# BANANA (*MUSA* AAA; CAVENDISH SUB-GROUP) CULTIVAR/DENSITY TRIALS IN THREE BIOCLIMATIC GROUPS ON THE NORTH COAST OF KWAZULU-NATAL

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## ABSTRACT

The North Coast of KwaZulu-Natal is a relatively new banana production area, for which there is an absence of local norms, specifically for choice of cultivar and population density. Three co-operative split-plot banana cultivar/density trials were established in December 1991, January 1992 and February 1992 on farms at Eshowe, Nkwaleni and Mposa, respectively. These sites represent Phillips' (1973) Bioclimatic Groups 2, 10 and 1 respectively, and have widely divergent climatic potential, ranging from cool, to warm, to hot subtropical. Each randomised trial block, 0.92 ha in extent, comprised five replications of five cultivar main plots, each of which was split into three density sub-plots. The five cultivars planted represent those registered at the time of planting, *viz*. 'Dwarf Cavendish', 'Williams', 'Grand Nain', 'Valery' and 'Chinese Cavendish'. Sub-plots were planted at 1 666, 2 105 and 2 500 plants ha$^{-1}$ and tissue culture plants were used to establish all three trials. The field trials were evaluated over three full cropping cycles and culminated in October 1996.

Morphological differences such as pseudostem height and circumference, leaf length and width, number of functional leaves at flowering and harvest, as well as phenological differences such as monthly leaf emergence rates, emergence-to-harvest intervals and harvest cycles, were evaluated. The yield component data comprised measurements of bunch mass, number of hands per bunch and number, length and mass of fingers on the third hand. Productivity was expressed as tonnes per hectare per annum (t ha$^{-1}$ an$^{-1}$). Each cultivar and density treatment was evaluated independently. However, it was the evaluation of the cultivar/density interaction which formed

the basis of the recommendations for the three different Bioclimatic Groups.

At the relatively cool Eshowe site, 'Williams' proved to be the most productive cultivar (47 t $ha^{-1}$ $an^{-1}$) over all densities. The highest production (49.8 t $ha^{-1}$ $an^{-1}$) was achieved from a density of 2 500 plants $ha^{-1}$, but due to lower costs per hectare, the intermediate density of 2 105 plants $ha^{-1}$ generated the highest gross margin. When the cultivar/density interaction was evaluated, the combination producing the highest gross margin was 'Williams' at 2 105 plants $ha^{-1}$. This substantiated the independent evaluations and is consequently the recommended combination for Bioclimatic Group 2. However, the faster cycling of 'Chinese Cavendish' could conceivably result in this cultivar outperforming 'Williams' in future ratoons.

At the warmer Nkwaleni site, 'Grand Nain' (57.8 t $ha^{-1}$ $an^{-1}$) proved to be the most productive cultivar. The density of 2 500 plants $ha^{-1}$ was the most productive (64 t $ha^{-1}$ $an^{-1}$) and also generated the highest gross margin. However, the cultivar/density interaction indicated that 'Williams' at 2 500 plants $ha^{-1}$, was the highest producing combination yielding the highest gross margin, and is consequently the recommended combination for Bioclimatic Group 10.

At the hot Mposa site, 'Chinese Cavendish' (54.2 t $ha^{-1}$ $an^{-1}$) proved to be the most productive cultivar. The density of 2 500 plants $ha^{-1}$ outproduced (57.4 t $ha^{-1}$ $an^{-1}$) the lower densities and also generated the highest economic returns. However, when the cultivar/density interaction was evaluated, 'Chinese Cavendish' at the lower density of 2 105 plants $ha^{-1}$ realised the highest gross margin and is consequently the recommended combination for Bioclimatic Group 1.

# DECLARATION

I hereby certify that the research work reported in this dissertation is the result of my own original investigation except where acknowledged

SIGNED.................................................

G.B. LAGERWALL

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| Banana Control Board | :- Electronic scale and computer. |
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# INTRODUCTION

Banana (*Musa acuminata*, AAA group; Cavendish sub-group) is one of the most important tropical fruits in South Africa and the crop is grown largely under warm and hot subtropical conditions by about 800 producers covering six distinct areas (Standard Bank, 1991). South Africa currently produces about 200 000 tonnes of bananas in a normal year.

Historically, the banana industry in KwaZulu-Natal has experienced a somewhat chequered existence. The first commercial planting in South Africa took place on the lower South Coast in 1904, after which the industry expanded rapidly until 1954, when there were some 4 850 ha in production. However, the advent of large scale banana production in the Eastern Transvaal (Mpumalanga), which is climatically better suited to producing bananas (Kuhne, 1975;1978; Robinson, 1981), resulted in an overproduction scenario with a resultant decline in Natal to some 700 ha in 1975. Subsequently, improved production efficiency and marketing encouraged a resurgence of plantings in KwaZulu-Natal and in 1991 the province accounted for 3 218 ha (22.6 %) of the 14 243 ha planted to bananas in South Africa (NAU, 1991). By all accounts (not officially documented), the national production area subsequently declined to around 12 000 ha as a result of the 1992 to 1995 drought.

Data reflecting production on the North Coast of KwaZulu-Natal were derived from farmers who marketed through the now defunct Banana Control Board and this accounted for a little over 300 ha (Fiske, 1990; Robinson, 1993a). This produce was channelled through formal markets in the major centres. However, a situation survey by the author in 1991 (unpublished) indicated that production on the North Coast in fact exceeded an area of 1 000 ha and current estimates are that approximately 1 200 ha are planted to bananas on the North Coast. Prior to the demise of the Banana Control Board, much of this produce was and is still, marketed directly off the farm.

Prior to rationalization in the sugar industry, which commenced in 1985, there were approximately 20 ha of bananas planted on a commercial scale north of Durban. Declining profitability from sugarcane production resulted in farmers seeking alternative crops with better potential economic returns. Notwithstanding the much talked about threat of overproduction, about 55 commercial farmers have ventured into banana production on the North Coast, between Durban and Pongola, over the past decade. Banana industry deregulation and the abolition of the Banana Control Board in 1993, led to increased price variability and financial insecurity for farmers, particularly those on the Lower South Coast who had previously marketed most of their quality fruit through the Board (Kuhn *et al.*,1995a;b). North Coast producers who, in the main, were not as reliant on the Banana Control Board for their marketing, were not significantly affected by the deregulation. Coupled to their superior resource potential (climate and soils) and larger farms, the scene is set for a gradual yet steady increase in banana production on the North Coast. The diversification from sugarcane into bananas, by farmers with little experience other than sugarcane production, necessitated some form of extension service from the Department of Agriculture. Due to the North Coast being a new production area with no relevant norms established by research trials, such trials were a natural corollary. With the ever-increasing price of prime farm land, the need to optimise productivity and thereby maximise economic returns, became a quest of paramount importance.

One of the most important components of banana productivity and consequently profitability, is the population density. Due to the perennial nature of the crop, an incorrect choice of population density at planting time will have major economic ramifications over a long period of time. The need to establish optimum density norms for each production area is therefore vital. A further important consideration in the quest to maximise profitability is the correct choice of cultivar for a particular production area. Up until 1974 when the 'Williams' cultivar was released, 'Dwarf Cavendish' was the mainstay of the Banana industry. The release of a further three cultivars in 1989 focussed attention on the need for correct cultivar selection in a specific area. Although cultivar evaluations were carried out at the Burgershall Research Station prior to the release of the new cultivars it was felt that locality variations in climate and soil type could have an influence on cultivar choice, hence the need for trials in each of the major banana producing areas (Robinson *et al.*, 1994c).

The advent of commercially available tissue culture planting material, at much the same time as the new cultivar releases, also demanded attention. It was felt (Robinson-pers. comm., ITSC, Nelspruit) that the production advantages of tissue culture material had been sufficiently researched. However there was a dire need to promote and advocate the use of this new form of planting material, both for it's superior production capabilities and, equally important in a new production area, to minimise the risk of disease and pest transfer.

The expansion of the banana industry on the North Coast of KwaZulu-Natal has taken place in a very haphazard manner with production units being established over a widely divergent range of climatic potential, from the relatively cool, high lying coastal hinterland (eg. Eshowe, Doornkop, Inanda) to the relatively hot coastal lowlands (eg. Mposa, Richards Bay, Monzi flats). It became patently obvious that no single trial could provide the production norms required for such a vast range of potential. Consequently a decision was taken to establish a split-plot cultivar/density trial at three different sites, with the objective of establishing production norms regarding recommended cultivars and population densities for Bioclimatic Regions 1,2, and 10 on the North Coast. These norms would, in turn, be relevant for most of the areas in KwaZulu-Natal with banana production potential. The prime objectives of the trials were therefore to generate more reliable recommendations regarding choice of cultivar and plant densities (spacing) in three Bioclimatic regions on the North Coast of Kwa Zulu-Natal.

# CHAPTER 1

# LITERATURE REVIEW

This chapter provides a perspective of the South African banana industry by reviewing it's importance relative to the rest of the world and, most importantly, by evaluating the limitations of producing bananas in the subtropics. The potential of the North Coast of KwaZulu-Natal relative to the rest of the country is investigated, as is the national and international scenario regarding choice of cultivar and population densities.

## 1.1 GLOBAL PRODUCTION SCENARIO

Grown almost exclusively in the developing countries of the tropics, bananas and plantains are collectively one of the world's most important crops ( Price, 1995). Total world production was estimated at over 76 million tonnes (FAO, 1993; Hallam, 1995) of which exports (essentially of Cavendish sub-group bananas) to the richer developed nations, represented less than 11 million tons (McNeil, 1995 ; Price, 1995). Jaramillo (1987) estimated that the area cultivated to *Musa* bananas and plantains in tropical American and Caribbean countries exceeded 1.5 million ha, of which about 12 % was dedicated to planting Cavendish sub-group banana for exports. Banana export earnings represented 21 % (Panama) 28 % (Costa Rica, Honduras) and more than 60 % (Windward Islands) of the value of total exports in 1981 (Novoa, 1983). The value of United States importation of bananas from Caribbean and Central American countries in 1995 reached a record total of \$630 million ≈ R2.83 billion (USDA, 1996).

FAO (1993) records Africa as producing 6.4 million tonnes of banana and almost 20 million tonnes of plantain, with Uganda and Rwanda alone accounting for 41 % of the world-wide plantain production. According to Stephenson (1992), South Africa's banana production accounts for only 0.3 % (± 200 000 t ) of the total world crop, with Australia, one of the other subtropical producers, accounting for a similar percentage.

## 1.2 CLIMATIC REQUIREMENTS RELATED TO POTENTIAL PRODUCTION

Bananas are tropical plants that are grown under sub-optimum, subtropical conditions in South Africa and production is severely limited by climate, as ideal conditions do not exist anywhere in the country ( Robinson, 1993i).

### 1.2.1 Definition of Tropical and Subtropical Climates

According to Wilson (1977), tropical lowland climates are those with a mean annual temperature higher than 25°C and a mean for each month exceeding 18°C, situated in the tropical latitudinal zone. Subtropical climates suitable for bananas are those at latitudes exceeding 23.5°C with short, mild winters in which there is a period of two to three months when cold temperatures may occur, but frost is rare and the mean minimum temperature of the coldest month remains above 6°C. Summer temperatures are as high or higher than those in tropical climates. The climatic classification scheme of Trewatha (1962) lists tropical climates as those with an average temperature of at least 18°C for all months of the year, with killing frosts absent, whilst subtropical climates have eight or more months with a mean temperature of at least 10°C and the coolest month below 18°C. In view of these definitions, Joubert and Bredell (1982) state that "We have no area in South Africa with a truly tropical climate. Tropical crops such as bananas are grown under subtropical conditions which are sub-optimal for growth and production".

### 1.2.2 Banana Growth and Development Threshold Temperatures

Although bananas are a fairly adaptable crop (Kuhne, 1978; Samson, 1980; Jaramillo, 1987; Stover and Simmonds, 1987; Robinson, 1996), it is important to have some insight into their production limitations in the subtropics. Where water is not limiting, the rate of banana growth and development is determined by temperature (Turner and Lahav, 1983; Robinson, 1996). The optimum temperature range (°C) for dry matter production is in the lower 20's and for leaf emergence rate in the lower 30's ( Turner and Lahav, 1983; Robinson and Anderson, 1991a; Turner, 1995). Smith (1991), in his "Banana Yield Estimation", used temperature thresholds (annual mean, mean annual maximum and mean annual minimum) as the major determinants of banana yield potential, with adjustment factors for soil, irrigation, humidity, evapotranspiration, wind and rainfall. This again emphasises the importance of temperature in determining banana production potential.

Robinson (1996) stated that the general consensus on mean daily temperature thresholds ((maximum + minimum) ÷2) for banana growth and development is that new leaf emergence stops below 16°C (mean minimum ≈ 11°C) in the subtropics and dry matter assimilation stops below 14°C (mean minimum ≈ 9°C). At the other extreme, growth stops at 38°C and field observations have associated under-peel discolouration with temperatures of 33 to 35°C (Stover and Simmonds, 1987). The overall mean temperature for an optimum balance between growth (assimilation) and development (leaf emergence) is about 25 to 27°C (Champion, 1963; Simmonds, 1966; Robinson, 1996).

### 1.2.3 Physiological Problems Related to Temperature

In addition to the temperature threshold values listed above, Robinson (1992; 1993b; 1996) listed a number of specific temperature related hazards encountered in growing bananas in the subtropics:-

#### *1.2.3.1 Problems Due to Cold Weather*

a. Frost: Bananas cannot be grown in areas where frost occurs regularly. Exposure to temperatures below freezing level for only a few minutes is sufficient to ruin a plantation.

b. Winter chill: Chlorophyll destruction and progressive yellowing of the leaves takes place with exposure to temperatures between 0 and 6°C. Physiological efficiency of the leaf is then impaired significantly.

c. Cessation of growth: When the mean monthly minimum temperature falls to 9°C, dry matter assimilation stops and the plant enters a dormant phase.

d. "Choke throat": This phenomenon occurs when normal leaf emergence is restricted by cold winter temperatures. The inflorescence is prevented from emerging fully through the top of the pseudostem by leaf petioles with short internodes which have become compacted and congested at the opening.

e. November dump: A southern hemisphere term, this phenomenon occurs when flower initiation inside the pseudostem coincides with very low night temperatures (eg. July). Bunches then emerge some three to four months later (November) and are generally small and malformed.

f. Under-peel discolouration: This occurs when night temperatures drop to below 13°C during fruit development and is caused by latex coagulation and subsequent browning of the latex by phenolic oxidation. If severe, the fruit will not ripen to a bright yellow due to the brown streaks in the peel.

#### *1.2.3.2 Problems Due to Hot Weather*

a. Winter leaf sunburn: This occurs when day temperatures exceed 30°C, the relative humidity is low and the feeder root system is depleted due to cold winter temperatures. The leaves wilt with the upper surface becoming bleached, generally only on the western half of the lamina which is exposed to the afternoon sun. This is an advanced form of photo-inhibition, referred to as photo-oxidation, resulting from chlorophyll degradation.
b. Summer heat stress: Temperatures > 38°C induce temporary wilt. If ambient temperature rises above 40°C and leaf temperature reaches 47°C, patches of leaf tissue may dry out and burn black.
c. Mixed ripe fruit: This occurs due to heat stress on fruit before and after harvest. These fruit then ripen prematurely and can spoil a carton which may have been mixed with other unripe fruit.
d. Ripe fruit breakdown: This occurs when temperatures of 40 to 45°C are experienced during the period from just before to just after flower emergence. Symptoms are only manifested after harvest when the fruit pulp collapses into a mushy consistency, severely reducing the shelf life.

### 1.2.4 Other Climatic Problems in the Subtropics

Robinson (1993b,1996) recorded a number of other climatic problems, some of which can have fairly severe restrictions on the production potential of a banana plantation:-

a. Hail: Almost every year some subtropical banana locality in South Africa has a severe hail storm which devastates some plantations and damages others. Hail damage to banana bunches can be partly offset by the use of polyethylene covers, depending on the severity of the hail and the thickness of the cover. During a light hail, covers certainly afford some protection and they should be seriously considered over summer for both wind and hail protection.

b. Wind: Wind can cause different types of damage in a banana plantation. Gale force winds (more than 50 km $h^{-1}$) cause "blowdowns" which are periodically responsible for total crop losses. Regular, strong seasonal winds in the subtropics (20 to 50 km $h^{-1}$) cause leaf tearing which may reduce productivity when severe. Winds between 10 and 20 km $h^{-1}$ can also reduce fruit quality by enhancing leaf and dust abrasion. Lastly, hot, dry winds induce water stress and temporary wilting, thus damaging the plant physiologically. There is no evidence that moderate tearing of leaves into strips at right angles to the midrib is damaging to the banana plant. In a study by Eckstein (1994) at Burgershall, leaves were torn experimentally into strips of 200, 100, 50, 25 and 12.5 mm width. Photosynthetic efficiency per unit of leaf area was not reduced on leaves torn to 50 mm strips. However, with 25 and especially 12.5 mm tears (representing a severe wind storm), photosynthetic efficiency was reduced as was functional leaf area due to the terminal dieback of the narrow leaf strips. Bunch mass was 31 and 27 kg, for plants on which leaves were torn to 100 and 12.5 mm strips, respectively. Windbreaks are recommended if such severe winds are experienced regularly, such as along the coastal belt.

c. Drought: Nearly all bananas in South Africa are irrigated. However, when drought reduces or removes the supply of irrigation water, the plants quickly become damaged. When soil water content is reduced, heat stress and leaf scorch occur more readily than in well-watered soil. Prolonged drought produces small, stunted plants with wilted yellow leaves, delays in flowering and choke throat with small bunches, and when severe, shrivelled blackened fingers. The effects of drought in winter are much less severe due to the reduced growth potential and lower temperatures.

d. Radiation damage: Excessive radiation can cause sunburn under certain conditions. Excessive light can bleach leaves in a subtropical winter and exposed bunches along roadways and in open plantations can be burnt on the top hand and bunch stalk. The fruit peel turns yellow with mild sunburn and black with severe burning.

e. Lightning damage: This is a rare phenomenon in the tropics but not so rare in the subtropics where convectional thunderstorms occur. Where lightning strikes a plantation, a dozen or more plants may be affected in a patch, within an area of otherwise healthy plants. The entire leaf eventually becomes discoloured and collapses around the psuedostem which in turn begins to rot from the top downwards.

### 1.2.5 Climatic Data From South African Banana Production Areas

#### *1.2.5.1 Temperature Values*

Reference to Fig.1 (all climatic data provided by the Institute for Soil Climate and Water (ISCW)) indicates that the temperatures experienced at two of South Africa's main production areas (Burgershall and Komatipoort) are sub-optimal in that the mean monthly minima are too low for maximum production, particularly during the winter period. Komatipoort's long term mean monthly minimum during June is 8.4°C, which is below the minimum threshold for dry matter assimilation. At the opposite end of the scale, Komatipoort experiences excessively high mean maximum summer temperatures, with absolute maxima in excess of 40°C from the months of September through to March. These wide temperature extremes, in what is now the most important production area in the country, highlight the adaptability of the banana plant. Most South African banana production areas experience lower temperatures than Komatipoort. Of relevance to the present study is that the mean temperatures experienced at three North Coast production sites (Eshowe, Mtubatuba and Nkwaleni) do not differ markedly from temperatures at Burgershall and Komatipoort. The same limitations caused by mean monthly minima, particularly in winter, apply to these sites as well. The Nkwaleni data reflect extremes similar to those at Komatipoort although the mean maxima are not as high. It is clear that Komatipoort is generally the hottest site and Eshowe the coolest, while Empangeni and Nkwaleni are very similar, but somewhat warmer than Burgershall.

#### *1.2.5.2 Heat Units*

An appraisal of heat units allows for a better cumulative temperature comparison of the different sites considered. Table 1 reflects the heat units experienced at each of the sites shown in Fig. 1. These were derived from the annual sum of the average daily temperatures ((mean max + mean min) ÷ 2) in excess of 10°C which, for the sake of this comparison, is regarded as the minimum threshold level for banana growth and productivity.

The Eshowe site with 3 254 heat units is the coolest and in view of the discussion above must rank as the site with the lowest production potential. Nkwaleni, Empangeni and Mtubatuba are all hotter than Burgershall, with Mtubatuba experiencing 17 % more heat units than Burgershall.

