift contamination to other trees.

3.3.6 Statistical analysis

Analysis of variance (ANOVA) was used for the two cultivars separately to test differences among thinning treatments in each season separately and combined. The test for the data distribution proved to be normal with homogeneous treatment variances. The data was analysed using GenStat (2000). Treatment means were separated using Fishers' protected t-test least significant difference (LSD) at the 5% level of significance (Snedecor & Cochran, 1980).

3.4 RESULTS

3.4.1 Quantitative parameters

The results of the quantitative parameters of the different experiments are summarised in Tables 3.2 and 3.3. As expected with no thinning, the control trees bore a significantly higher number of fruit when counted immediately after treatment application (Table 3.2). Treatments 2 and 4 (1fr/pan and 2fr/pan) had a significantly higher number of fruit at harvest for experiments 1a (179 and 182) and 1b (181 and 186) respectively (Tables 3.2 and 3.3). Treatment 1 (Corasil.E) showed the highest number of fruit (191) for experiment 2 (Table 3.3).

In the current experiment, trees treated with Corasil.E, in spite of producing smaller sized fruit, retained more fruit per tree. As would be expected, it was observed that, when a higher number of fruit was left on the tree (no thinning or less thinning intensity) the lower

was the fruit retention percentage (Tables 3.2 and 3.3). Consequently, treatment 3---1fr/pan+50%pan had 26.5% increment in the percentages of fruit retained as compared to the control. The same trend was followed for fruit mass and hence there was a relationship between thinning intensity and the individual as well as average fruit weight at harvest. The treatment with the highest thinning intensity (treatment 3---1fr/pan+50%pan) produced a significantly higher average fruit weight (346 g) as compared to the control (331 g) in experiment 1a (Table 3.2).

The result was also significantly higher than all the other treatments. In experiments 1b and 2, the same trend as above was seen except that treatment 2 (1fr/pan) showed a better average fruit weight (340 and 338 g respectively) equivalent to treatment 3 (1fr/pan+50%pan) (347 and 337 g respectively) (Table 3.3). The lowest fruit mass was recorded for the control trees of experiment 1a (331 g) and treatment 1 (all fruits thinned and Corasil.E sprayed) of experiments 1b and 2 (327 and 245 g) respectively (Tables 3.2 and 3.3). Fruit size variations and distribution of fruit in different counts (number of fruit per box) due to the treatments are shown in Fig. 3.1, 3.2 and 3.3.

In these experiments, leaving one or two fruit per panicle proved to increase the yield significantly higher than all the other treatments for all the three trials (Tables 3.2 and 3.3). There was a 6.5 and 7% yield increment after application of treatment 2 (1fr/pan) and treatment 4 (2fr/pan) respectively, as compared to the control in experiment 1a. In experiment 1b and 2, the two treatments had 8.4/8.2 and 8.7/7 % yield increment over the control.

Table 3.2 Mean fruit quantitative and qualitative data of 'Sensation' for experiment 1a

Thinning treatments	FNAT	FNAH	FRP	AFWAH	Y	FIRM	TSS	pH	TA	PP
2(1fr/pan)	213b	179cd	83.9bc	340bc	27.8cd	0.71a	16.2bc	4.2abc	65.9a	13.9a
3(1fr/pan+50%pan)	189c	163b	86.9d	346d	25.8a	1.02c	16.3c	4.1ab	63.7a	15.3a
4(2fr/pan)	225d	182d	81.1b	335ab	27.9d	0.80ab	15.1ab	4.4bcd	67.9a	11.1a
5(2fr/pan+50%pan)	201e	170a	84.5cd	340c	26.4ab	1.13c	16.2bc	4.0a	66.7a	13.9a
6(control)	251a	173ac	68.7a	331a	26.1ab	0.82ab	13.7a	4.4bcd	69.7a	11.1a

Means followed by different letters in the same column are significantly different by LSD test at P<0.05

Keys

FNAT: Fruit number after treatment

FRP: Fruit retention percentage (%)

AFWAH: Average fruit weight at harvest (g)

Y: Yield (t ha^{-1})

FIRM: Firmness (kg cm^{-2})

TSS: Total soluble solids (^{o}Brix)

TA: Titratable acids (m eq l^{-1})

PP: Physiological problem (%)

'mule' and small sized fruit

Figure 3.1 Fruits harvested from the treatments of all fruits thinned (A) and Corasil. E chemical fruit thinning (B) in experiments 1b and 2 during 2002-2003 season.

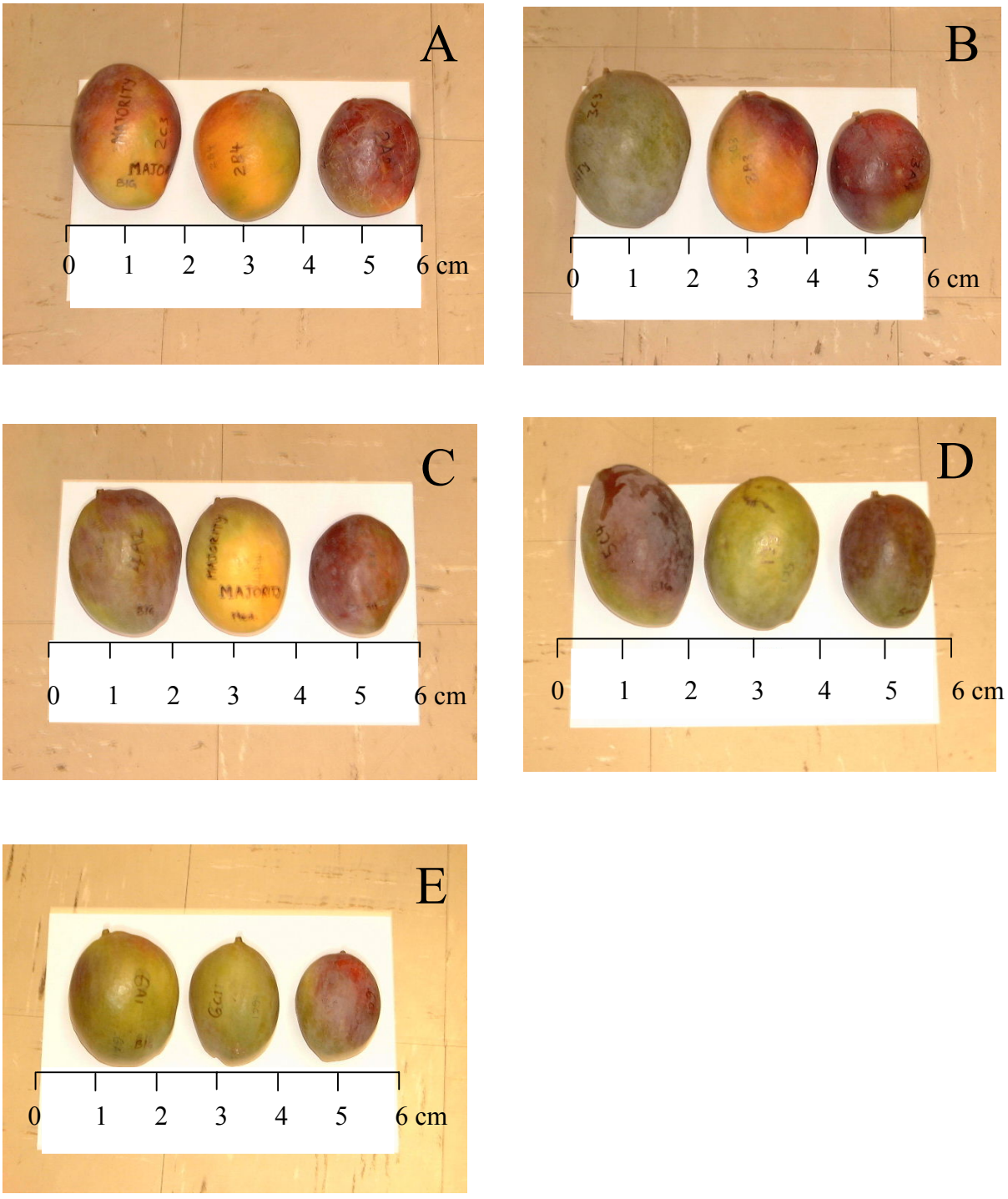

Figure 3.2 **Fruit size groups among treatments and their majority category for experiment 1a: (A) 1fruit per panicle; Majority, big. (B) 1fruit per panicle and 50% panicles removed; Majority, big. (C) 2 fruits per panicle; Majority, medium. (D) 2 fruits per panicle and 50% panicles removed; Majority, big. (E) No thinning (control); Majority, small.**

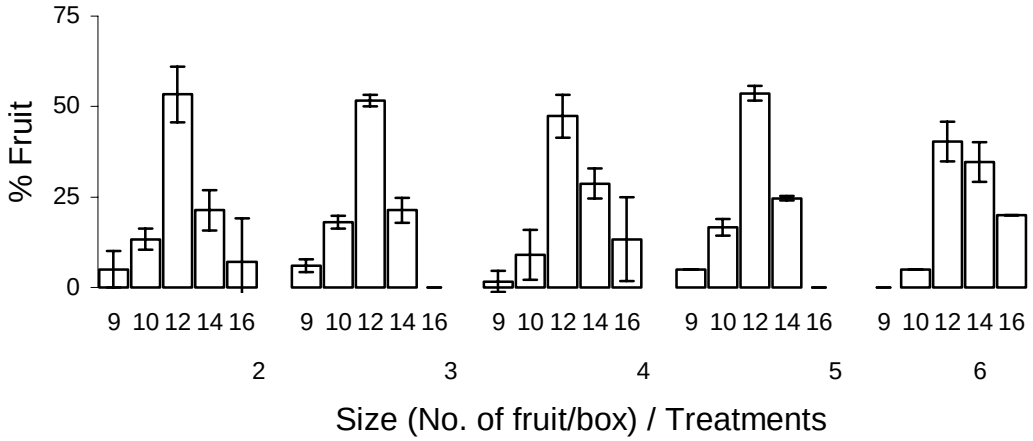

Figure 3.3 **Size group (fruit/box) distribution of fruits due to treatments during February 6 2002 harvest. Line bars indicate standard deviations with in the size groups.**

Keys for Fig. 3.3

Grade	9	10	12	14	16
Wt. (g)	439-472	350-438	295-349	241-294	220-240

Treatments:

2-One fruit per panicle

3-One fruit per panicle & 50% of panicles removed

4-Two fruits per panicle

5-Two fruits per panicle & 50% of panicles removed

6-Control

Table 3.3 Mean quantitative yield data of 'Sensation' fruit for experiments 1b and 2

Thinning treatments	No. of fruit per tree at harvest		Fruit retention (%)		Average fruit weight (g)		Yield (t ha^{-1})	
	Exp. 1b	Exp. 2	Exp. 1b	Exp. 2	Exp. 1b	Exp. 2	Exp. 1b	Exp. 2
1(all thinned (exp.1b)/ Corasil.E (exp. 2))	179a	191a	83.0a	78.0bc	327a	245a	27.1a	21.6a
2(1fr/pan)	181ab	177bc	80.0ab	76.0ab	340bc	338c	28.5b	27.8c
3(1fr/pan+50%pan)	167d	160e	85.0a	82.0c	347c	337c	26.7a	24.8b
4(2fr/pan)	186b	179b	76.0b	72.0a	333ab	331bc	28.6b	27.5c
5(2fr/pan+50%pan)	172c	167de	79.0ab	77.0b	339b	336c	26.9a	26.1b
6(control/av. fr.)	173c	166de	60.0c	80.0bc	328a	334bc	26.3a	25.7b
7(control)	--------	170e	--------	62.0d	--------	328b	--------	25.7b

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

3.4.2 Qualitative parameters

The results for the qualitative parameters for the different experiments are summarised in Tables 3.2 and 3.4. There was a slight difference in the pH of the fruit juice among the treatments, where the lowest acidity (high pH) was recorded for treatment 5 (2fr/pan+50%pan) in experiments 1b (5.06) and 2 (5.03) (Table 3.4). The result was not significantly different between all treatments except treatment 4 (2fr/pan) and the control. Thinning treatments did not affect the titratable acids of the fruits in experiments 1a and 2. However, a significantly higher TA was recorded for treatments 4 (2fr/pan) (72 m eq/l) and the control (73.8 m eq/l) in experiment 1b (Table 3.4). There was a significantly higher TSS (16.3 ^{o}Brix) for treatment 3 (1fr/pan+50%pan) in experiment 1a, which was not

significantly different from treatments 2 (1fr/pan) (16.2 ^{o}Brix) and 5 (2fr/pan+50%pan) (16.2 ^{o}Brix) (Table 3.2). In experiments 1b and 2, fruit from the control trees recorded a significantly lower TSS (15 and 15.07 ^{o}Brix respectively) as compared to all treatments except treatment 4 (2fr/pan) (15.8 ^{o}Brix) in experiment 2 (Table 3.4). In experiment 2, fruit were significantly firm from trees sprayed with Corasil.E and where treatment 5 (2fr/pan+50%pan) was applied. In experiment 1a fruit from trees where treatment 3 and 5 were applied had firm fruit. There was no significant difference in fruit firmness among treatments in experiment 1b. On the other hand, even if there was no significant difference, the highest incidence of the physiological problem (jelly seed) was observed for treatment 3 (1fr/pan+50%pan) while the lowest for treatment 1 (Corasil.E) (Table 3.4).

Table 3.4 Mean fruit qualitative data of 'Sensation' fruit for experiments 1b & 2

Thinning treatments	TSS (^{o}Brix)		pH		Titratable acids (m eq/l)		Firmness (kg/cm^2)		Physiological problems (%fruits)	
	Exp.1b	Exp.2	Exp.1b	Exp.2	Exp.1b	Exp.2	Exp.1b	Exp.2	Exp.1b	Exp.2
1(all thinned/Corasil.E)	17.1a	17.0ac	5.96a	4.88bc	56.4a	62.0a	1.38a	2.13c	11.8a	10.1a
2(1fr/pan)	16.9a	17.0ac	4.95a	4.83ab	60.0a	64.0a	1.43a	1.64a	12.4a	11.8a
3(1fr/pan+50%pan)	17.8a	17.4ac	5.00a	4.97bc	53.0a	56.0a	1.83a	1.82ab	13.1a	12.9a
4(2fr/pan)	16.5a	15.8ab	4.65b	4.67a	72.0b	70.0a	1.75a	1.78ab	12.0a	11.4a
5(2fr/pan+50%pan)	17.8a	18.2c	5.06a	5.03bc	52.2a	50.0a	1.55a	2.02bc	12.1a	12.0a
6(control/av. fr.)	15.0b	17.1ac	4.63b	4.94bc	73.8b	60.0a	1.42a	1.80ab	12.5a	12.4a
7(control)	--------	15.07b	--------	4.67a	--------	71.6a	--------	1.64a	--------	12.0a

Means followed by different letters in the same column are significantly different by LSD test at P<0.05

3.4.3 Tree phenology and starch reserve

During October, when the first samples were collected to do the analysis right before treatment application, the wood starch concentration for all treatment trees was high especially when compared to the months of January, March and May (Fig. 3.4). Treatment 1 (all fruit thinned) had a significantly lower wood starch reserve than all the other treatments (18.31 mg/g). The overall wood starch status of the trees in January was low as compared to all the other months except being relatively better than that of March, especially for the control (1.83 mg/g) and treatment 1 (all fruit thinned) (2.92 mg/g) (Fig. 3.4). Wood starch status during early March was even lower than that of January (lower than all other periods) and there was no clear variation among the treatments (Fig. 3.4). There was a substantial build-up of wood reserve for all treatments towards May and more especially, a significantly higher wood reserve (24.2 mg/g) was recorded for treatment 1 (all fruit thinned) (Fig. 3.4). There was a clear increasing trend of wood reserve for treatment 1 (all fruit thinned) in July even if the value was not significant from the other treatments (Fig. 3.4).

The general bark starch status of the trees during January was very low as compared to October and the various treatments did not cause a significant variation on the bark starch status of the trees during both months (Table 3.5). The same trend as that of wood reserve was observed for bark starch status of the trees. Since the fruit were small in size and still had to develop further, their starch concentration during October was low (Table 3.5). After attaining the full-grown size (elapsing the different fruit developmental phases), the starch concentration of the fruit in January was higher than other months. Of all the periods and

the plant parts for which starch analyses were done, starch concentration in the fruit during January was the highest. Nevertheless, no significant differences were observed among the treatments during both analyses periods (Table 3.5). The starch analyses results for the fruit of treatment 1 (all fruits thinned) were from the second (2003) harvest. The reason for this being that, there was no fruit for the 2002 harvest as to the nature of the treatment. Leaf starch followed the same trend as that of bark and wood starch and there were no significant differences among the treatments in both analyses periods (Table 3.5).

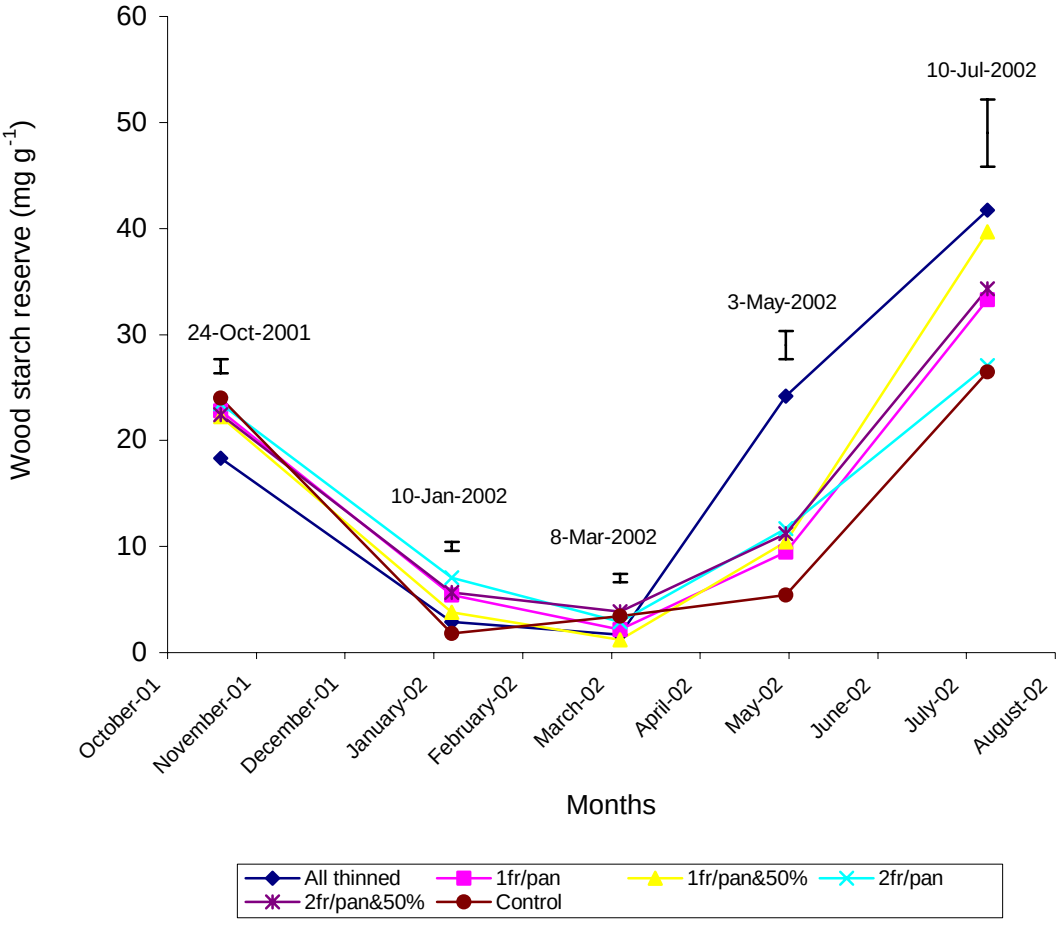

Figure 3.4 **Wood starch reserve of 'Sensation' mango as influenced by treatments at various tree phenological periods. The vertical line bars indicate LSD between means at P<0.05 level.**

Table 3.5 Bark, fruit and leaf starch status of the trees as affected by the treatments during October 2001 and January 2002

Thinning treatments	Bark starch (mg/g)		Fruit starch (mg/g)		Leaf starch (mg/g)	
	October	January	October	January	October	January
1(all thinned)	15.43a	1.43a	6.33a	138.4a	4.84a	1.62a
2(1fr/pan)	18.16a	3.27a	8.56a	135.5a	5.96a	1.38a
3(1fr/pan+50%pan)	17.47a	3.90a	9.12a	111.2a	5.10a	3.20a
4(2fr/pan)	17.08a	3.89a	8.40a	128.3a	5.18a	2.32a
5(2fr/pan+50%pan)	17.62a	5.32a	6.85a	141.2a	6.01a	4.01a
6(control)	20.00a	4.47a	7.20a	164.4a	4.58a	3.55a

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

3.4.4 Vegetative growth parameters

Significantly higher numbers (185.69) and the longest new flushes (23.32 cm) were seen in treatment 1 (all fruits thinned) (Fig. 3.5 and 3.6). The control as well as treatment 4 (2fr/pan) had the lowest numbers (65.32 and 58.46 respectively) and shortest new flushes (14.31 and 11.74 cm respectively). The significantly higher number of new leaves per new flush (14.57) was observed for trees that received treatment 1 (all fruit thinned) and the lowest for the control trees (8.78) (Fig 3.5). The average leaf area of the forty sample leaves proved not to be affected by the treatments (data not shown).

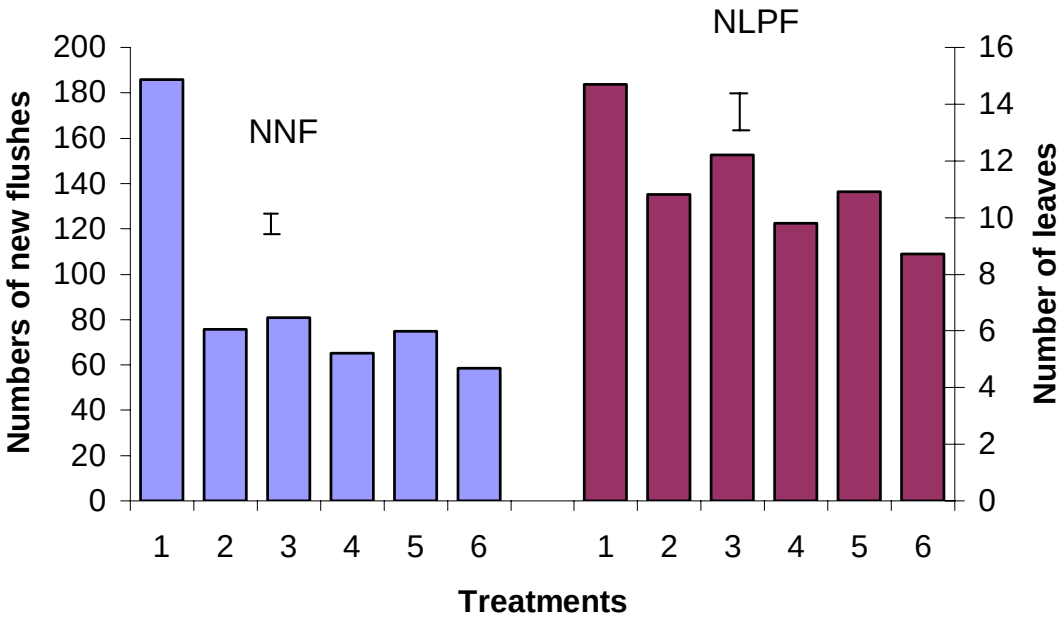

Figure 3.5 **Number of new flush growth and leaves per new flushes on 'Sensation' mango trees as affected by thinning treatments. The vertical line bars indicate LSD between means at P<0.05 level.**

Treatments

1. All fruit thinned
2. One fruit per panicle
3. One fruit per panicle and 50% panicles removed
4. Two fruit per panicle
5. Two fruit per panicle and 50% panicles removed
6. Control

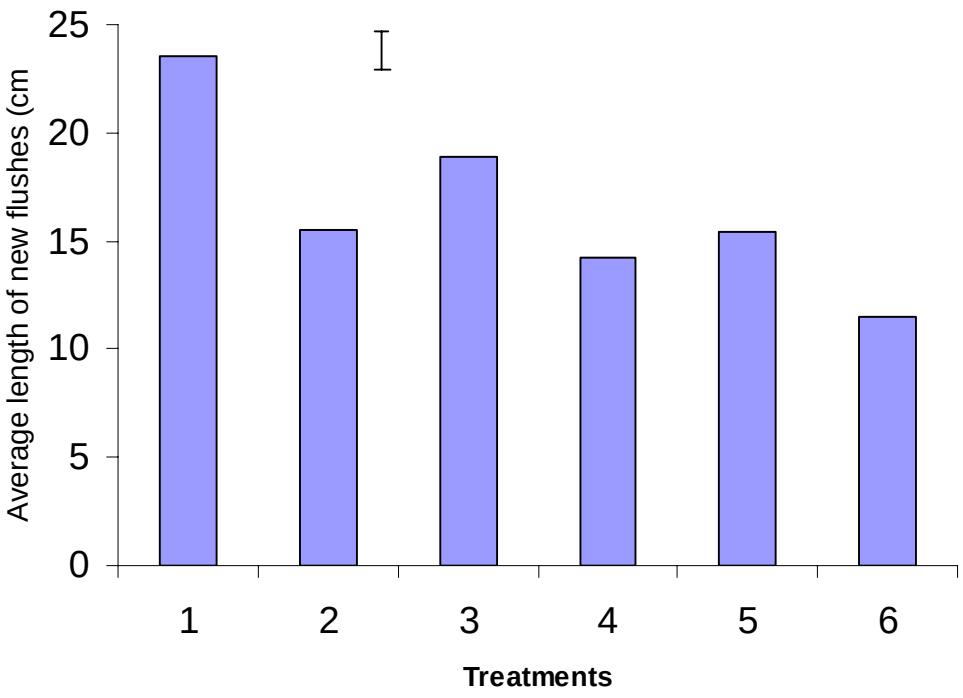

Figure 3.6 **Average length of new flush growth on 'Sensation' mango trees as affected by thinning treatments. The vertical line bars indicate LSD between means at P<0.05 level.**

Treatments

1. All fruit thinned
2. One fruit per panicle
3. One fruit per panicle and 50% panicles removed
4. Two fruit per panicle
5. Two fruit per panicle and 50% panicles removed
6. Control

3.5 DISCUSSION

The higher fruit number at harvest of treatments 2 and 4 (1fr/pan and 2fr/pan) were achieved by leaving one or two fruit per panicle, which minimised fruit abscission unlike with the control trees. At the same time the thinning intensity was lower compared to other treatments, which ended up with higher fruit numbers at harvest. On the control trees, with the initial high fruit number, more fruit abscised and less fruit of smaller size were harvested. Hence, a significant negative correlation (r = -0.949*) was found between lower fruit thinning intensity (higher number of fruit after treatment) and fruit retention percentage. The regression graph for the relationships of the two parameters is presented in Fig. 3.7.

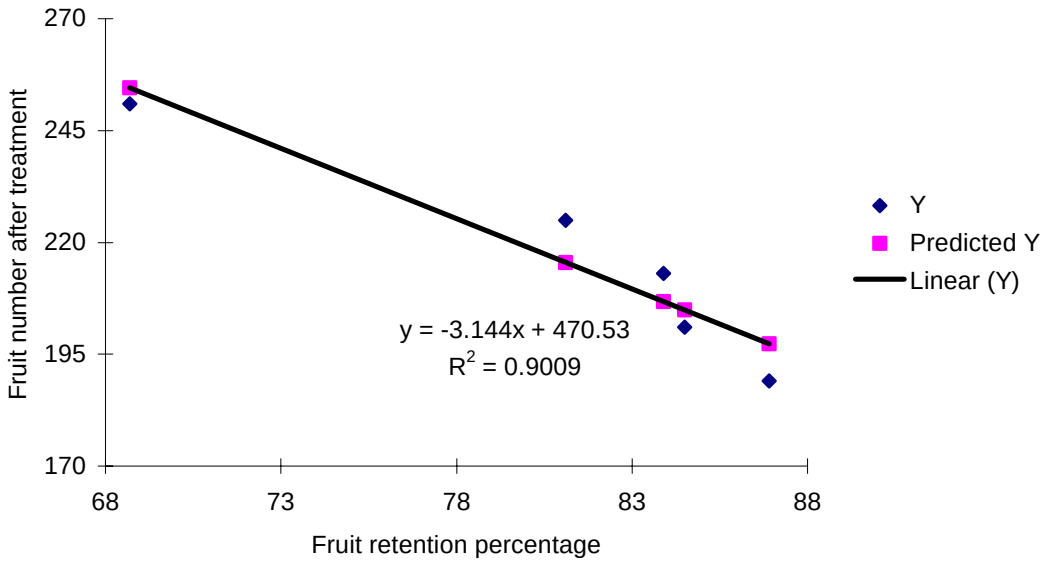

Figure 3.7 Regression between fruit number after treatment (indication of fruit thinning severity) and fruit retention percentage.

Davie *et al.* (1995) explained that, early reduction of the number of mango fruit on the tree, to a quantity the tree can nurture up to harvest, greatly reduced further fruit drop. Subsequently, trees from treatment 3 (1fr/pan+50%pan) retained a significantly higher percentage of fruit. Fruit retention percentage was calculated considering fruit number directly after treatment application and fruit number at harvest. The actual numbers of fruit at harvest for treatment 3 (1fr/pan+50%pan), however, were lower than that of the control in all the experiments due to the intensity of the fruit thinning treatment. In these experiments, very high intensity of thinning (like in the case of treatment 3---1fr/pan+50%pan) caused a reduction in yield. That was due to a very high thinning intensity, where the trees had very low number of fruits directly after treatment application. That is why thinning intensities that do not leave excess or very low numbers of fruit on the tree should be selected.

Corasil.E is a chemical fruit thinner normally used for oranges and mandarins in order to increase fruit size. Hence, reduction in fruit size by Corasil.E treatment was not expected. In addition, of the very small sized fruit attained, about 12% of the sampled fruit from Corasil.E treated trees were 'mules' (without seed). The mechanism causing the seed degeneration or abortion, however, was not clear. Fruit without seeds were not observed in any of the manual thinning treatments. Hence, it may be one research area to test the chemical for reducing fruit size on cultivars with excess fruit size like 'Keitt' and where fruit without seeds are needed.

It was also observed that, when the number of fruit per tree gets lower, the higher would be the accumulation of assimilates (like TSS) per fruit. This is compared to treatments with

high initial fruit number per tree as for the control. Horscroft & Sharples (1987) found that fruit thinning, by reducing competition for carbohydrates between fruit, also improves fruit quality in terms of soluble solids content, firmness and anthocyanin formation, hence red skin colour on apples. Jackson (1989) also stated that the effects of fruit thinning on market quality appear to result from reducing competition for assimilates between fruit.

A significant negative correlation (r =-0.902*) was observed between the total soluble solids and the titratable acids in experiment 1a . The correlation indicated that, the increase in the other soluble solids content of the fruit reduced the proportion of titratable acids. There was no clear trend of fruit firmness with the thinning intensities since both small (fruit from Corasil.E treated trees) and big sized fruit (fruit from treatments 3 and 5) were firm in the different sets of experiments.

Jelly seed (soft-nose) is the breakdown of the fruit flesh at the fruit apex as evidenced by marked cell separation and cell wall degeneration (Burdon *et al.*, 1991). Jelly seed was given emphasis since it is one of the main physiological problems affecting South African mango produced for export and is usually associated with fruit size. Cull (1991) indicated that there is evidence for fruit physiological problems such as jelly seed to be associated (in susceptible cultivars) with excess growth vigour (as observed for treatment 3---1fr/pan+50%pan). Excess growth vigour may be associated with light crop loads due to severe thinning treatments.

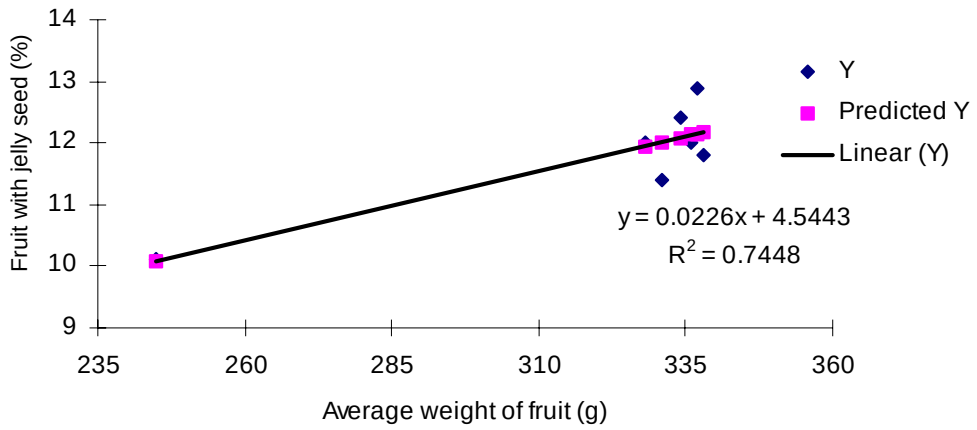

Figure 3.8 Regression between average weight of fruit and the occurrence of jelly seed in the fruit.

There was a lower wood starch concentration especially for the control trees in January. That was due to excess fruit production beyond the trees capacity and the period coincided with active fruit growth stage. The starch content in March was even lower than that of January because it was a period directly after fruit harvest and the trees did not recover the assimilates they lost due to fruiting, and therefore, fruit is already known to be a heavy sink. In general, Heim *et al.* (1979) reported severe effects of fruiting on stem dry matter accumulation, accounting for over 40% of the dry matter fixed in non-fruiting apple tree stems compared with over 10% for heavily fruiting tree stems. A reduction in dry matter partitioning to shoots, leaves and roots due to fruiting has been demonstrated in a wide range of species (Wright, 1989). He also explained that it is perhaps not surprising that fruiting commands such a large proportion of a plant's resources since it usually leads to

the production of seeds for the continuation of the species. In general, it was observed that, if trees are thinned at earlier fruit developmental stages, to have fruit numbers which the tree can nurture up to harvest, there will be no wastage of reserves due to fruit that would ultimately abscise being over the tree's capacity. Consequently the phenomenon of alternate bearing can be alleviated. Fruit thinning may therefore be the answer for starch conservation, and alleviating alternate bearing.

A positive relationship was observed between fruit thinning intensity and the vegetative growth parameters considered. Sufficient vegetative growth will have its own implication on the amount of assimilates to be produced by the new and young leaves and finally complement the reserve replenishment process. Consequently, the reserve and currently produced assimilates play their role on the number, size and qualitative aspects of fruit to be produced in the coming season. On the other hand, a significant positive correlation (r = 0.863*) was observed between fruit size and the occurrence of jelly seed. The regression graph indicating their positive relationship is presented in Fig. 3.8.

3.6 CONCLUSION

There was a yield reduction after severe thinning intensity treatments. However, fruit from intense fruit thinning treatments had a higher quality and the trees a more intensive vegetative growth. With low intensity thinning (like that of the control trees), a higher degree of assimilate wastage due to the high number of fruit that were abscised at an advanced developmental stage was noted. These trees were more liable to alternate bearing, which is a common phenomenon in many fruit trees. Spraying of Corasil.E, which

increased fruit size in oranges and mandarins through fruit thinning (J. Fivas, personal communication), had a reverse effect on mangoes. The treated trees produced small sized mule fruit.

The principle of chemical or manual fruit thinning is to conserve tree carbohydrate reserves by reducing fruit number during early growth stage. The aim of the current experiment was to determine the intensity of fruit thinning. With this two-season experiment, thinning 'Sensation' mango to one and two fruit per panicle produced a significantly larger yield compared to the control while fruit quality, vegetative growth as well as tree reserve status parameters were within acceptable limits. In addition, no alternate bearing was observed on trees where thinning fruit to one and two fruit per panicle treatments were applied. Monitoring the carry-over effects of the applied treatments will give additional information. An acceptable practice, however, would be to apply moderate fruit thinning every season.

CHAPTER 4

PACLOBUTRAZOL SUPPRESSED VEGETATIVE GROWTH AND IMPROVED YIELD AS WELL AS FRUIT QUALITY OF 'TOMMY ATKINS' MANGO (*MANGIFERA INDICA*) IN ETHIOPIA.

4.1 ABSTRACT

The effects of paclobutrazol (1- (4-chlorophenyl) –4,4-dimethyl-2- (1,2,4- triazol-1-yl) pentan-3-ol) on the vegetative growth, reproductive development, total non-structural carbohydrate of the shoots and nutrient mobilisation to the leaves of 'Tommy Atkins' mango trees grown in the rift valley of Ethiopia were evaluated during the 2002/2003 season. The trees used were characterised by excessive vegetative growth, erratic flowering and fruiting with declining productivity that validated the evaluation of paclobutrazol. Uniform trees were selected for a randomised complete block design experiment with two application methods (soil drench and spraying) at four rates of paclobutrazol (0, 2.75, 5.50, 8.25 g a.i. per tree) in factorial combinations. There were three blocks and three trees per plot for each treatment. The results indicated that application of paclobutrazol at rates of 5.50 and 8.25 g a.i. per tree both as a soil drench and spray application, were effective in suppressing vegetative growth as compared to the control. Trees from these treatments also had a higher level of total non-structural carbohydrates in their shoots before flowering. Compared to the control, paclobutrazol treated trees had a higher percentage of shoots flowering, number of inflorescences produced, percentage of

hermaphrodite flowers, yield as well as fruit quality. Applications of paclobutrazol did not affect the leaf macronutrient content levels analysed (N, P, K and Ca), but except for manganese, the micronutrient (Cu, Zn and Fe) levels in the leaves of the treated trees leaves were significantly higher than the control.

Key words: paclobutrazol; mango; leaf mineral content; total non-structural carbohydrate

- **Published in *New Zealand Journal of Crop and Horticultural Science*, vol. 32(3). (*In press*) (The Royal Society of New Zealand)**

4.2 INTRODUCTION

Dwarfing rootstocks can reduce scion vigour, make the tree manageable and stimulate fruiting. The disadvantages of dwarfing rootstocks, such as high establishment and management costs and poor anchorage, associated with scions, led to the introduction of effective chemical retardants (Quinlan, 1980).

The improvements in crop productivity in modern agricultural systems are increasingly dependent on manipulation of the physiological activities of the crop by chemical means (Subhadrabandhu *et al*., 1999). The first report about the use of paclobutrazol (PBZ) on mango came from India where Kulkarni (1988) tested concentrations of 1.25 to 10 g a.i. per tree on the cultivars Dashehari and Banganepalli.

PBZ is a synthetic plant growth regulator, which has been used in fruit tree crops to control vegetative growth and to induce flowering (Swietlik & Miller, 1985). Rademacher (1991); Sterrett (1985) also confirmed that PBZ is one of the known effective retardants in tree crops. PBZ can be applied to mango trees as a foliar spray or as a soil drench (Tongumpai *et al*., 1991). Reports on the use of PBZ in temperate tree fruits show differences between species and locations in response to methods of application. Davenport & Nunez-Elisea (1997) elaborated that unlike the other classes of growth retardants that are normally applied as foliar spray, PBZ is usually applied to the soil due to its low solubility and long residual activity. PBZ is taken up through the root system and is transported primarily in the xylem through stem and accumulates in the leaves and fruit if applied to the soil (Wang *et al.,* 1986; Lever *et*

al., 1982). Hence some of PBZ residues may remain in the fruit. Voon *et al.* (1991) explained that PBZ is systemic and can be taken up by plant roots or through lenticels and bark perforations while foliar spray uptake occurs through shoot tips, young stems and leaves.

In commercial mango plantations, it is desirable to control the vegetative growth and the canopy size to prevent or reduce alternate bearing and to facilitate cultural practices. Flowering in mango is also associated with reduced vegetative growth often induced by lower activity of gibberellins (Voon *et al.,* 1991). Exogenous application of GA as well as endogenous high levels of gibberellins has proven to be a major hindrance in the way of flower bud differentiation in a number of temperate as well as tropical fruits including mango (Tomer, 1984).

Considering the above inhibitory role of GA for flower development in mango, PBZ, owing to its anti-gibberellin activity, (Dalziel & Lawrence, 1984; Quinlan & Richardson, 1984; Webester & Quinlan, 1984; Voon *et al.,* 1991) could induce or intensify flowering by blocking the conversion of Kaurene to Kaurenoic acid. Such alterations could be important in restricting vegetative growth and enhancing flowering by altering assimilate partitioning and patterns of nutrient supply for new growth. The cropping manipulations possible with PBZ ranged from off-season or early season harvests to simply increased yields (Voon *et al*., 1991).

Ethiopia being situated very close to the equator is characterized by two erratic and unreliable flowering periods due to bimodal rainy periods and low temperature (the main raining season is June-August and a shorter one in February-March). This

situation exhausts the tree and usually the yield obtained is below expected. Excessive vegetative growth is a common characteristic of most mango cultivars resulting in unmanageable and large trees. The above situations validated the evaluation of PBZ (Cultar) for growth suppression and consequent advantages in increasing flowering, yield and fruit quality. However, because of negative connotations towards the use of PBZ, regulations for export of fruit from PBZ treated trees to certain countries must be cleared. The maximum residue limit of PBZ accepted by FAO in stone fruit is 0.05 mg/kg (Singh & Ram, 2000).

This report discusses the results of an experiment done to determine the effect of PBZ on vegetative growth, shoot total non-structural carbohydrate contents, leaf mineral content, flowering, yield and fruit qualitative aspects of 'Tommy Atkins' mango trees grown at Upper Awash Agro-industry farm in Ethiopia. This is the first study in Ethiopia on the effect of growth retardants on fruit trees and other crops.

4.3 MATERIALS AND METHODS

4.3.1 Area description

The trial was conducted during the 2002/2003 season at Upper Awash Agro-industry Enterprise in the rift valley of Ethiopia (latitude: 8^0 27'N; longitude: 39^0 43'E; elevation: 1000 m.a.s.l.; mean annual temperature: max. 32.6 ^{0}C, min. 15.3 ^{0}C; mean annual rain fall: 500 mm; soil type: calcic xerosol and 50% loam soil). The area is situated at 180 km South East of Addis Ababa.

4.3.2 Plant material

Ten-year old 'Tommy Atkins' mango trees, uniform in vigour and size were selected for this study based on their volume. The trees were characterized by excessive vegetative growth (average tree height and canopy diameter more than 5.5m and 5.8m respectively), erratic flowering and poor yield. All treatment trees received the standard orchard management practices as applied by the company.

4.3.3 Design, method, rate and time of PBZ application

The experiment was designed in a randomised block with three replications. Three trees were included per plot. Treatments were factorial combinations of two application methods (soil drenching Vs spraying) each at four PBZ levels (0, 2.75, 5.50 and 8.25 g a.i. per tree). The PBZ application rates were determined based on the average volume of the selected uniform trees. A suspension concentrate of Cultar (250 g a.i. paclobutrazol per litre, Zene Co. Agrochemicals SA PTY LTD, South Africa) was used.

The required quantity of PBZ was dissolved in 5 liters of water and sprayed uniformly on a single tree. During spray application, the soil underneath the canopy was covered with plastic sheeting to prevent contamination of the soil. PBZ drift to the neighbouring trees was avoided by using a mobile canvas shield. Soil drenching treatments were applied according to Burondkar & Gunjate (1993), in which 10 small holes (10-15 cm depth) were made in the soil around the collar region of the trees, just inside the fertilizer ring. A solution was prepared by mixing the required quantity of

PBZ for each concentration into five litres of water and drenched uniformly (500 ml per hole) into the holes. The control trees were sprayed or soil drenched with pure water. All treatments were applied once only on 15th of August 2002, 90 days before the expected date of flower development.

4.3.4 Data recorded

Flower and fruit related developments

Prior to treatment applications, one hundred uniform terminal shoots per tree were tagged randomly, for recording the percentage of flowering shoots. The beginning of flowering was registered for all treatments, as the number of days passed after treatment application to a stage where at least 25 inflorescences per tree had reached bud break. Twenty inflorescences per tree were also tagged randomly for recording the percentage of hermaphrodite flowers per panicle. Another twenty inflorescences per tree were tagged to observe average fruit set. Fruit set was quantified at pea size stage. Data on fruit number and weight per tree were also recorded during harvesting to estimate yield per tree.

Fruit quality

Fruit quality was determined nine days after harvesting using 30 fruit per tree. The fruit used for the quality test were ripened at room temperature. Fruit Total Soluble Solids (TSS) was measured with a bench top 60/70 ABBE refractometer (No. A90067, Bellingham & Stanley Ltd, England) with a reading range of 0 to 32 ^{0}Brix. After each reading, the prism of the refractometer was cleaned with tissue paper and methanol, rinsed with distilled water and dried before re-use. The refractometer was

standardised against distilled water (0% TSS). Reducing and total sugars were estimated from the fruit mesocarp by using the technique of Somogyi (1945). Titratable acid was determined by applying an acid base titration method using a 5 g sample and 0.1 N NaOH with phenolphthalein colour indicator.

Leaf nutrient content

Thirty matured and completely developed leaves per tree from the central position of branches were collected and analysed both before (1st of August 2002) and six months after PBZ application (15th of February 2003). Nutrient contents of leaves were determined on composite samples where leaves were composited from each tree in each plot per treatment.

The samples were analysed for selected macro (N, P, K, Ca) and micronutrients (Fe, Mn, Zn, Cu). Samples were oven-dried, ground and analysed for Nitrogen using Kjeldahl method (Chapman & Pratt 1973), phosphorous by spectrophotometer and potassium with flame photometer. Calcium and all the minor nutrients were analysed using atomic absorption.

Total non-structural carbohydrates

Samples for determining total non-structural carbohydrates were collected from the leaf flush that occurred on the current year shoots of each tree per plot, two weeks before the expected period of flowering (October 30/2002). Samples were oven-dried, ground and analysed for total non-structural carbohydrates (TNC) using the methods of Hodge & Hofreiter (1962); Smith *et al*. (1964).

Vegetative growth

Vegetative growth parameters (different parameters on new vegetative flushes development) were determined from the 100 shoots tagged before the onset of the experiment. The parameters were studied four times, at three month intervals, during the course of the experiment (data collection dates were Nov. 15 2002, Feb. 15 2003, May 15 2003 and Aug. 15 2003 for the 1^{st}, 2^{nd}, 3^{rd} and 4^{th} rounds respectively). The following growth patterns were observed: tree height (m), canopy diameter (average of N-S and E-W) (m), trunk perimeter (cm), tree volume (m^3), percent tagged shoots with new vegetative flushes, average length of the new shoots (cm), average internode length of the new shoots (cm), average number of leaves developed per tagged shoots and leaf area (cm^2) were observed and data recorded. Leaf area of forty latest matured leaves per tree from the tagged branches was calculated using the formula:

$$Y= -0.146+0.706X \ (r^2=0.995)$$

where Y= leaf area (cm^2) and X = leaf length (cm) × leaf width (cm) (Nii *et al.*, 1995). Tree volume was calculated considering the tree canopy as a cylinder (Westwood, 1988). According to him, the volume of a cylinder equals its cross sectional area times its length; thus tree volume was determined using the formula:

$$V= 1/4\pi D^2 \alpha H$$

where V is the volume (m^3), D= canopy diameter (average of N-S and E-W canopy diameters) (m), α=0.667 (constant), H= tree height (m).

4.3.5 Statistical analysis

Differences between treatments were determined with Analysis of Variance (ANOVA) using MSTATC statistical package (MSTATC, 1989). Whenever significant differences were detected, means were separated using Least Significant Difference (LSD) test at the 5% level of significance. Co-variance analysis was done in analysing data on vegetative growth as well as leaf nutrient status. The means presented in the table for nutrient analysis results are the output of the adjusted means from the co-variance table of means.

4.4 RESULTS

4.4.1 Effect of PBZ on flowering

There was a significant difference for the interaction effects between methods and rate of PBZ application (except for foliar application of 2.75 g a.i. per tree) with respect to percentage tagged branches flowered and days needed for floral bud break after treatment application (Table 4.1). Trees treated with soil drenching at a rate of 8.25 g a.i. per tree produced a significantly higher percentage of tagged branches flowered and the lowest number of days required for attaining bud break stage (Table 4.1). In the foliar spraying treatments, 8.25 g a.i. per tree also produced a significantly higher percentage of tagged branches flowered and the lowest number of days required for attaining bud break stage as compared to the control (Table 4.1). The main treatment effects of application methods and rate, but not the interaction effects, significantly affected the number of inflorescences produced (Table 4.2). Trees treated with soil

applications of PBZ had higher number of inflorescences as compared to spray applications (Table 4.2). Applying PBZ at a rate of 8.25 g and 5.50 g a.i. per tree resulted in the highest number of inflorescences per tree (Table 4.2). Application of 8.25 g a.i. per tree PBZ increased number of inflorescences by 80.95% as compared to the control.

Significant differences between the interaction effects of the method and rate of PBZ application were observed for the percentage of hermaphrodite flowers within the inflorescences (Table 4.1). Trees that received 8.25 and 5.50 g a.i. per tree PBZ as a soil drench or foliar spray and soil drench at 2.75 g a.i. per tree had significantly higher percentages of hermaphrodite flowers per panicle as compared to the control.

Table 4.1 Effect of methods and rates of PBZ application on flower related parameters of 'Tommy Atkins' mango

Treatments		Tagged branches flowered (%)	Number of days for inflorescence development	Hermaphrodite flowers (%)
Soil drench	0 (control)	41.67e	116.0a	43.08ef
	2.75 g a.i. per tree	60.00c	105.0b	56.30c
	5.50 g a.i. per tree	69.00b	87.78d	69.35a
	8.25 g a.i. per tree	76.89a	82.22e	73.09a
Foliar spray	0 (control)	40.78e	116.8a	41.84f
	2.75 g a.i. per tree	48.78d	115.7a	46.21e
	5.50 g a.i. per tree	57.33c	106.3b	50.36d
	8.25 g a.i. per tree	66.44b	99.44c	60.82b

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

4.4.2 Effect of PBZ on Total Non-structural Carbohydrates (TNC)

Both rates and methods of paclobutrazol applications affected the shoot's TNC but there was no significant effect for the interaction. Trees treated with soil application of paclobutrazol had higher TNC than sprayed trees (Table 4.2), while irrespective of the rates applied, all PBZ treated trees had a significantly higher TNC than the control (Table 4.2).

4.4.3 Effect of PBZ on fruit development

PBZ treatments enhanced fruit set and total fruit number per tree as compared to the control (Table 4.2). Averaged across the application methods, the highest average fruit set per 20 inflorescences (7.95) was observed with the application of PBZ at a rate of 5.50 g a.i. per tree (Table 4.2) as compared to the control trees (4.29). The main treatment effects of method and rate of PBZ application significantly affected the total fruit number at harvest. The results illustrated that higher numbers of fruit were obtained from soil drenching than from spray applications (Table 4.2). A significantly higher number of fruit per tree at harvest was obtained from trees that received PBZ at a rate of 8.25 g a.i. per tree (299.3) as compared to the control (131.80) (Table 4.2). With the same trend like fruit number per tree, total fruit weight at harvest was significantly increased by soil drenching compared to foliar spray treatments (Table 4.2). Trees treated with PBZ at 8.25 and 5.50 g a.i. per tree had the highest weight of harvested fruit (Table 4.2). The increase in fruit weight per tree was caused by the increased fruit number per tree but not as a result of fruit size (Table 4.2). Applications of 8.25 g a.i. per tree PBZ increased the weight of fruit harvested

by 152.87% when compared to the control. Average weight of fruit was not significantly affected by PBZ application (Table 4.2).

Table 4.2 Effects of PBZ application methods (averaged across PBZ rates) and PBZ rates (averaged across PBZ application methods) on flowering, fruit growth and shoot total non-structural carbohydrate of 'Tommy Atkins' mango.

Treatments	Number of inflorescences developed	Av. fruit set per 20 panicles (no.)	Total fruit no. per tree	Total fruit weight per tree (kg)	Average fruit weight (kg)	Total non-structural carbohydrate (mg glucose/g dw)
Methods						
Soil	164.25a	6.53a	253.17a	95.77a	0.371a	176.25a
Spray	128.00b	5.95a	177.75b	68.35b	0.378a	165.0b
Rates						
0	104.17c	4.29c	131.80d	47.85c	0.368a	149.3c
2.75	131.80bc	6.28b	183.7c	66.12bc	0.362a	168.2b
5.500	160.00ab	7.95a	247.0b	93.28ab	0.368a	176.0b
8.25	188.50a	6.44b	299.3a	121.00a	0.398a	189.0a

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

4.4.4 Effect of PBZ on fruit qualitative parameters

All fruit qualitative parameters were significantly affected by PBZ applications as compared to the control (Table 4.3). The main treatment effects, viz., method and concentration of PBZ application affected the TSS of the fruit. Soil drenched trees

with PBZ had a significantly higher TSS (14.77 ^{o}Brix) in their fruit than foliar sprayed trees (14.26 ^{o}Brix). Irrespective of the different rates, all PBZ treatments increased the TSS of the fruit as compared to the control and the highest TSS was recorded at PBZ concentration of 8.25 g a.i. per tree (Table 4.3). The other fruit quality parameters observed in this study (titratable acids, TSS per acid ratio, reducing and total sugars) were significantly affected only by PBZ rates (Table 4.3). Averaged across application methods, PBZ treated trees produced fruit with significantly lower titratable acids than the control (Table 4.3). Regardless of the concentrations used, PBZ treatments significantly increased TSS per acid ratio, reducing and total sugars (Table 4.3).

Table 4.3 Effect of different rates of soil/foliar applied PBZ on fruit qualitative parameters of 'Tommy Atkins' mango

Rates of PBZ (g a.i. per tree)	TSS (^{o}Brix)	Titratable acids (mg/100g)	TSS: Acid	Reducing Sugar (%)	Total Sugar (%)
0 (control)	13.33c	0.51a	26.17b	4.215b	11.22b
2.75	14.42b	0.44b	32.94a	5.212a	12.72a
5.50	14.67b	0.45b	33.43a	5.913a	12.77a
8.25	15.63a	0.45b	35.47a	5.057a	12.93a

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

4.4.5 Influence of PBZ application on leaf mineral composition

The result from the current experiment revealed that PBZ had no significant effect with respect to the macronutrient (N, P, K and Ca) content of the leaves analysed (Table 4.4).

Conversely, there was a statistically significant difference (both interaction and main effects) among the treatments (for some elements lower and for others higher than the control) with regard to the analysed leaf micronutrient contents in this study even if no clear trend was observed (Tables 4.4 & 4.5).

Methods and rates of PBZ application affected copper content of the leaves. Soil application had significantly increased the leaf copper content (6.33 ppm) as compared to foliar spray applications (5.89 ppm). PBZ rate that significantly increased the copper content in the leaves was 5.50 g a.i. per tree (Table 4.4). Regardless of the methods and rates used, PBZ treatments increased leaf Zinc contents as compared to the control (Table 4.4).

Significant differences were observed for the interaction results between methods and rates of PBZ applications with respect to leaf iron and manganese content (Table 4.5). Regardless of the concentrations, soil as well as foliar applied PBZ increased leaf iron content and reduced leaf manganese content as compared to the control (Table 4.5).