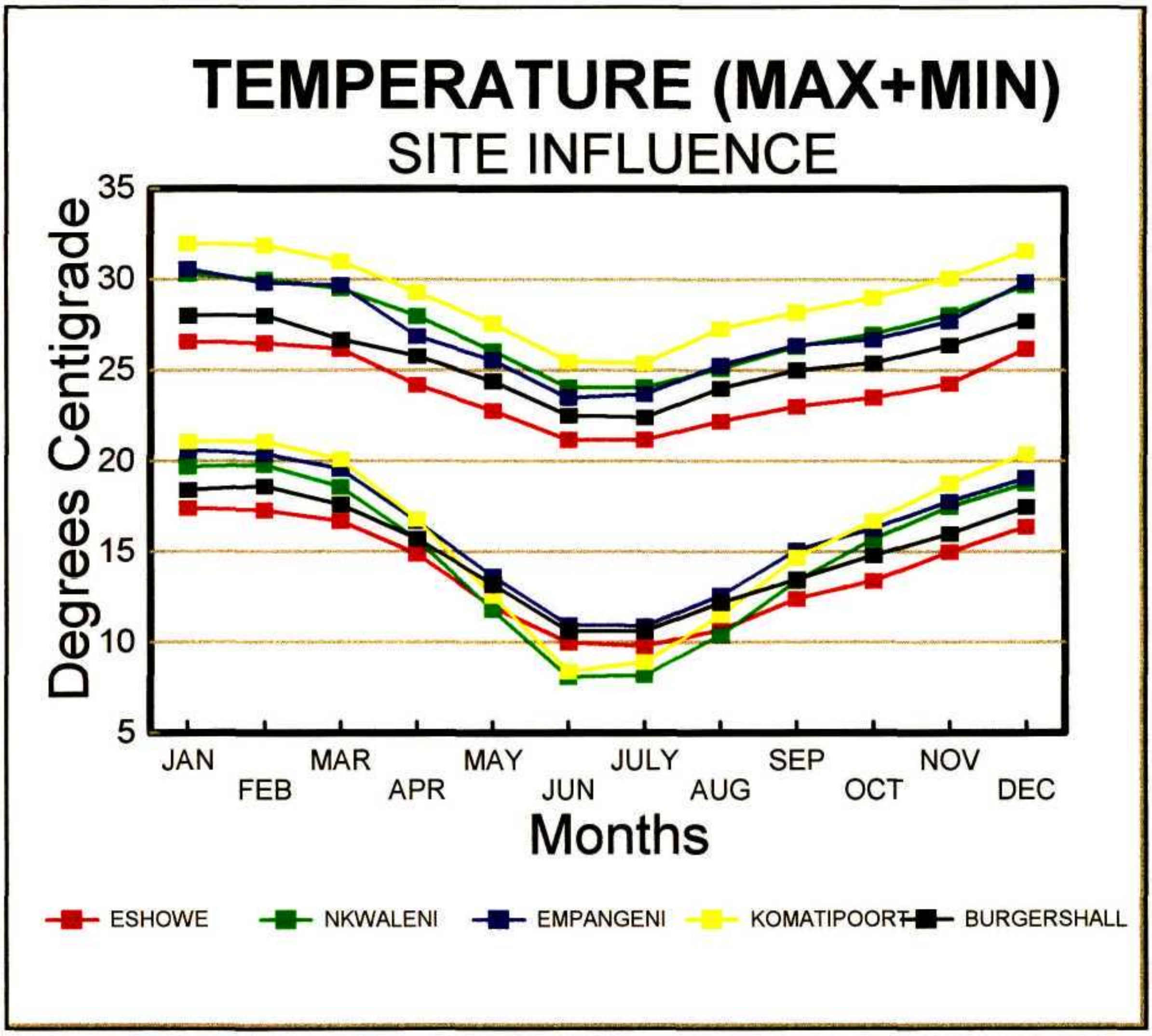


**Figure 1**: Temperature (mean monthly maximum and minimum values) experienced at various production sites in South Africa

Komatipoort, in turn has 4.3 % more heat units than Mtubatuba and would, on this basis, have the best production potential of all of the sites. However, what is not taken into account is the distribution of the heat units. Those daily heat units causing temperatures in excess of 38°C, which is regarded as the maximum threshold for banana growth (Robinson, 1996) are counter productive. Conversely, days in winter would benefit from extra heat units. If temperatures in excess of 38°C were excluded from the heat units presented, the effective heat units at Komatipoort could be reduced without adversely affecting growth. Stated differently, Burgershall is still arguably the most productive area, despite having lower heat units than Komatipoort. It must also be borne in mind that mean relative humidity differs between the sites, and strongly affects the degree of "stress" experienced by banana plants.

**Table 1 : Annual Heat Units > 10°C at Various Production Sites**

| Site | Heat Units |
|---|---|
| Eshowe | 3254 |
| Burgershall | 3718 |
| Nkwaleni | 4013 |
| Empangeni | 4241 |
| Mtubatuba | 4364 |
| Komatipoort | 4553 |

### 1.2.6 North Coast Banana Production Potential

Wolstenholme (1976) used Phillips' Bioclimatic Groups to determine the production potential of tropical and subtropical fruit crops in Natal. He noted that while bananas are concentrated in the comparatively cool Port Edward - Port Shepstone area, (warm subtropics) "the warmer but equally humid coastal strip from Durban northwards may well be climatically the best banana area in South Africa". Phillips (1973) rated the area north of Cape St. Lucia as having the highest potential for crops requiring a high level of winter heat units. Mean minimum temperatures for Cape St. Lucia, accumulated over a 16 year period, reflect a June value of 14.0°C and a July value of 13.9° C, which are significantly higher than the corresponding temperatures experienced at Burgershall and Komatipoort, and this fact gives great credence to Phillips' and Wolstenholme's claim, as far as North Coast banana production potential is concerned. It is evident from the preceding appraisal of climatic data that, although the North Coast, particularly the low lying coastal areas north of St. Lucia, have some of the best banana production potential in South Africa, there is a fairly divergent range of production potential within the North Coast area. It consequently became obvious that no single trial site could claim to be representative of the North Coast from a climatic point of view and the need to replicate trials at different sites was self evident.

Wolstenholme (1976) in his "Generalised rating of Phillips' Bioclimatic Groups for Specified

Crops" on a scale of 1= best adapted, to 5= unsuitable, rated Bioclimatic Group 2 (Coastal Hinterland) as 3-5 for bananas. Eshowe, altitude ± 500 m, and in the lower altitude range of Bioclimatic 2, would rate a 3-3½ which could be interpreted as marginally suitable. Bioclimatic Group 10 (Interior and valley thornveld) represented by the Nkwaleni production area, rated a 2-5 for bananas. The actual rating would be determined by the specific location within a valley and the incidence of frost in that locality. Bioclimatic Group 1 (Coastal lowlands) was rated a 1-2. This coastal lowlands grouping extends the full length of KwaZulu-Natal and the further north one goes the better the rating would be. A number of commercial production units are interspersed along the length of the North Coast in Biogroup 1. The only other Bioclimatic Groups rated as having some potential for bananas are Group 9 (2-3) and Group 11 (2-3). This "Zululand bushveld" and "Zululand arid lowveld" respectively could relate to conditions intermediate between Biogroups 10 and 1.

For the sake of representation on the North Coast it was decided that a number of trial sites would have to be selected. However, for logistical and practical reasons it was decided to limit the selection of trial sites to three, namely, a site in each of Bioclimatic Groups 1, 2 and 10.

## 1.3 PHENOLOGY OF THE BANANA IN THE SUBTROPICS

Phenology is the study of plant developmental behaviour in relation to climate, and in particular, temperature (Kuhne *et al.*, 1973; Robinson 1993c). For most citrus, deciduous and tropical fruit tree species, phenological studies are facilitated by specific flowering and harvest times which are determined seasonally. With the banana, however, floral initiation seems to be independent of external factors, thus flowering and harvesting can occur at any time of the year. This makes reproductive phenological studies with banana more complicated, especially in subtropical areas like South Africa. Due to the variation in temperature within South African banana production areas (Fig. 1), production of leaves and fruit follow a cyclical pattern. This pattern is even more pronounced in areas which experience greater seasonal extremes of temperature such as in Israel where 80 % of the plants flower during a 3 month period from July to September (Israeli *et al.*, 1988). By contrast Simmonds (1966) stated that the effect of season in the humid lowland tropics is negligible and that flower distribution throughout the year reaches almost uniform proportions within a few years of planting. Any variation is the result of dry spells or a temporary drop in temperature. Robinson (1996) stated that very few phenological studies have been conducted in the tropics over the past ten years due to a lack of relevance. By contrast many detailed studies have been conducted in the subtropics and Mediterranean countries, where a knowledge of banana phenology is important for management decision making.

According to Robinson ( 1992; 1993c; 1996), the most important phenological parameters are:-

1. Planting to harvest intervals for different planting dates and localities.

   Robinson (1996) stated that, whereas the time taken from planting to harvest in the humid tropics of Costa Rica and Honduras is ten months, this contrasts greatly with cycle times in South Africa where, in the cool Burgershall district, the respective cycles for December and March planting dates are sixteen and twenty months. Robinson and Nel (1986a) established the effect of season (essentially temperature) on the cycle interval from planting to harvest. They found that the total cycle time for a September (spring) planting was almost 2.5 months shorter than a March (autumn) planting, due to the latter cycle extending over two winter periods, before harvest. In the warmer Komatipoort district the total cycle time for a summer planting is thirteen months (Morse and Robinson, 1996a - in press). A knowledge of planting to harvest cycle time is important in the subtropics for two reasons:

   a. One can avoid planting in a period that will result in a high incidence of so-called "November dump" bunches.

   b. Due to the cyclical production in the subtropics there is a consistent tendency for fruit to be oversupplied in spring and under-supplied in autumn. Strategic planting and crop timing can allow for harvest spread and optimum economic returns (Robinson and Nel, 1986a; Robinson and Anderson, 1991c).

2. Seasonal leaf emergence rates.

   Turner (1970) stated that the rate of appearance of new leaves is a measure of the progression of the plant towards maturity. When combined with the total number of leaves to be produced and a knowledge of plant ontogeny, it can provide an estimate of the time to bunch emergence for any given planting date. Robinson (1981), Turner and Hunt (1984), Allen *et al.* (1988), Mekwatanakarn and Turner (1989) and Liao and Chen (1990) all demonstrated the strong association between the rate of leaf emergence (LER) and temperature. Turner (1995) illustrated the profound effect of temperature by stating that the rate of appearance of new leaves increased 10-fold from 13°C to 28°C. Kuhne *et al.* (1973) stated that irrespective of other influences, temperature is the main factor controlling banana LER. In their study of the seasonal growth and development components of 'Williams' cultivar, Robinson and Nel (1989a) found that leaf area increment was 35 times greater in summer than in winter, once again highlighting the profound influence of temperature on the vegetative development of the plant. Although other factors such as nutrient and water supply and cultivar, have a bearing on total leaf production, Mekwatanakarn (1987) and Turner and Hunt, (1987) believe that temperature also influences the total number of leaves produced.

3. Seasonal root growth rates.

   Primary root extension rate (RER) is another index of the vegetative development of a banana plant. Root development is closely correlated with soil temperatures just as LER is correlated with aerial temperatures. In a rhizotron at Nelspruit, Robinson and Alberts (1989) measured the RER of 'Williams' at 200 mm depth on a weekly basis and related this to minimum soil temperatures. RER ranged from 10 mm week$^{-1}$ at 11°C to 200 mm week$^{-1}$ at 25°C. Below 11°C RER ceased entirely. Seasonally, peak RER occurred during February in South Africa, coinciding with highest soil temperatures. Peak RER measured was 275 mm week$^{-1}$ at Nelspruit whereas the peak RER measured in the tropics of the Ivory Coast was 245 mm week$^{-1}$ (Lassoudière, 1978a). Knowledge of the RER is of great practical value to the banana farmer in the subtropics. Due to the cessation of root development during the winter months, there is no need to fertilize during this period and irrigation can be reduced considerably.

4. Seasonal variations in flower emergence to harvest interval.

   The interval from bunch emergence to harvest varies greatly according to season of emergence with a close correlation between fruit development and prevailing temperatures (Kuhne *et al.*, 1973; Israeli and Lahav, 1986; Robinson and Human, 1988). Kuhne (1980b) recorded an emergence to harvest interval of 113 days for a November emergence and 212 days for an April emergence at Burgershall. In the extreme climate of Israel, the variation in emergence to harvest is very wide, from 86 days for late May flowering, to 208 days for flowering only 3½ months later in mid-September (Israeli *et al.*, 1988). If one is able to establish the date of bunch emergence for any one locality and cultivar, it is then also possible to estimate the date of harvest (Turner, 1995). Using temperature alone, this approach was used in the tropics (Hord and Spell, 1962 ) as well as in the subtropics (Ticho, 1960; Robinson and Human, 1988 ). Turner and Barkus (1982) also measured fruit growth in a subtropical climate and found a strong relationship between relative fruit growth rate and the mean daily temperature during growth.

5. Seasonal variations in bunch mass.

   In the subtropics, bunch mass can vary significantly according to season (Robinson and Human, 1988; Turner, 1995 ). This is due to the effect of temperature at flower initiation. The sensitivity to flowering date is obvious at Burgershall, where Robinson and Human (1988) measured a decrease in bunch mass from 57.8 to 37.2 kg as flower date was delayed three months from late July to late October. Using prevailing leaf emergence rates and the accepted norm of eleven leaves emerging between flower initiation and flower emergence (Stover, 1979), the approximate date of flower initiation can be retrospectively estimated. Thus, October-flowering bunches with the lowest bunch mass were initiated during the cold temperatures of July, whereas July/August-flowering bunches with the highest bunch mass were initiated during the optimum warm period of February/March.

These five components all play an important role in productivity, which is the mass of fruit produced per unit area per unit time (t $ha^{-1}$ $an^{-1}$ ). A knowledge of the influence of temperature on banana plant phenology is important for planning the planting date to enable harvesting to coincide with the optimum marketing period. This decision-making must take cognisance of extended cycle times due to cooler localities or autumn planting (reduced productivity) as well as the effect of season on fruit mass and quality. This knowledge also enables the farmer to forecast crop harvest dates from known flower dates, and allows for adjustments on management intensity during cooler conditions (Robinson 1993c; 1996).

## 1.4 PHYSIOLOGY

While phenological phenomena outlined above describe the developmental processes of the plant, the processes of growth (assimilation of dry matter) are described by physiological responses. Although physiology did not form part of the present study, it is important to be able to identify environmental constraints on the physiological efficiency of the plant. Just as leaf emergence rates and flowering to harvest intervals, characterised vegetative and reproductive development, so measurements of photosynthesis and dry mass describe the physiological activity of the plant throughout its whole cycle. Limited studies on the physiological responses of the banana plant to seasonal influences were made by Ke (1979) and Robinson and Bower (1988). In an effort to understand the interaction between climatic conditions and growth of the plant, Eckstein and Robinson (1995a) undertook an intensive field evaluation by measuring both leaf photosynthesis and transpiration. They found that young plants measured in the vegetative growth phase during late summer had the highest physiological activity. With this combination of factors, the most efficient leaves, 3 to 5, were being replaced every month; temperature conditions allowed for the highest assimilation potential and young tissue culture plants were at their peak of physiological efficiency. Eckstein and Robinson (1995b) also found that the highest annual photosynthesis levels were measured during the early morning of the summer months and the lowest midday values were during the winter, following low night temperatures.

These phenological and physiological studies highlight the very important range of influences that temperature has on the growth and development of the banana plant. Armed with this knowledge, one can plan to coincide the growth stages of maximum physiological activity with optimum seasonal conditions.

## 1.5 CULTIVARS

### 1.5.1 Historical Overview in South Africa

Until 1974 when 'Williams' was released, 'Dwarf Cavendish' was the only cultivar grown commercially in South Africa. At the time, it was regarded as the cultivar most adapted to the extremes of climate in a subtropical zone (Kuhne, 1978; Samson, 1980). However, due to its susceptibility to the "choke-throat" phenomenon, it is in fact less tolerant or adapted to areas that suffer from cold winter temperatures than other Cavendish cultivars (Robinson 1981; 1993h). Due to reduced susceptibility of 'Williams' to choke throat, coupled with it's superior yield and fruit quality, this cultivar has rapidly replaced 'Dwarf Cavendish', particularly in cooler areas such as the KwaZulu-Natal South Coast and the Burgershall district in Mpumalanga.

Following evaluation of ten Cavendish sub-group banana cultivars and selections over four crop cycles at Burgershall, a further three cultivars were released to the South African banana industry in 1988 (Robinson *et al.*, 1993a). These were 'Chinese Cavendish', 'Grand Nain' and 'Valery'.

### 1.5.2 The Ideal Banana Cultivar

It has been stated ( Robinson, 1993h; Robinson *et al.*, 1993a) that the ideal commercial banana cultivar for the subtropics has the following main criteria:-

1. The pseudostem should be relatively short and sturdy which enables the plant to have stability against strong subtropical winds. This characteristic also facilitates easier bunch management such as propping, bunch covering, bunch spraying and harvesting.
2. The pseudostem should have a high leaf emergence rate and/or a low total leaf production potential before flower emergence. Either of these traits will shorten the vegetative cycle time which tends to be excessively long in the subtropics due to the cold winter when little leaf development takes place.
3. There should be an absence of, or a reduced tendency towards the phenomena of winter induced "choke throat" and "November dump".
4. Bunch quality should be high. This comprises a long peduncle(fruit stalk), a cylindrical non-tapering bunch, long fingers and high bunch mass.

5. There should be resistance, or a degree of tolerance, to race 4 of *Fusarium oxysporum f.sp.cubense*.

Following the release of three additional cultivars in 1988, there was a selection of five commercial cultivars in South Africa, all of which belonged to the same genotype, *viz. Musa acuminata* ( AAA group) and all to the same Cavendish sub-group.

### 1.5.3 Classification of Banana Cultivars

An overview of the classification and naming of banana clones is important in gaining an appreciation of the genetic diversity and allied to this, the production potential and market suitability of the worldwide pool of bananas and plantains.

Simmonds and Shepherd (1955) devised a scheme for naming bananas according to their genus, genome (genetic composition) and cultivar name. The following is an example:-

| Genus | Genome | Cultivar Name |
|---|---|---|
| *Musa* | AAB Group | 'Lady Finger' |
| *Musa* | AAA Group, Cavendish sub-group | 'Williams' |

All bananas belong to the genus *Musa*. Within the genus there are seven common ploidy groups which differ in their genetic make-up (or genome). These are:

| Diploids (2 Sets of Chromosomes) | Triploids (3 Sets of Chromosomes) | Tetraploids (4 Sets of Chromosomes) |
|---|---|---|
| AA | AAA | AAAA |
| AB | AAB | ABBB |
| | ABB | |

Edible bananas have developed from two distinct species, *Musa acuminata* (A) and *Musa balbisiana* (B) and their genetic make up and ploidy reflects their origins. Dessert bananas which account for the bulk of the world trade, primarily belong to the AAA triploid grouping (Stover and Simmonds, 1987). Over 1 000 banana cultivars have been named throughout the world (Turner, 1984), although many of these are regarded as synonyms - the same cultivar having a different name in different countries. Simmonds and Weatherup (1990), using the same numerical scoring system devised many years earlier, recorded 960 entries in their attempt to classify the world's known *Musa* cultivars. This presents some idea of the genetic diversity available to the world's researchers in their quest to find the ideal banana. Simmonds (1954) reviewed the origins and characteristics of the Cavendish sub-group of *Musa* AAA and this forms the basis of *Musa* classification today. Five of these cultivars, all of which have arisen by mutation in the field, form the basis for international trade. Stover (1988) in his study of 'Grand Nain' variant banana plants identified six pseudostem height classes. All were somaclonal variations of 'Grand Nain' plants produced by *in vitro* mass production. These height classes represent the entire range of Cavendish sub-group morphological variation and are normally represented by other known cultivars as follows:

| | | |
|---|---|---|
| 1. | 'Extra Dwarf Cavendish' | ± 152 cm |
| 2. | 'Dwarf Cavendish' | ± 208 cm |
| 3. | 'Dwarf Grand Nain' | ± 253 cm |
| 4. | 'Grand Nain' | ± 295 cm |
| 5. | 'Gaint Cavendish -Robusta' | ± 373 cm |
| 6. | 'Lacatan' | ± 477 cm |

### 1.5.4 International Cultivar Comparisons between Cavendish and Non-Cavendish Bananas and Plantains

Daniells and O'Farrell (1988) found that as a result of larger bunches, more hands and longer fingers, the Cavendish sub-group cultivars generally outproduce non-Cavendish types. In their study in North Queensland, Australia, 21 cultivars from the genomic groups AA, AAA, AAB and ABB were evaluated. Bunch weights of the Cavendish sub-group cultivars were about twice those of other cultivars, with the heaviest, 'Williams', averaging 51 kg. Daniells and Bryde (1993) evaluated seven hybrids against the local 'Williams' in North Queensland. The average yield for the parent crop and first ratoon was also highest in 'Williams' (61.9 t ha$^{-1}$) which exceeded its nearest rival by 29 %. Taste panels also preferred the 'Williams'. In their study of 30 banana cultivars in New South Wales, Turner and Hunt (1985) found similar trends. The three Giant Cavendish cultivars, 'Williams', 'Chinese' and 'New Guinea Cavendish' were the most productive. Cultivars of the ABB group (cooking bananas) yielded about half as much as the Cavendish dessert types.

Israeli (1985) supports the claim that Cavendish cultivars are high producers. In his study in Israel, the higher productivity of 'Cavendish' was due to a shorter crop cycle which in turn was due to a faster leaf emergence rate and reduced total leaf production. He evaluated the non-Cavendish cultivar 'Red' (*Musa* AAA) and compared it with 'Williams'. The rate of leaf emission was 15 % lower with 'Red' and the total number of leaves 20 % higher, which resulted in a marked delay in flowering. Furthermore, the bunch mass was 58 % of 'Williams' so the overall productivity of 'Red' was only about half that of 'Williams'.

In their evaluation of plantain cultivars for high yield in Nigeria, Obiefuna *et al.*(1991) did not compare with the Cavendish types. However, the yield obtained from the best performing plantains ( 21.8 t $ha^{-1}$ from the plant crop and 14.2 t $ha^{-1}$ from the best ratoon crop ), was comparatively low. Evaluation of cultivars other than Cavendish types by Syamal and Mishra (1989) , Irizarry and Goenaga (1995) and Ram *et al.*, (1989) also reflect relatively low bunch mass and/or low productivity (t $ha^{-1}$ $an^{-1}$). All this gives credence to the general claim that non-Cavendish genotypes do not have the same production potential as Cavendish types. An exception to this is the performance of the 'Goldfinger' cultivar in North Queensland, where yield was comparable with that of 'Williams' at two sites (Daniells *et al.*, 1995). However, recent South African trials on "Goldfinger" (unpublished) have realised yields that are significantly lower than the Cavendish sub-group.