Table 4.4 Effect of different rates of soil/foliar applied PBZ on leaf nutrient contents of 'Tommy Atkins' mango

Rates of PBZ (g a.i. per tree)	Nitrogen (%)	Phosphorous (%)	Potassium (%)	Calcium (%)	Copper (ppm)	Zinc (ppm)
0 (control)	0.962a	0.10a	0.66a	2.01a	8.60bc	12.81b
2.75	1.053a	0.10a	0.65a	2.45a	9.01ab	16.61a
5.50	1.000a	0.08a	0.66a	1.67a	9.38a	16.72a
8.25	1.010a	0.07a	0.64a	2.06a	8.24c	16.65a

Means followed by different letters in the same column are significantly different by LSD test at P<0.05

Table 4.5 Effect of methods and rates of paclobutrazol applications on leaf iron and manganese contents of 'Tommy Atkins' mango

		Methods of PBZ application	
	Rates of PBZ applied	Soil	Spray
Iron (ppm)	0 (Control)	282.1b	283.8b
	2.75	323.6a	315.3a
	5.50	328.4a	336.5a
	8.25	326.8a	318.5a
Manganese (ppm)	0 (Control)	244.1a	246.5a
	2.75	226.5b	226.4b
	5.50	226.5b	226.5b
	8.25	226.4b	226.4b

Means followed by different letters in the same column are significantly different by LSD test at P<0.05

4.4.6 Effect of PBZ on Vegetative growth

During the first round of observations, three months after treatment application, no statistically significant differences were found in trunk perimeter, percent tagged shoots with new vegetative flushes or leaf number between the control and treated trees (data not shown). For canopy diameter and leaf area parameters, only the rate of applied PBZ had an effect, irrespective of the methods of applications. Regardless of the different rates used, PBZ treatment significantly reduced canopy diameter and total leaf area as compared to the control (Fig. 4.1). On the other hand, there were significant differences for the interaction results between method and rate of PBZ application with respect to tree height, tree volume and shoot length (Table 4.6). With respect to tree height, both soil and spray applications of PBZ treatments at a rate of 8.25 g a.i. per tree and soil application of PBZ at 2.75 g a.i. per tree had significantly lower values as compared to the control (Table 4.6). Regardless of the concentrations applied, PBZ treated trees had lower values for tree volume and length of new shoots compared to the control. In all the figures below for the different rounds of observations, treatments 1, 2, 3 and 4 represent application of 0 (control), 2.75, 5.5 and 8.25 g a.i. PBZ per tree respectively.

During the second round of observations, six months after treatment application, there were significantly lower results for PBZ treated trees than the control trees for all the vegetative parameters considered. (Table 4.7). In all of the cases, rates of PBZ applied had an impact on the parameters and the methods of application did not affect the results. PBZ at a rate of 8.25 g a.i. per tree significantly reduced leaf number and leaf area as compared to the control trees (Table 4.7). Irrespective of the rates used, tree height & canopy diameter (Fig. 4.2); trunk perimeter & tree volume (Fig. 4.3),

internode length, percent tagged shoots with new vegetative flushes and shoot length (Table 4.7) were significantly reduced by PBZ application as compared to the control.

During the third (Table 4.7, Fig. 4.4 and 4.5) and fourth (Table 4.7, Fig. 4.6 and 4.7) round of observations, nine and twelve months after treatment application respectively, similar trends like those of the second round were recorded.

Table 4.6 Effect of methods and rates of PBZ application on tree height, volume and length of new shoots of 'Tommy Atkins' mango three months after treatment application

Treatments		Height of trees (m)	Tree volume (m^3)	Length of new shoots (cm)
Soil drench	0 (control)	5.64a	98.55a	26.50a
	2.75 g a.i. per tree	5.24b	90.06b	23.09b
	5.50 g a.i. per tree	5.31ab	90.07b	23.24b
	8.25 g a.i. per tree	5.22b	86.53bc	22.99b
Foliar spray	0 (control)	5.62a	95.99a	26.02a
	2.75 g a.i. per tree	5.30ab	89.96b	23.16b
	5.50 g a.i. per tree	5.30ab	87.85bc	23.13b
	8.25 g a.i. per tree	5.19b	85.78c	22.96b

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

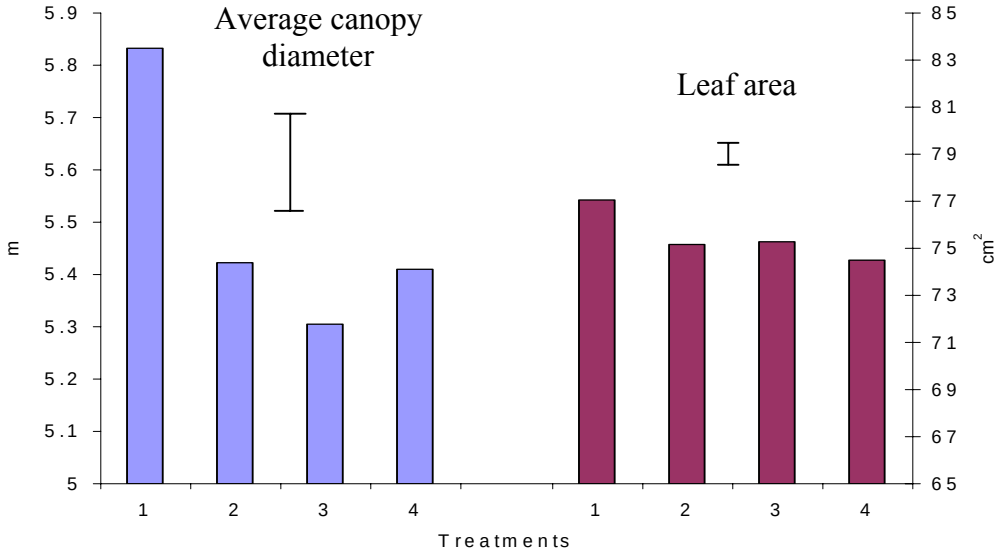

Figure 4.1 **Effect of different rates of soil/foliar applied PBZ on canopy diameter and leaf area three months after treatment application. The vertical line bars indicate LSD between means at P<0.05 level.**

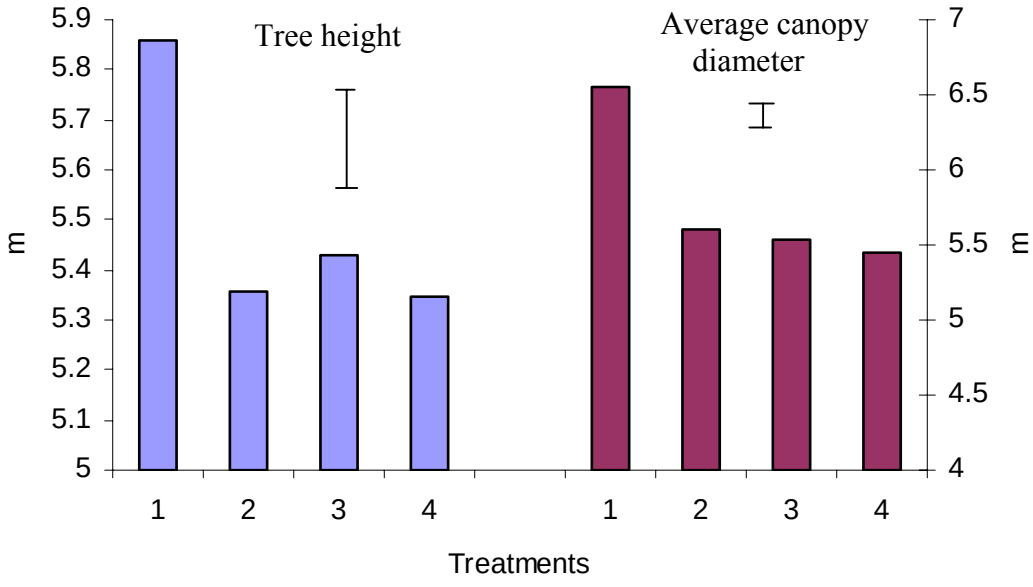

Figure 4.2 **Effect of different rates of soil/foliar applied PBZ on tree height and average canopy diameter six months after treatment application. The vertical line bars indicate LSD between means at P<0.05 level.**

Table 4.7. The effects of different rates of soil/foliar applied PBZ on some vegetative growth parameters of 'Tommy Atkins' mango six, nine and twelve months after treatment application.

Period of observations	Rates of PBZ (g a.i. per tree)	Leaf number	Leaf area (cm^2)	Shoot length (cm)	Internode length (cm)	Tagged shoots with vegetative flushes (%)
6 months	0 (control)	13.59a	77.77a	25.41a	3.87a	50.37a
	2.75	12.31b	74.77b	22.93b	3.71b	47.78b
	5.50	11.97b	74.89b	22.98b	3.67bc	46.92bc
	8.25	10.62c	73.64c	22.83b	3.51c	46.46c
9 months	0 (control)	14.27a	78.60a	26.56a	4.04a	52.55a
	2.75	12.81b	74.49b	22.96b	3.70b	47.78b
	5.50	11.97b	74.96b	22.98b	3.66b	46.38bc
	8.25	10.45c	71.46c	22.79b	3.47c	46.19c
12 months	0 (control)	15.26a	79.94a	27.55a	4.18a	55.09a
	2.75	13.31b	74.36b	22.98b	3.71b	47.85b
	5.50	12.14bc	74.75b	22.98b	3.65b	46.35bc
	8.25	10.62c	69.40c	22.75c	3.45c	45.94c

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

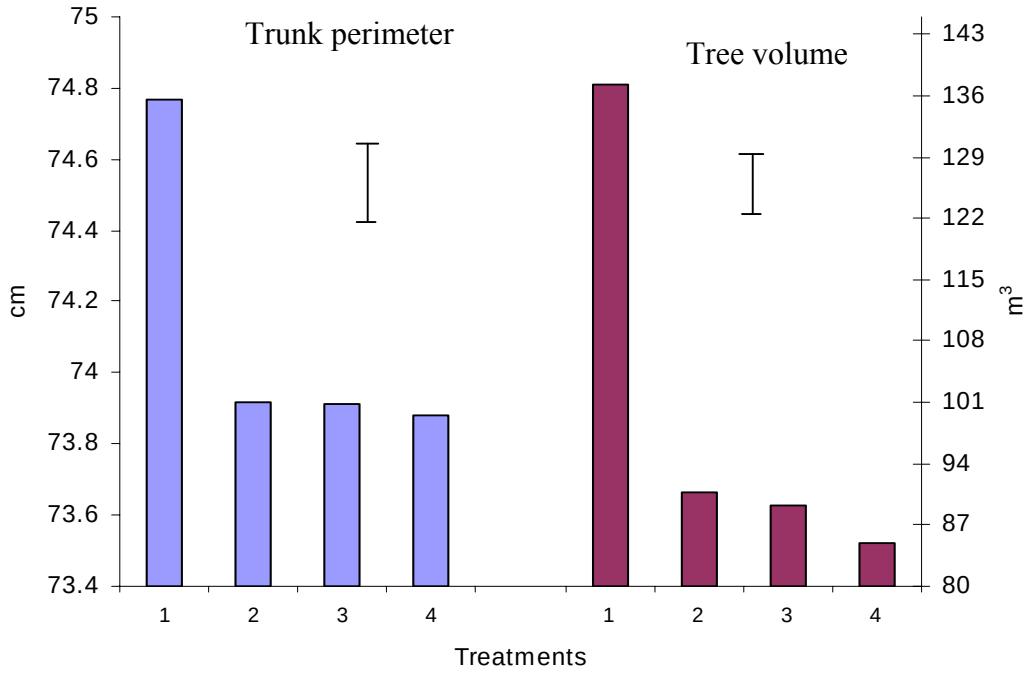

Figure 4.3 **Effect of different rates of soil/foliar applied PBZ on trunk perimeter and tree volume six months after treatment application. The vertical line bars indicate LSD between means at P<0.05 level.**

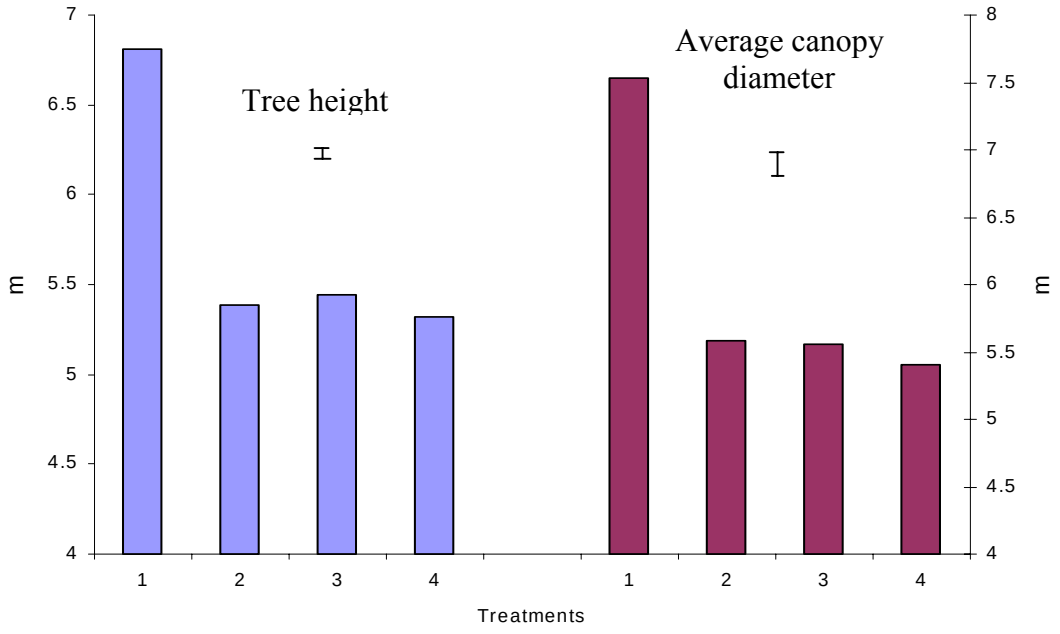

Figure 4.4 **Effect of different rates of soil/foliar applied PBZ on tree height and average canopy diameter nine months after treatment application. The vertical line bars indicate LSD between means at P<0.05 level.**

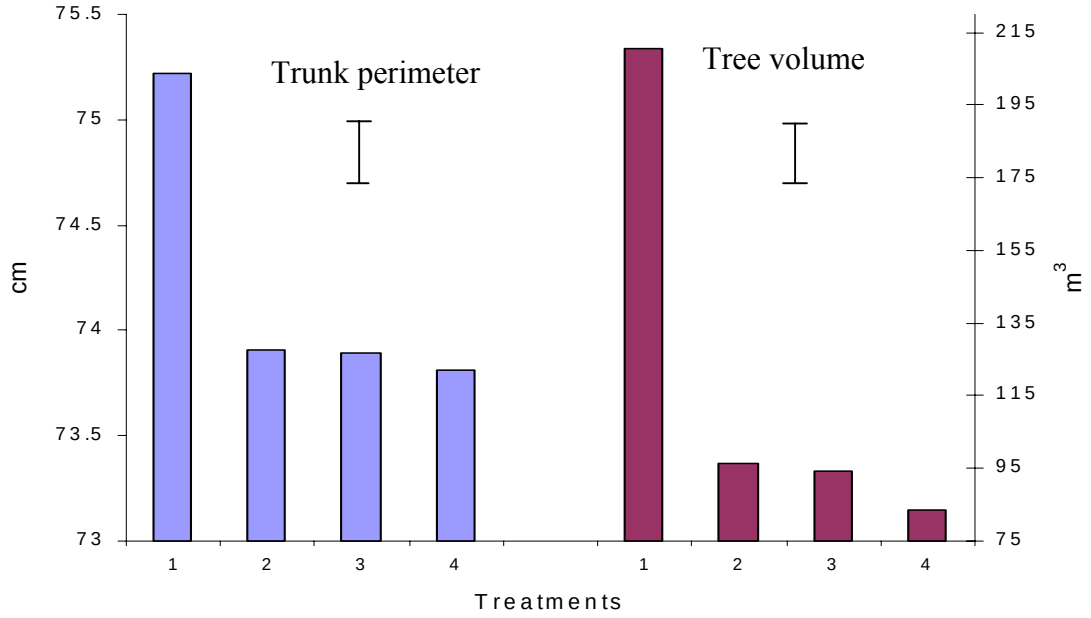

Figure 4.5 **Effect of different rates of soil/foliar applied PBZ on trunk perimeter and tree volume nine months after treatment application. The vertical line bars indicate LSD between means at P<0.05 level.**

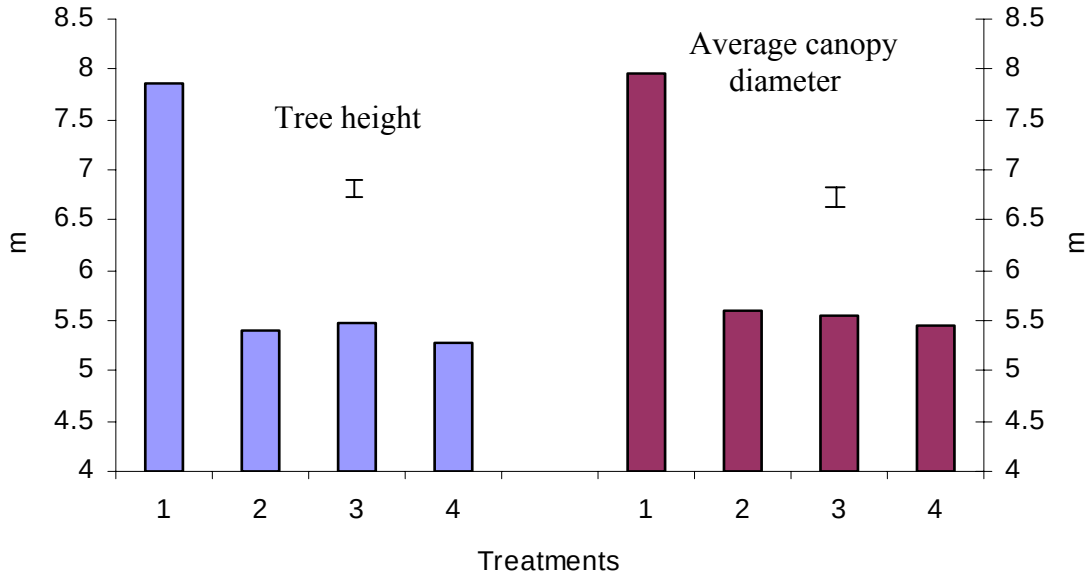

Figure 4.6 **Effect of different rates of soil/foliar applied PBZ on tree height and average canopy diameter one year after treatment application. The vertical line bars indicate LSD between means at P<0.05 level.**

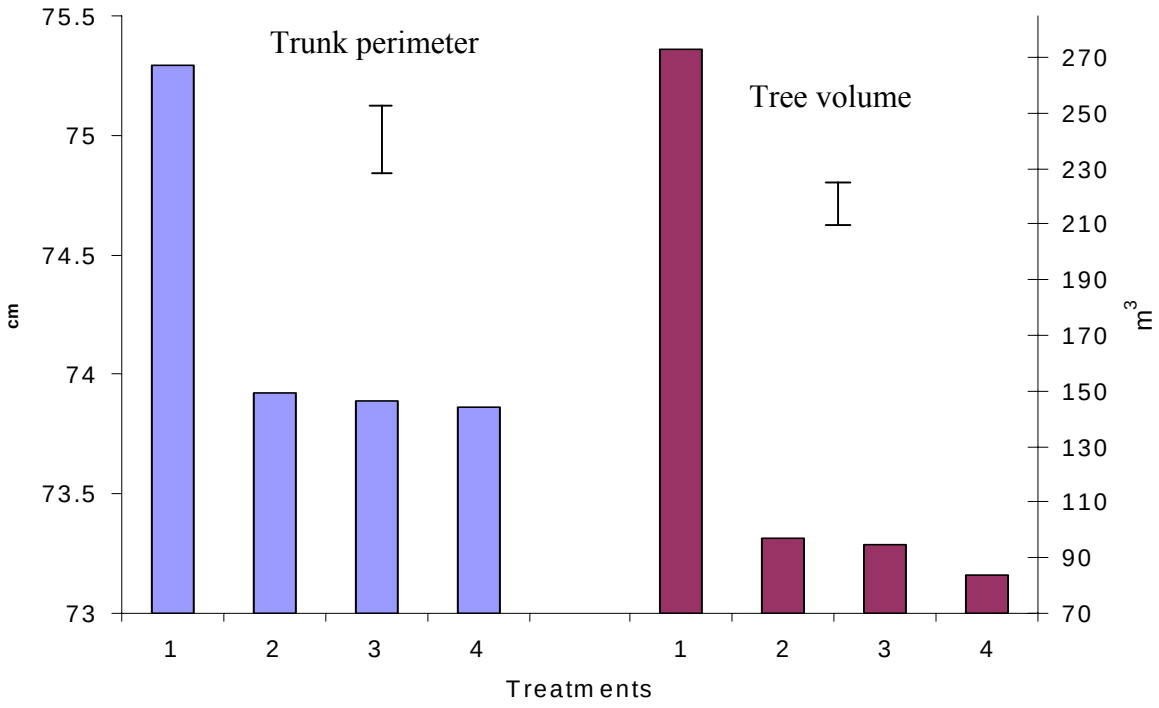

Figure 4.7 **Effect of different rates of soil/foliar applied PBZ on trunk perimeter and tree volume one year after treatment application. The vertical line bars indicate LSD between means at P<0.05 level.**

4.5 DISCUSSION

Most of the results obtained in the current experiment (with respect to vegetative and reproductive growth) are in line with a previously conducted controlled experiment, where PBZ (1- (4-chlorophenyl) –4,4-dimethyl-2- (1,2,4- triazol-1-yl) pentan-3-ol) was applied to potted plants grown in a temperature regulated growth chambers (Chapter 6 in this Thesis).

Flowering in mango is associated with reduced vegetative growth often induced by lower activity of gibberellins (Voon *et al*. 1991). In the current experiment, higher values for the percentage of tagged branches flowered was obtained by all PBZ treated trees compared to an excessive vegetative growth on the control trees. The buds in the treated trees were forced to be in a quiescent state for some time while some of the buds on the control trees burst into vegetative shoots before the normal flowering period. Forcing the buds to a quiescent state, might be linked to reduction of an expansion growth in the treated trees due to lower activity of GA_3. During this period, the buds had sufficient cold units of the winter and vegetative parameters like canopy diameter, tree volume and shoot length were highly suppressed in the treated trees. PBZ might have also supplemented the insufficient cold units for the buds. Following the reduction of the vegetative growth parameters in response to PBZ treatment, there was a higher TNC in the shoots of the treated trees, compared to the control, as per the analysis made two weeks before flowering. As indicated in Fig. 4.8, there was a significant positive correlation (r=0.98*) between shoot TNC and number of flowers developed. This signifies that a higher TNC in the shoots two weeks prior to flowering likely encouraged higher intensity of flowering in the treated trees (77% of the tagged shoots were flowering as compared to only 41% in the control trees) beside the sufficient cold spell the buds received. The results of an experiment by Burondkar & Gunjate (1993) also indicated that PBZ application increased the number of flowering shoots due to lower vegetative growth and higher reserves in the tree. A higher accumulation of reserves in the current year's shoots prior to flowering was also observed by Stassen & Janse Van Vuuren (1997b); Phavaphutanon *et al*. (2000).

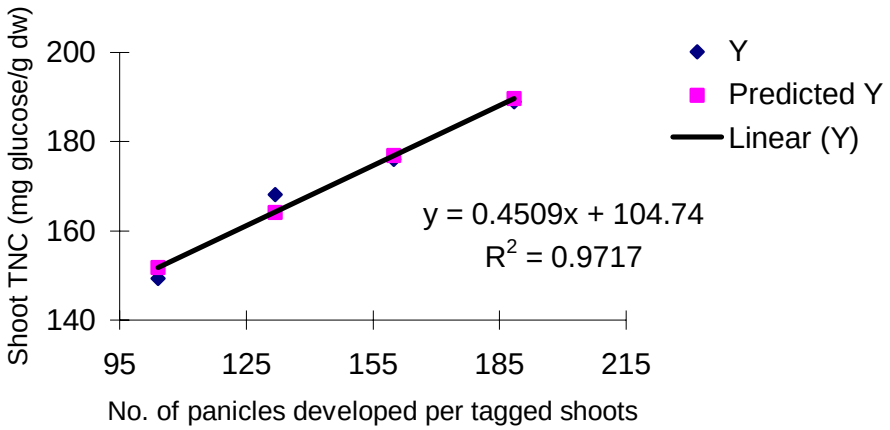

Figure 4.8 **Regression line indicating a positive relationship between shoots total non-structural carbohydrate and number of inflorescences developed.**

The majority of the dormant buds of the treated trees were released from their quiescent state more or less simultaneously soon after the cold period. This situation in addition to the higher TNC in the trees led to earlier and intense flowering in the treated trees. In this experiment, soil drenched trees that received PBZ treatment at a rate of 8.25 g a.i. per tree required 82.22 days for visible inflorescence development as compared to the control trees that needed 116.0 days as can be seen from Table 4.1. Hence, flower initiation in the PBZ soil drenched trees with 8.25 g a.i. per tree occurred about 34 days earlier than those of the control. It is probable that the application of PBZ caused an early reduction of endogenous gibberellin levels within the shoots as also observed by Anon (1984), causing them to reach maturity earlier

than those of untreated trees. This result is similar to that of Van Hau *et al*. (2002) where PBZ induced flowering 85 days after treatment application.

One of the principal effects of GA_3 is to mobilise carbohydrate by stimulating their degradation to glucose (Jacobson & Chandler, 1987). According to them, in an environment where GA levels are high, no starch accumulation can take place and consequently there will be lower tendency of flowering. The hormonal concept of flowering in mango implies that the cyclic synthesis of floral stimulus in the leaves and the difference between two such cycles would determine the flowering behaviour of a cultivar (Kulkarni, 1986). In general, PBZ, owing to its anti-gibberellin activity, could induce or intensify flowering by blocking the conversion of kaurene to kaurenoic acid (Dalziel & Lawrence, 1984; Quinlan & Richardson, 1984; Webester & Quinlan, 1984; Voon *et al.*, 1991).

The most important advantage observed on the flowering behaviour of the trees due to application of higher PBZ application was that, the bimodal flowering nature of the trees was greatly reduced. It could be due to an increased flowering intensity during the main flowering period and greatly reduced vegetative growth of the trees.

The development of complete (hermaphrodite) flowers probably needs more reserves from the tree than unisexual flowers due to the additional structures. Singh (1987) estimated that less than 0.1% of the hermaphrodite flowers develop into mature fruit while the rest falls to the ground. Assuming there are 100,000 flowers and each flower contains 10 micro gram of nitrogen, then each time a tree flowers, it loses 1 kilogram of nitrogen. The tree will, therefore, need to have adequate reserves for flower and

subsequent fruit formation. The higher TNC level (reserve) in the shoots due to PBZ soil drenching especially at rates of 8.25 as well as 5.50 g a.i. per tree increased the percentages of hermaphrodite flowers and consequently fruit set as can be seen from Table 4.1 and 4.2. These results are similar to the observations made by Vijayalakshmi & Srinivasan, (2002); Hoda *et al*. (2001).

Fruit set showed a direct impact on yield depending on number of fruit retained. The impact of higher rates of PBZ in enormously suppressing vegetative growth, especially during peak fruit development stage, contributed to the superior yield observed. In the literature, soil application of PBZ has consistently been found to increase tree yield (Kulkarni, 1988; Burondkar & Gunjate, 1993; Kurian & Iyer, 1993; Singh & Dhillon, 1992; Singh, 2000). Our results confirm the findings of Hoda *et al*. (2001) that soil treatment is more effective than foliar spraying for increasing yield.

Fruit quality improvements with respect to TSS, TSS to acid ratio, total sugars and reducing sugars in response to PBZ treatments can be related to assimilate partitioning of the plant. As the assimilate demand is unidirectional to the developing fruit, due to the great suppression of vegetative growth, PBZ treated trees had higher fruit quality attributes. With the same justification, the control trees had lower TSS and sugars but higher titratable acidity as can be seen in Table 4.3. In agreement with the current experiment, Vijayalakshmi & Srinivasan (1999); Hoda *et al*. (2001) also reported that PBZ treatments improved fruit quality. The result of Medonca *et al*. (2002) was, however, contradictory to these findings. Caution, however, must be taken to the export regulations of some countries about fruit from PBZ treated trees. Singh & Ram (2000) calculated that an application of PBZ at 2.3 g a.i. per meter tree canopy on

'Dashehari' and 'Langra' mangoes resulted in fruit containing 0.004 mg kg^{-1} PBZ, which was much lower than the international maximum value (0.05 mg/kg fruit weight). Subhadrabandhu *et al.* (1999) also used 8 g a.i. per tree on 'Nam Dok Mai' mango and no chemical residues were detected in the mature fruits. They suggested that the rate of PBZ they applied could be used for mango production in terms of food safety. The rates of PBZ used in the current experiment were lower than the rate used by Subhadrabandhu *et al*. (1999).

It can be understood from the current study that, there is no increased mobilisation of major elements (N, P, K, Ca) to the leaves, either from the soil or from other plant parts, due to PBZ treatment. Leal *et al*. (2000) also reported a non-significant effect of PBZ on the macronutrient levels of leaves. Werner (1993), however, reported increase of N, Ca and Mg due to PBZ application and reduction in P and K. Salazar-Gracia & Vazquez-Valdivia (1997) reported a decrease in P, Mg and Ca due to PBZ rates above 10 g PBZ/tree and no effect on N and K. The significant effect of PBZ in increasing the Cu and Fe concentration and a significant decrease in Mn concentration in the leaves, was contrary to and the increase in Zn was in line with the findings of Werner (1993) who reported an increase of Mn and Zn but reductions of Cu while no effect on Fe. This topic has not yet been researched properly and needs further investigation.

The effect of PBZ on reducing most of the vegetative growth parameters was noticed especially with higher concentrations. A cultivar difference in response to PBZ was previously observed where PBZ was far more effective in retarding extension and expansion growth in 'Tommy Atkins' than in 'Sensation' (Oosthuyse & Jacobs, 1997). In the current experiment, the effect of PBZ on all the vegetative growth

parameters was recorded soon after treatment application but enormously higher values were observed six months after treatment application. It was also observed that, after the first round of observation, there was no significant difference between the two methods of PBZ application and only the rates of PBZ had an effect on the vegetative parameters. High concentrations of both spray and soil application of PBZ treatments produced the most obvious inhibiting effect for almost all the vegetative parameters during the third round (Fig. 4.4 & 4.5). This period coincided with a stage after peak fruit set and development (fruit about to be harvested) that had an additional impact on vegetative growth. During this time, most of the assimilate might have been partitioned to the developed fruit, and therefore restricted new vegetative growth on the trees in addition to the effect of PBZ treatment.

The positive correlation (r=0.95*) observed between internode length and leaf area, indicated that while the internode length tapered (as a result of PBZ treatment), the leaves became crowded. This can possibly be ascribed to a limited cell enlargement in the leaves of the treated trees, which ended up with reduced leaf surfaces. The regression line in Fig. 4.9 indicates the positive relation between internode length and leaf area.

According to Steffens *et al*. (1985) PBZ has the greatest effect on immature tissues, which are still growing and differentiating, through which it affects predominantly the apical growth. Vijayalakshmi & Srinivasan (1999) reported PBZ to increase the leaf area of the treated trees, which is contrary to the observation of this report as well as to that of Kurian & Iyer (1993).

According to Esau (1977), the plate meristem constitutes a major part of the intercalary growth by means of which the leaf reaches its mature size. PBZ treatment might then reduce leaf size as observed in the current study, by diminishing the enlargement of cells derived from the plate meristems. This is due to its obvious effect on reducing levels of gibberellins, since gibberellins encourage cell growth. Generally, triazoles, reduce leaf area, but increase epicuticular wax, width and thickness (Gao *et al*., 1987) and hence leaf dry weight per unit area (Davis & Curry, 1991). According to Gao *et al*. (1987), PBZ increased chloroplast size along both the long and short axes, being 34 and 30% longer than the control, respectively, intensifying the dark green colour compared to the controls (Fletcher *et al*., 2000). This situation perhaps might increase the photosynthetic potential of the treated trees.

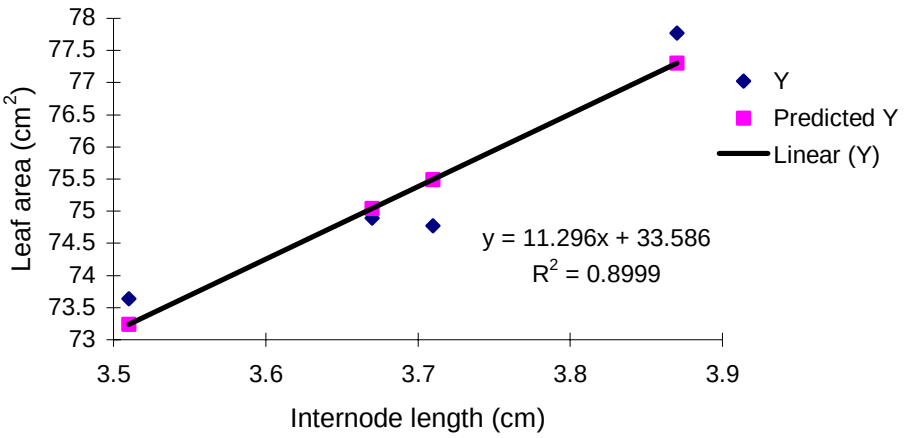

Figure 4.9 Regression line indicating a positive relationship between internode length and leaf area.

4.6 CONCLUSION

Although this chapter was based on the results of one season, the following important outcomes were noted that can have practical values to Ethiopian mango farmers. The productivity of the trees was increased due to higher intensity of flowering, higher percentages of hermaphrodite flowers and higher fruit set. The increase in the flowering parameters and fruit set is linked to reduced vegetative vigour, increased non-structural carbohydrate content of the shoots and increased chlorophyll content of the leaves. These situations ultimately increased the yield obtained. The fruit quality was also improved. Moreover, the bimodal flowering behaviour of the trees was reduced. Generally, soil application of PBZ was recommended and rates of either 5.50 or 8.25 g a.i. per tree can be used.

CHAPTER 5

THE IMPACT OF PANICLE AND SHOOT PRUNING ON INFLORESCENCE AND FRUIT RELATED DEVELOPMENTS IN TWO MANGO CULTIVARS.

5.1 ABSTRACT

The effects of different pruning treatments were studied in Keitt and Tommy Atkins mango cultivars over two seasons (2001-2003). The trial was conducted at Bavaria Estate, in the Hoedspruit region of the Northern Province of South Africa. Uniform trees were selected for a randomised complete block design experiment with the two cultivars and seven pruning treatments in factorial combinations. There were three blocks and three trees per plot. Trees that received the panicle pruning (during full bloom) treatment at the point of apical bud attachment were observed to be induced for synchronised re-flowering. These trees also attained early fruit set and more fruit per panicle than the other panicle pruning treatments. Trees on which renewal pruning (early in the season when the fruit were on the tree) as well as post-harvest pruning (especially for early cultivars) treatments were applied, developed an adequate number of inflorescences per season. Post-harvest pruning treatments also resulted in more vigorous vegetative growth on both cultivars. Promising increment in yield could be expected in the long run, especially from panicle pruning at apical bud attachment and shoot pruning (time of pruning is crucial) treatments in 'Tommy Atkins' with vigilant management of the trees. The fruit quality, especially the TSS content, was greatly improved by renewal and post-harvest pruning treatments. 'Keitt', being a late cultivar, was found to be non responsive to the pruning treatments especially for quantitative fruit parameters. Inflorescence removal together with apical

whorl of leaves subtending the inflorescence, had an adverse effects on the various parameters studied in both cultivars.

Key words: apical bud, apical whorl of leaves, renewal pruning, post-harvest pruning

- **Revised and sent back for publication in Australian Journal of Experimental Agriculture**

5.2 INTRODUCTION

It has been recorded that the average number of flowers per inflorescence in mango (*Mangifera indica L.*) varies from 200-4000 depending on the cultivar, the cultural practices adopted and the climatic conditions (Chadha & Pal, 1986). The mango is andromonoecious, which means that each inflorescence bears both hermaphrodite and staminate flowers (Coetzer *et al.*, 1995). The removal of the apical bud or inflorescence on terminal shoots of mango just prior to or during the flowering period results in the development of normally inhibited axillary buds adjacent to the point of pruning (Reece *et al.*, 1946). These buds usually develop as inflorescences, particularly if pruning is performed shortly before or after the start of normal floral bud development (Issarakraisila *et al.*, 1991). If inflorescences do develop from these buds, a delay in flowering of four to eight weeks is effected (Reece *et al.*, 1946; Singh *et al.*, 1974; Gazit, 1975), resulting in a delay in harvest (Issarakraisila *et al.*, 1991; Oosthuyse, 1995).

'Sensation' mango trees grown in the Northern and Mpumalanga province of South Africa are known to flower unevenly and consequently differences in stage of flowering between trees as well as individual branches in the same tree are encountered (Oosthuyse & Jacobs, 1996). Uneven flowering has also been reported to occur in other mango cultivars (Reece *et al.*, 1946; Lin & Chen, 1981). Consequently, the fruit show pronounced variability in time of set, stage of growth and development before harvest, stage of maturation at harvest, and rate of ripening after harvest (Oosthuyse & Jacobs, 1996). Growers then find it difficult in adhering to cultural and other management practices based on a particular phenological stage.

Clearly, relative light flowering can limit yield in most fruit and nut species (Stover, 1999). This commonly occurs before mature bearing commences and in 'off' years for varieties that display alternate bearing. During mature bearing, many species will bear fruit numbers that exceed commercially desirable levels, resulting in excessively small fruit and accentuating alternate bearing.

In general, tree height exceeding more than 80% of the distance between rows is not advantageous in the orchard situation, as it has some disadvantages like shading, decreasing leaf water potential with height, delayed bearing and poor resource allocation to fruiting (Wolstenholme, 1990). Fivas & Stassen (1995) indicated that fruit trees are pruned to create a sturdy tree framework and to facilitate the adoption of high density planting. Bearing mango trees should also be pruned to maintain their size (Oosthuyse, 1993b) and reduce excessive tree vigour. Timing is however one of the most important factors determining the success of pruning (Fivas & Stassen, 1996).

Many farmers are still afraid to apply panicle pruning since they consider it to be a loss of the whole crop. Farmers are also reserved about pruning their trees since they consider it to be loss of vital vegetative parts. The lack of a synchronised approach to evaluate the pros and cons of the different pruning methods validated the current experiment that tested the farmers' hypothesis about the negative effects of both vegetative parts and inflorescence pruning on mango trees. Hence, this report supplies information about the effects of different pruning methods that were applied in Keitt ('KT') and Tommy Atkins ('TA') mango cultivars, on various inflorescence and fruit development aspects over a period of two seasons.

5.3 MATERIALS AND METHODS

5.3.1 Area description and season

The varying types of pruning trials were conducted in 'KT' and 'TA' mango cultivars at Bavaria Estate around Hoedspruit area, Northern Province of South Africa (latitude: 24^0 25'S; longitude: 30^0 54'E; elevation: 600 m.a.s.l.) during 2001/2002 as well as 2002/2003 seasons.

5.3.2 Selecting and tagging of experimental trees

Inflorescence development stages of the treatment trees were studied during early July 2002 before applying the treatments and tagging branches. For this purpose, numbers (1-8) were assigned during data gathering to describe the different stages of inflorescence development (Fig. 5.1) (Oosthuyse, 1991). This was to select uniform trees from both cultivars based on the developmental stages of the majority of the inflorescences. Trees with visible inflorescence buds in early June 2002 were studied to select uniform trees for applying treatment 6.

During that observation period (July 2002), 'KT' inflorescence development was in an advanced stage (stages 4-5 in Fig. 5.1) while those of 'TA' were still in the inflorescence elongation stage (stages 1-3 in Fig. 5.1). This was not in line with the normal trend in the inflorescence development of the two cultivars since 'TA' is supposed to be an early and 'KT' a late cultivar.

Trees with shoots having similar stages of inflorescence development were selected from both cultivars.

Figure 5.1 Stages of inflorescence development in Mango.

Key: 1: quiescent bud stage, 2: swollen bud, 3: on set of inflorescence axis elongation, 4: apical inflorescence about to sprout, 5-6: opening of individual flowers and branching of the inflorescence, 7: well developed inflorescence, 8: inflorescence about to set fruit

After selecting trees, twenty randomly selected shoots per tree (five from each of the four wind directions) were tagged on all the treatment trees to study flowering dynamics. Twenty panicles (from the re-flowers for treatments 1, 2, 3 and 6) were also tagged from all treatment trees to study fruit set. Another twenty randomly selected branches per tree from each of the four directions (other than used for observations of flowering) were tagged for all treatment trees to observe the effects of panicle and shoot pruning on the vegetative growth parameters.

For analysing fruit quality parameters, twenty sample fruits per tree were taken. All treatment trees were subjected to the standard orchard management practices as applied at the Fruit Estate.

5.3.3 Treatments, their periods of application and experimental design

The following seven treatments were applied on whole of the trees' in both cultivars and for convenience; only the treatment numbers designated for each treatment below are used in the results and discussion.

(1) Inflorescence removal (when the inflorescences were at stage 7 in Fig. 5.1) at the point of apical bud attachment during full bloom (early August 2002 for both cultivars)

(2) Inflorescence removal (when the inflorescences were at stage 7 in Fig. 5.1) together with apical whorl of leaves subtending the inflorescence (about 5 cm deep from the attachment) during full bloom (early August 2002 for both cultivars)

(3) Inflorescences on every alternate shoots of the tagged branches (50% of inflorescences on the tagged branches) were removed (when the inflorescences are at stage 7 in Fig. 5.1) together with apical whorl of leaves subtending the inflorescence during full bloom (early August 2002 for both cultivars). Therefore trees that received this treatment had half of their inflorescences on the tagged branches unpruned and on the other half, pruned together with apical whorl of leaves

(4) Renewal pruning where 20-30% of terminal shoots with weak, misshaped and small fruit were cut back to a suitable node (October 2002 for 'TA' and November 2002 for 'KT')

(5) Post-harvest pruning where terminal shoots that had been bearing fruit the previous season were cut back to a suitable node (January 2002 for 'TA' and March 2002 for 'KT')

(6) Terminal buds removed (when the inflorescence was at stage 1 in Fig. 5.1) just before bud break (mid June 2002 for both cultivars)

(7) No pruning (control trees).

A randomised complete block design with two cultivars ('KT' and 'TA') and seven pruning treatments in factorial combinations was used. There were three blocks and three trees per plot.

5.3.4 Observations on flowering and fruit set

The tagged shoots were used to follow up the impact of the treatments on the average number of inflorescences developed (NID) in September and October 2002. The percentage tagged shoots with panicles (PTSP), were also recorded during September and October 2002.

In addition, for applying the three panicle pruning treatments (treatments 1, 2 & 3) and bud pruning treatment (treatment 6), only shoots bearing a single inflorescence per terminal branch were tagged before treatment application. This was done to study the extent of re-flowering from the axillary buds (which is the same observation as number of panicles developed). Extent of re-flowering was determined only for panicle and bud pruning treatments where the number of panicles developed per tagged shoots after inflorescence removal was recorded and compared with the single panicle per tagged shoot before inflorescence removal.

Tagged panicles from the treatment trees were used to determine percent tagged panicles setting fruit (PTPF) during September, October and November 2002 observation periods. The fruit may have been of different sizes or at different stages of development, but a panicle that set a visible fruit was grouped into panicles that started fruit bearing.

5.3.5 Observations on vegetative growth

The following vegetative parameters were recorded per tagged shoots, once the development of new vegetative flush had hardened off: average number of new vegetative flushes developed, average length of new flushes developed, average number of new leaves developed on the new flushes as well as average leaf area of forty newly developed leaves randomly selected from the newly developed flushes. The leaf area of each of the forty leaves tagged was calculated using the formula:

$$Y= -0.146+0.706X \ (r^2=0.995)$$

where Y= leaf area (cm^2) and X = leaf length (cm) $\times$ leaf width (cm) (Nii *et al.*, 1995).

5.3.6 Yield and fruit quality observations

Quantitative parameters like fruit number and weight per tree were recorded during harvesting. Fruit harvested from trees and sampled for quality analysis were treated according to commercial pack house procedures. The quality analysis was done after

shipping simulation (storing the fruit in a cold store for 28 days at 10 ^{0}C and then ripening them at room temperature for three days).

The total soluble solids (TSS) from the sample fruit's pulp was measured using a EUROMEX handheld digital Refractometer and expressed as ^{o}Brix. The pulp of the sampled fruit was also used to determine the titratable acids (Ta) after mixing the pulp with a juice blender and centrifuging it for ten minutes at 1000-rpm. A METTLER TOLEDO DL 25 (Mettler-Toledo Inc., USA) Titrator was used to determine the titratable acids, and it is expressed in m eq. L^{-1}. The fruit firmness was measured using a Penetrometer probe after peeling a portion of the exocarp and expressed as Kg cm^{-2}.

5.3.7 Statistical analysis

Logarithmic transformations were done where necessary, to normalise a highly variable data set before accomplishing data analysis. The final data was acceptably normal with homogeneous treatment variances. Differences between treatments were determined with Analysis of Variance (ANOVA) using MSTATC statistical package (MSTATC, 1989) for each season separately and combined. Whenever significant differences were detected, means were separated using Least Significant Difference (LSD) test at the 5% level of significance.

5.4 RESULTS

Data for yield and quality parameters are presented for two seasons (2001-2003). Since there was no significant difference between the seasons for all parameters

considered, data were pooled together. Data for the inflorescence as well as vegetative growth is only presented for the 2002-2003 season due to technical problems that resulted in incomplete data.

5.4.1 Effect of treatments on inflorescence development

Flowering and fruit set in September, October and November 2002

The various treatments produced significantly different results on the trees during the September observation. Averaged across cultivars, trees from treatments where inflorescence pruning was not involved (treatments 4, 5 and control) had a significantly larger number of inflorescences (Table 5.1). Among the inflorescence pruning treatments, treatment 2 did not produce any inflorescences at all compared to treatments 1, 3 and 6 during this period. Lateral buds on decapitated branches of trees that received treatments 1, 3 and 6 in both cultivars started producing lateral inflorescences and there were no significant differences among them on the number of inflorescences developed during the September observation (Table 5.1). The numbers of panicles developed is an expression of the extent of re-flowering for panicle and bud pruning treatments. Accordingly, significantly larger re-flowering percentages were recorded for treatments 1, 3 and 6 as compared to treatment 2 during the September observations (Table 5.1).

In September, there was a significant difference for the interaction effects between cultivars and treatments regarding to a response on percent tagged shoots with panicles (Table 5.2). The highest result from 'TA' was by trees that received treatments 4, 5 and the control where 93.05, 84.72 and 94.44% of their tagged branches had panicles respectively, while trees that received treatment 2 did not have

any panicles on their tagged shoots. 'KT' trees followed the same trend where trees that received treatments 4, 5 and the control had 50, 54.17 and 75% of their tagged branches with panicles respectively. The lowest result obtained for 'KT' was by the trees that received treatment 2 (0%).

Table 5.1 Effects of pruning treatments on the development of lateral inflorescences (Figures pooled over cultivars)

Pruning treatments	Av. number of inflorescences developed per tagged branch in September 2002	Av. number of inflorescences developed per tagged branch in October 2002	Percent tagged shoots with panicles in October 2002
1	0.62b	1.14a	75.00a
2	0.00c	0.38c	34.72c
3	0.64b	0.80b	59.03b
4	1.36a	--------	--------
5	1.18a	--------	--------
6	0.54b	1.24a	72.92a
7 (control)	1.44a	--------	--------

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

There was also a significant difference between the interaction effects of cultivars and treatments with respect to percent tagged panicles that started to bear fruit in September (Table 5.2). 'TA' trees that received treatments 4, 5 and control had larger percentages of panicles that started setting fruit (90.28, 75 and 93.06% respectively). 'KT' trees where treatment 5 was applied and the control had a larger percentage of panicles that started to bear fruit (45.83% and 62.50% respectively). Trees in both cultivars that received treatment 2 did not produce inflorescences. In addition, treatment 6 in 'TA' did not produce inflorescences during this period of observation.

Among inflorescence pruning treatments, it was observed that some of the lateral buds of treatment 1 in 'TA' trees had given rise to an inflorescence (re-flowered) and some of these inflorescences produced marble-sized fruit (with an approximate fruit diameter of 1 cm). Hence treatment 1 had a larger percentage of panicles fruiting than treatments 2 and 6 (Table 5.2). Trees that received treatment 3 produced a lot of inflorescences from the unpruned tagged shoots (on both cultivars), and some of these inflorescences were at different stages of fruit development (Table 5.2). Trees on which either inflorescence or bud pruning treatments were not applied, showed fruit development on most of their inflorescences, where in most cases, were golf ball-sized fruit (with an approximate fruit diameter of 3 cm) on both cultivars.

Table 5.2 Interaction between cultivars and pruning treatments on flowering and fruit set in September 2002

Cultivars	Treatments	Percent tagged shoots with panicles	Percent tagged panicles with fruits
Tommy Atkins	1	45.83c	43.06cde
	2	0.00d	0.00g
	3	52.78bc	47.22cd
	4	93.05a	90.28a
	5	84.72a	75.00ab
	6	0.00d	0.00g
	7 (Control)	94.44a	93.06a
Keitt	1	29.17c	13.89fg
	2	0.00d	0.00g
	3	34.72c	22.22efg
	4	50.00bc	36.11def
	5	54.17bc	45.83cde
	6	38.89c	29.17def
	7 (Control)	75.00ab	62.50bc

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

The parameters measured in September were considered during the October 2002 observation period. During this observation period, there was a clear developmental variability amongst trees that received the inflorescence/bud removal treatments (treatments 1, 2, 3 and 6), and the rest of the treatments. Therefore, only the inflorescence/bud removal treatments were compared amongst each other. Main effects, viz., cultivars and treatments affected the number of inflorescences developed on the tagged shoots during October observations. 'KT' trees had a significantly higher number of inflorescences developed on their tagged shoots as compared to 'TA' (Table 5.4).

There was a significant difference amongst the treatments considered, where treatments 1 and 6 on average had a 213% increment on the number of panicles developed as compared to treatment 2 (Table 5.1). A significantly higher re-flowering percentage was observed for treatments 1 and 6 as compared to treatments 2 and 3 (Table 5.1). Averaged across cultivars, treatments 1 and 6 had significantly higher percentages of shoots with panicles (75 and 72.9% respectively) during October, as compared to treatments 2 and 3 (34.7 and 59% respectively) (Table 5.1).

There was also a significant difference between the interaction effects of cultivars and treatments with respect to percent tagged panicles that started to fruit in October (Table 5.3). Amongst the considered treatments, significantly higher percentages of panicles bearing fruit (56.95 and 51.39) in 'TA' were recorded by trees that received treatment 1 and 3 respectively. The lowest percentage of fruit bearing panicles was recorded for trees that received treatment 2 (9.72%). In 'KT' trees, treatments 1 and 6 had significantly higher percentages (50.00 and 52.78 respectively) of panicles

bearing fruit and the lowest of them was for treatment 2 (22.2%). It was observed during this time that, the fruit development process of some of the control tree's panicles was weak and fruit drop occurred.

Table 5.3 Effect of the interaction between cultivars and pruning treatments on fruit set in October and November 2002

Cultivars	Treatments	Percent tagged panicles with fruits in October	Percent tagged panicles with fruits in November
Tommy Atkins	1	56.95a	80.56a
	2	9.72c	20.83c
	3	51.39a	54.17b
	6	25.00b	47.22b
Keitt	1	50.00a	69.45a
	2	22.22bc	43.05b
	3	33.34b	54.17b
	6	52.78a	73.61a

Means followed by different letters in the same column are significantly different by LSD test at P<0.05

Table 5.4. The response of 'Tommy Atkins' and 'Keitt' on flowering, yield and vegetative growth parameters

Cultivars	Av. number of inflorescences developed per tagged branch in October	No. of new vegetative flushes developed per tree	Av. Leaf area per new flushes (cm^{-2})	Fruit number per tree	Fruit weight per tree (kg)	Av. Weight of fruit (g)	Yield (ton ha^{-1})
Tommy Atkins	0.78a	168a	31.32a	63.23a	26.01a	0.41a	23.94a
Keitt	1.01b	64.40b	14.99b	40.84b	22.28b	0.56b	15.91b

Means followed by different letters in the same column are significantly different by LSD test at P<0.05

As in the October observation period, the inflorescence and bud removal treatments (treatments 1, 2, 3 and 6) were compared amongst each other to observe fruit setting during November 2002. There was also a significant difference between the interaction effects of cultivars and treatments with respect to panicles bearing fruit in November (Table 5.3). Treatment 1 in 'TA' trees and treatment 1 as well as 6 in 'KT' trees had significantly higher percentages (80.56, 69.45 and 73.61 respectively) of tagged panicles that set fruit. In both cultivars trees that received treatment 2 had the lowest percentage of panicles bearing fruit (20.8% in 'TA' and 43.1 in 'KT'). A significant amount of the fruit produced by 'TA' trees that received treatment 1 were larger than a golf ball-size. The size of the majority of the fruit produced from the tagged panicles of 'KT' trees that had received treatment 6, during this observation period, was between marble and a golf ball-size.

5.4.2 Effect of treatments on vegetative growth

In general, all pruning treatments, except treatment 2, enhanced new vegetative growth than the controls. The main effects of cultivars and treatments affected the number of new flush development. 'TA' trees had a significantly larger average number of new flush development per tagged shoot as compared to 'KT' (Table 5.4). Treatments 4 and 5 had a significantly higher average number of new flush development, on average 21% higher as compared to the control (Fig. 5.2). There was also a significant difference between the interaction effects of cultivars and treatments with respect to the length of new flush developed (Table 5.5). In 'TA' trees, significantly longer flushes (20.78 and 21.11cm) were recorded on trees that received treatments 4 and 5 respectively as compared to the controls (15.78 cm). 'KT' trees

that received treatments 4 and 5 had significantly longer flushes (21.78 and 26.56cm respectively) as compared to the control trees (13cm) and all the remaining treatments.