### 1.5.5 International Cultivar Comparison Within the Cavendish Sub-group

The Cavendish sub-group is extremely important in world banana trade, both for export from the tropics and for local trade within the subtropics (Robinson, 1996). In the nomenclature of the Cavendish cultivars there has been confusion caused by grouping certain cultivars together as synonyms. For example 'Grand Nain' and 'Williams' are grouped together as 'Giant Cavendish' types (Stover, 1988). Many of the Cavendish cultivars in the different height categories can only be distinguished when grown side by side. Stover (1988) recommends that for comparative purposes one or more of the widely grown and studied Cavendish cultivars should be included as a benchmark in cultivar evaluations.

Within the Cavendish sub-group of bananas, numerous trials have been conducted in an effort to establish the most suitable cultivar for a particular locality. Turner and Hunt (1984) carried out one of the largest comparative studies of the Cavendish cultivars. Fourteen cultivars from five different height classes (excluding 'Dwarf Grand Nain') were compared. The largest differences among cultivars were in plant height, bunch mass and bunch mass to height ratio. Most productive were the three Giant Cavendish cultivars - 'Williams' (due to heavy bunch weight) and 'Chinese Cavendish' and 'New Guinea Cavendish' (both due to shorter cycling periods). Mobbs (1961) stated that the 'Mons Mari' cultivar, a mutation from the 'Dwarf Cavendish' is probably identical to a similar mutation, *viz.* 'Williams'. He regards the 'Mons Mari' as more tolerant than 'Dwarf Cavendish' to adverse conditions such as poor soils and climate and recommended that it replace 'Dwarf Cavendish' in Queensland, Australia. Hill *et al.* (1992) evaluated four Cavendish sub-group banana cultivars in Western Australia and found that 'Williams', with a marketable yield of 70.2 t $ha^{-1}$ was the highest producer. It outperformed 'New Guinea Cavendish', 'Chinese Cavendish', and 'Hsien Jen Chio' by an average of 38 % in the plant crop and had almost double the production of the others in the first ratoon crop. This was due to fewer bunch losses through choke throat and pseudostem breakage in 'Williams' than in the other cultivars. They concluded that it was unlikely a new cultivar would be found to replace 'Williams' in the semiarid subtropics of Western Australia in the short term.

Holder and Gumbs (1983) and Holder and Taylor (1986) found that 'Williams' out-yielded 'Robusta' which is the dominant cultivar in the Windward Islands, by 13.4 % over 3 cropping cycles. This was because of fewer bunch losses from lodging as a result of 'Williams' lower stature. Walker (1970) studied the growth and yield of 'Valery', 'Lacatan' and 'Robusta' in Jamaica. He found that 'Valery' out-yielded 'Robusta' by 79 % and 'Lacatan' by 53 % because of its faster rate of ratooning, heavier bunches and much reduced incidence of lodging. In an evaluation of five "dwarf " banana cultivars in Puerto Rico's mountain region, Irizarry *et al.* (1994) obtained similar production levels from 'Valery', 'Grand Nain', 'Ziv' (regarded as the same as 'Williams'), 'Johnson' and 'Selection A'. In his evaluation of 'Valery' and 'Grand Nain' in Honduras and Panama, Stover (1982) found that 'Grand Nain' out-yielded 'Valery' and other Giant Cavendish cultivars. 'Grand Nain' also produced 20 % less foliage than 'Valery'. He recommended that a true comparison should be made at population densities for each cultivar that allow for a comparable Leaf Area Index (LAI). In other words, 'Grand Nain', with less foliage and less competition between plants should be planted at a 20 % higher population than 'Valery' for an accurate comparison.

In their attempt to select dwarf types with good performance, Tang and Chu (1993) evaluated five *Musa* lines screened in Taiwan since 1986. A line of 'Cavendish Black Farm', introduced from Barbados and re-named 'Tai Chiao 2' was some 50-60 cm shorter than the control yet gave similar production. In an attempt to save their banana industry, the emphasis of cultivar research in Taiwan, has been on breeding *Fusarium*-tolerant clones of 'Giant Cavendish'. In other words the emphasis is not necessarily on selecting for maximum production. Galan Sauco *et al.*(1991;1995) evaluated 'Williams' and 'Grand Nain' against the traditionally grown 'Dwarf Cavendish' in the Canary Islands. They concluded, on the evidence available from five crop cycles, that 'Grand Nain' should replace 'Dwarf Cavendish' in the Canary Islands, due largely to it's longer fingers and consequently better potential for competitive export. This is in line with the tendency in many tropical and subtropical banana producing countries to cultivate 'Grand Nain' (Soto, 1985).

In one of the very few trials on Cavendish bananas in Africa, outside of South Africa, Wilson (1981) compared 'Williams' and 'Dwarf Cavendish' in the Zimbabwe lowveld. He found that at the same density, 'Williams' had a longer cycle time from sucker selection to harvest (508 days vs 372 days). However, the bunch yield was much greater in the case of 'Williams', 107 vs 68 t $ha^{-1}$ in one trial and 125 vs 67.98 t $ha^{-1}$ in another. He concluded that both 'Williams' and 'Dwarf Cavendish' are suited to the Zimbabwe lowveld, the former for it's greater yield potential and better fruit quality, and the latter for it's faster cycling and shorter stature.

Due to historical reasons different cultivars tend to dominate in different parts of the world. 'Williams' is a commercial favourite, particularly in the subtropics. However, the trend is for 'Grand Nain' to replace other cultivars, eg. 'Williams' in Israel and 'Valery' in Central America. Robinson (1966) stated that, due to it's many advantages, 'Grand Nain' should eventually become both the premier export cultivar in Central America and commercial cultivar in the subtropical countries.

### 1.5.6 South African Banana Cultivar Evaluations

Until very recently, local South African cultivar trials have been confined to evaluations of bananas from the Cavendish sub-group. The initial comparisons in South Africa, were between 'Williams' and 'Dwarf Cavendish'(Kuhne, 1980a ; Robinson and Nel, 1985) and 'Williams' and local Cavendish selections (Robinson, 1983). These initial comparisons favoured 'Williams' due to its superior yield and higher percentage of marketable fruit. Kuhne (1979) stated that the major advantage of 'Williams' over 'Dwarf Cavendish' is its long "neck" which renders it less susceptible to choke throat in cooler areas. However, the disadvantage of greater height coupled with the attendant management problems meant that 'Williams' was not necessarily the ideal banana for South Africa.

The search for better cultivars continued and in the late 1970's and early 1980's a further six cultivars were imported into South Africa. Together with two local selections and the industry standards, 'Williams' and 'Dwarf Cavendish', a long term trial commenced in 1983 at Burgershall. Data from four successive crop cycles were compared. Cumulatively, 'Grand Nain' and 'Chinese Cavendish' jointly yielded the highest with an average of 58.1 t $ha^{-1}$ $an^{-1}$, compared with 53.0 and 43.4 t $ha^{-1}$ $an^{-1}$ respectively for 'Williams' and 'Dwarf Cavendish'. 'Valery' also out-yielded 'Williams' and in addition it is a cultivar with long fingers which makes it suitable for possible future export use. Based on the performance of 'Grand Nain', 'Chinese Cavendish' and 'Valery', these three were released to the South African banana industry in 1988 and were commercially available in 1989 ( Robinson and Nel ,1988a; Robinson, 1990a; Robinson *et al.*,1993a).

Subsequent Cavendish cultivar trials in various production centres in South Africa have produced variable results, highlighting the fact that no single banana cultivar can be recommended for all production areas in the country. On the South Coast of KwaZulu-Natal, and at Levubu 'Williams' gave the highest average yield for plant crop (P) and 1st ratoon ( R1), (48.6 and 40.3 t $ha^{-1}$ $an^{-1}$ respectively) and its continued recommendation remains valid in these areas (Robinson *et al*; 1994c). In Natal 'Williams' outperformed the next best cultivar,'Valery', by 6 % and at Levubu,'Grand Nain', by 1¼ %. In both trials productivity differences between the Cavendish cultivars evaluated were small and non-significant, showing how similar the Cavendish cultivars are in respect of productivity. At Burgershall, Robinson and Anderson (1990), Robinson and Anderson (1991b) and Robinson and Fraser (1993) further evaluated the three new cultivars against 'Williams'. 'Grand Nain' produced the best average yield per annum (72.2 t $ha^{-1}$), followed by 'Chinese Cavendish' (71.2 t $ha^{-1}$), 'Valery' (70.9 t $ha^{-1}$) and 'Williams' (67.3 t $ha^{-1}$). In the hot Komatipoort production area, Morse and Robinson (1996b- in press) showed that an Israeli selection of 'Grand Nain' slightly outperformed 'Chinese Cavendish' over 3 cropping cycles. Despite mean yields of over 60 t $ha^{-1}$ $an^{-1}$, these two cultivars did not significantly out-yield 'Grand Nain' (Central American selection) 'Valery', 'Williams', or 'Dwarf Cavendish'. Due to increased physical stability of the shorter cultivars they therefore recommended a choice of the three shortest cultivars tested, *viz.* 'Dwarf Cavendish', 'Chinese Cavendish' or 'Grand Nain' (Israel).

It is evident from the review of local and international literature that the Cavendish sub-group of banana cultivars generally outperform other types of bananas and plantains. It is also evident from this review that within the Cavendish sub-group, South Africa possesses five of the most popular and productive cultivars. Trials to select specific cultivars best suited to each locality have been conducted in four of the six production areas *viz.* Burgershall, Komatipoort, Levubu and KwaZulu-Natal South Coast. Results achieved and recommendations with regard to choice of cultivar varied between the different areas. It was clear that the need to identify a cultivar or cultivars, best suited to the KwaZulu-Natal North Coast production area, became a priority that had to be addressed.

## 1.6 POPULATION DENSITY/SPACING

According to Simmonds (1966) and Robinson (1993d; 1993e; 1995a; 1996) the spacing of banana plants is a subject of extreme complexity and no general recommendation can be made to suit all situations. Robinson adds that it is vitally important that the appropriate planting density be chosen because it is one of the major determinants of annual yield per hectare and once chosen it cannot easily be adjusted at a later stage. Robinson (1996) defined the optimum density as that at which annual economic gross margin returns per hectare are maximised over the entire plantation life. This wide definition incorporates both input costs and marketable yield per annum over the long term. An increase in density will increase the total number of bunches harvested, thereby increasing the yield per hectare (Robinson and Nel, 1989b). However, with increasing density, costs per ha also increase, bunch size is reduced, fruit quality deteriorates and the cycle time increases. These disadvantages all have to be considered in determining the optimum density ( Daniells *et al.*, 1985; 1987 ; Robinson *et al.*, 1994b).

### 1.6.1 Factors Affecting Choice of Density

Simmonds (1966) identified the following nine factors that affect the choice of density:-

1. Choice of cultivar. A shorter cultivar with lower Leaf Area Index (LAI) such as 'Dwarf Cavendish', should always be planted at a higher population than taller cultivars like 'Giant Cavendish'.
2. Inherent soil fertility and fertilizing regime. Generally, the more fertile the soil and the heavier the fertilising, the closer the plant spacing can be.
3. Pruning or de-suckering regime. This determines the effective population of the field. Retaining more than one sucker per mat will increase the density.
4. Economic factors. If the market requires high grade fruit with long fingers a lower density must be chosen. The converse is also true.
5. Management level. Practical considerations such as mechanisation can determine spacing requirements.
6. Weed suppression. High density plantations require less weed control due to the shading effect.
7. Wind speed. Densely planted bananas are believed to be more resistant to wind damage than sparsely populated fields.
8. Topography. On slopes, contour rows are preferable to square planting and this will affect spacing.
9. History of the land: Existing drainage systems, tree stumps, etc., will impose restrictions and affect the spacing.

Robinson (1993d; 1993e; 1995a; 1996) introduced other factors that are more specific determinants of density choice :-

1. Prevailing climate: A hot, dry locality with excessive heat units and regular heat stress (such as in North-Western Australia) requires that a high ratoon density be used (>3 000 plants ha$^{-1}$) to maximise yield and to provide shade and micro-climatic protection. Conversely, a mild, subtropical climate with cold winters requires that a lower ratoon density be used (<2 000 plants ha$^{-1}$) to allow light penetration, enhance growing temperatures and accelerate the cycle time. Turner (1982) reported a four-fold variation in yield at 2 000 plants ha$^{-1}$ depending on climatic zone and cultivar.

2. Plantation vigour: Vigour is generally determined by soil characteristics (compaction, fertility) and management level which includes fertilisation, irrigation and other cultural practices. Stover (1984) recommended the use of LAI and the transmission of photosynthetically active radiation (PAR) to correlate with yield levels to determine optimum density for a given level of vigour. He recommended an LAI of 4 to 5 and a PAR transmission of 14 to 18 % in plantations of optimum density. In general, highly vigorous plantations can have a low density and still maximise economic returns and those with medium vigour can be planted at a higher density. However, Robinson and Nel (1989c) showed that it is not possible to compensate for lack of plant vigour in a weak plantation by simply increasing the density to achieve a higher LAI. At the high density required for this, the individual plants become so weak and bunches so small, that overall yield per annum and fruit quality are drastically reduced. A high level of vigour is regarded as a pre-requisite for high yields in a banana plantation. In their study of plantains, Swennen and de Langhe (1985) indicated that high yield is determined by conditions inducing vigorous initial growth of the plant.

3. Plantation longevity: The intended life of the plantation plays a major role in the choice of optimum density. It was clearly demonstrated by Robinson *et al.* (1994b) with 'Chinese Cavendish' at Burgershall, that the best economic returns from bananas planted for a single crop cycle were from a density of 3 333 plants ha$^{-1}$ which was much higher than that normally recommended for a long term ratoon plantation (1 666 to 2 222 plants ha$^{-1}$).

Given these numerous determinants of planting density, it follows that with a wide range of cultivars, soil resources, climate, cultural and commercial practices, the chosen densities in different world banana localities vary tremendously. Although the performance of bananas and plantains in different parts of the world may be used as a guide, it is imperative that specific long term density trials are conducted in each locality to determine the optimum for that locality.

### 1.6.2 International Density Studies on Non-Cavendish Bananas and Plantains

Although cultivar choice, soil and climate are likely to have an overriding influence on optimal density in a research situation, it is worthwhile gaining an overall impression of world trends in all spheres of banana and plantain production.

It is evident from the review of literature below that an increase in density generally causes increased yield per hectare, but smaller fingers and longer cycles. In traditional rural production systems, finger size is not that important. Most studies on plantains have, however, been conducted with commercial markets in mind, where fruit size plays a greater role and must ideally exceed a minimum of 270 g. Notwithstanding this factor, it would appear that optimum densities for plantains are generally higher than those for Cavendish bananas (Robinson, 1996).

In Asia (India), Anil *et al.* (1994) studied 'Nendran' banana (AAB) at five densities, ranging from 1 975 to 6 400 plants ha$^{-1}$. Both cultivation costs and yield per hectare increased with increasing plant density but finger length, girth and mass decreased. A density of 3 265 plants ha$^{-1}$ spaced at 1.75 x 1.75 m resulted in the highest profit per unit area. Bose *et al.*(1992) studied 'Giant Governor' in West Bengal, India, at seven densities ranging from 1 600 to 10 000 plants ha$^{-1}$. Although yield per hectare increased linearly with increase in density, both in the P and R1, they established an optimal density of 2 500 plants ha$^{-1}$. This regime provided the maximum yield of 71.9 t ha$^{-1}$ over the two crop cycles without major compromise to size and quality of fruit. The yield at 10 000 plants ha$^{-1}$ actually exceeded 200 t ha$^{-1}$ over the two cycles but the fruit was deemed unacceptable in the market.

In Central America (Puerto Rico), Irrizarry *et al.* (1978) found, in their density study on the Horn-type 'Maricongo' plantain (*Musa* AAB), that the highest yields without detriment to bunch and fruit size were obtained at 4 303 plants ha$^{-1}$. At this spacing the average production for the P and

R1 crops was 36.75 t ha$^{-1}$ over a 30 month period. In a further study of densities ranging from 1 890 to 3 460 plants ha$^{-1}$ Irizarry *et al.*(1981) found that the highest density of 3 460 plants ha$^{-1}$ gave the highest yield without decreasing fruit size below commercial standards of 270 g per fruit. In a recent study of plantains in Colombia, Belalcazar *et al.*(1994) suggested that the optimum density for maximum economic returns was 5 000 plants ha$^{-1}$.

In Africa (Nigeria) Obiefuna *et al.*(1982), in their study of plantains, reported that an initial planting of 1 600 plants ha$^{-1}$, with subsequent retention of two suckers per rootstock, was the optimum density. This effective density of 3 200 plants ha$^{-1}$ produced the best combination of sustained high yields (47.68 t ha$^{-1}$) and acceptable finger size (>270 g) over three harvest cycles. Higher yields of 66.14 t ha$^{-1}$ were obtained at a density of 6 000 plants ha$^{-1}$ over three cycles but the fruit size of 170 g was deemed commercially unacceptable.

Although some of the reviews represent data from the plant crop only and therefore cannot be regarded as definitive, it is evident that the world-wide trend is towards higher densities in plantain producing areas. It is also apparent from the literature reviewed that the scope of many of the plantain density studies has been restricted by limitations on the range of densities planted, with maximum yields being achieved from the upper limits of the plant densities (Echeverri-Lopez and Garcia-Reyes, 1981; Mustaffa, 1983; Arango-Bernal, 1987; Lichtemberg *et al.*,1986). These upper limits generally did not exceed 2 500 plants ha$^{-1}$ and were often a lot less.

### 1.6.3 International Density Studies on Cavendish Bananas

Unfortunately many banana density research trials are not taken beyond the plant crop or first ratoon. In the case of a density trial where the competitive effects are only really apparent from the first ratoon onwards, a trial of shorter duration can produce distorted values. Much of the literature also refers only to yields per hectare and disregards the very important component of productivity, *viz.* cycle interval between harvests. Turner (1970) states that with bananas, floral initiation can occur at any time of the year and is not directly dependent on external factors such as temperature and light. The harvesting period therefore becomes extended and is largely unrelated to season, unlike most fruit tree crops. In any banana trial it is important that the crop-to-crop cycle time be brought into the productivity equation. Daniells *et al.* (1985) and Robinson and Nel (1988b) demonstrated that the cycle times are extremely sensitive to changes in plant density and consequently they cannot be excluded from the productivity equation. For example, the results achieved by Singh and Kashyap (1992) in their study of 'Robusta' at three densities (3 704, 4 444, and 5 555 plants $ha^{-1}$) in India, must be treated with circumspection. The highest yield (67.82 t $ha^{-1}$) was obtained at 5 555 plants $ha^{-1}$ in the plant crop but time to harvest was not mentioned, neither was a ratoon crop included. Similarly, the trial of Mustaffa (1988) on 'Robusta' in India does not represent the whole picture. The highest yield of 50.97 t $ha^{-1}$ was achieved at the highest density of 3 086 plants $ha^{-1}$ in the plant crop, with no regard for cycle time or economic analysis of increased costs at high density.

In their trial with 'Williams' in North Queensland, Daniells *et al.* (1985) found that increasing the plant density from 930 to 3 980 plants $ha^{-1}$ increased the productivity (t $ha^{-1}$ $an^{-1}$) by 200 % in the plant crop and by 50 % in the first ratoon. These increases resulted from the greater number of bunches per unit area despite a 16 % reduction in average bunch mass in the plant crop and a 43 % reduction in the R1. Densities giving acceptable yield and fruit quality ranged from 1 710 to 2 780 plants $ha^{-1}$. Subsequently, Daniells *et al.* (1987) determined that the optimum density for ratoon plantations in North Queensland was in the order of 2 100 plants $ha^{-1}$. These trials made use of a large range of spacings with a constant 5 m inter-row between double rows. Although less efficient from a physiological point of view, the 5 m inter-row allows easy access to farm machinery, which is important in North Queensland.

It is evident that "optimum" density will vary according to the longevity of the plantation. In the humid tropics of Central America, plantations are regarded as permanent and commercial plantations are established with 1 500 to 2 000 plants $ha^{-1}$ in an attempt to achieve a leaf area index of about 4.5 (Stover, 1984). In the Sao Paulo state of Brazil the average commercial density is about 1 650 plants $ha^{-1}$ (Caser *et al.*, 1993). There is obviously a wide range of commercial practices regarding Cavendish banana plant densities and these reflect the determinants of density choice discussed earlier in section 1.6.1. A number of other international studies with Cavendish bananas have realised optimum yields at densities ranging from 2 222 to 2 500 plants $ha^{-1}$ (Robinson and Singh, 1974; Kohli *et al.*,1976; Anon, 1980; Chattopadhyay *et al.*,1980 ; Sandrini *et al.*, 1991), which, together with other credible trials, indicates that the optimum densities achieved with Cavendish bananas, is somewhat lower than that achieved with plantains.

### 1.6.4 Local Density Trials With Cavendish Bananas

In a 'Williams' banana density trial at Burgershall, Robinson and Nel (1986b; 1988c; 1989d) demonstrated that in the plant crop, yield per annum was 30 % higher at 2 222 plants ha$^{-1}$ than at 1 666 plants ha$^{-1}$ (46.3 t ha$^{-1}$ vs 35.6 t ha$^{-1}$). However, the mean increase in yield at 2 222 plants ha$^{-1}$ over five crop cycles, was only 6 % greater than at 1 666 plants ha$^{-1}$. This clearly indicated a progressive intensification of competition from P to the R4 cycle. In the P cycle the absence of canopy inhibition allowed plants at all densities to develop almost equally with a virtual linear increase in annual yield per hectare, as density increased. When cumulative annual yield per hectare alone was considered, the optimum density was determined to be 2 200 plants ha$^{-1}$ (LAI=6). However the lower density of 1 666 plants ha$^{-1}$ (LAI=5) was actually recommended to growers after calculating economic returns and considering ease of management. In a subsequent high density trial with 'Chinese Cavendish' at Burgershall, the maximum marketable bunch yield (67.7 t ha$^{-1}$ an$^{-1}$), for the plant crop only, was achieved at a density of 5 555 plants ha$^{-1}$ (Robinson *et al.*, 1993b). This compares with the results achieved by Singh and Kashyup (1992). However, when gross margin analysis was conducted it was established that the optimum annual economic return of R9 890 ha$^{-1}$ was obtained at only 3 333 plants ha $^{-1}$. Analysis of a further ratoon cycle resulted in a maximum economic return of R14 858 (average for P and R1) at 2 777 plants ha$^{-1}$ (Robinson *et al.*, 1994b) and a maximum for three cycles at a density of 2 222 plants ha$^{-1}$ (Robinson, 1996). Thus, it is illustrated once again that optimum density for maximum gross margin is reduced according to the expected plantation life. It is also evident that in order to maximise economic returns the shorter 'Chinese Cavendish' should be planted at a higher density than the taller 'Williams'.