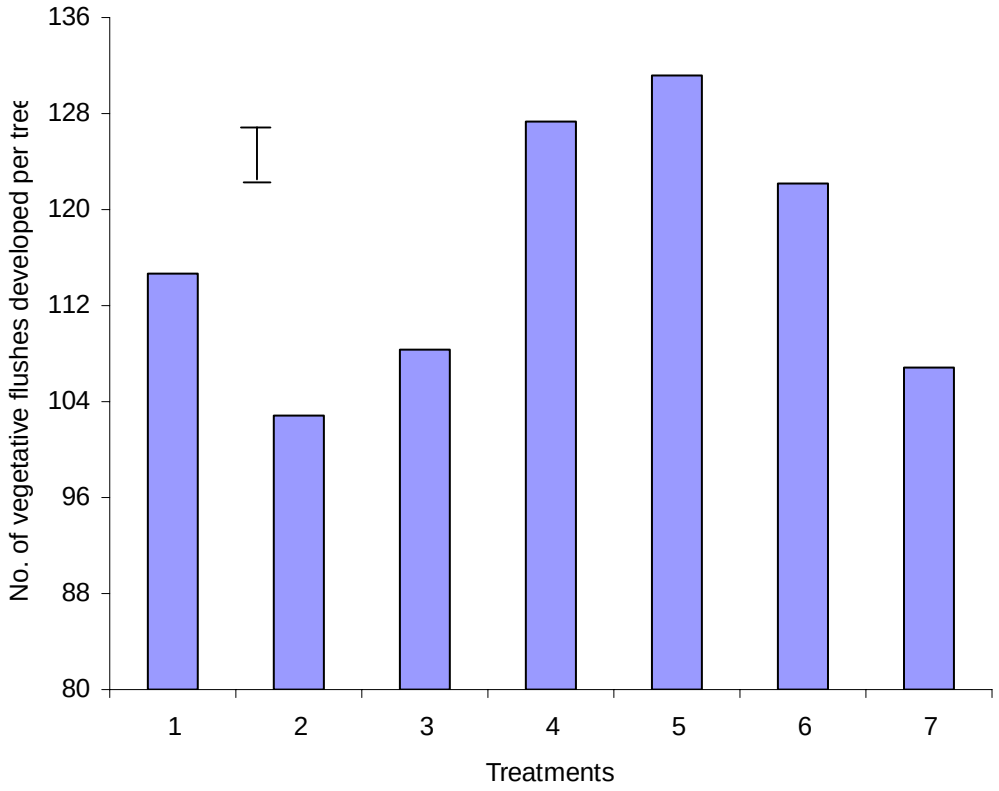

Figure 5.2 **Effect of pruning treatments on the number of new vegetative flushes developed per tree. The line bar is LSD between means at P<0.05 level.**

The number of leaves developed per new flush was also affected by the interaction between cultivars and treatments (Table 5.5). 'TA' trees that received treatment 5 had higher number of new leaves developed, by 106.7% higher as compared to the control. In 'KT' trees, higher number of leaves were recorded for treatment 5, however, the results were not significantly different to the results obtained for the control trees.

Table 5.5 Interaction between cultivars and pruning treatments on number of leaves per flush and length of new flushes

Cultivars	Treatments	Length of new flushes (cm)	Number of leaves per flush
Tommy Atkins	1	16.89e	10.89efg
	2	16.00ef	17.00b
	3	19.11b-e	14.44cd
	4	20.78bcd	17.56b
	5	21.11bc	20.44a
	6	18.11cde	16.44bc
	7 (Control)	15.78ef	9.89fg
Keitt	1	18.11cde	9.56g
	2	10.00g	9.89fg
	3	13.00fg	10.67efg
	4	21.78b	12.56de
	5	26.56a	14.00d
	6	17.67de	12.11def
	7 (Control)	13.00fg	12.11def

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

The main effects viz., cultivars and treatments affected the average leaf area of the newly developed leaves. The average surface area of the newly developed leaves in 'TA' trees was significantly higher as compared to 'KT' (Table 5.4). Treatment 5 produced a significantly higher average leaf area (32.80 cm^2) as compared to the control trees (19.58 cm^2) (Fig. 5.3).

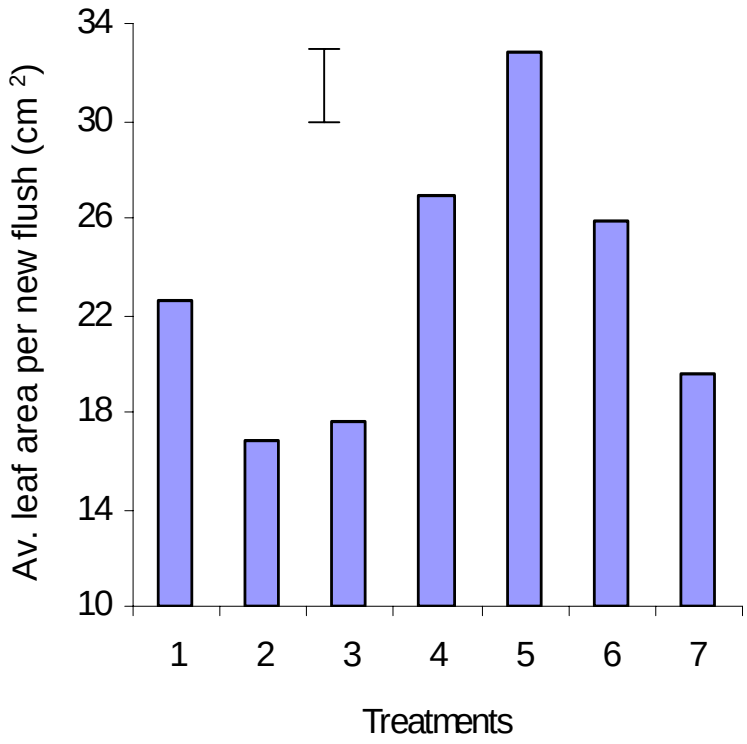

Figure 5.3 **Effect of pruning treatments on the average leaf area per new flushes. The line bar is LSD between means at P<0.05 level.**

5.4.3 Fruit yield related observations

The main factors influenced the number of fruits produced on the trees independently. 'TA' trees produced significantly higher numbers of fruits as compared to 'KT' trees (Table 5.4). Trees that received treatment 1 produced significantly higher number of fruit (by 14.6% higher) as compared to the control trees (Table 5.6). The lowest fruit number was recorded for trees that received treatment 2.

The same trend was observed for total fruit weight per tree, where the main effects (cultivars and treatments) were the factors, which determined the parameter results. Fruit in 'TA' trees were significantly heavier than the fruit from 'KT' trees (Table

5.4). Treatments 1, 4 and 5 produced significantly higher total fruit weight per tree (on average by about 19.1% higher) as compared to the control trees (Table 5.6). **N**o significant difference was observed amongst the treatments, with respect to the total yield ha^{-1} and average weight of fruit harvested per tree for both cultivars. However, there was a significant difference between the two cultivars and consequently, the average weight of fruit from 'KT' trees was significantly higher than 'TA' while the total yield ha^{-1} in 'TA' trees was significantly higher than 'KT" (Table 5.4).

Table 5.6 Effect of pruning treatments on yield

Pruning treatments	Fruit number per tree	Fruit weight per tree (kg)	Av. Weight of fruit (g)	Yield (ton ha^{-1})
1	56.30a	26.23a	0.48a	20.14a
2	47.60c	21.36d	0.48a	19.57a
3	53.94ab	22.97cd	0.43a	19.57a
4	53.46ab	26.21abc	0.51a	21.11a
5	53.51ab	26.45ab	0.52a	21.15a
6	50.31bc	23.21bcd	0.48a	18.94a
7 (control)	49.12bc	22.20d	0.48a	18.99a

Means followed by different letters in the same column are significantly different by LSD test at $P<0.05$

Although there was no significant difference amongst the treatments effect on the average weight of fruit in both cultivars, an apparent fruit size difference within the treatments was noticed, and they fall down in different size counts. An increase in occurrence of 'jelly seed' and delay of ripening for over sized fruit ($\geq$ 700 g) than medium (400-600 g) and small sized fruit (< 400 g) was noted as can be seen in Fig. 5.4 below.

This delay in ripening causes variability in ripening and complicates marketing of the fruit at a given period of time.

Figure 5.4 Delayed fruit ripening (A) and development of Jelly seed (B) among over sized 'KT' fruit.

5.4.3 Fruit quality parameters

After the shipping storage simulation procedure, a significant interaction was observed between cultivars and treatments with respect to TSS, titratable acids, ratio of TSS to acids and firmness of the fruit. 'TA' trees that received treatments 4 and 5 produced fruit with significantly higher TSS (15.18 and 15.24 ^{0}Brix respectively) as compared to the fruit from the control trees that had only 13.95 ^{0}Brix (Table 5.7). Fruit from 'KT' trees that received treatment 2 had the highest TSS even if the results were not significantly different to that of the control and rest of the treatments (Table 5.7). 'TA' trees that received treatment 6 had significantly lower titratable acids (about 46%) in their fruit as compared to fruit on the control trees (Table 5.7). In 'KT'

trees, the lowest titratable acids in the fruit was recorded by trees that received treatment 2, even if the results were not significantly different to the remaining treatments including the control (Table 5.7). Fruit from 'KT' trees that received treatments 2 and 5 had significantly higher TSS to acid ratio as compared to the control and the other treatments (Table 5.7). In 'TA' trees, even if the highest value was obtained for fruit from treatment 6 and the lowest on the control trees, there was no significant difference (Table 5.7). 'TA' trees that received treatment 1 had significantly softer fruit as compared to fruit from the control trees (Table 5.7). Fruit from 'KT' trees that received treatments 2, 4, 5 and 6 had softer fruit as compared to the control (Table 5.7).

Table 5.7 Interaction between cultivars and pruning treatments on fruit qualitative parameters

Cultivars	Treatments	Total soluble solids (^{o}Brix)	Titratable acids (%)	TSS:acid	Firmness (Kg cm^{-2})
Tommy Atkins	1	14.26cd	0.38bc	37.97d	1.74cd
	2	13.95d	0.53a	38.51d	2.11ab
	3	14.19cd	0.40bc	38.80d	2.05ab
	4	15.18a	0.41bc	39.35d	2.26a
	5	15.24a	0.36bc	42.82d	1.97bc
	6	14.60bc	0.31c	48.46cd	2.04ab
	7 (control)	13.95d	0.45ab	31.13d	2.06ab
Keitt	1	15.19a	0.13d	123.00b	1.47ef
	2	15.44a	0.08d	252.40a	1.25f
	3	15.09ab	0.13d	123.10b	1.47ef
	4	15.17a	0.13d	121.40b	1.36f
	5	15.28a	0.09d	207.60a	1.32f
	6	15.10ab	0.14d	115.30b	1.41f
	7 (control)	14.95ab	0.15d	103.40bc	1.69de

Means followed by different letters in the same column are significantly different by LSD test at P<0.05

5.5 DISCUSSION

Growth of lateral buds is normally inhibited by the presence of terminal buds due to apical dominance. When the apical bud was removed, the inhibited but induced axillary buds adjacent to the point of cuttings were released and started developing lateral inflorescences corresponding to the observations of Reece *et al*. (1946). Similar to what was observed in the current study, Singh *et al.* (1974); Issarakraisila *et al*. (1991) indicated that these buds usually develop as inflorescences, particularly if pruning is performed shortly before or after the start of normal terminal bud development. Nunez-Elisea & Davenport (1995) indicated that growth of induced buds in the presence of cool temperature was found to be essential for floral initiation. In both cultivars, up to 3-4 inflorescences were produced from below the pruning cut, especially for treatments 1 and 6 of this experiment.

Most buds from trees where treatment 2 and 3 were applied, did not sprout since they had not yet reached the minimal developmental stages. Oosthuyse & Jacobs (1996) also found a higher rate of re-flowering in 'Sensation' when the inflorescence was removed at the site of apical bud or inflorescence attachment as compared to when pruning included the leaves clustered around the shoot apex. They explained this to be due to the presence of intercalation (clustering of axillary buds at the shoot apex) giving rise to an increased number of axillary buds developing in response to pruning. In the current experiment, even if inflorescence development was earlier in 'KT' trees, fruit development did not proceed accordingly.

It is clear from this experiment that, either inflorescence or bud pruning treatments did not cause a failure in re-flowering and fruiting, however, there was a delay in harvesting. According to Reece *et al.* (1946); Gazit (1975), if inflorescences do develop after inflorescence pruning, a delay in flowering of four to eight weeks is effected, resulting in a delay in harvest (Issarakraisila *et al*., 1991; Oosthuyse, 1995).

Terminal bud pruning when temperature is high (post-harvest and renewal pruning), on the other hand, led to sprouting of lateral buds into vegetative growth. The direct relationship between flush length and leaf number implies a direct relationship between flush length and number of axillary buds per flush, thus increasing the scope for subsequent pruning. Fruiting appears to 'exhaust' the shoot, and it may not even flush post-harvest unless stimulated by pruning and this is even more so in relatively cooler climates or after late harvest (Wolstenholme & Whiley, 1995). Lateral buds from the other trees, especially those of treatments 1 and 6, which did not sprout into inflorescence during the winter, grew into vegetative flushes. The control trees were not encouraged to stimulate new shoot development by pruning and the old flower stalks that remained on the shoots inhibited sufficient vegetative growth. Limited new shoot development and flowering on these shoots, therefore, was due to sprouting of apical buds that didn't sprout the previous season. Issarakraisila *et al*. (1991) found that only 4% of shoots that matured a fruit flushed after harvest in cool subtropical Australia. Shoot development and flowering on the control shoots can also be due to random development from previous harvest and inflorescence development scars that might have activated axillary buds as also been stated by Oosthuyse (1994) in 'Sensation' mango. The total average leaf area of the newly developed leaves,

together with the existing foliage of the tree, will determine the amount of carbohydrate to be produced.

The assimilate produced could be used for reserve demanding processes like flowering and fruiting and any surplus, for replenishing the reserve of the tree. This will ultimately have an impact on regular bearing and quality of fruits to be produced. Immediate post-harvest pruning proved to produce better results for all the vegetative parameters observed in both cultivars. That was because pruning trees immediately after harvest encouraged the trees to produce enough new vegetative growth that matured early in the season especially for an early cultivar. Therefore, pruning immediately after harvest may be extrapolated to any early cultivar. Like what is observed in this study for 'TA', it has been generally recognised that the ideal time to apply terminal shoot pruning is directly after harvest (Mullins, 1986; Ram, 1993). The rationale for early pruning is the allowance of maximum time for canopy recovery, shoot maturation and quiescence to maximise the likelihood of flowering of the new shoots. The need for quiescence might be linked to the reduction of endogenous gibberellins (Chen, 1987) and accumulation of starch reserves (Suryanarayana, 1987). Consequently, pruning by hastening post-harvest flushing to occur uniformly, may effect earlier and more complete reserve replenishment (Oosthuyse, 1994; Davie *et al*., 1995). Flushing is important because new mango leaves are efficient producers of carbohydrates, the tree's building materials (Oosthuyse, 1995) and sources of energy. The results for number of new shoot development after post-harvest pruning were in line while that of new shoot length and number of leaves per new shoots contrary to the observations of Oosthuyse (1994) in 'Sensation' mango.

Flowering and fruiting from trees that received post-harvest pruning was delayed as compared to the control (on average by about 2-3 weeks). Oosthuyse (1994) also indicated that post-harvest pruning would result in slightly delayed flowering. He explained that vegetative re-growth caused by pruning after harvest, elevates the level of endogenous gibberellins, and thereby effects a delay in bud development and a delay in flowering. This connotation is contradictory to the fact that gibberellins normally encourage sprouting of buds. A delay in flowering is generally considered advantageous, since inflorescence development when temperatures are higher, results in an increase in the proportion of perfect as opposed to male flowers formed (Mullins, 1986), and gives rise to more effective pollination (Robbertse *et al*., 1986; Shu *et al*., 1989; Issarakraisila & Considine, 1994).

Practicing post-harvest pruning on late cultivars like 'KT' may have a negative effect, especially with a very late harvest, on the development and maturation of vegetative growth required for bearing the coming season's crop. This phenomenon may lead to the occurrence of biennial bearing. Renewal pruning, consequently, was primarily developed for late cultivars where 30% of the shoots were pruned before harvest when the fruit are still small. Stassen *et al*. (1999) promoted the applicability of renewal pruning for late cultivars. Fivas *et al*. (1997) and Fivas & Stassen (1996) also advocated the merits of renewal pruning on different mango cultivars. In general, pruning is essential for a timely development of vegetative flush. The absence of flushing during February, March and April may be followed by flushing instead of flowering during August and September that could result in a crop failure.

Pruning treatments, especially renewal and post-harvest pruning, involve removal of vegetative plant parts. However, not all pruning treatments had a negative effect on yield, more particularly in 'TA'. That was because pruning encouraged the development of new vegetative shoots. Those shoots can replenish the tree's carbohydrate reserve and also mature, flower and bear the coming season's crop. This advantage of pruning was also observed by Oosthuyse (1994) in 'Sensation' mango. If the tree stores a good carbohydrate reserve due to sufficient vegetative growth (as obtained by treatments 4 and 5 in this experiment) a larger total fruit weight per tree can be expected. The larger fruit weight obtained in this experiment due to post-harvest pruning was contrary to the results for the first year observations of Fivas & Stassen (1996) in 'TA'. Fivas & Stassen (1996) explained that the lower fruit weight result for the first season could be due to pruning the trees two months after harvest (late) and the time available for new shoot development was limited. This indicated that post-harvest pruning should be done directly after harvest as has been done in the current experiment. Their second season result on pruning of 'TA' was perspective to the results of the current experiment. Stassen *et al.* (1999) observed that fruit weight was always better with pruning while yield was lower during the first year but not for the consequent years.

The higher fruit numbers from for treatment 1, which is indicated in Table 5.6, may be due to increased fruit setting and fruit retention after re-flowering. The larger fruit setting in turn may be due to a favourable higher temperature during the growth of the different parts of the flowers. Mean monthly maximum and minimum temperatures were 22/10, 26/12 and 30/12 ^{o}C for September, October and November 2002 respectively (data recorded but not included in the thesis). In line with the

current observations, several practical advantages in the induction of axillary panicles after panicle pruning of mango (as in the case of treatment 1) have been reported in previous experiments. The primary advantage is to assure a good crop by escaping from or by making up the damages to the panicles caused by prevailing low temperature, frost and incessant rain (Singh *et al*., 1974). Another benefit of inducing axillary panicles is to provide a remedy for trees render unproductive by malformation (Majumder *et al*., 1976; Pal & Chadha, 1982). Moreover, orchard owners in the central part of Taiwan have used this technique to produce off-season mango fruits (Shu & Sheen, 1987). Chang & Leon (1987) also indicated that deblossoming of the terminal inflorescence could lead to inflorescence development from axillary buds but a 20-30 day later harvest. The result for the increase in fruit number and weight due to some of the pruning treatments in the current study is in contrary to the results of Oosthuyse & Jacobs (1996) in 'Sensation' mango. It is worthy to note, however, that fruit quantitative factors may vary based on different cultivars, weather variations in different seasons and tree physiological conditions.

The lowest fruit number and weight per tree by trees that received treatment 2 could be due to additional leaf removal. This in turn may affect inflorescence and fruit development as well as fruit retention as also observed by Oosthuyse & Jacobs (1996). They noted that a reduction in fruit number, retention and tree yield was associated with pruning the terminal shoots 5 cm beneath the site of apical bud or inflorescence attachment as opposed to this site. Hence, especially 'TA' trees that received treatments 1, 4 and 5 produced larger fruit weight as compared to trees that received treatments 2, 3 and the control because of the above-mentioned reasons.

The treatments, however, did not have any impact on the total yield ha^{-1} for both cultivars as also been observed by Oosthuyse (1994); Oosthuyse & Jacobs (1996); Stassen *et al*. (1999) in 'TA' and other cultivars. The result was perspective to the observations of Fivas & Stassen (1996) while contradictory to that of Oosthuyse (1997), where reduced yield due to pruning was obtained. Chang & Leon (1987), on the contrary, obtained a larger yield by deblossoming the terminal inflorescence.

There was a trend towards synchronised flowering and ultimately fruiting after applying treatment 1 compared to the control trees. About 90% of the fruit from trees that received treatment 1 were ready for harvest (physiologically matured) on average with in two week period as compared to about a month required to complete harvesting of the fruit from the control trees. Oosthuyse & Jacobs (1996) indicated that flowering synchronisation in their studies might be ascribed to the simultaneous wound stimulation and release from apical dominance of distally situated axillary buds in similar states of quiescent dormancy at a time when root produced growth substances were not limiting.

Higher fruit TSS of 'TA' by renewal and post-harvest pruning treatments can be ascribed to trees getting enough time to produce a new flush and those flushes mature early in the season especially for early cultivars. As compared to old flushes, new and matured leaves can efficiently manufacture more photsynthate and consequently attain higher reserve levels. The implication with sufficient reserve and fruit number not exceeding the tree's capacity is that all the developing fruit would receive an adequate supply of carbohydrates. Regarding renewal pruning, by removing dead and dying plant parts, which are with reduced photosynthesis efficiency, as well as poorly

developed and excess fruit, the plant reserve is conserved for the developing fruit. Wolstenholme & Whiley (1995) indicated that by practising renewal pruning, firstly it removes 'carbon starved, exhausted' fruiting shoots which will not fruit the next season. Secondly, old leaves with reduced efficiency are replaced with young and active leaves that make a better chance to build up carbohydrate reserves (even with winter photo inhibition).

In general, there was a trend that fruit with higher TSS would normally have lower titratable acids, which ultimately affects the TSS to acid ratio. Lakshminarayana (1980) explained that the titratable acids of fruit decrease during ripening. The reduction of acidity during ripening, he explained, plays a great part in the acid: sugar balance and consequently, in influencing the taste and flavour of the fruit. The predominant acid in common mango cultivar's pulp is citric acid and the secondary acids are malic and tartaric acid in varying proportions depending on the cultivars and ripening stage (Lakshminarayana 1980).

5.6 CONCLUSION

The hypothesis of some researchers and growers on the adverse effects of pruning treatments especially on the quantitative fruit parameters was not observed in the current study. Panicle pruning at the point of attachment, renewal and post-harvest pruning treatments were found to be promising for attaining higher results on vegetative growth, fruit number, TSS as well as synchronisation of flowering and fruit development. Time of applying post-harvest pruning is very crucial in that delayed pruning of the trees after harvest may lower or cause failure of cropping especially for

late cultivars. Renewal pruning should be practiced on late cultivars rather than post-harvest pruning. Panicle pruning together with apical whorl of leaves showed adverse effects on flowering and fruit harvested. It should be noted that, an increase in the parameters mentioned might not occur over seasons and a combination of pruning treatments should be applied than a single treatment. Adequate management as to the standard requirements of each mango cultivars is also mandatory to attain the desired response out of pruning treatments.

CHAPTER 6

EFFECTS OF VARIOUS INDUCTIVE PERIODS AND CHEMICALS ON FLOWERING AND VEGETATIVE GROWTH OF TOMMY ATKINS AND KEITT MANGO CULTIVARS.

6.1 ABSTRACT

The effects of potassium nitrate and paclobutrazol on flowering and vegetative growth of 'Tommy Atkins' and 'Keitt' mango were studied under various periods of exposure to inductive and non-inductive temperature regimes. The experiment was done at the University of Pretoria experimental farm in temperature-regulated cabinets on 2-year-old potted 'Tommy Atkins' and 'Keitt' mango cultivars. 'Keitt' was more sensitive towards low temperature floral induction than 'Tommy Atkins'. For both cultivars, the trend revealed that, incomplete floral induction could be complemented by paclobutrazol application. Paclobutrazol also significantly reduced vegetative growth and number of days required for a visible inflorescence emergence in both cultivars. Potassium nitrate promoted the sprouting of buds for vegetative growth under non-inductive temperature conditions and reproductive growth under inductive conditions. The minimum inductive period at 10/15^{o}C (12 h light/12 h dark) required for "complete" floral induction and development was found to be 35 days for both cultivars.

Surpassing the inductive (cold) period showed adverse effects on normal development of the reproductive parts and also delayed inflorescence emergence.

Key words: cold units, flowering, paclobutrazol, potassium nitrate, vegetative flush

- **Published in *New Zealand Journal of Crop and Horticultural Science*, vol. 32(2), 209-215 (The Royal Society of New Zealand)**

6.2 INTRODUCTION

Induction refers to the commitment of buds to evoke a particular shoot type, i.e., vegetative shoot (vegetative induction), generative shoot (floral induction) or mixed shoot (combined vegetative–floral induction) (Davenport & Nunez-Elisea, 1997). Floral induction of most plants involves sensing some environmental cue, i.e., day length, water stress, or vernalising temperature in some organs (Davenport & Nunez-Elisea, 1997). The event is translated to the production of a putative floral stimulus or alteration in the ratio of florigenic and anti-florigenic components that may be translated to target cells in meristems (Bernier *et al*., 1981). However a specific compound that acts as a floral stimulus has never been isolated, casting doubt on its existence (Lang *et al*., 1977).

Studies in mango, on the other hand, revealed the existence of a floral stimulus, which is continuously synthesised in mango leaves during exposure to cool, inductive temperatures (Davenport & Nunez-Elisea, 1990). Unlike other plants requiring vernalisation for induction (Bernier *et al*., 1981), mango leaves appear to be the only site where the putative floral stimulus is produced (Nunez-Elisea & Davenport, 1992). Complete defoliation of girdled branches during inductive conditions results in vegetative shoots instead of generative shoots (Nunez-Elisea & Davenport, 1991b; Nunez-Elisea & Davenport, 1992). The putative temperature regulated floral stimulus is short-lived *in situ*, its influence only last 6-10 days (Nunez-Elisea & Davenport, 1992; Nunez-Elisea *et al*., 1996). Temperatures below 15^{o}C readily promote floral induction, whereas vegetative growth is generally promoted by warmer temperatures (Whiley *et al*., 1989; Nunez-Elisea & Davenport, 1991b). Ravishankar *et al*. (1979)

however, found that low temperature appears to exert a depressing effect on the further development of flower buds of mango. Under field conditions, the duration of cool inductive temperature (cold units) for reproductive morphogenesis might not be sufficient as required by a specific cultivar, or may revert from inductive to non-inductive conditions before complete floral induction is achieved. These conditions only favour partial floral induction or complete vegetative morphogenesis. This is why attainment of floral induction does not ensure initiation of floral morphogenesis (Nunez-Elisea & Davenport, 1995). According to the latter authors, growth of induced buds in the presence of cool temperature was found to be essential for floral initiation (resumed growth), because insufficiently induced apical buds that resumed growth after trees were transferred to warm temperatures outdoors, produced a vegetative flush instead of an inflorescence.

Initiation of apical buds was stimulated at the start of temperature treatment by defoliating shoot tips (Nunez-Elisea & Davenport, 1991b). Bud initiation (resumed growth) was characterised as the swelling and initial elongation of the apex (about 5mm in height), which assures a distinct conical shape, and had tightly clasped outer bud scales (Nunez-Elisea *et al*., 1993). Bud break is considered the stage at which external bud scales loosened and began to open (Nunez-Elisea & Davenport, 1991a).

Growth regulators should be assessed for their complemental or total substitution effects (for some cultivars) of cold temperature requirement for reproductive morphogenesis. Positive results with growth regulators may have special attributes in places with poor floral inductive climatic conditions or with frequent and sudden changes in temperature for sufficient floral induction. In countries like Ethiopia, such

incomplete floral induction is often experienced and sometimes leads to crop failures. Hence, this experiment was designed to determine the ability of paclobutrazol (PBZ) and potassium nitrate (KNO_3) to complement or intensify flowering and also their effect on vegetative growth. A field experiment using the same chemicals was simultaneously done in Ethiopia.

6.3 MATERIALS AND METHODS

6.3.1 Area description and season

The experiment was done at the University of Pretoria experimental farm in temperature-regulated chambers. The growth chambers provided a photosynthetic photon flux of 334-399 μmol m^{-2} s^{-1} at the upper tree canopy level and a relative humidity above 75%. The experiment began in early December 2002 when the average day/night temperatures were around 31/16^{o}C and therefore non-floral inductive.

6.3.2 Plant materials

Uniform 2-year-old potted Tommy Atkins ('TA') and Keitt ('KT') mango trees were used for the experiment. The plants were decapitated by removing the terminal 2-3 cm of the stem, including the terminal bud, to induce a new vegetative flush before the onset of the experiment. The plants were watered every third day and received 250 ml of a standard Hoagland solution once a week. The trees had almost equal numbers of leaves ($\pm$10) and not more than 2 flushes per tree.