A 'Williams' density trial at Levubu resulted in a maximum yield of 40.1 t ha$^{-1}$ an$^{-1}$ at 2 222 plants ha$^{-1}$ after two cycles ( Robinson and Nel, 1989e). A further cycle resulted in maximum economic returns being achieved at the lowest density of 1 333 plants ha$^{-1}$ (Robinson and Nel, 1991; Robinson, 1993e). This has been ascribed to the relatively low vigour of the plants, probably as a result of poor water availability and soil compaction problems.

In trials conducted in the much hotter area of Komatipoort, Morse and Robinson (1996a;1996b- in press) evaluated six cultivars and three densities ranging from 2 005 to 2 618 plants ha$^{-1}$. There was a significant interaction between cultivar and density with the optimum density for the smaller 'Dwarf Cavendish' and 'Chinese Cavendish' being established at 2 618 plants ha$^{-1}$ after three cycles. Optimum density for 'Grand Nain' (Israel and Central American selections) and 'Valery' was established at between 2 005 and 2 339 plants ha$^{-1}$, with the optimum for 'Williams' being at 2 005 plants ha$^{-1}$. In the same trial Robinson *et al.*(1990) and Morse and Robinson (1996a- in press) found that the hot climate at Komatipoort induced a faster leaf emergence with consequent faster cycling time than in the cooler Burgershall district. However, bunch mass in the cooler environment of Burgershall was considerably higher than in the hot area.

In a 'Williams' density trial on the south coast of KwaZulu-Natal, it was revealed that a density of 2 222 plants ha$^{-1}$ produced the highest average yield over five cycles (56.2 t ha$^{-1}$ an$^{-1}$) which was 11.7 % more than that at 1 666 plants ha$^{-1}$. In this case, the density of 2 222 plants ha$^{-1}$ also proved to be the optimum density in terms of economic returns (Robinson and Reynolds, 1985;1986; Robinson, 1993e). In a further small scale trial on the South Coast, 'Williams' bananas were compared at three densities ranging from 1 666 to 3 333 plants ha$^{-1}$. (Robinson and Reynolds, 1986). They again demonstrated that optimum returns were achieved at a density of 2 222 plants ha$^{-1}$.

There is a world-wide trend towards the use of higher densities in most horticultural crops. This has been induced by the ever-increasing capital requirements for land and development, with the resultant need to maximise returns from a unit area of land. The banana researcher has undoubtedly been under pressure to investigate this trend, with the consequence that many of the short duration trials, or those that have failed to take account of economic returns have presented a distorted viewpoint of the situation. From the results of the more credible trials it is obvious that lower densities often give the highest gross margins and ease of management. The need for density norms, based on more than just plant crop or P and R1, as evidenced by the review, is extremely important. It is also vital that norms incorporate an economic evaluation. Growers must then heed the recommendations for a specific locality and should not attempt to plant at a higher density.

### 1.6.5 Disadvantages of Non-Optimum Densities

According to Robinson (1993e; 1995a) planting too densely has a greater number of disadvantages than planting too sparsely. These are:-

1. Yield per annum becomes progressively lower as the plantation ages.
2. Harvest spread widens very quickly, thus crop timing potential is rapidly lost. The higher the density the quicker the loss.
3. As density increases, input costs per hectare rise due to increased use of planting material, props, bunch covers, fertilisers, nematicides and labour. Economic analysis must take this into account.
4. There is a progressive scarcity of healthy follower suckers at high density as the plantation ages. As a result, spatial arrangement can degenerate from a systematic to a random situation in which both accessibility and physiological efficiency are reduced.
5. Reduced plantation accessibility causes increased management problems.
6. Fruit on the distal hands may become undersized especially with dwarf cultivars.
7. Economic life span of the plantation is reduced.
8. Development of fungal diseases is promoted and control is more difficult.

Conversely, there are some disadvantages of planting too widely:

1. Bunches are larger which makes them more difficult to harvest and transport.
2. Greater sunlight penetration causes increased weed growth.
3. Wind penetration is easier, resulting in increased mechanical damage of leaves and fruit.
4. In areas with heat stress, evaporative water loss is increased and micro-climatic protection is reduced.

Robinson (1993e; 1995a) states that on balance, it is better to choose a density that is somewhat too low, rather than one that is somewhat too high. This merely serves to reinforce the dire need to establish optimum density norms at each and every production locality.

## 1.7 TISSUE CULTURE PLANT MATERIAL

The recent expansion of bananas on the North Coast of KwaZulu-Natal has been due, in part, to the ready availability of *in vitro* tissue cultured (TC) planting material. Many of the farmers converting from sugarcane to bananas have planted 10 to 30 ha over a 2 month period. Considering the large numbers of plant material required for such an operation, it is unlikely from a logistical and practical point of view, that this conversion could have taken place with the use of conventional suckers only.

### 1.7.1 Advantages of Tissue Culture Material

One of the biggest single advantages in using TC material is that the two major South African problems of panama wilt disease (*Fusarium oxysporum)* and burrowing nematode (*Radopholus similis*) cannot be transferred via the planting material (Robinson, 1993f ). This is especially important in a new production area such as the North Coast. There is widespread agreement that the potential benefits of using tissue culture material in combatting the spread of pests and disease are considerable ( Hwang *et al.*, 1984; Krikorian, 1989; Visser, 1994).

There is also similar agreement on the superior production potential of TC as compared to the use of conventional planting material. Hwang *et al.* (1984), Daniells (1988), Drew and Smith (1990), Robinson (1990b) and Robinson *et al.* (1993c) all reported an increase in plant crop bunch size when using T C material. This increase ranged from 2 % to 17 %. Robinson *et al.* (1993c) also reported a significant 6 % reduction in the plant crop cycle time when using large (500 mm) TC plants, giving an overall 20.4 % increase in yield an$^{-1}$ in favour of TC plants. Drew and Smith (1990 ), by comparison, reported less than a 3 reduction in the plant crop cycle time and no carry-through benefits to the R1. Robinson and Anderson (1991b;c) reported a 28.6 % higher annual plant crop yield per hectare with a January planting of 'Dwarf Cavendish' TC compared with conventional suckers. The overall percentage yield per annum increase of TC over conventional planting material in the R1 was 18.5 %. Tissue cultured plants reached flowering stage two weeks to a month earlier than suckers because they were established as undisturbed whole plants with several leaves present at planting. The benefits of using TC planting material are considerable and the need to use such material in the present series of trials became highly obvious. The trials, which form the basis of this research were all established from commercially-available TC plants.

# CHAPTER 2

# MATERIALS AND METHODS

## 2.1 LOCATION AND RESOURCES OF THE EXPERIMENTAL SITES

Due to the need to replicate trials in different Bioclimatic Groups, and the lack of formal research facilities in these respective areas, a decision was taken to conduct on-farm co-operative trials. Such trials are not regarded as ideal from a research point of view. However, the major benefit of such co-operative trials, from an extension viewpoint, is that whatever the results obtained, they would be perceived by the farming community as being that much more relevant. The trial sites could also be easily used for demonstration purposes and for dissemination of information pertinent to the trial as well as for highlighting general cultural practices. In a relatively new production area, the need for demonstration plots was regarded as essential. Consequently, farmers who are highly regarded as leading producers in their respective districts were approached for the purpose of establishing co-operative research trials on their farms. Each of the three fields selected were established to sugar cane which had to be destroyed and the fields re-established to bananas.

### 2.1.1 Mposa Site (± 20 km North-East of Empangeni)

Situated in Phillips' Bioclimatic Group 1, Mr Anthony Larsen of the farm Redcroft consented to the establishment of a randomised block, split plot banana cultivar/density trial. At latitude 28° 8' 0"S, longitude 32° 00' 38"E, and altitude 107 m, this site is situated on the transitional boundary between Wolstenholme's (1976) warm subtropical and hot subtropical zones. The average annual rainfall recorded on this farm over 43 years is 979 mm, with the main period of rain being from September to April. Rainfall averages approximately 50 mm in each of the four winter months (May to August). Temperatures for the nearest weather station at Empangeni are shown in Fig.1 and the respective heat units for Empangeni and Mtubatuba are shown in Table1. Long term evaporation averages 1 816 mm $an^{-1}$ and sunshine, 6.6 hrs $day^{-1}$. Phillips' (1973) "Geobioclimatic Groups" provides a broad ecological framework and has been used for many years as the official basis for agricultural planning in the KwaZulu-Natal Province. The subsequent ecological classification of Acocks (1975) is more widely referred to on a national basis and for the sake of reference this relates to Phillips as follows:-

| Phillips' Bioclimatic Groups | Acocks' Veld Types of S.A. |
|---|---|
| 1 - Coastal lowland | 1- Coast forest and thornveld |

Further refinements in classification by the Land Type Survey Staff (1988), Soil and Irrigation Research Institute, place the farm Redcroft in the Land Type Fb341a. Still further refinements in classification by the Dept of Agriculture, KwaZulu-Natal, place this farm in the Bioresource Unit Number 289 Empangeni Ya6 (Camp, 1995). The use of these BRU's will supercede the use of Phillips' Bioclimatic Groups in future agricultural planning in KwaZulu-Natal. Soils on the trial site are derived from basalt and are deep, red and well drained. They belong to the Vimy series of the Hutton form (MacVicar *et al.,* 1977) or according to the more recent classification, Hayfield family of the Hutton form ( Soil Classification Working Group, 1991).

Textural analysis of the top 300 mm revealed the following:-

| | | | |
|---|---|---|---|
| Clay (<0.002 mm) | ............... | 56 % | Textural Class |
| Fine Silt (0.002-0.02 mm) | ............... | 8 % | Clay |
| Coarse Silt and Sand (0.02 - 2 mm) | ............... | 35 % | |

Slope of the land ranges from 5 to 7 %.

Irrigation water is extracted from the Mbabe stream, a tributary of the Nseleni river.

### 2.1.2 Eshowe Site (± 5 km South-West of Eshowe)

Situated in Phillips' Bioclimatic Group 2, Mr James Stevenson of Woodgarth farm, agreed to the establishment of a similar trial to that at Mposa. At latitude 28° 50' 01"S, longitude 31° 25' 35"E and altitude 520 m, Woodgarth is situated in Wolstenholme's (1976) cool subtropical zone. The average annual long term rainfall recorded in the nearby town of Eshowe is 1 244 mm with most falling from September to April. Rainfall averages approximately 42 mm for each of the four winter months (May-August). Temperatures and heat units recorded by the Borough of Eshowe are shown in Fig. 1 and Table 1 respectively. Long term evaporation averages 1 726 mm an$^{-1}$ and sunshine, 6.6 hrs day$^{-1}$. This "Coastal Hinterland" after Phillips, relates to Acocks' number 5 - Ngongeni Veld. Land Type Survey Staff (1988) places Woodgarth in Land Type number

Aa4a. Camp (1995) places this farm in Bioresource Unit number 253 Eshowe Z61. Soils are derived from sandstone and are deep and well drained with a high humic content (± 4 % organic carbon). They belong to the Inanda series of the Inanda soil form (MacVicar *et al.*, 1977) or the Mayfield family, Inanda soil form (Soil Classification Working Group, 1991).

Textural analysis of the top 300 mm revealed the following:-

| | | Textural Class |
|---|---|---|
| Clay (<0.002 mm) | 30 % | Sandy Clay Loam |
| Fine Silt (0.002-0.02 mm) | 8 % | |
| Coarse Silt and Sand (0.02 - 2 mm) | 62 % | |

Slope of the land ranges from 3 to 5 %.

Irrigation water is extracted from farm catchment dams and boreholes.

### 2.1.3 Nkwaleni Site (± 35km West of Empangeni)

Situated in Phillips' Bioclimatic Group 10, Mr Dave McCarter of Bedhlane Farm agreed to the establishment of a trial similar to the other two sites. At latitude 28° 42' 39"S, longitude 31° 32' 58" E and altitude 189 m, Bedhlane is situated in Wolstenholme's warm subtropical zone. The average annual long term rainfall recorded on a nearby farm is 719 mm with most recorded from September to April. The average winter rainfall for the months of May-August is 20 mm per month. Temperatures and heat units are given in Fig.1 and Table 1 respectively. Long term evaporation averaged 1 807 mm an$^{-1}$ and sunshine, 7.4 hrs day$^{-1}$. Wind-run over 12 years averaged 98.6 km day$^{-1}$. This "Valley Bushveld" site according to Phillips (1973), relates to Acocks' (1975) number 23 - Valley Bushveld. The Land Type Survey Staff (1988) places Bedhlane in Land Type number Fb322a. Camp (1995) places this farm in Bioresource Unit No. 256 Nkwaleni Tua3. Soils belong to the Shortlands form, Richmond series (MacVicar *et al.*, 1977) or the Shortlands form, Sebati family (Soil Classification Working Group, 1991)and are derived from dolerite.

Textural analysis of the top 300 mm revealed the following:

| | | Textural Class |
|---|---|---|
| Clay (<0.002 mm) | 64 % | Clay |
| Fine Silt (0.002-0.02 mm) | 13 % | |
| Coarse Silt and Sand (0.02 - 2 mm) | 22 % | |

Slope of the land ranges from 8 to 12 %

Irrigation water is sourced from the Mhlatuze River downstream of the Goedertrouw Dam.

## 2.2 EXPERIMENTAL DESIGN

All three trials were identical and were laid out as randomised blocks with split plots.

For each trial, design particulars are as follows-:

MAIN PLOTS: CULTIVARS

1. 'Dwarf Cavendish' 2. 'Williams' 3. 'Grand Nain' 4. 'Valery' 5. 'Chinese Cavendish'

SUB-PLOTS : DENSITIES

a) 1 666 plants ha$^{-1}$ b) 2 105 plants ha$^{-1}$ c) 2 500 plants ha$^{-1}$

TOTAL NUMBER OF SUB-PLOTS

5 Cultivars x 3 Densities x 5 Replications = 75

NUMBER OF PLANTS PER SUB-PLOT

9 Data Plants + 16 Guard Plants = 25

TOTAL NUMBER OF DATA PLANTS

5 Cultivars x 3 Densities x 5 Replications x 9 plants sub plot$^{-1}$ = 675

TOTAL NUMBER OF PLANTS PER TRIAL

5 Cultivars x 3 Densities x 5 Replications x 25 plants sub plot$^{-1}$ = 1 875

TOTAL TRIAL AREA

= 9 218 m$^2$

Fig.2 gives a diagramatic representation of one cultivar main plot and three density sub-plots.

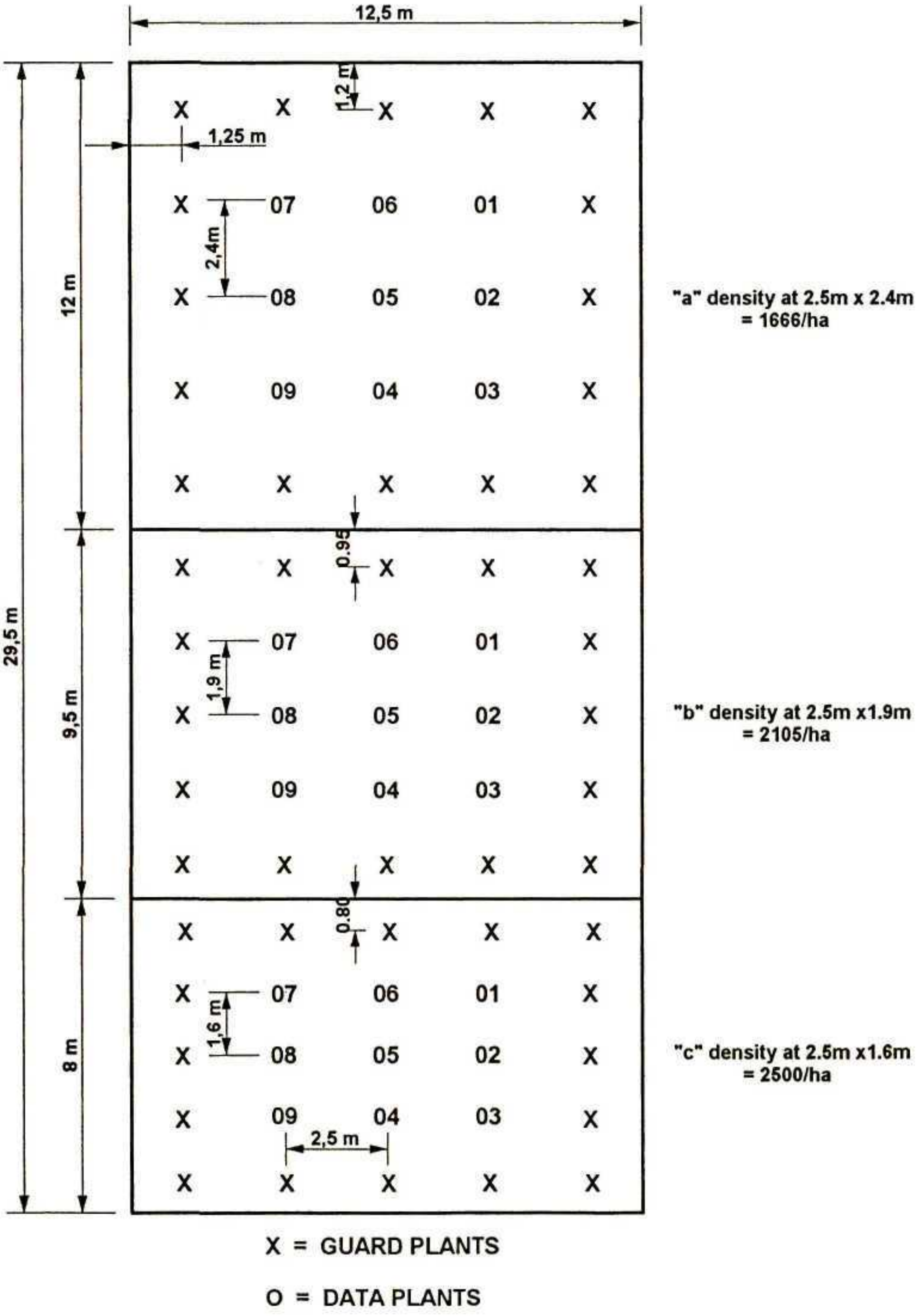
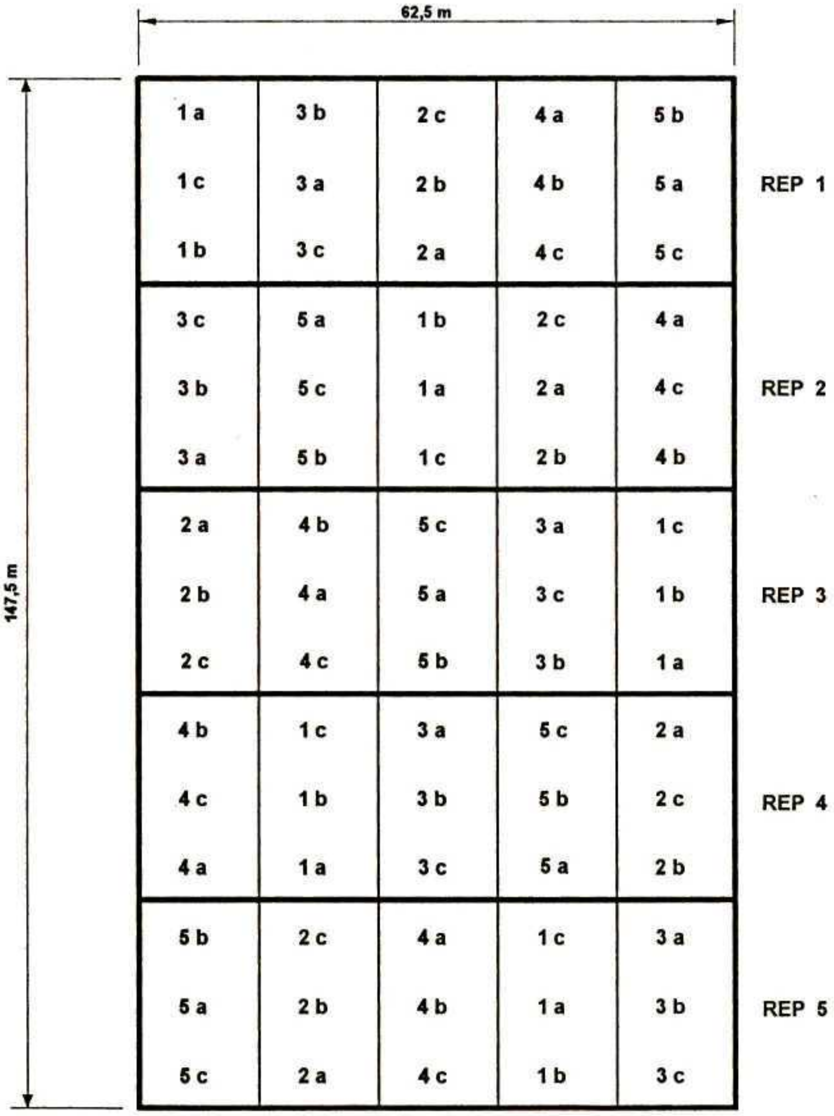


**Figure 2:** Diagrammatic representation of a single main plot (cultivars), with three sub-plots (densities). Sub-plots comprise 9 data plants and 16 guard plants.