6.3.3 Treatments and experimental design

The experiment was a three factor factorial combination in a randomised complete block design with three replications. Randomly assigned three plant replications per treatment were used to apply four chemical treatments (no treatment (control), 3% potassium nitrate (KNO_3), 500 ppm paclobutrazol (PBZ) or 2000 ppm PBZ) in a factorial combination. The trees were kept under inductive temperature conditions (15/10^{o}C 12 h/12 h light/dark) for four durations, 0 (control), 15, 35, or 60 days. After the trees were induced with cold treatment for the above-mentioned durations, they were transferred to a non-inductive warm temperature cabinet (25/20^{o}C).

Due to limited space per chamber, three cabinets of the same make, temperature and light settings were used.

6.3.4 Parameters recorded

The number of days the trees were exposed to a low temperature regime for each treatment was taken as the number of cold units (Robbertse & Manyaga, 1998). The date of flowering (beginning of flowering) was recorded as the number of days passed after first spray and/or beginning of inductive or non-inductive temperature treatment to the production of a visible inflorescence (bud break stage). Only trees that were subjected to the low temperature for 35 and 60 days (both sprayed with the chemical treatments or non-sprayed) were compared since all trees in the three replications flowered. It was difficult to compare the other treatment combinations since all or most

of their replicated trees did not flower. To detect differences in flowering time in relation to treatments, inflorescence development was monitored every day.

The number and length of the inflorescences produced was recorded at the end of the experiment. The number and surface area (length (cm) x width (cm) = cm^2), of any new leaves that were produced and length of new flushes (cm) produced were also recorded. The total duration of the experiment was 130 days.

6.3.5 Statistical analysis

Logarithmic transformations were done where necessary, to normalise a highly variable data set before data analysis. Statistical analysis was performed using the Genstat, (2000) computer package (release 2.2) and comparison of means was done using Least Significant Difference (LSD) at 5% level of significance. Flowering response was analysed using a General Linear Model (GLM) for unbalanced designs (Joubert *et al*., 1993).

6.4 RESULTS

6.4.1 Numbers of inflorescences produced

Regardless of the cultivars, the numbers of inflorescences developed were affected both by the time the trees were kept under inductive condition and by chemical spray (Tables 6.1 and 6.2). Duration of the inductive temperature for 35 days and above had significantly increased the number of inflorescences developed per tree as compared to

the control for both cultivars (Table 6.1). Trees that were under inductive temperature for 60 days had significantly higher number of inflorescences than all the other exposure periods (Table 6.1, Fig. 6.1). On the other hand, even if the interaction between duration and chemicals was not significant, the trend showed that both 'TA' and 'KT' trees sprayed with 500 and 2000 ppm PBZ did flower, where the supplemental chemical spray was applied to trees exposed to the inductive temperature for only 15 days (Table 6.2). Non-sprayed and trees that were sprayed with 3% KNO_3 did not flower after 15 days stay in the inductive temperature. Averaged across cultivars and duration period in the inductive temperature, on the other hand, trees sprayed with 2000 ppm PBZ had a significantly higher number of inflorescences than the control as well as from trees sprayed with 3% KNO_3. The result, however, was not significantly different to spraying with 500 ppm PBZ. (Table 6.3, Fig. 6.2, 6.3 A&B). There was a 55.42% increase in the number of inflorescences developed when trees were sprayed with 2000 ppm compared with the control.

Table 6.1 Effect of different exposure periods to the inductive temperature on flowering and vegetative growth parameters

Duration in the inductive temperature (days)	Number of inflorescences	Length of new flushes (cm)	Number of new leaves developed	Leaf size (cm^2)
0 (control)	0.08c	20.07a	10.50a	86.91a
15	0.08c	17.12b	8.00b	77.63a
35	1.87b	11.67c	6.29bc	63.80b
60	2.21a	8.62d	4.87c	52.63b

Means followed by different letters in a column are significantly different by LSD test at P<0.05

Table 6.2 **Effects of various duration in the inductive temperature and chemicals on flower development of Tommy Atkins and Keitt mango cultivars.**

	Chemicals			
Duration (days)	0 (no chemical)	3% KNO_3	500 ppm PBZ	2000 ppm PBZ
0	0.00a	0.17a	0.00a	0.17a
15	0.00a	0.00a	0.17a	0.17a
35	1.33a	1.50a	2.17a	2.50a
60	2.00a	2.17a	2.33a	2.33a

Means followed by different letters in columns and rows are significantly different by LSD test at P<0.05

Figure 6.1 **'Tommy Atkins' trees exposed for 60 days to inductive temperature resulted in inflorescence development without additional chemical spray.**

Table 6.3 The effect of different chemical treatments on flowering and vegetative growth of 'Tommy Atkins' and 'Keitt'

Chemical treatments	Number of inflorescences per tree	Days from first day of induction to bud break	Length of new flushes (cm)	Number of new leaves developed per tree	Leaf size (cm^2)
0 (control)	0.83c	114.8a	17.05b	7.00b	74.78b
3% KNO_3	0.96bc	103.5b	21.54a	9.62a	89.76a
500ppm PBZ	1.17ab	96.25c	11.64c	7.35b	66.66b
2000ppm PBZ	1.29a	90.58d	7.24d	5.67b	49.76c

Means followed by different letters in a column are significantly different by LSD test at P<0.05

Figure 6.2 Inflorescence development in 'Tommy Atkins' trees after 35 days induction and application of 500 ppm paclobutrazol.

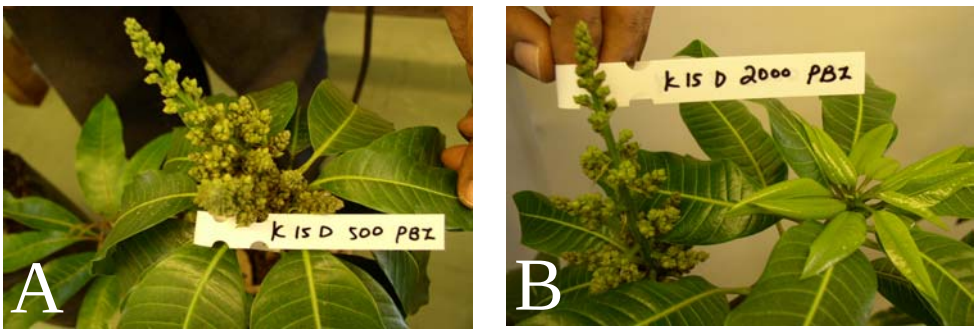

Figure 6.3 Paclobutrazol at 500 ppm (A) and 2000 ppm (B) concentration complemented the flower induction process in 'Keitt' trees that were exposed for only 15 days to inductive temperature.

6.4.2 Length of inflorescences produced

There was a significant difference for the interaction among cultivars, duration in the inductive temperature, and chemical spray for the length of inflorescences developed (Table 6.4). 'TA' trees that stayed 35 or 60 days under inductive temperature and were sprayed with 3% KNO_3 produced significantly longer inflorescences (25.5 cm) compared with the control (Table 6.4, Fig. 6.4). In 'KT' trees, the longest inflorescences were observed for trees that stayed 35 days under inductive temperature and were sprayed with 3% KNO_3 , even if the result was not significantly different to that of the control. Most of the trees that were not induced had no inflorescences at all and those sprayed with PBZ produced only short inflorescences (Fig. 6.5).

Figure 6.4 **Potassium nitrate at 3% concentration resulted in a significant increase in the length of inflorescence in 'Keitt' trees after the trees were exposed for only 35 days to inductive temperature (as for 'Tommy Atkins').**

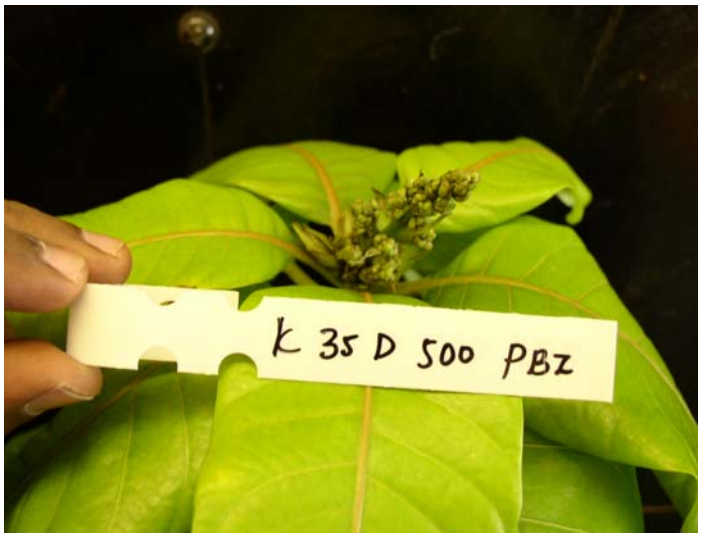

Figure 6.5 **Short inflorescences developed by spraying paclobutrazol unlike Potassium nitrate sprays in 'Keitt' trees.**

Table 6.4 **Effect of cultivars, varying induction periods and chemicals on the length of inflorescences (cm) in two mango cultivars**

Cultivar	Duration (days)	Chemical			
		0	3% KNO_3	500 ppm PBZ	2000 ppm PBZ
'TA'	0 (control)	0.00e	0.00e	0.00e	4.17e
	15	0.00e	0.00e	0.00e	0.00e
	35	15.87cd	25.50a	19.37a-d	16.27bcd
	60	20.00a-d	22.37ab	18.47a-d	15.43bcd
'KT'	0 (control)	0.00e	22.47ab	5.13e	0.00e
	15	0.00e	0.00e	5.07e	5.83e
	35	21.97abc	22.67ab	17.17bcd	13.60d
	60	21.97abc	21.27abc	17.67bcd	14.67cd

Means followed by different letters in columns and rows are significantly different by LSD test at P<0.05

6.4.3 Days from first day of induction to floral bud break

There was a significant interaction between cultivars and duration of low temperature treatment with respect to number of days required for floral bud break (Table 6.5). Chemical spraying also significantly affected the days required for floral bud break (Table 6.3). Both 'KT' and 'TA' trees that were exposed to the inductive temperature for 60 days required less number of days for flower bud break compared with trees that stayed only 35 days. The results also showed that 'KT' trees were induced and reacted to floral bud break prior to 'TA' trees. Bud break on trees sprayed with PBZ at a concentration of 2000 ppm was significantly advanced compared with control trees as well as trees of other treatments. It was observed from the current experiment that within 35 and 60 days inductive temperature period, the number of days elapsed for inflorescence emergence, declined from non-sprayed to KNO_3 and from KNO_3 to PBZ sprayed in both cultivars (Table 6.3).

Table 6.5 Reaction of 'TA' and 'KT' to two low temperature exposure periods on days required for floral bud break from the day of treatment application

	Duration (days)	
Cultivars	35	60
'Tommy Atkins'	112.75a	107.75b
'Keitt'	101.00c	83.58d

Means followed by different letters in columns and rows are significantly different by LSD test at $P<0.05$

6.4.4 Vegetative growth

The lengths of new vegetative flushes were affected by both the duration of exposing the trees to the inductive temperature and by the chemical treatments (Tables 6.1, 6.2). Irrespective of the cultivars used, the longer the trees were exposed to the inductive temperature, the shorter were the new vegetative flushes (Table 6.1). Consequently, the trees induced for various periods had significantly shorter vegetative flushes than the control (non-induced) (Fig. 6.6 A&B). Generally, there was a decrease in the length of new flushes developed from KNO_3 sprayed to the control trees and then from lower to higher PBZ concentration spray. In both cultivars, significantly longest flushes were observed on trees that were sprayed with 3% KNO_3 (Table 6.3, Fig. 6.7) (21.54 cm) and the shortest on trees sprayed with 2000 ppm PBZ (Table 6.3, Fig. 6.3B) (7.24 cm).

Figure 6.6 **'Tommy Atkins' (A) and 'Keitt' (B) trees that remained under non-inductive condition for the course of the experiment had longer vegetative flushes and more leaves.**

Figure 6.7 Longest new vegetative flushes were observed on trees sprayed with 3% potassium nitrate in 'Keitt' trees.

The number of new leaves per flush was affected by the duration in the inductive temperature and by chemical spray, independently (Tables 6.1, 6.2). In both cultivars, the induced trees had significantly shorter flushes with fewer new leaves compared with the control trees (Table 6.1, Fig. 6.6 A&B). Trees induced for 60 days had 115.61% reduction in new leaf development over the control. Averaged across cultivars and the duration period in the inductive temperature, trees sprayed with 3% KNO_3 produced a significantly higher number of leaves as compared with all the other spraying treatments (Table 6.3).

The size of the newly developed leaves was also affected by the nature of the cultivar, duration in inductive temperature, and chemicals sprayed, independently. Averaged across duration and chemical treatments, 'KT' trees had a significantly greater leaf size (76.47 cm^2) than 'TA' trees (64.02 cm^2) (Table 6.6). Keeping trees under inductive temperature for 35 or 60 days significantly reduced leaf size by approximately 41.31%

compared with the control, as well as trees that were induced for 15 days (Table 6.1, Fig. 6.8). Averaged across cultivars and duration in the inductive temperature, where trees were sprayed with 3% KNO_3 had a significantly greater size of newly developed leaves (by 20 % higher) than the control trees (Table 6.3). On the contrary, application of PBZ especially at a concentration of 2000 ppm significantly reduced the size of newly developed leaves (Table 6.3, Fig. 6.9).

Table 6.6 Effect of cultivar differences on the size of the newly developed leaves

Cultivars	Leaf size (cm^2)
'Tommy Atkins'	64.015a
'Keitt'	76.467b

Means followed by different letters in a column are significantly different by LSD test at P<0.05

Figure 6.8 Larger size of newly developed leaves is obtained for trees with no or lower number of exposure days in the inductive temperature in 'Tommy Atkins'.

Figure 6.9 Paclobutrazol at 2000 ppm concentration highly reduced the size of newly developed leaves in 'Keitt'.

6.5 DISCUSSION

Critical low temperature requirement and the minimum duration thereof, required for flower induction is determined by visible floral differentiation, which may be variable in different cultivars (Chaikiattiyos *et al.*, 1994). In the current experiment, the minimum number of cold units required for effective floral induction was found to be 35 days for both cultivars. Although the interaction between the duration and chemicals was not significant, the trend showed that PBZ applied at either 500 or 2000 ppm concentration had the potential to complement the cold temperature requirement for floral induction.

During the first round of this experiment that was done during the previous season (not described in this report) showed very similar results but due to unacceptable variations caused by defects in the growth cabinets, the data are not presented. Therefore, there

seems to be a practical possibility of using PBZ for better floral induction under poor inductive conditions as often experienced in Ethiopia. This statement can be supported by the results of a field experiment done (Chapter 4 in this thesis). In addition flowering intensity was increased both by longer duration of the trees under inductive temperature and by spraying trees, particularly by increasing the concentration of PBZ up to 2000 ppm. PBZ, owing to its anti-gibberellin activity (Quinlan & Richardson, 1984), could induce or intensify flowering by blocking the conversion of kaurene to kaurenoic acid. From the current experiment, a combination of an inductive temperature for 35 days and spraying of 500 ppm PBZ on the trees is found to be sufficient and economical for successful floral induction and higher flowering intensity.

Applications of higher concentrations of PBZ had a negative effect with regard to length of both inflorescence and vegetative growth of the trees, as well as number and size of new leaves developed. According to Steffens *et al.* (1985), PBZ has the greatest effect on immature tissues, which are still growing and differentiating. This could explain why PBZ affected predominantly the apical growth. Gao *et al*. (1987) also indicated that triazoles reduce leaf area. The result of a decrease in the vegetative growth parameters resulting from PBZ application in the current study agrees with that of Salazar-Gracia & Vazquez-Valdivia (1997); Hoda *et al*. (2001).

The increase in length of inflorescences and new flushes in response to KNO_3 treatment may be a result of the enhanced cell division and enlargement in the meristematic zones. A similar growth pattern was observed for the vegetative growth parameters of trees that stayed in the non-inductive temperature for long periods. Surpassing the required inductive cold period also hindered and delayed normal

inflorescence development. Hence, as indicated above, induction periods of 35 days or less may be sufficient for successful floral induction without adversely affecting the development of the reproductive parts. Ravishankar *et al.* (1979) also found that low temperature appears to exert a depressing effect on further development of flower buds of mango. A negative correlation occurred between number of inflorescence and length of flushes developed (r=-0.96*). The regression graph for the two parameters indicates the antagonistic development pattern of the two important plant parts (Fig. 6.10). According to Wolstenholme & Hofmeyer (1985), vegetative growth and fruiting in mango trees are largely antagonistic and that excessive vegetative growth, especially if there is no marked dry season, is likely to cause poor yields.

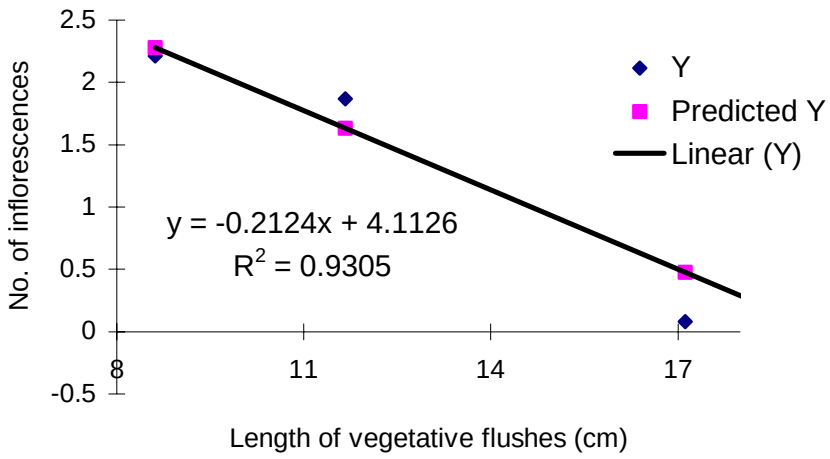

Figure 6.10 Regression between number of inflorescences developed and length of new vegetative flushes produced.

There was a significant positive correlation (r=0.98) between number of leaves and length of flushes developed. A regression graph of the two parameters signifies the direct relationship between flush length and number of nodes for leaf development (Fig. 6.11). From a pruning perspective, the direct relationship between flush length and leaf number implies a direct relationship between flush length and number of axillary bud per flush, thus increasing the scope for subsequent pruning.

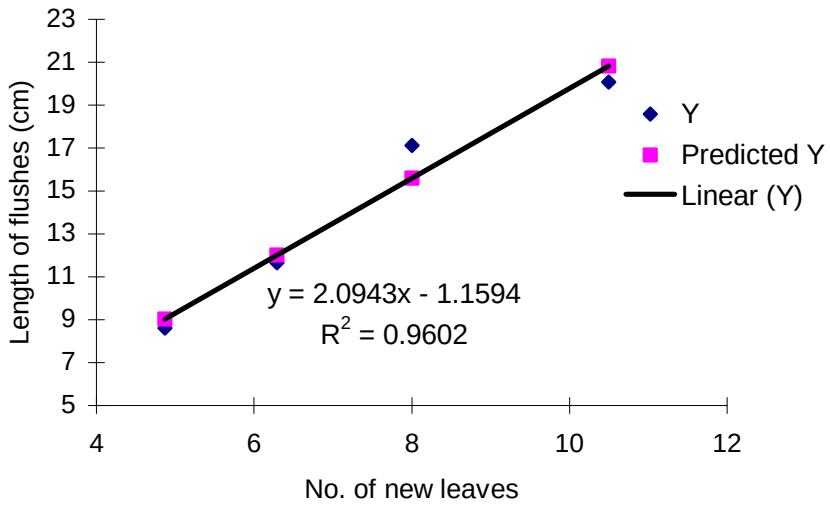

Figure 6.11 Regression between length of new vegetative flushes and number of new leaves developed.

Trees sprayed with 2000 ppm PBZ had their floral bud break 91 days after treatment applications (96 days for 500 ppm) whereas the control required 115 days. Thus, trees sprayed with the 2 PBZ concentrations advanced flowering by 22 days on average. It is probable that the application of PBZ caused an early reduction of endogenous gibberellin levels within the shoots as also observed by Anon (1984), causing them to

reach maturity earlier than those of untreated trees. The interaction between cultivar and duration revealed that 'KT' trees that stayed 60 days in the inductive temperature had their floral bud break 24 days earlier than 'TA'. This was also observed under field conditions on panicle pruning experiments conducted in South Africa (Chapter 5 in this thesis). In the latter study, it was revealed that even if flower induction and inflorescence development was earlier in 'KT' than 'TA' trees originally, the stage of fruit development in 'KT' became very slow to end up with an early fruit development and maturation in 'TA'. That situation proved the normal physiological characteristics of 'KT' to be a late cultivar. The effect of 500 ppm PBZ on the reduction of days for floral bud break may be sufficient as against applying 2000 ppm PBZ. This depends on the market situation for an early crop and economic analysis for the benefit of the two concentrations in a given country and orchard. The effect of PBZ on the reduction of days for inflorescence bud break in this experiment is similar to the observation of Tongumpai *et al*. (1996). On the other hand, the results for the floral and vegetative parameters considered in this trial are similar to the experiments of Nunez-Elisea & Davenport (1991a; b); Davenport & Nunez-Elisea (1997).

6.6 CONCLUSION

In general, bud development in to either a vegetative or a reproductive plant part is determined by the temperature to which the plants are exposed as reported by Nunez-Elisea (1985). In the current experiment, the minimum number of cold units required for sufficient floral induction was found to be 35 days for both cultivars. Nevertheless, PBZ application at 500 or 2000 ppm concentration also showed the potential to complement cold temperature requirement for trees that stayed only 15 days at floral

inductive temperature. It was also observed that the impact of KNO_3 and PBZ on various parameters is considerable. Applications of 3% KNO_3 spray in combination with a minimum inductive period of 35 days had a significant effect on increasing the length of inflorescences, especially in 'TA'. It can be deduced from the current experiment that spraying of 500 ppm PBZ may be sufficient to suppress vegetative growth that will in turn have an impact in encouraging reproductive growth. It was also found to be successfully sufficient to reduce the number of days for attaining floral bud break.

CHAPTER 7

POTASSIUM NITRATE AND UREA SPRAYS AFFECTED FLOWERING AND YIELDS OF 'TOMMY ATKINS' MANGO IN ETHIOPIA.

7.1 ABSTRACT

The effects of applications of potassium nitrate (KNO_3), alone and in combination with urea at different concentrations on flowering, fruit set and fruit quality of 'Tommy Atkins' mango grown in the rift valley of Ethiopia were evaluated. The trees were characterised by erratic flowering, continuous and high intensity of vegetative growth as well as irregular bearing. Uniform trees were selected for a randomised complete block design experiment with three replications and three trees per plot. Spraying was conducted initially on the immature post-harvest flushes and then repeated after the flushes had matured and dark green leaves. Potassium nitrate concentrations especially in combination with urea (5 litre solution of 4% KNO_3+0.5 g urea tree^{-1} and 5 litres of 4% KNO_3+1 g urea tree^{-1}) produced better results for most of the flowering and yield parameters. There was a non-significant difference for the qualitative parameters between the treated and non-treated trees. The supplementation of nitrogen through the spraying of KNO_3 and urea is believed to be the reason for the greater flowering and yields results of the sprayed relative to the unsprayed trees.

Key words*:* mango, potassium nitrate, urea, flowering, fruiting

- **Accepted for publication in South African Journal of Plant and Soil.**

7.2 INTRODUCTION

Subsequent to the discovery and use of ethephon to replace smudging and stimulate flowering of mango, Barba (1974) reported the use of potassium nitrate (KNO_3) for the same purpose. In subtropical regions, where winter conditions are sufficiently inductive for flowering in mangoes, flowering enhancement by KNO_3 has not been reported (Oosthuyse, 1996). KNO_3 sprays, however, have been used to stimulate off-season flowering of mango, especially in tropical regions (Bondad & Linsangan, 1979; Nunez-Elisea, 1985). Goguey (1993) asserted that the responses of plants to different flower inducing treatments differ according to cultivar, climatic conditions and geographical location.

KNO_3 has been shown to affect the date of flowering and number of panicles per tree formed in mango in some tropical regions (Fierro & Ulloa, 1991). Results concerning the effects of KNO_3 treatments on flower promotion and fruiting have not been consistent in India (Pal *et al.*, 1979, cited by Fierro & Ulloa, 1991) and Australia (Winston & Wright, 1986), or even negative in Florida as reported by Davenport (1987). Similar inconsistent results were obtained in experiments involving date of application, interval between applications, concentrations or component salt effects (Fierro & Ulloa, 1991; Machado & Sao Jose, 2000).

In the low- and mid- latitude tropics, receptive trees responded by initiating floral buds within two weeks after treatment, and the effective spray concentration ranges from 1 to 10% KNO_3 with the optimum concentration varying with the age of the trees and climate (Davenport & Nunez-Elisea, 1997). KNO_3 concentrations of 2-4%

or 1-2% ammonium nitrate (NH_4NO_3) have been found to be effective for initiating floral buds under tropical climatic conditions (Nunez-Elisea, 1985; Nunez-Elisea & Caldeira, 1988). Rojas & Leal (1996) stated that the concentration of KNO_3 used to induce mango flowering varies between 10-60 mg l^{-1}. Maas (1989) found that foliar spraying with a 2% KNO_3 solution proved to be very effective for inducing mango trees to bloom. Oosthuyse (1996) reported that KNO_3 application especially at 4% level was slightly phytotoxic to the leaves and inflorescences and caused the distal margins of some to the leaves and the extremities of some of the inflorescence branches to became necrotic. Some authors attribute the above-mentioned inconsistencies to the following factors: (1) inefficient application of the product; (2) physiological maturity of the plants; (3) yield of the previous harvest and (4) age of the shoots. The inconsistent results obtained with KNO_3 in different cultivars, climatic conditions and geographical locations necessitated further investigation of the effects of KNO_3.

The effect of urea on mango is also not well documented. In Ethiopia, erratic flowering, intensive vegetative growth and irregular bearing are typical of most orchards. The two flowering periods experienced in Ethiopia (being located near the equator) also lead to poor and unreliable yield. The cost of production is also high due to the two cycles of tree management and harvesting per year. Thus, the reputed beneficial effects of KNO_3 and urea as a remedy for flowering and fruiting would be invaluable. In this report, the results for the effects of KNO_3 and urea on different flowering, quantitative as well as qualitative aspects of 'Tommy Atkins' mango are discussed. The results may also give answers to some of the controversies in previous experiments.

7.3 MATERIALS AND METHODS

7.3.1 Area description

The trial was conducted during the 2002/2003 season at Upper Awash Agro-industry Enterprise in the rift valley of Ethiopia (latitude: 8^0 27'N; longitude: 39^0 43'E; elevation: 1000 m asl.; temperature: mean annual max. 32.6 ^{0}C, mean annual min. 15.3 ^{0}C; mean annual rain fall: 500 mm; soil type: calcic xerosol). The area is situated 180 km S.E. of Addis Ababa.

7.3.2 Plant material

Ten year old 'Tommy Atkins' mango trees, uniform in vigour and size, were selected to study the effects of KNO_3 and urea on flowering, yield and fruit quality parameters. All treatment trees were subjected to the standard orchard management practices as applied by the company.

Before applying the treatments, 100 terminal shoots were marked randomly on each tree prior to spraying for recording the percentage of flowering branches. After inflorescence development, 20 panicles per tree were marked randomly on each tree for recording percentage of hermaphrodite flowers per panicle, whereas an additional 20 panicles per tree were used for monitoring fruit set.

7.3.3 Design, rate and periods of KNO_3 and urea application

A randomised complete block design with three replications and three trees per plot was used. The treatments applied were:

1. 2% KNO_3
2. 2% KNO_3+0.5 g urea
3. 2% KNO_3+1 g urea
4. 4% KNO_3
5. 4% KNO_3+0.5 g urea
6. 4% KNO_3+1 g urea
7. Control

Reagent grades of KNO_3 and urea were used. For all treatments, the required quantities of active ingredients (KNO_3 alone or with urea) were dissolved in 5 litres of water to be sprayed on a single tree. For the sake of convenience, however, only the concentrations of KNO_3 and the quantity of urea used will be mentioned in the paper. The control trees were sprayed with water only.