A diagrammatic representation of the entire trial layout at Eshowe is shown in Fig.3. This standard design varied slightly at each of the three sites according to variations in topography. Randomisation of main and sub-plots can be clearly seen for each replication.



| | | | | | |
|---|---|---|---|---|---|
| 1 a | 3 b | 2 c | 4 a | 5 b | |
| 1 c | 3 a | 2 b | 4 b | 5 a | REP 1 |
| 1 b | 3 c | 2 a | 4 c | 5 c | |
| 3 c | 5 a | 1 b | 2 c | 4 a | |
| 3 b | 5 c | 1 a | 2 a | 4 c | REP 2 |
| 3 a | 5 b | 1 c | 2 b | 4 b | |
| 2 a | 4 b | 5 c | 3 a | 1 c | |
| 2 b | 4 a | 5 a | 3 c | 1 b | REP 3 |
| 2 c | 4 c | 5 b | 3 b | 1 a | |
| 4 b | 1 c | 3 a | 5 c | 2 a | |
| 4 c | 1 b | 3 b | 5 b | 2 c | REP 4 |
| 4 a | 1 a | 3 c | 5 a | 2 b | |
| 5 b | 2 c | 4 a | 1 c | 3 a | |
| 5 a | 2 b | 4 b | 1 a | 3 b | REP 5 |
| 5 c | 2 a | 4 c | 1 b | 3 c | |

**Figure 3:** Randomised layout of the entire experimental block at Eshowe. Main plots represent the five cultivars and sub-plots represent the three densities.

## 2.3 PLANTING DATES

Based on research to determine the influence of planting date on crop timing (Robinson and Alberts, 1983; Robinson and Nel, 1986a; Robinson, 1993g), planting dates were planned to allow for a compromise between maximum productivity and for harvesting during the traditionally high price period from autumn to early winter. Staggered plantings were also necessary in order to give full attention to each site at planting and immediately post-planting. Furthermore, because of climatic differences between the three sites, it was deemed necessary to split the planting dates and, based on the estimated cycle times for each site, the trials were established on the following dates:

| | |
|---|---|
| Eshowe | 16th December 1991 |
| Nkwaleni | 24th January 1992 |
| Mposa | 6th February 1992 |

Plant material was acquired from Valley Seedlings Nursery in Nkwaleni, in 2½ L bags. All plants were initially produced by means of *in vitro* mass propagation at Leeways Nursery in Mpumalanga. The dimensions of the plant material used are discussed in detail in section 3.1.1

## 2.4 STANDARD AGRONOMIC PRACTICES

### 2.4.1 Land Preparation and Planting

Pre-plant fertiliser applications took place two months before planting and recommendations (ITSC norms) were based on prior soil sampling and analysis. Normal recommended procedures for land preparation and planting of tissue culture material were used (Robinson, 1994) . Cultivation included a 0.6m deep ripping operation prior to ploughing . This was deemed necessary to eliminate any compaction layers that may have built up over the years of sugarcane production. The one deviation from the current norm for land preparation in KwaZulu-Natal was a lack of ridging. The trial layout required exact espacement between plants and rows and this was difficult to achieve in a ridged field. Plots and planting holes were marked out with the use of calibrated ropes and marking pegs. Since the soil was well tilled it was only necessary to open holes to the dimension of a spade. Due to the tendency for plant crop tissue culture plants to "climb" out of the ground, plants were established at least 100 mm below ground level.

## 2.4.2 Post Plant Management

### *2.4.2.1 Fertilisation*

a) Nitrogen - 100 g Limestone Ammonium Nitrate (28 %N) were applied to each plant, 4 to 6 weeks after establishment, and subsequently 40 g were applied monthly for eight months of the year (excluding May to August). These amounts were standard for each trial.

b) Potassium - Application rates were based on soil and leaf analyses (ITSC norms) for each site. In certain instances as much as 800 g Potassium Chloride per mat were applied. Potassium was applied in three split applications ( September, November and February).

c) Trace Elements - Zinc and boron. Young plants were sprayed at ± 1m height with Solubor @ 75 g $100L^{-1}$ water and Agrizinc @ 50 ml $100L^{-1}$ water.

d) Leaf and Soil Analysis. Samples were taken at the stage when approximately 50 % of the plants had flowered. Leaf samples were taken from plants on which the first hand of the bunch had just become visible. Samples were analysed annually at both Cedara and the ITSC at Nelspruit. Fertilisation for all subsequent crop cycles resulted from recommendations based on the sample analyses.

### *2.4.2.2 Mutations*

Young plants were checked regularly after planting for signs of mutation (somaclonal variations). Those that were identified early enough were replaced with spare plants that had been allowed to grow out in large bags. Unfortunately, not many mutations were identified at these early stages. Most of those that could be categorised as mosaic or extreme mosaic foliage variants only exhibited symptoms after the onset of winter stress by which time they were too large to be replaced (Plate 10). This experience contrasts significantly with the findings of Israeli *et al.*, (1991) who state that such variants are easily detected at the nursery stage when plants are only 250 to 300 mm tall. A single consignment of tissue culture plants was obtained from Leeways Nursery for all three trials. Logically the best plants were selected for the first planting at

Eshowe. This is reflected in the fact that only 12 (1.8 %) mutant data plants were found. The respective figures for Nkwaleni and Mposa were 2.7 % and 3.7 %. The frequency of off-types quoted by Reuveni *et al.* (1986), Pool and Irizarry (1987) and Stover (1987;1988) ranges from 9 to 25 %. On the other hand frequencies as low as 1 % have been quoted by Arias and Valverde (1987). Locally, Robinson and Nel (1989f) reported an average mutation rate of 1.76 % in a trial, and Robinson (1994) suggests an acceptable commercial norm of less than 2 %.

#### *2.4.2.3 Dead plants*

At the Eshowe site, five plants were replaced as a result of rhizome destruction by moles. This potentially serious danger was combatted by various mole repellants. At both the Nkwaleni and Mposa sites, extremely hot weather was encountered at planting time. Temperatures at Nkwaleni during the week of planting exceeded 40°C on five consecutive days. These extreme temperatures, coupled with the inability of the overhead sprinkler systems on the farm to provide water on a daily basis for leaf cooling, resulted in severe mortality. At Nkwaleni, 93 data plants (13.8 % of total) had to be replaced. This was carried out on the 5 March, 1992. At Mposa 78 data plants (11.5 % of total) were replaced on the 9 March, 1992.

#### *2.4.2.4 Weed control*

Weeds compete very effectively with TC plants because the latter have a strong root system but no rhizome. Therefore, a weakening of the root system through weed competition immediately weakens the whole plant. Consequently effective weed control was vital in the early establishment of healthy, vigorous plants. Hand hoeing was used until the plants were about 1m in height and thereafter chemical weedkillers such as "Paraquat" and "Glyphosate"were used.

#### *2.4.2.5 Pest Control*

Although the use of TC plant material effectively rules out the threat of transferring *Radopholus similis*, a very important pathogen of bananas (Schipke and Ramsey, 1994), other nematodes in the soil can seriously affect bananas. Rabie (1991) reported a close correlation between root-knot nematode (*Meloidogyne spp*) population and numbers of diseased plants. It is therefore vital that nematodes remain within acceptable threshold limits and to this end, root and soil samples were taken on an annual basis. These were analysed by E. Rabe of the ITSC at

Hluhluwe and control measures (15 g Temik matt$^{-1}$ in September and February) were applied when necessary. A pest common to all three trial sites was the yellow banana slug (*Urocyclus flavescens*). Control was effected via the use of baits as well as by weed control. A particularly vexing and somewhat unique pest on bananas was the grey coffee snout beetle which only occurred at the Eshowe site. Damage was recognised by the brown corky blemish on the banana peel, which is very similar to that left by slugs. Control was effected by eliminating the bordering Napier Fodder, which acted as a host plant, and by the use of various non-registered pesticides. No pesticide is registered for the control of this pest on bananas. Pest damage on fruit resulted in some downgrading, but there was no discernable influence on actual production.

#### *2.4.2.6 De-suckering and Sucker Selection*

Tissue culture plants produce suckers from an early age and if the latter are left unchecked the competitive inhibition of yield potential can be highly significant (Robinson and Nel, 1990). For this reason, suckers were cut off at ground level until the mother plant was approximately 1 m high. The sectoral sucker selection technique (Eckstein and Robinson,1993) for plant crop bananas was followed. The author believed it was important to complete sucker selection before the onset of winter, and this was therefore carried out at the end of May 1992, four to five months after planting. Robinson *et al.* (1994a) concluded that early sucker selection (4 months after planting) on TC material was not competitive with the productivity potential of the parent plant. Subsequent ratoon sucker selection consisted of selecting the first sucker to appear in the correct position on the previous mother plant.

#### *2.4.2.7 Irrigation*

The intention was to design an accurate and reliable irrigation schedule based on:-

a) The water holding capacity of the soil.
b) An effective root-zone of 400 mm
c) A maximum water depletion of 33 %
d) A crop factor of 0.9 in summer and 0.5 in winter.

However, a serious drought, which commenced soon after planting, and continued for four consecutive growing seasons, thwarted any attempt at optimally controlling irrigation water. In practice, there were major constraints on the availability of irrigation water and this precious resource was applied as and when it became available, at a rate of 30-40 mm week$^{-1}$ in summer. The crop cycle and locality most affected by insufficient irrigation water was the R2 at the Mposa site where a significant decline in yield was experienced. The annual rainfall at Redcroft in 1992, 1993 and 1994, represented only 52 %, 78 % and 68 % of the long term average, resulting in a severe reduction of runoff into streams and dams. An extremely poor distribution of rainfall actually received, compounded the situation.

## 2.5 DATA CAPTURE

### 2.5.1 Weather Data

Full weather stations were established at each trial site by the Agricultural Research Council's Institute for Soil, Climate and Water (ISCW) These comprised equipment to record maximum and minimum temperatures, relative humidity, rainfall, wind run and evaporation. The intention was to establish correlations between weather conditions experienced at the different sites and the productivity achieved. However, the conditions of drought meant that the trials were not functioning optimally, and such correlations could therefore not be considered. In addition, the farmers concerned experienced difficulty in maintaining an acceptable degree of data capture and the ISCW withdrew the weather stations after two seasons:

### 2.5.2 Experimental Data

The following data were recorded for each data plant on all three crop cycles at all three localities, unless otherwise specified.

1. Date of planting.
2. Height of plant material, measured from ground level to the axis of the two youngest leaves.
3. Circumference of plant material measured at 100 mm above ground level.
4. Leaf emergence rate. Five randomly selected plants per plot were recorded on a monthly basis.
5. Date of flowering.
6. Plant height at flowering.
7. Pseudostem circumference at flowering. Measurements were taken 300 mm

above ground level.

8. Number of functional leaves at flowering.
9. Date of bunch harvest.
10. Bunch mass (kg).
11. Stalk mass (kg).
12. Mass of third hand.
13. Number of fingers on third hand.
14. Length of fingers on third hand.
15. Number of hands on each bunch.
16. Number of functional leaves at harvest.
17. Leaf area measurements at harvest (length and width). Measurements were conducted on two randomly selected plants from each sub plot.
18. Internal pseudostem temperature in the R2 cycle. The temperatures of two randomly selected plants of the 'Grand Nain' cultivar were taken at hourly intervals from 6 am to 6 pm, at each density and replication, on a sunny summer day at Nkwaleni.

All data captured were averaged to provide means for each treatment, and combinations of treatments.

## 2.6 ANALYSIS OF RESULTS

All data presented in chapter three were analysed using the Genstat 5, release 3.1 system of Rothamsted Experimental Station on an IBM compatible Personal Computer at the Cedara headquarters for the Department of Agriculture, KwaZulu-Natal. Analysis of variance was conducted for each treatment at each site. Comparisons between sites could not be statistically analysed. Data and computer programs as well as results not presented in this manuscript, are presented in Appendix Disks attached. Graphs were drawn using the Quatro Pro 6.0 graphics programme on a Pentium Personal Computer and printed on a Hewlett Packard (HP) Deskjet 850C Printer. The manuscript was typed using the word processing programme, Word Prefect 6.1 and printed on the HP, as well as a Brother Laserjet .

### 2.6.1 Morphological Criteria

Morphological differences between cultivars were evaluated by measurements of pseudostem height from soil level to the neck of the inflorescence axis, pseudo-stem circumference 300 mm above soil level at flowering stage, leaf length, leaf width and functional leaf number present at flowering. From these data two indices were calculated, *viz.* the pseudostem index (height ÷ circumference), and leaf area index (leaf area per plant divided by ground area.) Leaf area was calculated from the formula: L x W x 0.83, in which L = lamina length, W = width of the lamina at it's widest point (Summerville, 1944) and 0.83 an adjustment factor for leaf area according to Robinson and Nel (1985). Mean maximum leaf area per plant was calculated from mean area per leaf x number of functional leaves at flower emergence. LAI was then calculated from leaf area per plant ÷ ground area per plant.

### 2.6.2 Phenological Criteria

Phenological evaluation comprised monthly leaf emergence rate measurements on five randomly selected data plants from each sub-plot. These data, coupled with total leaf production per plant enabled theoretical vegetative cycles to be estimated. Recording of harvest dates permitted the mean harvest to harvest cycle intervals to be calculated for each cultivar/cycle combination. Analysis of flowering and harvest dates relative to season indicated the effect of season on the duration of time from emergence to harvest. Models were established to predict harvest date from flower emergence date.

### 2.6.3 Yield Criteria

Components of yield analysis comprised measurements of bunch mass at a finger maturity of three-quarters round, number of hands per bunch and number of fingers and their length on the third hand from the proximal end. The mass of every data bunch was recorded for each cultivar/density combination. Gross yield per ha was calculated from mean bunch mass multiplied by the number of plants per hectare. Productivity (annual yield per hectare) was computed as yield per hectare ÷ cycle duration x 365 days. In the plant crop cycle duration was from planting to plant crop harvest, whereas in the first ratoon this was from the mean P harvest to mean R1 harvest and so on.

### 2.6.4 Gross Margin Analysis

Economic analyses consisted of the determination of the gross margin for each of the main treatments as well as the interaction between cultivars and densities. Fruit production was determined by deducting the stalk mass from the bunch mass for each identifier. This figure was reduced by a nominal factor of 10 % to represent wastage. The average Durban market price for bananas over the period, May 1995 to April 1996, was assigned to the fruit produced to establish the gross income. Costs were assigned to every production, harvesting and packing related operation and deducted from the gross income. In addition, all marketing related costs and interest on operating capital were deducted to arrive at the gross margin. For detail on all income and costs pertaining to the gross margin analyses, refer to appendix 5.

### 2.6.5 Micro-Climatic Criteria

Internal pseudostem temperatures were recorded on a clear, sunny day in March 1995, during the R2 cycle at Nkwaleni. Pseudostem temperatures were measured over a diurnal cycle commencing 6 am and ending 6 pm, to investigate the temperature reductions due to increase in density. Hourly measurements were taken on ten selected plants, at each density, by means of a thermometer equipped with a thermo-probe, which was inserted 40 mm deep into the pseudostem one metre above ground level on the northern side of the plant.

## 2.7 COLOUR PLATES

Colour Plates, depicting various features of interest at the different trial sites, have been included in the following pages. Due to the cost of reproduction, these Plates have not been interspersed throughout the document, and as such, they do not appear in the section that is appropriate to that particular feature.

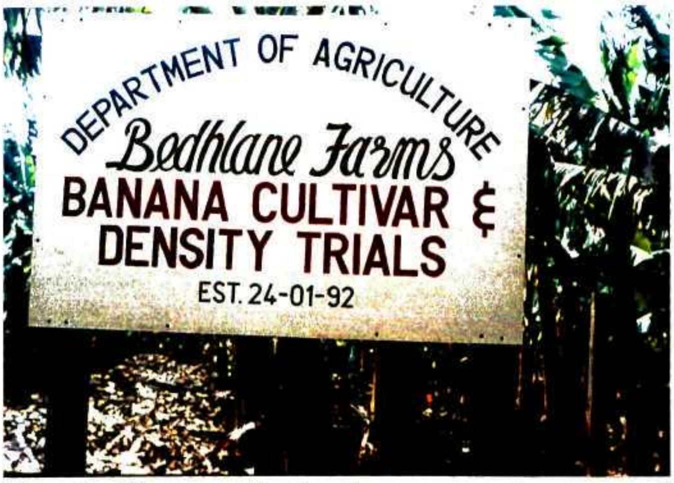


**Plate 1:** Signage reflecting the co - operative nature of the trial and date of establishment.

**Plate 2:** Paint markers on the base of the leaf petiole, reflecting monthly leaf emergence counts .

**Plate 3:** An example of a well developed, yet immature bunch, with a large number of well spaced hands .

**Plate 4:** Tissue culture plant crop reflecting uniformity of vegetative development.

**Plate 5:** A recently emerged bunch exhibiting good spacing between hands.

**Plate 6:** An example of severe "choke throat", with the bunch bursting through the pseudostem of a 'Williams' plant at the cool Eshowe site.

**Plate 7:** A 'Valery' bunch with the neck of the inflorescence at over 4m above ground level. Note the metal bunch marker.

**Plate 8:** A uniform stand of well developed bunches. Notice the double propping!

**Plate 9:** Mosaic, or "leather leaf" foliage variant, induced by somaclonal variation through *in vitro* propagation. A fairly common variant.

**Plate 10:** A tissue culture plant with normal lower leaves and young "leather leaves" induced by the onset of winter. An unusual phenomenon.

**Plate 11:** A 'Dwarf Cavendish' giant somaclonal variation - a somewhat rare variant.

**Plate 12:** Bunches from "leather leaf" variants with very small fingers. On the left is a bunch from 'Williams' and on the right one from 'Dwarf Cavendish'.

# CHAPTER 3

# RESULTS AND DISCUSSION

The most important results are presented below in the form of Figures and Tables. However, due to the sheer volume of data collected, not all these data have been presented. Data not presented here are accessible in the appendices attached in 1.44 MB disc form. The author felt it necessary to present the most important data in simple graphic form, using the same format and layout for each identifier. Consequently bar graphs have been used, where possible, to illustrate trends for the three cropping cycles at each site plus cumulative averages for each site. Cumulative averages have also been compared between sites, although these could not be statistically compared. Each identifier is therefore presented, in most instances, in the form of four bar graph Figures. In an effort to facilitate easy appraisal of the four Figures, these have been presented on the same page for every identifier and in certain instances the author has accordingly been compelled to leave blank spaces . The page margins in this chapter have also been reduced in order to accommodate the four Figures. Although there has been an attempt to maintain the same spacing between Figures this has not always been possible, due to the need to present all four Figures on one page. Figures are also somewhat on the small side, which has been necessary to present all of the most important data in graphic form. Results are presented and where possible, discussed in detail under that section. In many instances, a number of identifiers are interrelated and while there has been an effort to provide a detailed discussion for each specific section, one should refer to the chapter "Overall Discussion and Conclusions" for an overall impression.

A digression from the norm is the presentation of a brief summary of the method, prior to the presentation of the results. The author considers that an encapsulation of this summary, together with the results and discussion under each section, facilitates easier understanding of that identifier. Further digressions pertain to the use of certain terminology. The term "cumulative average" has been used in place of "mean" throughout this chapter. This is due to the fact that the data for each crop cycle have been annualised (reduced) prior to the calculation of an average. The author has also used the term "finger" instead of "fruit". The use of both of these terms is fairly commonplace in banana literature.
There are three distinct sections. The main plots deal with cultivar effects, and the sub-plots with density effects. The third section, which in many respects is the most important, deals with the cultivar/density interactions at each of the three sites.

## 3.1 CULTIVARS

The five cultivars planted, *viz.* 'Dwarf Cavendish', 'Williams', 'Grand Nain', 'Valery' and 'Chinese Cavendish', constituted the main plots of this trial. Each cultivar plot was split into three density sub-plots of 1 666, 2 105 and 2 500 plants $ha^{-1}$ and was therefore evaluated over an average density of 2 090 plants $ha^{-1}$. In this section, cultivar means are presented over all densities.

### 3.1.1 Morphological Results

Morphological variation between banana cultivars can be substantial. Karamura and Karamura (1995) indicate that cultivated banana varieties vary in height from 2 to 8 m and that some wild species may be from 10 to 15 m tall. Robinson *et al.* (1993a) highlighted the genetic diversity within the Cavendish subgroup by illustrating their morphological differences. These morphological differences are the most easily distinguishable features separating cultivars and rate as very important when determining the ideal cultivar selection.

#### *3.1.1.1 Plant Material Index*

The plant material index was established by measuring the height and stem circumference of every data plant at establishment. The diameter of the plant was then calculated by using the formula:-

$D = \text{circumference} \div \pi$. The index was calculated by dividing the plant height by its diameter. Results are summarised in Fig. 4.

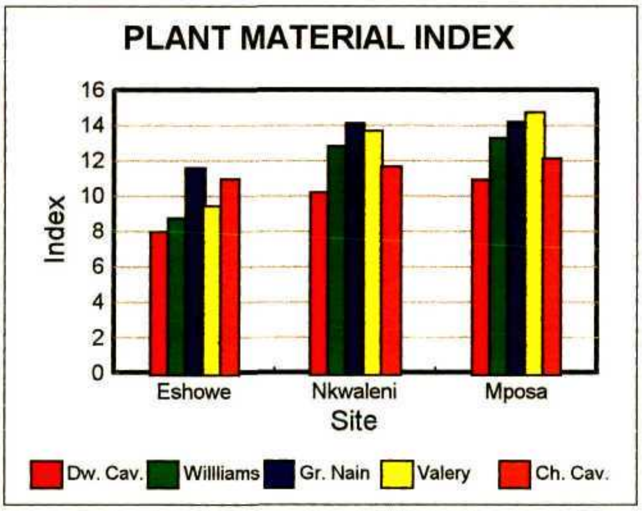


**Figure 4.** Morphological proportions (Height ÷ Diameter) of tissue culture banana plant material used at the three trial sites of Eshowe Nkwaleni and Mposa.

All the planting material used at both Nkwaleni and Mposa was regarded as being too tall and lanky, with proportions exceeding the ideal ratio of 10:1 (Fig. 4). Although 'Grand Nain' and 'Chinese Cavendish' were the only cultivars to marginally exceed this ratio at the Eshowe site, all cultivars exceeded this ratio at the other two sites with 'Grand Nain' in fact exceeding a ratio of 14:1 at Nkwaleni, and both 'Grand Nain' and 'Valery' exceeding 14:1 at Mposa. Of interest, is that with the later plantings, plant material dimensions of the different cultivars had begun to display a ranking order similar to that experienced for cultivar height at flowering (Fig 5). Pseudostem breakage as a result of wind damage was excessive at both sites. At the Mposa site each plant was physically propped by three stakes, in an attempt to prevent pseudostem breakage.

The importance of establishing plants of optimum height and morphological proportions has been illustrated by Robinson (1994) and Eckstein *et al.* (1996). Robinson (1994) stated that the pseudostem height-to-base diameter ratio at planting should not exceed 10:1. In other words, plants should not be allowed to become too tall in relation to their base diameter. Plants that are potbound in bags that are too small and held in the nursery for too long, tend to become lanky and etiolated. Although the plants in question were planted in 2½ L bags, the same consignment of plants was used at all three sites, with planting dates ranging from mid-December 1991 to early February 1992. Consequently the plants used for the trials planted later on became too tall and, as they were not re-potted into larger bags, the dimensions (Fig.4) exceeded that recommended by Robinson (1994). Average plant height was: Eshowe - 280 mm, Nkwaleni - 500 mm and Mposa - 510 mm. Eckstein *et al.* (1996) illustrated that optimum plant height was 200 to 300 mm. They experienced slightly reduced yields with heights of 500 mm. Robinson (1990b) however, experienced no difference in the annual yields between plants of 200 and 500 mm height at planting.

Planting in December/January/February is regarded as optimal in terms of maximising autumn/early winter yields for maximum profits. Robinson and Nel (1986a) and Robinson and Anderson (1991c) illustrated that this period of planting resulted in the optimum compromise between good yields and high prices achieved. The earlier December planting date was deemed necessary to achieve this optimum at the cooler Eshowe site, with progressive delays at the warmer sites being necessary to maximise early winter harvests. These delays resulted in the plants becoming potbound and lanky.

### *3.1.1.2 Plant Height*

Height rates as one of the most important morphological features used in differentiating between cultivars. As stated earlier, the ideal banana for the subtropics should have a short, sturdy pseudostem which simplifies management and provides it with stability against strong winds (Robinson, 1993h). The height of every data plant was measured from soil level to the neck of the inflorescence axis at the stage of inflorescence emergence. Results are summarised in Fig. 5.

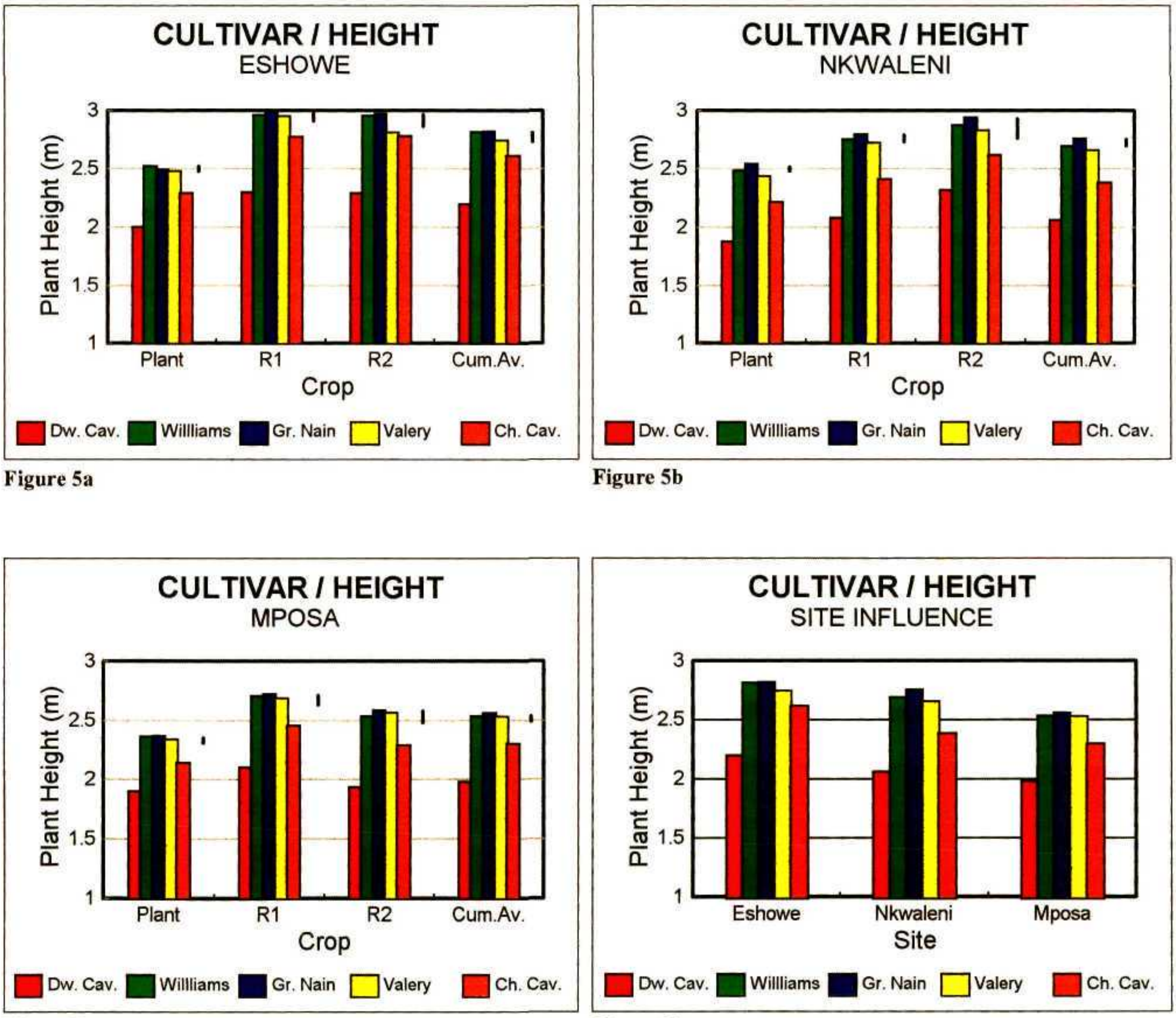


**Figure 5a**

**Figure 5b**

**Figure 5c**

**Figure 5d**

**Figure 5:** Pseudostem height (m) of five cultivars over three crop cycles, at three sites, with the respective cumulative averages at each site compared. Vertical bars represent LSD at P = 0.05.

The relative heights of the five cultivars evaluated remained much the same at the three different sites with 'Dwarf Cavendish' being the shortest, and 'Grand Nain' on average the tallest. 'Valery' was consistently shorter than both 'Williams' and 'Grand Nain' yet significantly taller than 'Chinese Cavendish' (Fig.5). With the exception of the R2 at Mposa, pseudostem height increased progressively with increase in plantation age. The relative heights of the cultivars tested conflict greatly with trials conducted in the tropics. Stover (1982) attributed greater production from 'Grand Nain' to the fact that it was 780 mm shorter than 'Valery' in Honduras and 930 to 980 mm shorter in Panama. The shorter height resulted in fewer wind losses than those from'Valery'. Pool (1984) also established that 'Valery' grown in Puerto Rico was taller than both 'Ziv' ('Williams') and 'Grand Nain'. On average 'Valery' was 300 mm taller than 'Grand Nain'. 'Dwarf Cavendish' was the shortest in the trial of Pool and in most other international trials. Simmonds (1954), Stover and Simmonds (1987) and Stover (1988) all found 'Valery' to be significantly taller than 'Grand Nain', with 'Williams' being intermediate between the two.

South African banana trials have varied somewhat in terms of relative cultivar heights . In a trial over four cycles at Burgershall , Robinson *et al.* (1993a) found that 'Valery' was slightly taller than 'Williams', which in turn was taller than 'Grand Nain', followed by 'Chinese Cavendish' and 'Dwarf Cavendish' respectively. These relationships are in keeping with international trends. At Levubu and on the KwaZulu-Natal South Coast, Robinson *et al.* (1994c) found that the relative order of the three taller cultivars varied slightly from that at Burgershall. In all local trials 'Dwarf Cavendish' has been the shortest with 'Chinese Cavendish' intermediate between that and the three taller 'Grand Nain','Williams' and 'Valery' cultivars. At Komatipoort, Morse and Robinson (1996a - in press) established the same relative pseudostem heights as experienced on the North Coast of KwaZulu-Natal, *viz.* 'Grand Nain' (CA) was tallest, followed in descending order by 'Williams', then 'Valery', which were all significantly taller than 'Chinese Cavendish' which, in turn, was significantly taller than 'Dwarf Cavendish'.

The cooler site of Eshowe produced the tallest plants, with a progressive reduction in height relative to an increase in heat units at Nkwaleni and Mposa (Fig. 5d). In comparing the production potential between the relatively cool Burgershall site to the relatively hot Komatipoort site, Robinson *et al.* (1990) reasoned that the temperatures at Burgershall would favour assimilation, plant growth and bunch size whereas the Komatipoort climate would favour leaf production rate and cycle time rather than growth. Based on height alone, 'Dwarf Cavendish' should rate as the most suitable cultivar for all three trial sites. However, other unsuitable characteristics such as "choke throat", particularly at the Eshowe site, short finger length, and tapered bunch shape mitigate against its unilateral acceptance.

### *3.1.1.3 Pseudostem Index*

The Physical stability of a plant is a function of height relative to girth, hence the importance of the pseudostem index in assessing a plant's ability to withstand strong winds. The greater the index the less stable the plant and *vice versa.*

Measurements were taken of the pseudostem height, as outlined above (3.1.1.2) and the pseudostem circumference (Table 2) 300 mm above soil level at flowering stage. The pseudostem index was then calculated by dividing the height by the circumference of every data plant. Results are summarised in Fig.6.

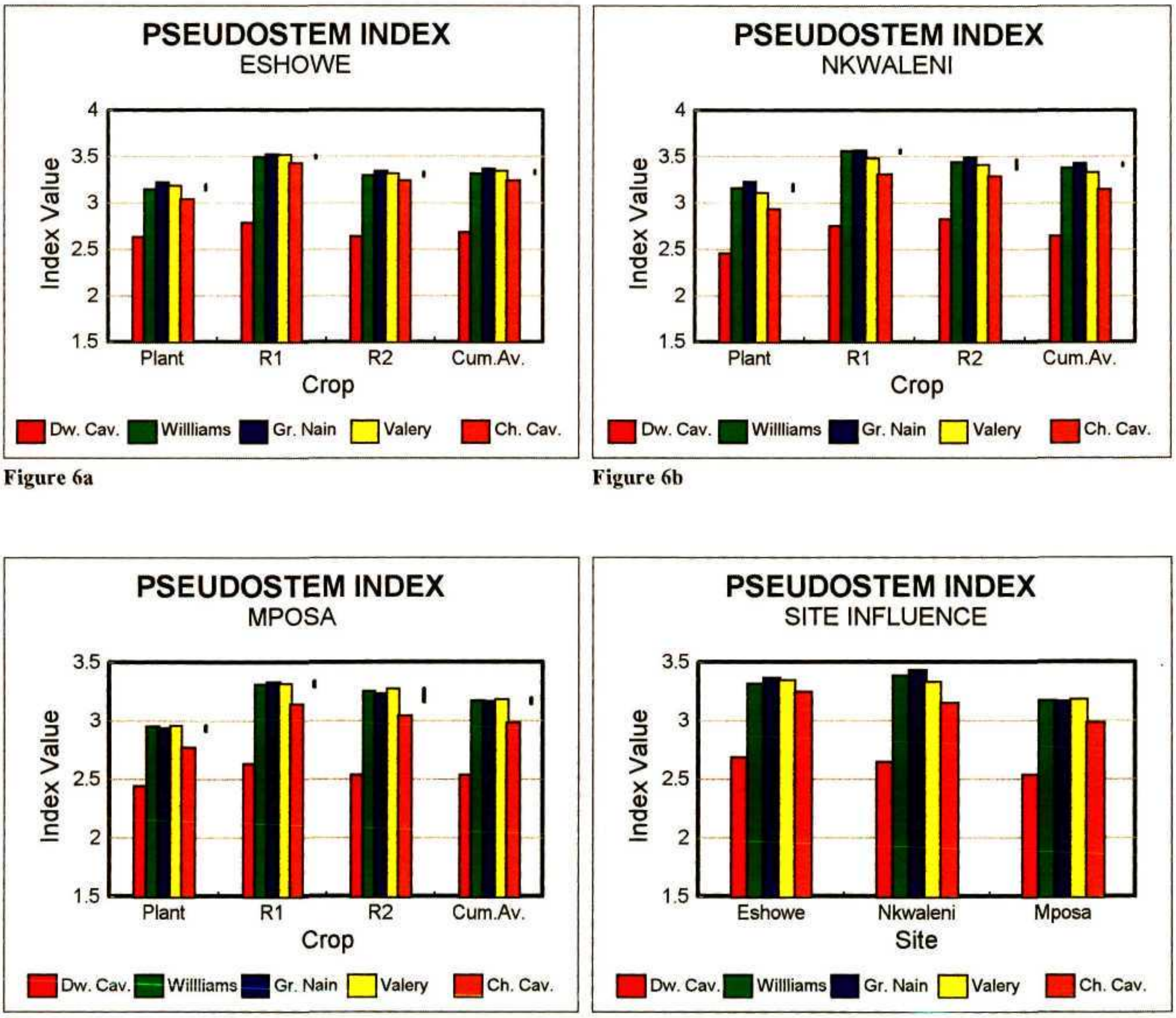


**Figure 6a**

**Figure 6b**

**Figure 6c**

**Figure 6d**

**Figure 6:** Pseudostem index (height ÷ circumference at flowering) of five cultivars over three crop cycles at three sites, with the respective cumulative averages at each site compared. Vertical bars represent LSD at P = 0.05

The cultivar ranking order was identical (Fig. 6) to that experienced for cultivar height (Fig.5), with 'Dwarf Cavendish' having the lowest index and 'Grand Nain' the highest at all sites, except Mposa, where 'Valery' had the highest index. 'Dwarf Cavendish' was significantly shorter than 'Chinese Cavendish' in all three cycles at all three sites, whereas the circumference of 'Dwarf Cavendish' was greater than that of 'Chinese Cavendish' in all crop cycles and sites (Table 2), giving 'Dwarf Cavendish' a much better (lower) pseudostem index (Fig.6). This clearly indicates that 'Dwarf Cavendish' is the most stable of all the cultivars tested and other factors being equal, this cultivar should experience fewer losses as a result of wind damage.

It is evident from Table 2 that, despite significant differences, pseudostem circumferences were fairly similar between cultivars. Height therefore had the greatest effect on pseudostem index and consequently on plant stability. These findings concur with those of Robinson *et al.* (1993a) and Morse and Robinson (1996a- in press), who state that plant stability against wind appears to be directly related to pseudostem height rather than stem circumference. Robinson *et al.* (1993a) recorded more windfalls and bunch losses with the tall 'Poyo' than with any other cultivars. The increased stability of shorter cultivars such as 'Dwarf Cavendish' can result, not only in reduced bunch losses from wind damage, but also in reduced plantation costs due, *inter alia,* to the requirement for shorter propping poles than that of the taller cultivars.

**Table 2 : The cumulative average pseudostem circumference (mm) of 5 cultivars over 3 crop cycles, at three sites.**

| CULTIVAR | ESHOWE | NKWALENI | MPOSA |
|---|---|---|---|
| 'Dwarf Cavendish' | 818.2 | 779.9 | 780.9 |
| 'Williams' | 848.1 | 796.0 | 799.3 |
| 'Grand Nain' | 837.6 | 804.9 | 808.0 |
| 'Valery' | 821.2 | 797.9 | 795.2 |
| 'Chinese Cavendish' | 806.9 | 757.1 | 770.0 |
| LSD (P = 0.05) | 21.9 | 19.8 | 22.7 |

### *3.1.1.4 Leaf Area Index*

Leaf measurements were made at harvest on all leaves of two randomly selected plants from each treatment. Measurements were conducted in the P and R1 cycles at all sites and also in the R2 at Nkwaleni. Results are summarised in Fig. 7.

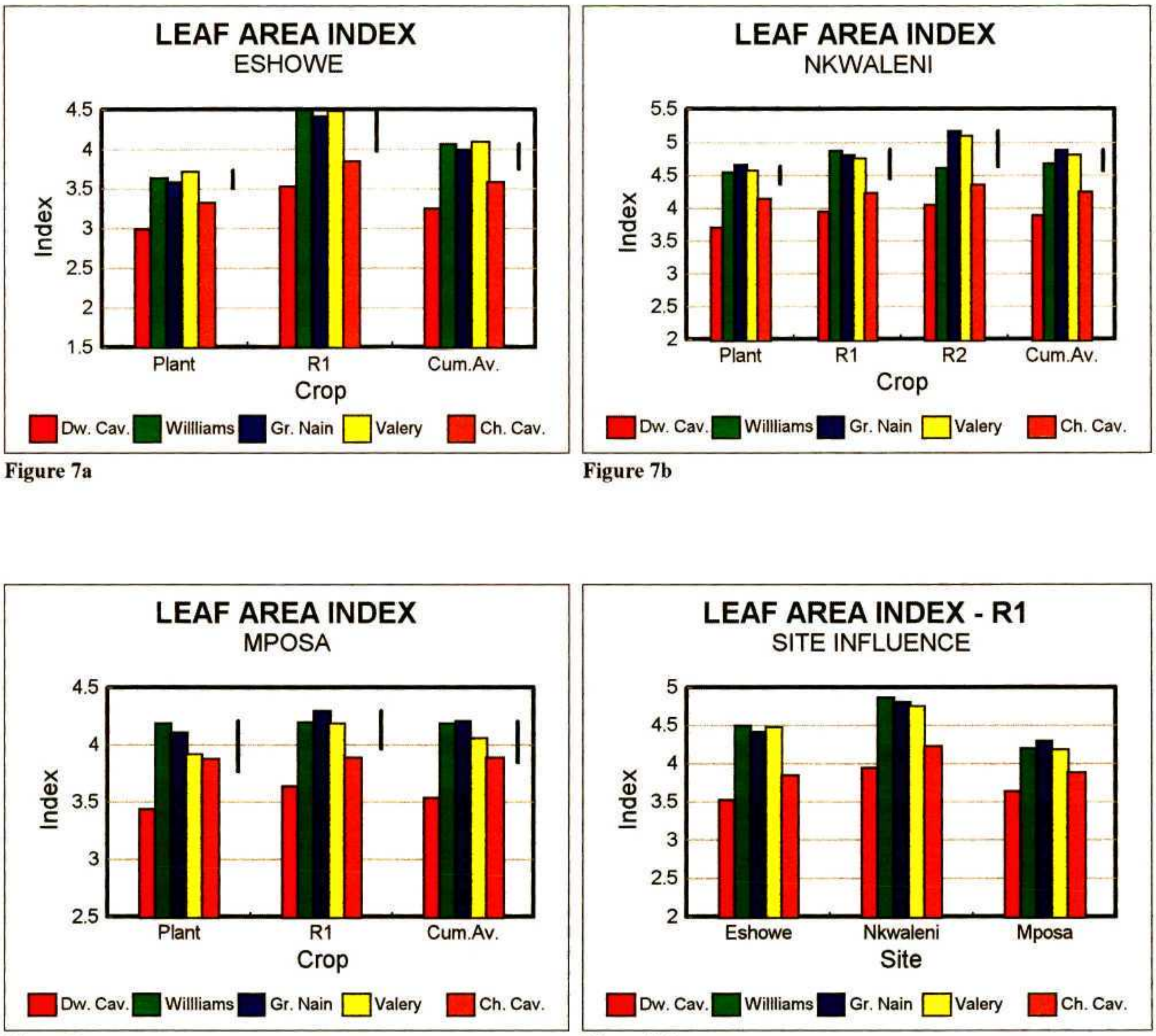


**Figure 7a**

**Figure 7b**

**Figure 7c**

**Figure 7d**

**Figure 7:** Maximum leaf area index (L x W x O.83 x number of functional leaves at flowering ÷ ground area) of five cultivars over two/three crop cycles at three sites. Sites are compared on the R1 LAI. Vertical bars represent LSD at $P = 0.05$.