The first spraying (30th August 2002) of all the chemicals was done about three and half months before the expected regular blooming period, on the immature post-harvest flushes. About two and half months after the first spray, the spraying was repeated on the same trees. During the second spray, it was noticed that the terminal shoots were mature with sclerophyllous, dark green leaves and some trees had started flowering. The spraying was done in the early morning of both application cycles. A

mobile canvas shield was also used during spraying operation to prevent spray from drifting to adjacent trees.

7.3.4 Observations

Observations on flowering and fruit set

The percentage of branches that flowered was recorded from the hundred tagged shoots. The beginning of flowering was recorded for all treatments as the number of days between the first spray and the stage where 25 inflorescences from the tagged shoots per tree were at bud break. The total numbers of panicles per tree were counted 40 days after the second spray. Fruit set was quantified at the pea size stage. During harvesting, data on fruit number and weight per tree were recorded for obtaining tree yield.

Determination of fruit quality

Fruit quality was determined nine days after harvest, by sampling 30 fruit per tree, which were ripened at room temperature. Fruit total soluble solids (TSS) was measured with a bench top 60/70 ABBE (No. A90067, Bellingham & Stanley Ltd, England) refractometer with a reading range of 0 to 32 ^{0}Brix. Between readings, the prism of the refractometer was cleaned with tissue paper and methanol, rinsed with distilled water and dried before use. The refractometer was standardised against distilled water (0% TSS). Reducing and total sugars were determined by using the technique of Somogyi (1945). Titratable acid was determined by means of an acid base titration method using a 5 g sample and 0.1 N NaOH with phenolphthalein color indicator.

7.3.5 Statistical analysis

Differences between treatments were determined with Analysis of Variance (ANOVA) using SAS General Linear Model procedure (SAS Institute, 1988). Treatment means were separated using least significant difference (LSD) at the 5% level of significance.

7.4 RESULTS

7.4.1 Effect of the treatments on Flowering

All treatments produced significantly higher values for average number of panicles per tree as compared to the control. There was also a slight relation between increase in concentration of nitrogen in the treatments and improved flowering parameters.

The highest percentage of flowering terminals was observed in the 4% KNO_3+1 g urea treatment (treatment 6) which had a 52% increase in flowering compared to the control trees (Fig. 7.1). The five treatments with higher nitrogen content (treatments 2-6) significantly reduced the number of days required between first spray and flowering as compared to the control (Fig. 7.2).

All treated trees produced a significantly higher number of panicles per tree than the control trees (Fig. 7.3). Application of 4% KNO_3+0.5 g urea (treatment 5) had about twice as many panicles than the control. Flowering amongst the treated trees, on the other hand, did not differ significantly (Fig. 7.3). Except for 2% KNO_3, all the other

treatments produced significantly higher percentages of hermaphrodite flowers than the control (Fig. 7.4). A 2% KNO_3+1 g urea spray produced the highest percentages of hermaphrodite flowers, which was a 54% increase compared to the control (Fig. 7.4).

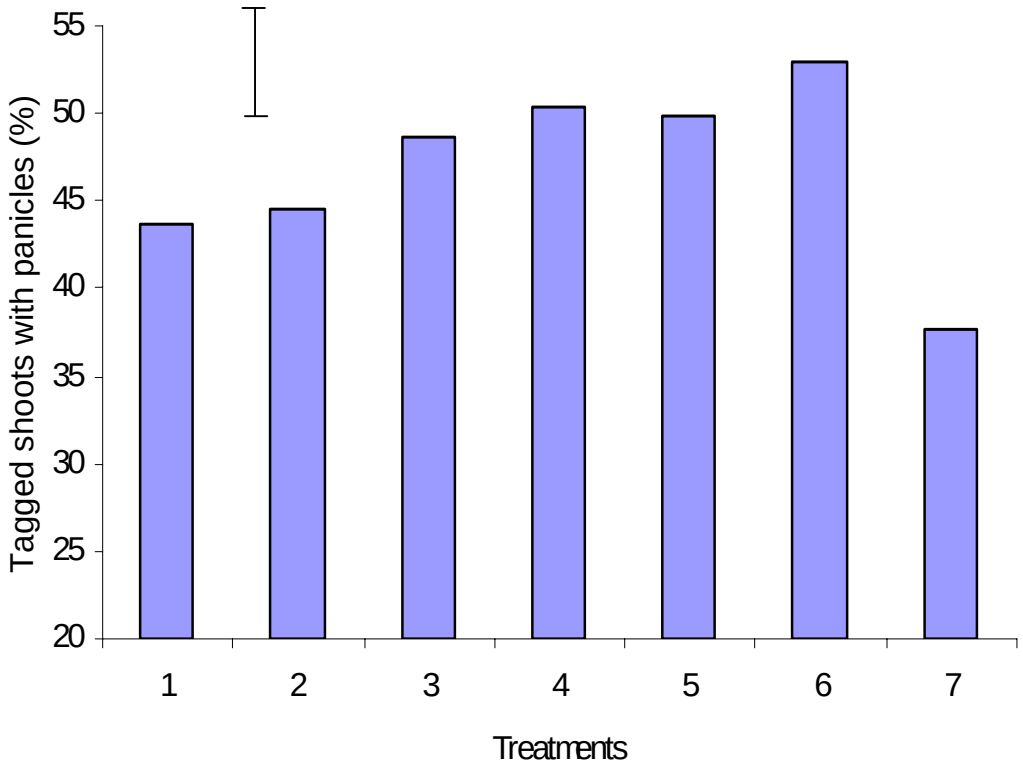

Figure 7.1 **Effect of potassium nitrate and urea spray on the percentage of tagged shoots flowering. The vertical line bars indicate LSD between means at P<0.05 level.**

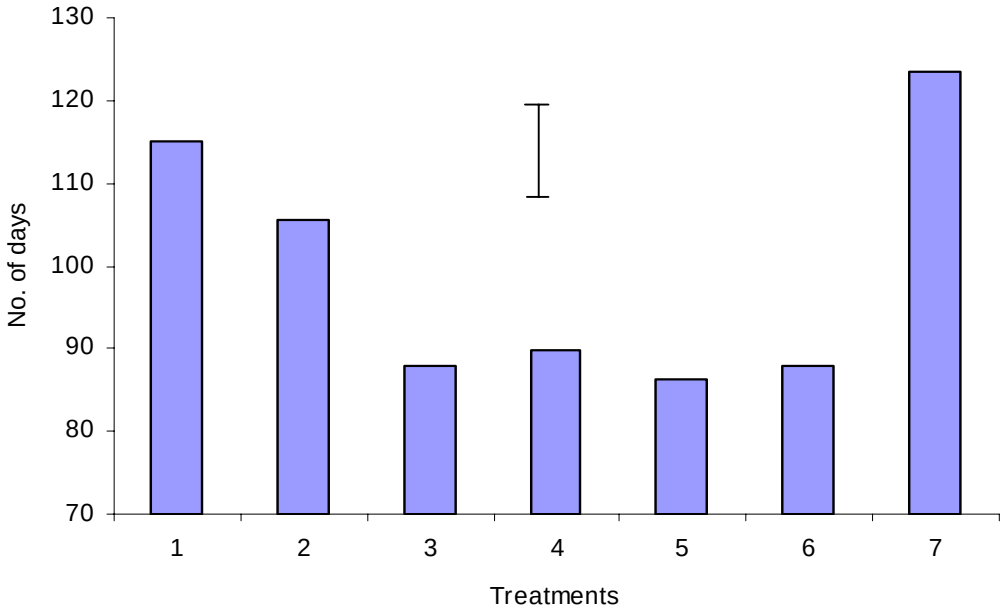

Figure 7.2 **Effect of potassium nitrate and urea on days between spraying and flowering. The vertical line bars indicate LSD between means at P<0.05 level.**

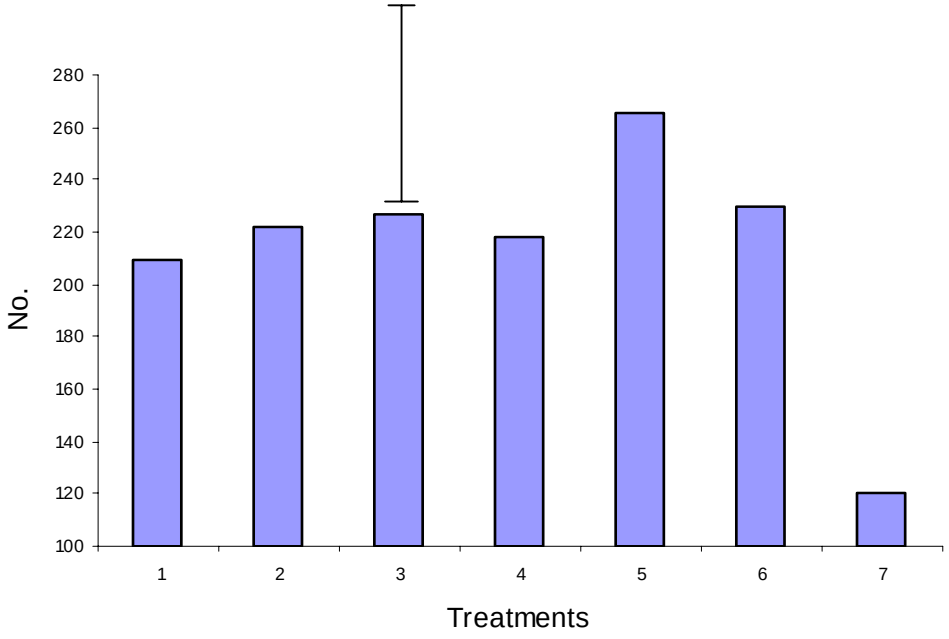

Figure 7.3 **Effect of potassium nitrate and urea on the number of panicles produced per tree. The vertical line bars indicate LSD between means at P<0.05 level.**

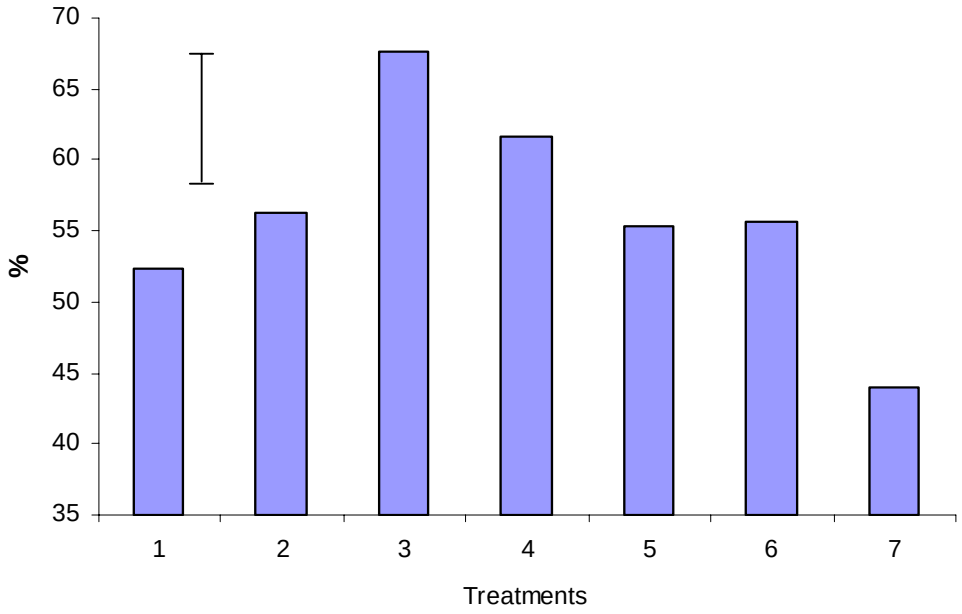

Figure 7.4 Effect of potassium nitrate and urea on the percentage of hermaphrodite flowers. Bars are LSD values between means and indicate significant differences at 5% level.

7.4.2 Effect of the treatments on fruit set and yield

All fruit set and yield results are presented in Table 7.1. Irrespective of the concentrations and different combinations of KNO_3 and urea applied, all treated trees had a significantly higher initial fruit set at pea size stage and fruit number and fruit weight per tree at harvest as compared to the control. There was no significant difference amongst the different concentrations of KNO_3 and urea with respect to initial fruit setting of the panicles.

There was a significantly higher fruit number per tree at harvest on trees sprayed with 4% KNO_3+0.5 g urea as compared with treatments that involve spraying of 2% KNO_3 and 2% KNO_3+ 0.5 g urea as well as the control trees (Table 7.1). The total fruit weight per tree in all treatments was significantly higher than the control (Table 7.1).

There was no significant difference, with respect to average weight of fruit at harvest, between treated and untreated trees. The trend, however, showed that treatments that had higher fruit number at harvest had lower average fruit weight.

Table 7.1 Effects of potassium nitrate and urea sprays on fruit set and yield of 'Tommy Atkins' mango

Treatments	Av. fruit set per 20 panicles (no.)	Fruit number per tree	Total fruit weight/tree (kg)	Average fruit weight (Kg)
Control	3.67b	164.67d	63.61b	0.387a
2% KNO_3	8.33a	208.33c	83.72a	0.403a
2% KNO_3+0.5g U	10.17a	216.33bc	82.71a	0.383a
2% KNO_3+1g U	12.17a	240.33ab	89.26a	0.373a
4% KNO_3	10.67a	238.33abc	88.59a	0.373a
4% KNO_3+0.5g U	10.50a	248.00a	88.86a	0.360a
4% KNO_3+1g U	11.17a	242.00ab	85.49a	0.357a

Means followed by different letters in a column are significantly different by LSD test at $P<0.05$

7.4.3 Effects of the treatments on fruit quality

Apparently, fruit quality was not affected by any of the treatments as indicated by non-significant differences for different parameters (Table 7.2).

Table 7.2 Effects of potassium nitrate and urea spray on fruit quality of 'Tommy Atkins' mango

Treat.	TSS (^{o}Brix)	Titratable Acids (mg/100g)	Reducing Sugar (%)	Total Sugar (%)
Control	13.33a	0.527a	4.00a	11.00a
2% KNO_3	14.20a	0.447a	3.83a	11.23a
2% KNO_3+0.5g U	14.78a	0.747a	3.91a	11.32a
2% KNO_3+1g U	14.71a	0.547a	4.02a	11.06a
4% KNO_3	15.49a	0.513a	4.04a	11.15a
4% KNO_3+0.5g U	13.89a	0.460a	4.12a	11.85a
4% KNO_3+1g U	14.70a	0.413a	4.09a	12.33a

Means followed by different letters in a column are significantly different by LSD test at P<0.05).

7.5 DISCUSSION

Some controversy regarding the time of KNO_3 application was noted in previous experiments with KNO_3. Some authors recommended KNO_3 application three months before the expected flowering (Fierro & Ulloa, 1991), that is during the initial stage of shoot growth (flushing), while others (Bondad & Linsangan, 1979; Perez-Barraza *et al*., 2000) obtained better results by applying KNO_3 on matured vegetative flushes. In our trial, the trees were sprayed twice – during the vegetative flush stage, and at the quiescent terminal bud stage of the matured flushes.

In the current study, a more or less ascending trend was noticed for the percentages of terminal shoots flowering as the concentration of KNO_3 and urea increased. This is a clear indication that the total nitrogen content of the spray solution was the critical factor. No phytotoxic effect to the leaves of the sprayed trees was observed I the

tropics by the higher concentrations of KNO_3, as opposed to the observations of Oosthuyse in the subtropics (1996). Phatak & Pandey (1978) observed that nitrogen status could be affected by foliar applications of KNO_3 and reported accumulation of nitrogen before flowering. Protacio (2000) mentioned the possibility of a threshold level for nitrogen concentration that, if exceeded, would allow the plant to flower. Consequently, the mechanism of KNO_3 and urea in triggering flowering could be a matter of exceeding this threshold level. In the current experiment, spraying trees with 4% KNO_3+1 g urea produced inflorescences on 53% of the tagged shoots. With the observations of Nunez-Elisea (1985), KNO_3 spray produced inflorescences on 60 and 76% of shoots in 'Haden' and 'Manila' mango, respectively, as compared to 32 and 20% in the corresponding controls.

Two flowering periods within a year is a common phenomenon in the semi-arid tropical regions such as Ethiopia. Due to the enhanced panicle development and fruiting, which had resulted from higher KNO_3 and urea concentrations, during the main flowering season (November-December), a very insignificant second flowering (April-May), which normally occurs in the same year, was noticed. This in turn has an implication of alleviating alternate bearing through conservation of reserves by reducing the second flowering.

Trees that received 4% KNO_3+ 0.5 g urea flowered 11 days after the second spray compared to the control trees that flowered 48 days after the second spray. This means that treating trees with 4% KNO_3+ 0.5 g urea advanced flowering by about 37 days as compared to the control trees, which is a significant improvement in attaining earlier yield. A negative correlation (r=-0.815*) was observed between duration

(number of days taken after spraying) for visible inflorescence development and number of panicles developed (Fig. 7.5). This possibly indicates that more favourable climatic conditions, as well as tree status conducive for flowering, prevailed early in the season but not towards the end of the season. Similar to the results of the current experiment, Sergent *et al*. (1996) observed that high KNO_3 dose (3.6 & 4.6%) induced early flowering and harvesting (30-45 days earlier) as compared to the control trees. Barros *et al*. (1998) also observed 43 days earlier flowering on 'Tommy Atkins' trees. Perez-Barraza *et al.* (2000), however, did not obtain earlier flowering on 'Tommy Atkins' after using NH_4No_3 and ethephon. They speculated that the lack of response could be due to presence of immature shoots at the time of treatment application.

In general, Protacio (2000) hypothesized that, once gibberellin levels fall below a threshold level, starch can start to accumulate, allowing the trees to flower. After sufficient starch has accumulated, floral initiation will ensure. However, the buds will remain quiescent until conditions are favourable for flowering. KNO_3 and urea, especially at higher concentrations (as observed in the current study) may activate those quiescent buds for floral initiation.

Trewavas (1983) also noted that KNO_3 could be used to break dormancy of buds, particularly flower buds, which is one of the direct effects of nitrate. The results obtained for KNO_3 in increasing the numbers of panicles produced and decreasing the days for visible inflorescence emergence are in line with an experiment conducted in controlled growth chambers before the field experiments (Yeshitela *et al*., 2004).

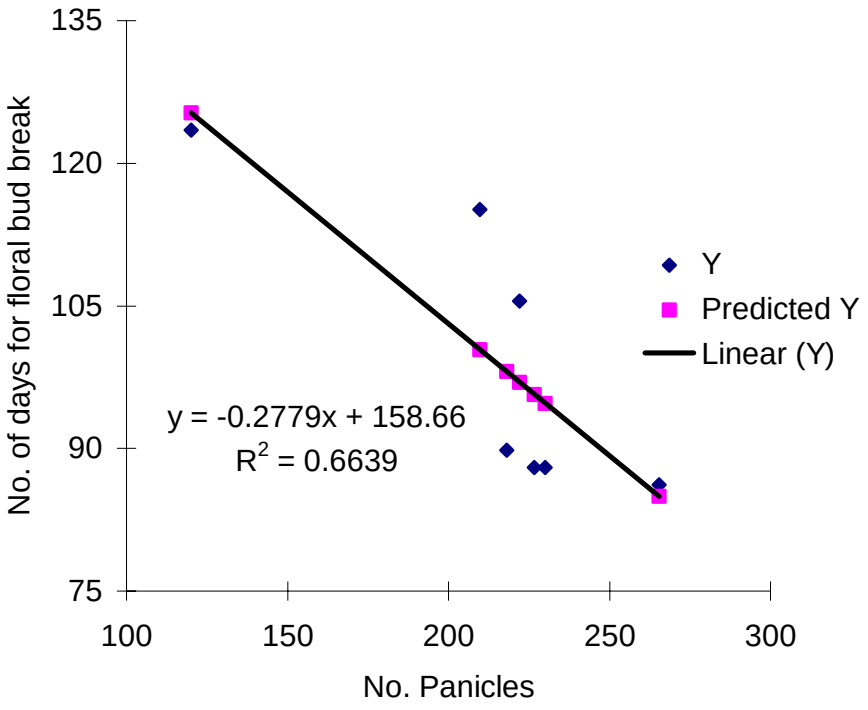

Figure 7.5 **A negative correlation between numbers of days required for floral bud break and numbers of panicles developed.**

Most of the treated trees in the current experiment had a narrow range of variability (12-16%) with regard to the percentage of hermaphrodite flowers. Singh (1987) estimated that less than 0.1% of the hermaphrodite flowers develop into mature fruit. He reasoned that, assuming there are 100000 flowers and each flower contains 10 µg nitrogen, then each time a tree flowers, it loses 1 kg of nitrogen. The tree will, therefore, need to have adequate nitrogen reserves for flowering and subsequent fruit set. In the current study, the percentages of hermaphrodite flowers produced did not show a linear relationship with the increase in nitrogen concentration. However, except for the 2% KNO_3 treatment, all the other treatments produced higher

percentages of hermaphrodite flowers signifying the importance of higher nitrogen level in the process up to a certain threshold level as shown in Fig 7.4.

There was a clear relation between flowering and fruit yield/tree. The amount of fruit set on a panicle and the number of set fruit retained to harvest is more important than the number of panicles per tree. In the current experiment treatments with higher KNO_3 and urea concentrations produced a higher fruit set, fruit number, and fruit weight per tree. Nitrogen supplement from KNO_3 and urea spray may be the reason for the increase in the quantitative parameters of yield.

The effect of KNO_3 on flowering and fruiting was higher when applied with urea, an additional nitrogen source. This is because the trees need to have adequate nitrogen reserves for flowering and subsequent fruit formation. Increased nitrogen fertilization via the soil has also been found to increase fruit retention and tree yield in mango (Smith, 1994). Hence, a nutritional effect cannot be discounted. In fact there should be a certain limit to the increase of nitrogen level, in view of the fact that surplus nitrogen application could cause fruit drop. This is because a higher nitrogen application favours excess vegetative growth and there will be limited assimilate diversion to the fruit.

Relatively higher average fruit weight from the application of 2% KNO_3 and the control trees could be related to lower fruit retention percentage of these trees as compared to trees sprayed with higher concentration of KNO_3 and urea. The result was similar to that of Oosthuyse (1996) and Machado & Sao Jose (2000). In general, similar to the current experiment, a yield increment due to KNO_3 application was also

observed by Barba (1974); Bondad & Linsangan (1979); Oosthuyse (1996); Sergent *et al*. (1996); Barros *et al*. (1998); Machado & Sao Jose (2000); Debnath & Kundu (2001). A highly significant positive correlation (r=0.886**), (r=0.949**), (r=0.948**) was observed, from the results of the current study, between the percentage of hermaphrodite flowers and fruit set, fruit set and fruit number as well as between fruit set and total fruit weight per tree respectively. The regression graphs for the relationships of the mentioned parameters are presented in Fig. 7.6, 7.7 and 7.8. This is an indication that treatments that receive a higher concentration of KNO_3 and urea spray also have higher fruit set at pea size stage, higher fruit number, higher total fruit weight per tree at harvest and higher fruit retention potential.

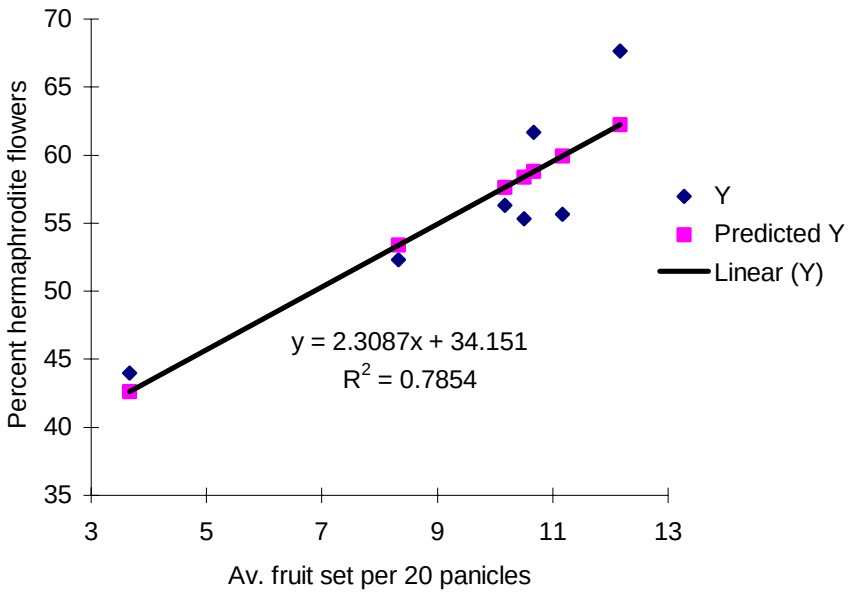

Figure 7.6 A positive correlation between percentages of hermaphrodite flowers and average fruit set per 20 panicles.

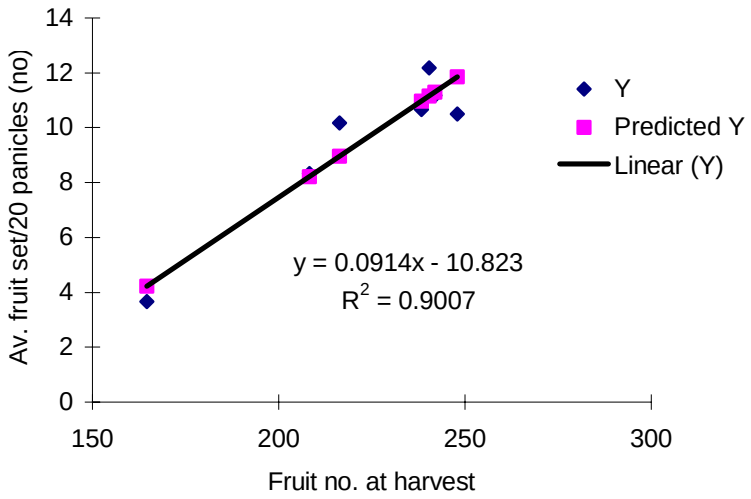

Figure 7.7 **A positive correlation between average fruit set per 20 panicles and total fruit number at harvest.**

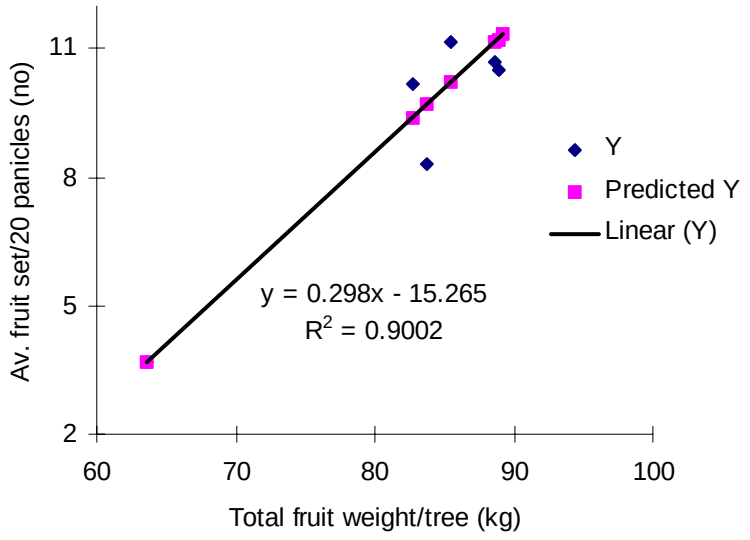

Figure 7.8 **A positive correlation between average fruit set per 20 panicles and total fruit weight at harvest.**

All the qualitative parameters, unlike the quantitative yield parameters, proved not to be affected by application of KNO_3 and urea. It can be deduced, therefore, the supplement of nitrogen through KNO_3 and urea was totally in favour of quantitative parameters and not to the qualitative parameters. As to the observation of Sergent *et al*. (2000), when urea was applied with KNO_3, plants grow larger than that of the control. The result of the current experiment with respect to the effects of KNO_3 on fruit qualitative parameters corresponds with that of Oosthuyse (1996).

7.6 CONCLUSIONS

Spraying 'Tommy Atkins' mango trees with 2% KNO_3+1 g urea or 4% KNO_3 was found to be beneficial for all the flowering and fruiting parameters. At the same time, it is more cost effective to spray these previously mentioned concentrations rather than the higher levels in a large orchard, similar to where this experiment was conducted.

Therefore, it would be possible to diminish the erratic flowering and alternate bearing in mango trees grown in tropical areas such as the Upper Awash Agro-Industry orchard in Ethiopia, by using the above mentioned concentrations of KNO_3 and urea in combination with other proper and modern cultural practices.

CHAPTER 8

GENERAL DISCUSSION

8.1 Major problem areas identified and initiation of experiments

Mango (*Mangifera indica*) is produced in many countries in the world and it is one of the most favourite fruit of human beings. The increase in the total world production every year is an indication of its worldwide importance. Nowadays, mangoes have dominated the global market both as fresh fruit and processed products. In Ethiopia, mango has become the dominant tropical fruit under production and it also has a great potential to be an export crop. The livelihood of a considerable number of farmers is highly dependant on the selling of mango fruit locally. Since the farmers apply subsistence farming systems, they could not afford to follow modern agricultural practices. The result is that, yield and quality of the fruit obtained from the trees is dwindling year after year. There are very few commercial mango farms in the country but they are struggling with various production problems, due to lack of trained man power (in the country in general) especially in the fields of fruit crops. Due to their poor income, the orchards could not afford to make use of expatriate professionals in their farms for advise. The main production problems in the country include:

a) Farmers normally do not prune their trees, and the trees have excessive vegetative growth. This has led to limited and in some cases complete crop failures.

b) Due to the bimodal climate and rainfall pattern in some parts of the country, the trees have adopted a mode of limited flowering and fruiting twice a year. Such trees usually bear the next crop after a minimum of two years due to exhaustion, insufficient induction and poor tree management activities.

c) Flowering is very erratic. In some cases, the inflorescence withers after development. In other cases, flowering is very early/ or very late in the season and both cases have major disadvantages.

d) There are also various management problems with regard to tree spacing, pruning, fertilisation, irrigation, harvesting etc. which demands an intensive and long term research strategy to improve both the small scale farmer's and the commercial orchards.

South African mango growers are also facing several production problems, especially with regard to mechanisms of fruit thinning. Shifting production to off-periods to exploit good export markets when the bulk of export fruit from different countries diminishes (when mango becomes scarce in the world market) is also being given higher attention.

Beside all these problems of the two countries, mango production is still reported to have various management problems worldwide especially with respect to flowering and fruit set. Mango is therefore still classified to be a poor yielding crop.

Flowering and fruit set are the most critical of all events occurring after establishment of a tree crop (Davenport & Nunez-Elisea, 1990). The flowering mechanism in mango is still poorly understood, although it clearly depends on environmental factors to bring

about the transition from vegetative growth to reproductive growth, after causing a check in vegetative growth (Davenport & Nunez-Elisea, 1997). This transition is known to be induced by cold weather or a combination of cold weather and water stress (Whiley, 1993). Other possible inductive factors in flowering can be photoperiod, carbohydrate and nitrogen status, plant hormones, and other yet undetermined factors (Bernier *et al*., 1981). Literature on previous experiments on different aspects of mango production is presented in Chapter 2 and a background in Chapter 1. Despite tremendous efforts to elucidate the mechanism of this critical biological event (mango flowering) and the vast body of literature, which has resulted, many important details still elude scientists (Davenport & Nunez-Elisea, 1997). Therefore, many experiments are still necessary to improve the yield and quality of mango.

The interaction and effects of the different treatments on the selected mango trees is schematically presented in Fig. 8.1, after the general discussion on each of the experiments conducted.

8.2 Why specific fruit thinning?

Many mango cultivars in general, and 'Sensation' in particular, set a huge number of fruit of which more than half are abscised from the tree prior to harvest. Consequently, with no human interference, a tree that has set a large crop will tend to abscise far more fruit, than if the fruit on the trees were thinned beforehand, thus reducing the yield to levels below the tree is capable of supporting (Davie & Stassen, 1997b). Therefore, the delay in ridding itself of the excess fruit results in a wastage of carbohydrate, which is

eventually reflected in the smaller size of the remaining fruit. Hence, it is an established fact that fruit thinning is very important for minimising wastage of plant reserves. The other question would then be, how much of the fruit should be thinned. Tree reserves, yield and quality of the fruit are determined by how severely the tree is thinned. Knight (1980) working with 'Cox's Orange Pippin' apple found that 'part tree' fruit thinning was not as effective as selective 'whole tree' thinning. The best results were obtained by thinning within fruit clusters, suggesting that the competitive effects are rather localised. The idea will ultimately lead us to a point that fruit thinning should be on a per panicle basis. Consequently, an experiment of fruit thinning per panicle basis will give an answer to the farmer as to how much of the fruit should exactly be thinned and the result thereof. The results of the two-seasons experiment gave information on the effects of different treatments.

As would be expected, when more fruit was left on the tree (in the case of the control or lower fruit thinning intensities), the lower was the fruit retention percentage. The higher fruit retention percentage was recorded for severe fruit thinning intensities. Even if there was a higher fruit retention percentage for these treatments, the total fruit number at harvest was low due to the severity of the fruiting intensity, which also lowered the total yield. Higher yield at harvest was recorded for one or two fruit per panicle treatments. These two treatments on average had 7.7 and 7.6% increase in yield over the control respectively; in the two seasons study period. That was because, leaving one or two fruit per panicle minimised fruit abscission unlike the control trees. At the same time, there was less severity in the thinning intensity as compared with other treatments, which resulted in higher fruit number at harvest. A higher fruit number at harvest was also observed from Corasil.E chemical fruit thinning treatments.

A higher average weight of the harvested fruit was recorded for the treatment where one fruit per panicle maintained and 50% panicles removed in the first season, and together with the treatment where one fruit per panicle maintained, in the second season. Considerable number of fruit from treatments one and two fruit per panicle and 50% panicles removed were in count 9 and 10 category (439-472 g/ 350-438 g respectively) unlike the other less severe fruit thinning treatments where the majority of their fruit were in count 12 (295-349 g).

Chemical fruit thinning with Corasil.E produced fruit with the lowest average fruit weight and about 12% of the sampled fruit were 'mules' (without seeds). It is pre mature to conclude about its effect and should be studied further. The current result indicated that Corasil.E can be used for reducing over-sized fruit as in the case of 'Keitt' mango and to obtain fruit without seed. Most fruit quality parameters, on the other hand, showed a trend of positive relationship with thinning intensity. Parameters like TSS increased while the thinning intensity was severe. However, there was a trend for a higher incidence of physiological problems in bigger sized fruit. Fruit from trees where no thinning and lower thinning intensities were applied, had higher titratable acidity and lower pH. Jackson (1989) proved the effects of fruit thinning on market quality to result from reducing competition for assimilate between fruit.

The main aim of fruit thinning is conservation of tree reserves. This was effected through thinning fruit to a number that the tree can nurture up to harvest. This phenomenon was clearly observed from the current experiment. The control trees and trees with lower thinning intensities were depleted from reserves by the heavy fruit load. The trees may then experience an alternate bearing rhythm. Trees where all their

fruit were thinned had a higher and faster starch accumulation in the tree wood during the winter. Bark and leaf starch revival from October to July followed more or less the same sigmoidal trend as in the case of wood starch. The highest starch content among the plant parts and months was recorded for fruit starch content during January. That was during peak fruit growth and development period. It is clear from the study that fruiting is a major sink of plant reserves. Davie *et al*. (1999) also mentioned that starch reserves of the different plant parts remain at their lowest level during the period of rapid fruit growth as the reserve is channelled to the fruit. Wright (1989) explained that it is perhaps not surprising that fruiting commands such a large proportion of a plant's resources since it usually leads to the production of seeds for the continuation of the species. Therefore, fruit thinning may be the answer for managing starch levels in the plant and thereby alleviating alternate bearing. There was a positive relation between severe thinning intensities to that of higher vegetative growth. When all fruit were thinned from a tree, the number of new flush growth, their average length and the number of leaves on them was significantly higher than the other treatments. The control and lower thinning intensity treatments produced lower vegetative growth. Wright (1989) explained that a reduction in dry matter partitioning to shoots, leaves and roots due to fruiting has been demonstrated in a wide range of species.

8.3 The need for growth retardants

In general the mango trees found in Ethiopia are characterised by excessive vegetative growth, but farmers and farm managers of the commercial orchards are sceptical towards pruning their trees. These situations necessitated the use of growth retardants where there will be a possibility of reducing vegetative growth vigour without physical

damage to the tree parts. Paclobutrazol (PBZ) was selected for this purpose due to its reported importance in reducing vegetative vigour in a number of fruit crops. Foliar as well as soil drench applications of PBZ increased the percentages of branches that flowered and reduced the number of days between treatment application and development of inflorescences. There was an excessive vegetative growth on the control trees and took more number of days for visible floral bud break. It is possible that the application of PBZ caused an early reduction of endogenous gibberellin levels within the shoots, as also observed by Anon (1984), causing them to reach maturity earlier than those of untreated trees. Soil application at 8.25 and 5.50 g a.i. per tree resulted in the highest number of panicles per tree. Flowering is normally associated with reduced vegetative growth, often induced by lower activity of gibberellin (Voon *et al*., 1991). Therefore, the higher PBZ rates suppressed vegetative growth and the assimilate that was to be expended for vegetative growth was diverted to intensifying flowering. This was proved by a higher total non-structural carbohydrate level of the shoots of the treated trees before flowering. Those trees also had higher percentages of hermaphrodite flowers. A higher fruit number per tree at harvest (299.3) and total fruit weight per tree (121 kg) was obtained by soil application of PBZ at a rate of 8.25 g a.i per tree as compared to the control (131.8 fruit harvested weighing 47.85 kg). The same treatment increased the TSS of the fruit significantly. Regardless of the concentrations, on the other hand, all PBZ treatments increased TSS: acid, reducing and total sugars but reduced titratable acids. The higher values of fruit qualitative parameters observed in this experiment due to PBZ application, were also observed by Vijayalakshmi & Srinivasan (1999); Hoda *et al*. (2001).

In the current experiment, PBZ treatment did not cause for an increase in the mobilisation of major elements studied (N, P, K, Ca) to the leaves. The result of Leal *et al*. (2000) was similar to the current result with respect to effect of PBZ on major elements. A decrease in P was, however, reported by Salazar-Gracia & Vazquez-Valdivia (1997); Werner (1993). In the current study, there was a significantly higher Cu, Fe and Zn while lower Mn irrespective of the PBZ rates used which needs further investigation. The vegetative growth parameters were studied in four rounds to determine as to when the effect of PBZ commenced. During the first round of observations (three months after treatment application), some of the vegetative parameters were not affected by application of PBZ indicating that the effect of PBZ may not be fully expressed within three months. During the second round of observations, trees treated with PBZ were significantly affected. Both methods of application were equally effective in reducing tree vigour while the rates 5.50 as well as 8.25 g a.i. per tree showed the greatest effect on all the parameters. A similar trend was observed for the third and fourth rounds of observation. After the first round, there was no significant difference between the two methods of PBZ application although the application rates affected the vegetative parameters. The highest impact of PBZ application on the vegetative parameters was observed during the third round of observations, probably because it coincided with a stage after peak fruit development phase that had an additional impact on reducing vegetative growth.

8.4 Is pruning essential?

Some mango growers are still sceptical about pruning their trees since they consider it to be a loss of the whole crop or loss of vital vegetative parts. The purpose of

conducting these experiments was to gain more evidence for the promotion of pruning. It is a well-known fact that when the dominating apical bud is removed during inductive conditions, the inhibited axillary buds below the cut end will be released and start developing lateral inflorescences (Reece *et al*., 1946). In the current experiment, successful re-flowering in 'TA' and 'KT' occurred one month after pruning for both inflorescence removal at the point of apical bud attachment and terminal bud removal treatments. Normally, the most terminal axillary buds are more developed as compared to the buds lower down. The higher number of inflorescences formed after the mentioned treatments could also be due to the presence of intercalation (clustering of axillary buds at the shoot apex) giving rise to an increase in the number of axillary buds developing in response to pruning corresponding to the observations of (Oosthuyse & Jacobs, 1996). On the contrary, after inflorescence removal together with apical whorl of leaves subtending the inflorescence, the cluster of more developed buds were removed together with the inflorescence, and only less developed axillary buds lower down were released to start developing, resulting in later and reduced re-flowering. It is important to realise that the presence of cool, inductive temperature during or after pruning is mandatory for inflorescence development from the axillary buds (Nunez-Elisea & Davenport, 1995).

The vegetative growth parameters of the trees were highly affected by shoot pruning treatments in both cultivars. In general 'TA' trees produced significantly higher figures for vegetative flush development and leaf area of the newly developed leaves as compared to 'KT'. In both parameters post-harvest and renewal pruning treatments had higher values as compared to the control and other treatments. The control trees had lower values for all the vegetative parameters since the trees were not encouraged to

stimulate new shoot growth with pruning. This has been the case on 'Sensation' as to the observation of Oosthuyse (1994). The new shoots expected from post-harvest pruning treatments should develop early in order to mature and bear the coming season's crop as well as efficiently supplement reserve replenishment. For this reason immediate post-harvest pruning is mandatory. For late cultivars, renewal pruning is recommended (Stassen *et al*., 1999) since if pruned post-harvest, the trees will either not flush or the flushes will be too late to bear the coming season's crop.

The allegation that pruning involves removal of vegetative parts and consequently reduces yield was not observed in the current experiment. That was because pruning encouraged the development of new vegetative shoots. Those shoots can replenish the tree's carbohydrate reserve and also mature, flower and bear the coming season's crop. This advantage of pruning was also observed by Oosthuyse (1994) on 'Sensation' mango. Non-significant yield difference of trees that received inflorescence removal together with apical whorl of leaves as compared to other pruning treatments was not expected. Lower yield was expected since the treatment involved additional removal of leaves and the trees produced fewer numbers of fruit. Flowering, fruiting and ultimately harvesting synchronisation was observed by applying panicle pruning at the site of apical bud attachment, which is an advantage in big farm operations. Oosthuyse & Jacobs (1996) indicated that flowering synchronisation in their studies might be ascribed to the simultaneous wound stimulation and release from apical dominance of distally situated axillary buds in similar states of quiescent dormancy at a time when root produced growth substances were not limiting. It is known that newly developed and matured leaves can efficiently manufacture more photosynthate and consequently, the trees can attain a higher reserve than old leaves. That should be the reason for a

higher TSS in the fruit from trees that received post-harvest and renewal pruning treatments. An increase in delay of the ripening process for over-sized fruit was also noted. This delay makes variability in ripening and complicate marketing of the fruit at a given period of time.

8.5 Use of chemicals for floral induction

Temperature has been found to be a significant factor on the flower formation of several fruit trees. Studies in mango revealed the existence of a floral stimulus, which is continuously synthesised in mango leaves during exposure to cool, inductive temperatures (Davenport & Nunez-Elisea, 1990; Nunez-Elisea & Davenport, 1992). In areas where insufficient cold units prevail; other means of supplementing the cold units is required. One means is to test chemicals for their effect on complementing or intensifying flowering.

From this study, it was found that the minimum duration in the inductive temperature for sufficient floral induction of TA and KT cultivars was 35 days. Trees exposed to the inductive temperature only for 15 days and sprayed with PBZ at 500 or 2000 ppm concentrations did flower. This shows that PBZ at these concentrations had the potential to complement cold temperature requirement for floral induction. Increasing the duration in the inductive temperature up to 60 days and increasing the concentrations of PBZ up to 2000 ppm also increased the intensity of flowering. Application of 3% KNO_3 caused an increase in the length of inflorescence (under inductive conditions) as well as vegetative growth (under non-inductive conditions). This may be due to increased cell elongation. Trees exposed for longer duration in the

inductive temperature produced shorter vegetative flushes compared to trees exposed for longer duration in the non-inductive temperature. Surpassing the necessary duration of cold temperature was also observed to cause a delay and production of malformed flowers. This has also been observed by Ravishankar *et al*. (1979). There was also anatagonistic growth between number of inflorescences and length of flushes developed.

8.6 Attributes of spraying potassium nitrate and urea

Accumulation of nitrogen before flowering was reported by Phatak & Pandey (1978). Protacio (2000) also mentioned, "Presumably there is a threshold level for nitrogen concentration that if exceeded, will allow the plant to flower". Consequently, the mechanism of KNO_3 and urea in triggering flowering could be a matter of exceeding this threshold level. In the current investigation also, the percentages of branches flowering and the number of panicles developed were higher with treatments of higher KNO_3 and urea treatments. Due to the enhanced intensity of flowering during the main season (November-December), the bimodal flowering pattern of the trees was greatly reduced. Spraying with KNO_3 and urea (except 2% KNO_3) also caused early flowering, more hermaphrodite flowers, increased fruit set, higher production and early harvesting. The effect of KNO_3 on flowering and fruiting was higher when applied with urea, which is an additional nitrogen source. Both KNO_3 and urea sprays had no impact on fruit quality parameters. In general nitrogen supplement from KNO_3 and urea and hence a nutritional effect is believed to be the reason for the increase in the quantitative parameters.

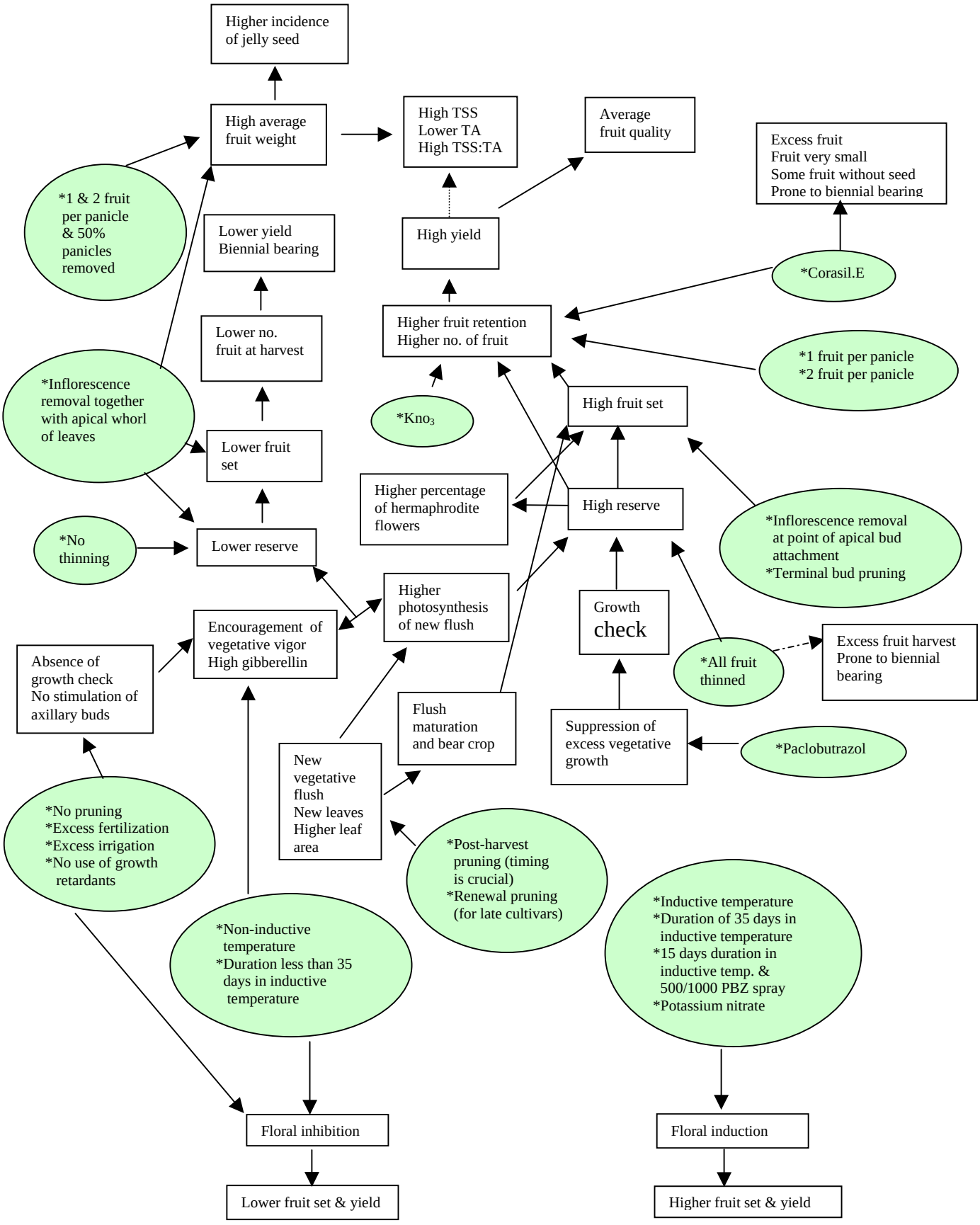

Figure 8.1 Schematic presentation of the effects of different treatments applied on Keitt, Sensation and Tommy Atkins mango cultivars.

8.7 Recommendations for both Ethiopian and South African farmers

1. Thinning fruit to one or two fruit per panicle, before the occurrence of excessive natural fruit drop, is recommended since higher yield as well as acceptable fruit quality, vegetative growth and tree reserve status was obtained. It is especially recommended for cultivars that produce a lot of fruit during initial fruit bearing stage like 'Sensation'.
2. Application of PBZ at 5.50 g a.i. per tree is beneficial to suppress vegetative growth and increase flowering. The result was based on one-year trial period. It may be advisable to repeat the trial for at least one more season. Caution, however, must be taken to the export regulations of some countries about PBZ residues in the fruit from treated trees.
3. Immediate post-harvest pruning for an early cultivar and renewal pruning for a late cultivar is mandatory for a successful tree management practice. Panicle pruning treatments can be practiced to increase productivity and shift harvesting into off-season. It can also be applied when a very cold and extended winter prevails during a particular flowering season that hampers normal development of the flower parts and when inflorescences become malformed for various reasons.
4. As a matter of fact, such a distinct switch from inductive to non-inductive temperature condition as has been manipulated in the regulated chambers for the pot experiments has not been experienced in the field. Therefore, it was not possible to exactly prove the results of the regulated growth chamber experiments in the field. However, PBZ is proved to intensify flowering under

field conditions and can therefore be sprayed when the winter of a particular season is detected to be less inductive with short duration.

5. Even if it was based on a one year result, spraying 5 litre solution of 2% KNO_3+1 g urea $tree^{-1}$ or 5 litre solution of 4% KNO_3 $tree^{-1}$ in 'TA' trees found at upper awash agro-industry enterprise in Ethiopia is beneficial to increase flowering intensity during the main season and also to attain a higher fruit retention potential of the trees.

Careful selection and combination of treatments is essential to obtain all rounded and satisfactory results. That is what is meant by sound management activity. All the results obtained from the experiments in South Africa will also be investigated and applied in Ethiopia to revive the current poor productivity of the farmer's as well as the commercial orchard's trees.

8.8 Aspects that need further investigation

1. Detailed investigation of Corasil.E especially for its effect on reducing fruit size and degenerating seeds.
2. Hand thinning is laborious even if a higher success rate can be achieved with its application since there is higher precision while thinning the fruit. Therefore, the search for more effective chemical fruit thinners should continue.
3. Residual effects of applied PBZ should be determined to know for how long the effects will still be active. This will give information as to how frequently should PBZ be applied.

4. Due to PBZ residues in the fruit after its application and prohibition of such fruit from PBZ treated trees in European and North American countries importing mango, the search for other mild chemical growth retardants should continue, especially if the production is meant for export. One such chemical is Prohexadione- calcium. It is a new plant growth regulator with low toxicity and limited persistence in the tree (Owens & Stover, 1999). It has been registered as Apogee in USA and as Regalis in some European countries for use as growth retardant on apples (Basak & Rademacher, 2000).
5. The mechanism as to how PBZ application significantly increased most of the micronutrients unlike all the macronutrients of the leaves in the current study needs further study.
6. The effects of PBZ on the complementation of partial floral induction period should be assessed under field conditions during seasons when the winter cold period is not sufficiently inductive or stay only for a limited period.
7. The effects of severe pruning of vegetative parts on the tree reserves should be investigated even if pruning is proved to be essential for new vegetative growth that can bear the coming season's crop.

SUMMARY

Although mango has been studied for many years, many problems still elude researchers. The objectives of the current trials were to study the effects of some cultural practices (fruit thinning, panicle/ bud/ renewal/ post-harvest pruning) and chemicals (Corasil.E, potassium nitrate/urea, paclobutrazol) on various vegetative, floral, fruit yield and quality parameters. The study meant to address problems of both South African and Ethiopian mango growers.

Based on the various experiments conducted both in Ethiopia and South Africa encouraging results have been obtained that can be useful to the farmers. Almost all of the hypotheses set up while proposing the experiments were proved positive. The most significant conclusions from the study can be summarised as follows:

1. Fruit thinning is important to conserve tree reserves and better development of the remaining fruit on the tree especially for cultivars like Sensation. Less severe fruit thinning intensities (one or two fruit per panicle) were found to be desirable in improving various fruit and tree features. There was yield reduction with severe fruit thinning intensities (one and two fruit per panicle and 50% panicles removed). High quality fruit were obtained from trees that received severe fruit thinning. Trees that were not thinned (control trees) had a higher degree of assimilate wastage due to increased fruit abscission. These trees are more likely to experience alternate bearing. Trees sprayed with Corasil.E produce many small sized fruit. Some of these fruit were ‘mules’.

2. Paclobutrazol applied at rates of 5.50 and 8.25 g a.i. per tree effectively restricted vegetative growth and increased the non-structural carbohydrate of the shoots leading to an increase in flowering intensity and earliness, fruit yield as well as fruit quality. PBZ was found to have no effect on mobilisation of major nutrients but increased leaf content of Fe, Cu, and Zn to the leaves.

3. Panicle pruning at the site of apical bud attachment, renewal and post-harvest pruning treatments were found to be promising for attaining higher intensity and synchronisation of flowering. Harvesting was also synchronised and better fruit quality obtained. Time of applying post-harvest pruning is crucial. Delayed post-harvest pruning may lower or cause failure of the crop especially in late cultivars. Renewal pruning rather than post-harvest pruning should be practiced on late cultivars. Panicle pruning together with apical whorl of leaves showed adverse effects on numerous parameters.

4. The results from the current experiment indicated that the minimum numbers of cold units (duration of the inductive temperature regime) for sufficient floral induction of both 'TA' and 'KT' was 35 days. However, application of PBZ at 500 or 2000 ppm showed the potential to complement cold temperature requirements for trees that received a deficit of cold units (15 days). Spraying PBZ also induced early flowering. Application of 3% KNO_3 in combination with the required cold units increased panicle size in 'TA'.

5. The problem of bimodal and erratic flowering nature of 'TA' trees in the Upper Awash Agro-industry Enterprise in Ethiopia was addressed by spraying the trees with potassium nitrate and urea to increase the nitrogen threshold value. Among the concentrations, 5 litre solution of 2% KNO_3+1 g urea $tree^{-1}$ or 5 litre solution of 4% KNO_3 $tree^{-1}$ applied on the immature post-harvest flushes and again on the matured flushes increased flowering. Fruit retention was also improved, but not fruit quality. The effect of KNO_3 was higher when applied with urea.

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