An increase in LAI was measured for each cropping cycle at each of the three sites (Fig.7). The relative performance of each cultivar in terms of LAI was almost exactly the same as the relative rating of each cultivar for pseudostem height (Fig.5). Morse and Robinson (1996a - in press ) found a strong correlation between plant height and leaf length, indicating that as plant height increases so the LAI increases for a given density provided leaf number is constant. The average LAI per locality, over all cultivars and densities in the R1 was: Eshowe - 4.16, Nkwaleni - 4.52, Mposa - 4.04. Differences between cultivars ranged from 4.5 ('Williams') to 3.5 ('Dwarf Cavendish') at Eshowe; 5.2 ('Grand Nain') to 4.1 ('Dwarf Cavendish') at Nkwaleni and 4.3 ('Grand Nain') to 3.6 ('Dwarf Cavendish') at Mposa.

Stover (1982; 1984), Robinson and Nel (1988b) and Robinson (1995a) have illustrated the importance of planting at a density that reflects optimum LAI, in order to obtain maximum production per ha. Turner (1982) maintained that a transmitted radiation through the leaf canopy of 10 %, was obtained from a plantation with an LAI of 4.0 and contended that 4.5 was optimum. Robinson and Nel (1989b) achieved maximum productivity with an LAI of 6 but recommended an LAI of about 5 if optimum production and maximum gross margin was to be achieved and maintained. This "optimum" was achieved with 'Williams' at 1666 plants ha$^{-1}$ at Burgershall.

The significant difference in LAI between cultivars indicates that the more compact cultivars such as 'Dwarf ' and 'Chinese Cavendish' should be planted at a higher density in order to achieve the same LAI as the taller cultivars. Assuming uniform plantation vigour, density compensation would be the only measure available to allow for an equal transmission of photosynthetically active radiation through canopies of cultivars with inherently different leaf area production potential. Theoretically they would then have similar production potential. Robinson and Nel (1989b) stated that as plant stature differs between cultivars and according to soil type, management, locality and water supply, it is logical that yield potential should be related to canopy characteristics rather than to density *per se*. Robinson (1996) added another dimension by stating that in general, plantations of high vigour and consequently larger plants with a greater LAI, can have a lower density for optimal gross margin. It is evident that cultivar LAI is but one of many factors that have to be considered in determining the optimum density for a particular plantation (refer to planting densities in section 3.2).

### 3.1.2 Phenological Results

"Phenology" refers to the vegetative and reproductive development cycles of a plant as determined by climate, in particular temperature, and forms an important component of the productivity of a particular cultivar.

#### *3.1.2.1 Leaf Emergence Rate (LER)*

New leaf emergence was recorded on a monthly basis on five data plants for each treatment combination, for the duration of the three cropping cycles at the three sites. Due to the lack of significant differences between cultivars on a monthly evaluation (see also Table 3) it was decided (Robinson - pers. comm., ITSC, Nelspruit) to combine the leaf emergence data for all cultivars and rather reflect the seasonal and crop cycle differences. Results are summarised in Fig. 8.

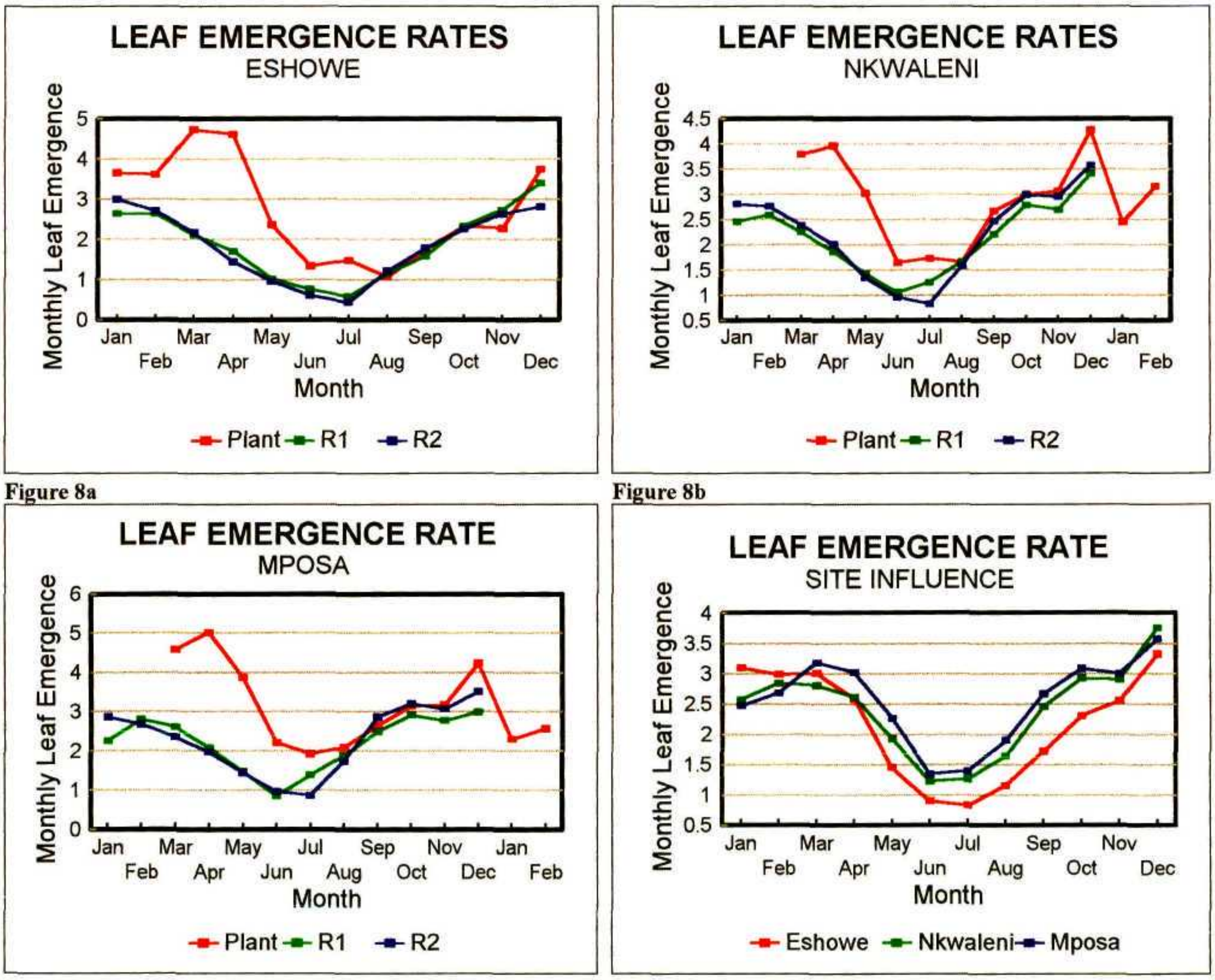


**Figure 8a**

**Figure 8b**

**Figure 8c**

**Figure 8d**

**Figure 8:** Leaf emergence rate (combined average of 5 cultivars) over three crop cycles at three sites, with the cumulative averages at each site compared.

By way of explanation: establishment at Eshowe took place in December, and the January and February LER of 3.6 leaves month$^{-1}$ includes the LER of the same month but in the latter part of the vegetative cycle, when plant ontogeny resulted in a drastic reduction in LER. Champion (1963), Barker (1969) and Lassoudiere (1978b) all demonstrated the effect of plant ontogeny on the reduced rate of appearance of new leaves. At both Nkwaleni and Mposa, where planting took place at the end of January and beginning of February respectively, LER recordings commenced in March. There is also an overlap of data at the beginning as well as the end of the plant line-graph, due to the long plant crop cycle.

The influence of season (temperature) is reflected in the LER of all crop cycles at all three sites (Fig.8). At the cooler site of Eshowe, leaf emergence dropped to less than half a leaf per month in the R2 in July. The corresponding LER in January was 7 times greater. The relative difference at Nkwaleni was a factor of 4.4 and at Mposa it was four times greater in summer. The explanation lies in the fact that the banana is a tropical lowland plant requiring uniformly warm and humid conditions for optimum growth and production. According to Turner and Lahav (1983) and Robinson and Anderson (1991a), the optimum mean temperature for developmental processes (leaf emergence) is about 31°C. At all three sites, LER in the R2 was below 1 leaf per month in June and July, with Eshowe also recording less than one leaf in May. This was due to the fact that mean minimum temperatures during this period were largely sub-optimum for development. The small amount of development recorded during this period was due to the mean maxima which are in excess of 23°C at Nkwaleni and Mposa and ± 21°C at Eshowe. Reference is to long term means (Fig.1). Mean maximum temperatures were not a limiting factor since they generally lie within the optimum range of 23-30°C. Robinson (1981) showed a highly significant correlation between monthly LER and mean monthly minimum temperature recorded at Burgershall during the period August 1975 to June 1978. Kuhne *et al.* (1973) recorded similar correlations between LER and monthly mean temperature. Robinson and Nel (1989a) further illustrated the effect of season on plant development by recording a leaf area increment that was 35 times greater in summer than in winter.

The association of leaf emergence to temperature has been demonstrated by numerous other researchers world-wide. Various models have been devised to estimate the rate of leaf production and these all use daily temperature as the basis for their calculation (Allen *et al.*,1988; Mekwatanakarn and Turner, 1989). The site influence in Fig. 8d clearly illustrates the overall lower leaf emergence rate at the cooler Eshowe site, with progressively greater emergence rates at the warmer Nkwaleni site and the hot Mposa site. These data reflect the temperature difference shown in Fig. 1. Drought effects are evident in that LER's seldom exceeded 4 in the hot summer months. Another important feature to consider is the very high LER of the tissue culture plant crop at all three sites, particularly during the first half of the crop cycle. This illustrates the significant development potential of tissue culture plants, particularly during the first few months of growth, when management should accordingly be optimal to benefit from this.

While Fig. 8 deals with the seasonal effect on leaf production, Table 3 illustrates the effect of cultivar and site on the annual LER, averaged over three crop cycles.

**Table 3. Cumulative Average Annual Leaf Production : Eshowe, Nkwaleni and Mposa**

| Cultivar | Eshowe | Nkwaleni | Mposa |
|---|---|---|---|
| 'Dwarf Cavendish' | 26.72 | 30.27 | 30.96 |
| 'Williams' | 25.50 | 29.46 | 30.58 |
| 'Grand Nain' | 25.93 | 29.16 | 30.33 |
| 'Valery' | 25.89 | 29.33 | 30.54 |
| 'Chinese Cavendish' | 26.46 | 30.44 | 31.12 |
| LSD ($P = 0.05$) | n.s. | 0.67 | n.s. |

Although there were very few significant differences between the monthly LER of the different cultivars over the full trial period at the three sites, Table 3 illustrates the somewhat greater rate of annual leaf production from 'Chinese' and 'Dwarf Cavendish' at all sites, with a significantly greater difference at Nkwaleni. Coupled with the relatively low total leaf production of 'Chinese Cavendish', in particular during the R1 and R2 at all sites (Fig. 9), the resultant quick cycling of 'Chinese Cavendish' is a natural corollary. Morse and Robinson (1996a - in press) also found that 'Dwarf' and 'Chinese Cavendish' had an overall faster leaf emergence than other Cavendish cultivars in the hot Komatipoort locality. Robinson *et al.* (1993a) on the other hand, found that 'Chinese Cavendish' and 'Grand Nain' exhibited both faster leaf emergence, as well as fewer total leaves than the other cultivars considered, in the cool Burgershall area. In their trial 'Dwarf Cavendish' had both slower leaf emergence and a greater number of leaves, suggesting a lack of adaptability of this cultivar to cooler subtropical sites. This phenomenon was again evident in the present trials (see 3.1.2.2 for total leaf numbers).

### *3.1.2.2 Total Leaf Production*

The number of new leaves produced were totalled on a monthly basis until flower emergence, on five data plants per subplot. In the case of the plant crop, the total number of leaves at planting-out-stage was counted and added to the cumulative total of the monthly counts. Strictly speaking, this is a morphological feature, yet has been dealt with in this section due to its close association with leaf emergence rate and vegetative cycle time. Results are summarised in Fig. 9.

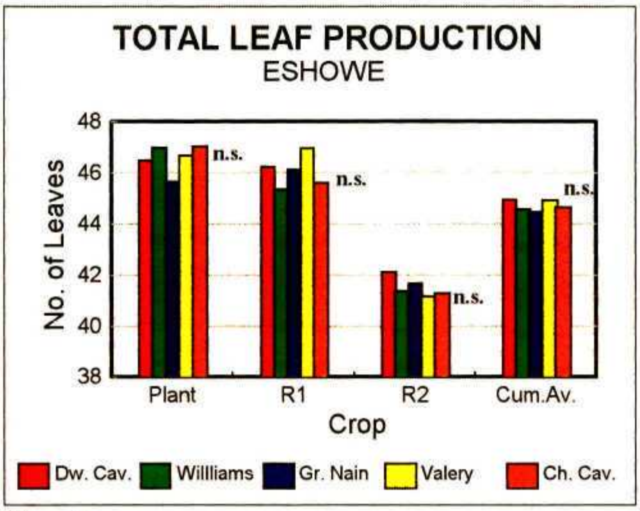


**Figure 9a**

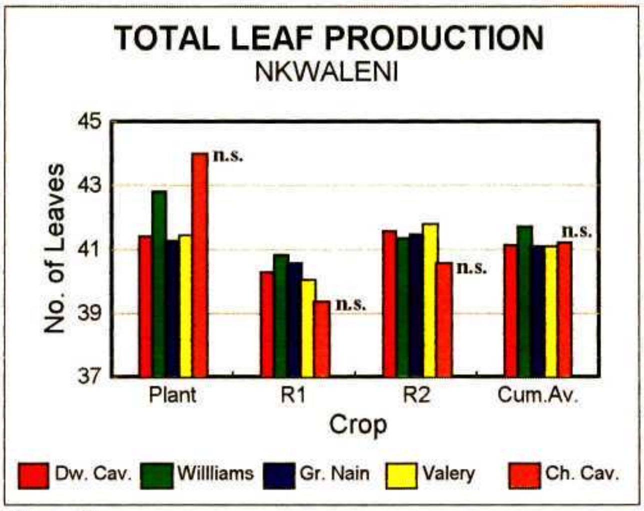


**Figure 9b**

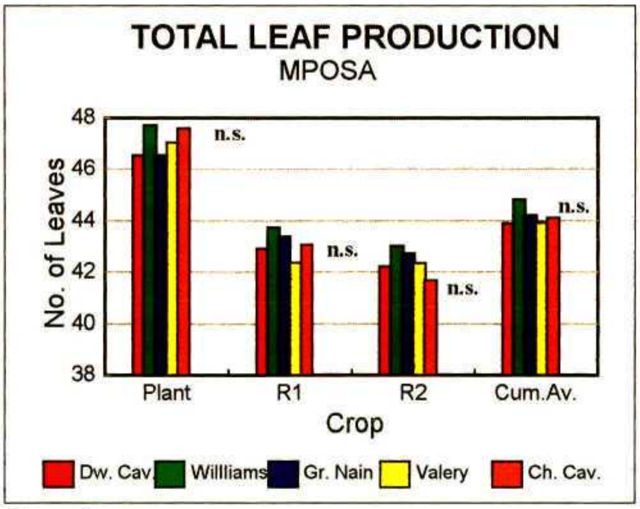


**Figure 9c**

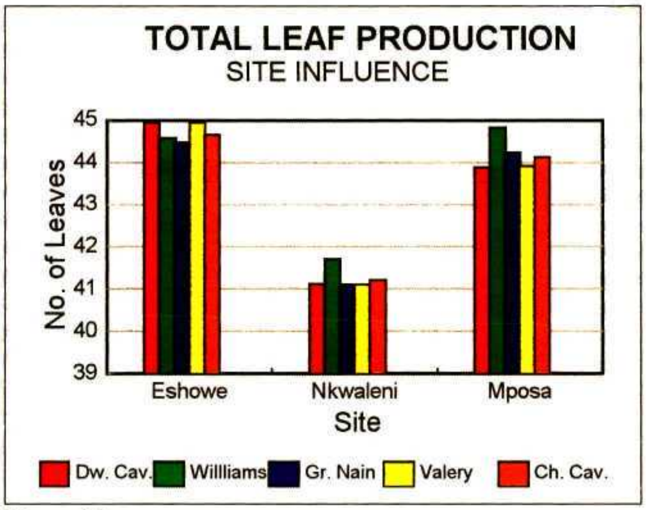


**Figure 9d**

**Figure 9:** Total leaf production of five cultivars over three crop cycles at three sites, with the respective cumulative averages at each site compared. n.s. represents LSD at P = 0.05

Although there were no significant differences between cultivars with regard to total leaf production, trends were observed between cropping cycles as well as between sites (Fig. 9). At all sites the plant crop produced more leaves than the R1 cycle. The Eshowe average was P - 46.6, R1 - 45.5; for Nkwaleni the average was P - 42.2 , R1- 40.2; and for Mposa : P - 47.1 and R1 - 43.1. This phenomenon may best be explained by Robinson (1989;1990b) who compared tissue culture and conventional plant material and found that TC plants produced 6 to7 more leaves than suckers. In reality tissue culture plants are established with a number of leaves already present at planting. This number varied from 8 to 10 at the three trial sites. At Eshowe and Mposa, there was a further reduction in total leaf production from the R1 to the R2, whereas at Nkwaleni there was an increase from the R1 to the R2. Robinson *et al.* (1993a) similarly, found that total leaf production increased from the R1 to the R2 due to compensation for increased levels of canopy competition between the R1 and R2.

The total number of leaves produced prior to bunch emergence may vary quite substantially (Turner, 1970). After reviewing the values presented by other authors, Simmonds (1966) estimated that as many as 60-70 leaves could be produced before bunch emergence. Oppenheimer (1960) illustrated the variation in total leaf production by pointing out that a rhizome planted in Israel may produce 33 leaves if initiation takes place before winter. If, on the other hand, initiation takes place after winter, the vegetative phase will be prolonged and 38-46 leaves are produced. This illustrates how time of planting can affect the total number of leaves produced and consequently, the cycle duration. Working with 'Grand Nain' in Honduras, Stover (1979) determined that depending on the time of peeper sucker emergence during the season, leaf production could vary from 39 to 44 leaves. These seasonal variations can quite easily account for the differences obtained, both between crop cycles as well as between the three sites. There was a major difference in total leaf production between sites with the cooler Eshowe site producing more leaves than the hotter Mposa site. Both these sites produced significantly more leaves than the Nkwaleni site (Fig. 9d).

Regarding cultivar characteristics, a short vegetative cycle is highly desirable and this is enhanced by either fewer leaves, or a faster rate of leaf emergence. Total leaf production cannot be considered in isolation and any evaluation must also take cognisance of leaf emergence rate. It is apparent that after a large number of leaves were produced in the plant crop, 'Chinese Cavendish' experienced a reduced leaf production in succeeding ratoons, relative to other cultivars. This genetic advantage, coupled to its faster rate of leaf emergence, causes the shortened cycle duration recorded for this cultivar, as also shown by other authors (Robinson, *et al.* 1993a; Morse and Robinson, 1996a - in press).

### *3.1.2.3 Bunch Emergence-to-Harvest (E-H) Cycle Models*

The dates of inflorescence emergence and the respective harvest date were recorded for every data plant over three cropping cycles and three sites. A mean flower emergence to harvest interval was calculated for 24 flowering periods of 15 days each. Regression analysis was applied and a practical crop forecasting model produced for each cultivar, density and site. Only where there are signs of significant differences have models been presented in this section. Results are summarised in Fig. 10.

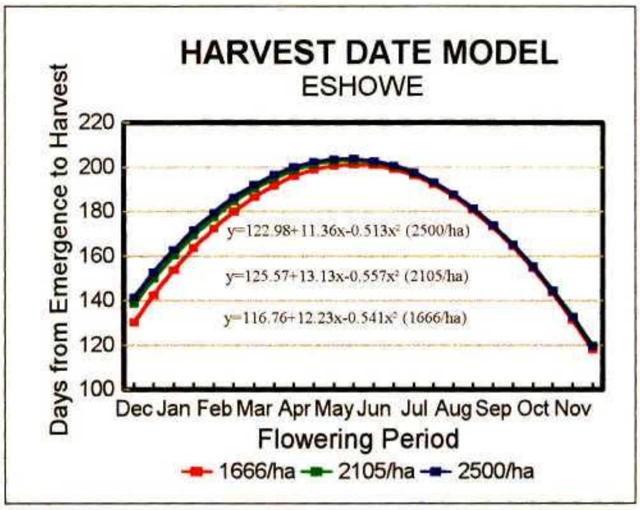


**Figure 10a**

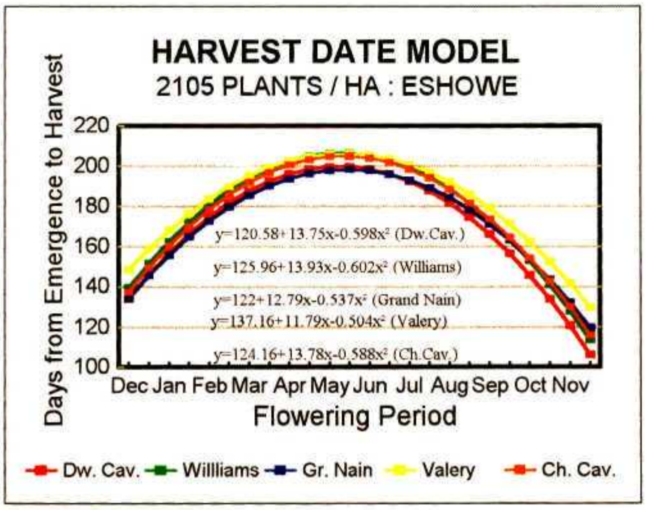


**Figure 10b**

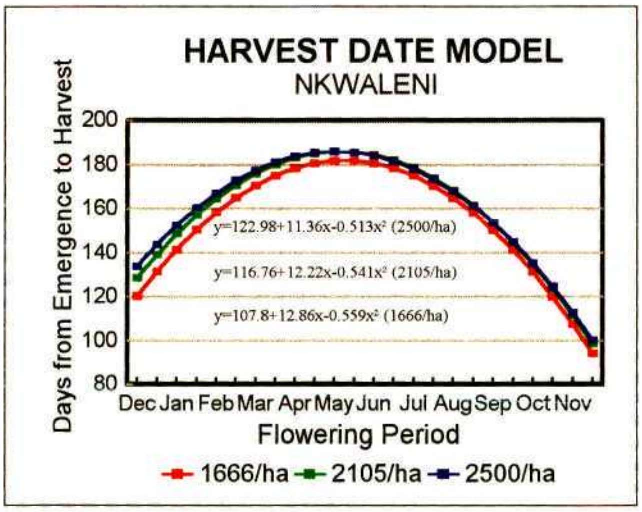


**Figure 10c**

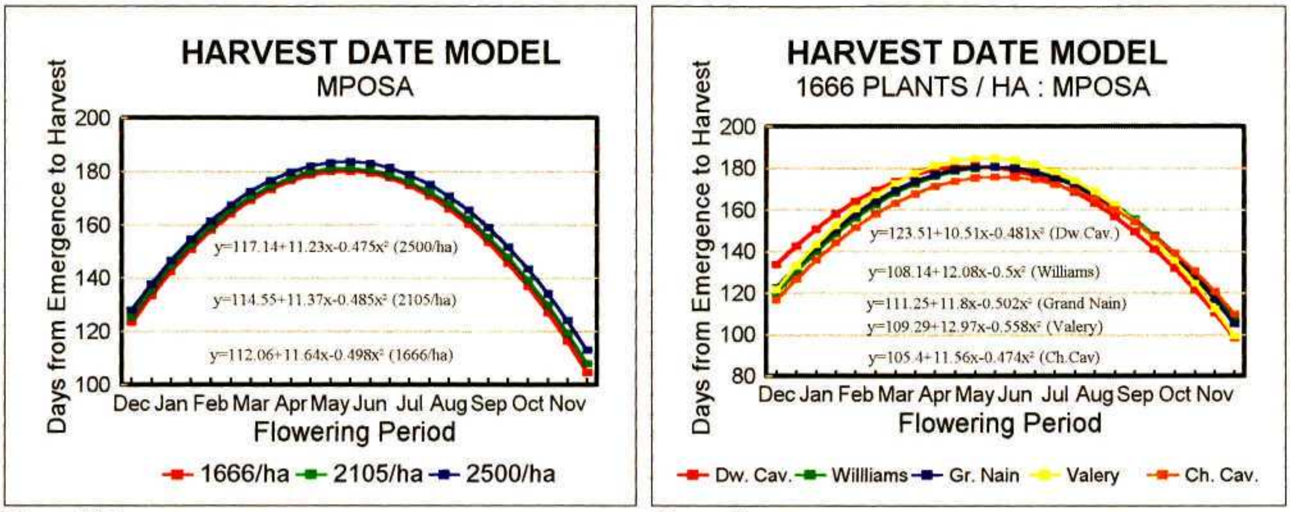


**Figure 10d**

**Figure 10e**

**Figure 10:** Effect of flowering period on length of time from bunch emergence to harvest for three densities and three sites. Cultivar differences, where close to significant, have been analysed separately. All three crop cycles are combined and the year is split into 15 day periods commencing 1st December. Regression analysis equations are quoted.

In all instances cultivar differences were non-significant (Fig 10). However, in the case of Eshowe, at 2 105 plants ha$^{-1}$ (Fig.10b) and Mposa, at 1 666 plants ha$^{-1}$ (Fig.10e), cultivar responses were only just non-significant. Separate cultivar models were formulated in those specific instances.

The effect of season on E-H interval was substantial (Fig 10). At Eshowe, the E-H interval at 1 666 plants ha$^{-1}$ for an end of November bunch emergence averaged 118 days, whereas the respective interval for a May emergence at 2 500 plants ha$^{-1}$ was 204 days. Differences between densities, although significant, were not marked. The effect of site on E-H interval is also substantial. Using the same comparison as above, but at Mposa, the respective intervals were 105 days for flowering at the end of November and 184 days at the end of May (Fig.10d). This is substantiated by the results obtained by Kuhne (1978),who demonstrated that E-H data differ between different areas. Robinson & Nel (1985) demonstrated differences between 'Williams' and 'Dwarf Cavendish' which were not really in evidence in the trials conducted on the North Coast, with the exception of those differences already mentioned.

Under tropical conditions, temperatures are uniformly high and the E-H interval is both short and consistent throughout the year. In Honduras, Stover (1979) recorded E-H intervals of 98 days and 117 days for April and October flowering respectively. In subtropical climates there is much evidence of a close correlation between banana fruit development and prevailing temperatures (Kuhne *et al.,* 1973;

Israeli and Lahav, 1986; Robinson and Human, 1988). The E-H interval differs greatly according to whether flowers emerge prior to winter or in summer. At Burgershall, Robinson (1981) recorded an E-H of 118 days for November emergence and 204 days for April flowering. Kuhne (1980b) recorded respective intervals of 113 and 212 days for the same periods of emergence at the same site. It is evident from the results presented and literature reviewed that the duration and seasonal variation of E-H in the subtropics differ greatly from the relatively uniform data presented by Stover (1979) for the tropics.

The concept of heat units is another method of illustrating the effect of temperature on fruit development. Studies by Robinson (1992) showed that an average of 1000 heat units or "degree days" above 14° C were required to develop a 'Williams' banana bunch from emergence to harvest maturity (range 950 to 1050). The range of heat units required is relatively constant in the subtropics irrespective of flower date, but only about 100 days are required to accumulate them over summer, compared with about 200 days over winter.

Forecasting banana supplies (harvesting) is an important priority for producers as well as for marketing organisations. The harvest data models created above will be extremely useful management tools for producers on the North Coast. The only requirement is for the producer to conduct flower counts every 15 days and, coupled to an estimate of average bunch mass, such producer will be in a position to forecast monthly production levels up to seven months in advance.

There will undoubtedly be variations to the models provided due to a number of factors. Variation in monthly heat units from year to year will be one such obvious factor. Other factors relate to the vigour of the crop, susceptibility to bunch fall or leaf shred from wind damage, soil type and general management and, perhaps most importantly, the extent to which evapotranspiration needs are met by rainfall and irrigation.

### *3.1.2.4 Crop Cycle Intervals*

In addition to the bunch mass produced per ha, the crop cycle interval is one of the most important components of productivity (t $ha^{-1}$ $an^{-1}$). The date of planting and the harvest date of every plant was recorded to provide the average planting-to-harvest interval. The harvest date of successive crops was related to the previous harvest date for each plant and averaged to provide a harvest-to-harvest interval. Results are summarised in Fig.11.

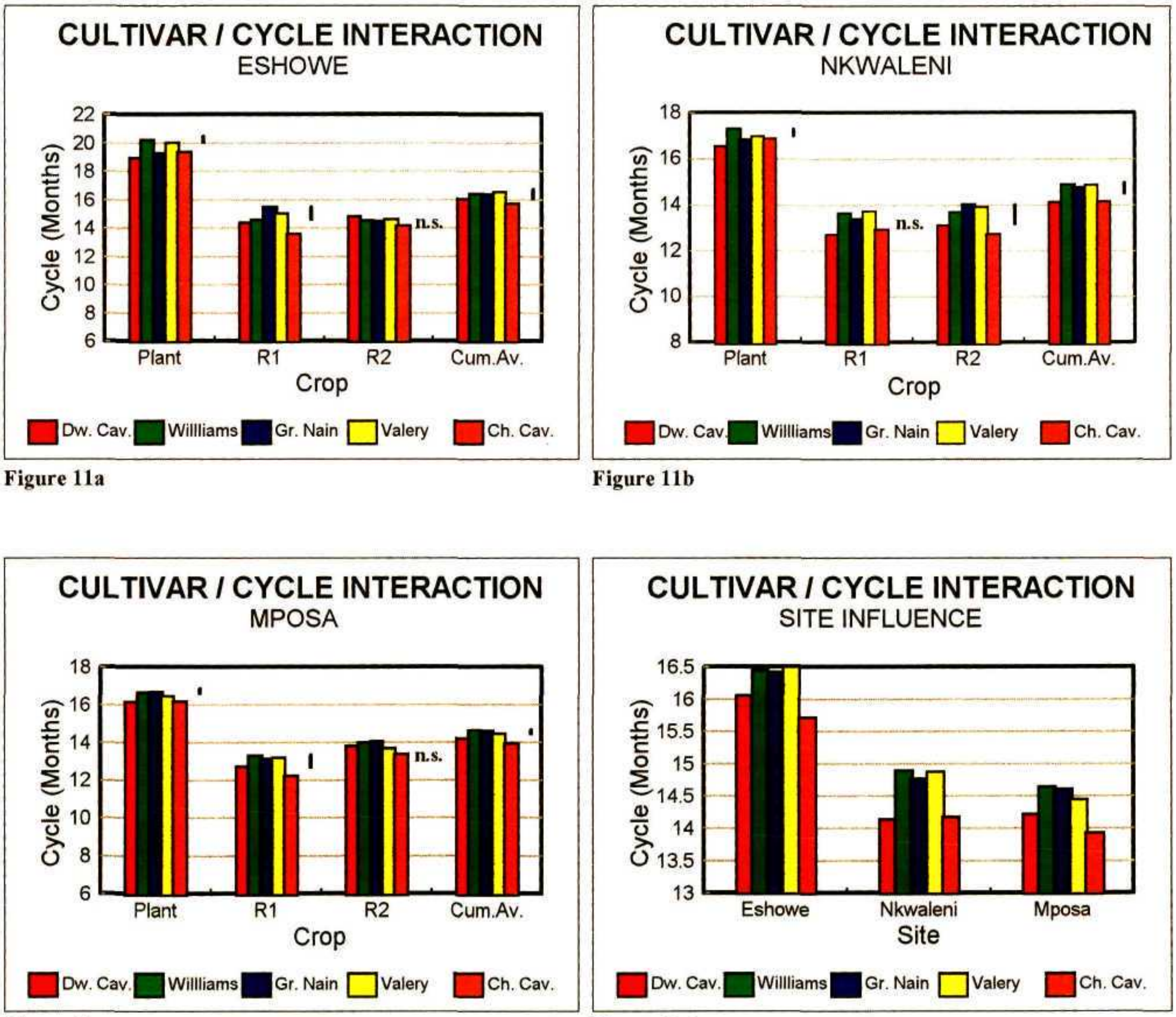


**Figure 11a**

**Figure 11b**

**Figure 11c**

**Figure 11d**

**Figure 11:** Plant-to-harvest and harvest-to-harvest intervals (months) of five cultivars over three crop cycles at three sites, with the respective cumulative averages at each site compared. Vertical bars represent LSD at P = 0.05 and n.s. represents non-significance.

The cycle intervals of different cultivars were significantly different in two out of the three crop cycles at all three sites (Fig.11). The cumulative average over three cycles was also significantly different at all three sites with 'Chinese Cavendish' having the shortest average cycle at both Eshowe (15.8 months) and Mposa (13.9 months) and only slightly longer (14.2 months) than 'Dwarf Cavendish' at Nkwaleni. On average 'Williams' had the longest cycle time at both Mposa (14.6 months) and Nkwaleni (14.9 months) with 'Valery' being slightly longer at Eshowe (16.5 months). This corresponds with the greater total leaf production of these two cultivars at the different sites (Fig.9).

Turner (1970) states that the rate of appearance of new leaves is a measure of the progression of the plant towards maturity. When combined with the total number of leaves to be produced it can give an estimate of the time to bunch emergence for any given planting date. Turner (1995) states that temperature has a profound influence on the rate of appearance of new leaves, which increases 10-fold from 13° to 28°C. Since floral initiation in bananas is not directly related to temperature or photoperiod (Turner, 1970), but probably a readiness to flower as determined by total leaf number (Barker and Steward, 1962; Champion, 1963), the LER and total leaf number directly affect cycle time and therefore annual yield potential of bananas.

The plant crop cycle appeared to be far longer than each of the two successive ratoons at all three sites. This is a normal phenomenon because the ratoon cycles are based on the harvest date of the previous crop to the harvest date of the succeeding crop and not from the date of sucker selection to harvest. When measuring from sucker selection to harvest, Robinson and Nel (1985) found that ratoon crop cycles were actually longer than that of the plant crop. A plant crop cycle could theoretically be reduced slightly by planting earlier in the season (Robinson and Alberts, 1983),but for strategic marketing reasons, planting dates were chosen to allow for harvesting during early winter of the following year, resulting in a slight extension of cycle time. As expected, the cycle times of all crops at Eshowe were far longer than those at Nkwaleni, which in turn were longer than those at Mposa. The reasons for this have been elucidated under section 3.1.2.1, which deals with leaf emergence rates. Crop cycle interval is one of the most important components of productivity and a short cycle is greatly desired. The vegetative cycle is influenced by the total number of leaves produced as well as by the leaf emergence rate. The bunch emergence-to-harvest interval is the reproductive component of crop cycle time and is dealt with in section 3.1.2.3. There were no significant differences between cultivars with regard to the E-H interval, which contrasts somewhat with the findings of Robinson and Nel (1985).

### 3.1.3 Yield Components

Where morphological considerations are important to the producer from a practical point of view such as propping requirements and density selection, the yield components, coupled to the cycling of a particular cultivar, determine the productivity and consequently the profitability of that cultivar. Yield components include bunch mass, the "harvest index" and finger length.

#### *3.1.3.1 Bunch Mass*

Bunches were harvested from every data plant at a commercial finger maturity of ¾ round and were weighed on an electronic scale to an accuracy of 0.02 kg. Data were averaged to provide the bunch mass for each cultivar, crop cycle and site. Bunch mass included the "stalk", but not the "bell". Results are summarised in Fig. 12.

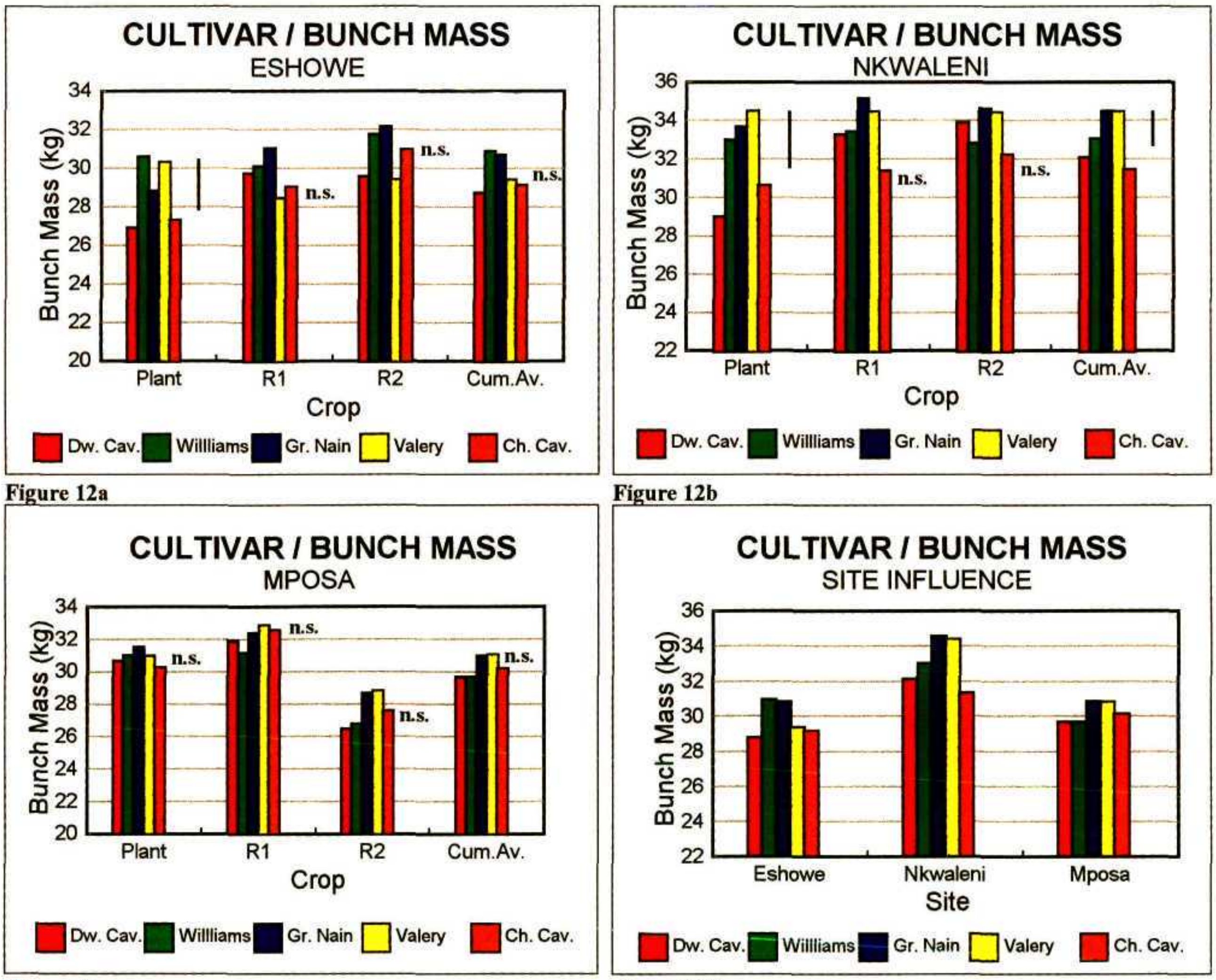


**Figure 12a**

**Figure 12b**

**Figure 12c**

**Figure 12d**

**Figure 12:** Bunch mass of five cultivars over three crop cycles at three sites with the respective cumulative averages at each site compared. Vertical bars represent LSD at P = 0.05 and n.s. represents non significance.

At Eshowe, 'Valery' and 'Williams' and, at Nkwaleni, 'Valery' and 'Grand Nain' bunches were significantly heavier than those of 'Dwarf Cavendish' and 'Chinese Cavendish' in the plant crop. There were no significant differences in bunch mass between cultivars at the Mposa site nor in any of the other cropping cycles at Eshowe or Nkwaleni (Fig.12). On average, 'Williams' (30.9 kg) and 'Grand Nain' (30.7 kg) produced the heaviest bunches at Eshowe. 'Grand Nain' (34.6 kg) and 'Valery' (34.4 kg) had the heaviest bunches at Nkwaleni, while 'Valery' (31.1 kg) and 'Grand Nain' (31.0 kg) produced the heaviest bunches at Mposa. Generally speaking therefore, the taller cultivars produced heavier bunches than the shorter cultivars. Although there were no significant differences, Morse and Robinson (1996b - in press) established similar trends at Komatipoort with 'Dwarf' and 'Chinese Cavendish' producing smaller bunches overall. In trials conducted by Turner and Hunt (1984) and Daniells and O'Farrell (1988) in Australia, 'Williams' produced the heaviest bunches with the latter trial measuring an average bunch mass of 51 kg. This relatively heavy bunch mass was due partly to the fact that bunches were harvested when there was a lack of angularity in the fingers. In other words, if harvested for commercial purposes, they would have been harvested at an earlier and lighter stage to ensure adequate greenlife. In both these Australian trials the 'Williams' cultivar proved superior to all other cultivars in respect of yield components . By contrast, Robinson *et al.* (1993a) found that at Burgershall 'Chinese Cavendish' and 'Grand Nain' consistently produced the largest bunches with long fingers and cylindrical bunch shape, while 'Williams' had below average bunch mass. They stated that 'Grand Nain' and especially 'Chinese Cavendish' are closer to the banana ideotype proposed by Stover (1982), in that they are both shorter in height, with a faster cycle time than 'Williams', while retaining good bunch characteristics.

With the exception of the R2 crop at Mposa, the mean bunch mass increased with each consecutive crop cycle. This was 28.8, 29.7 and 30.8 kg for the P, R1 and R2 at Eshowe (Fig. 12a) and 32.2, 33.5 and 33.6 kg at Nkwaleni (Fig. 12b). The corresponding figures for Mposa were 30.9, 32.2 and 27.7 kg respectively (Fig. 12c). Insufficient irrigation, as a result of the prolonged drought, was largely responsible for the substantial decline in the R2 bunch mass at Mposa. This general trend of increasing bunch mass with increase in plantation age is supported by the findings of Hill *et al.* (1992) and Morse and Robinson (1996b - in press ), provided that plantation management is good.

In this study the heaviest mean bunch mass for all cultivars and cycles was recorded at Nkwaleni (33.1 kg), with both the Mposa (30.3 kg) and Eshowe (29.8 kg) sites recording lighter bunches. This is contrary to a comparison of results between the cooler Burgershall site, where bunches were much heavier than those at the hotter Komatipoort site (Robinson *et al.* 1990). They measured an average bunch mass of 40.7 kg in the R1 at Burgershall and only 30.7 kg at Komatipoort. Despite this difference, production between these two sites was similar, due essentially to the quicker LER and cycle interval at Komatipoort. The mean maximum temperatures are approximately 4°C warmer in Komatipoort than Burgershall and the consistently warmer day temperatures favour faster LER and consequently shorter cycle interval. Conversely, the cooler temperatures at Burgershall favoured initiation of hands on the bunch and growth of the bunch itself, to produce thicker stems and larger bunches. One must attribute the lower bunch mass at Eshowe, the coolest site, to the fact that overall conditions were sub-optimal, or to the fact that the mean annual temperature ( ± 19°C) is generally below the optimum temperature required for assimilation. Drought may also have played a role.

The average bunch mass recorded at the three sites is far lower than that achieved in other subtropical sites. Wilson (1981), Daniells and O'Farrell (1988),and Robinson and Nel (1989b) recorded average bunch masses of 67.3, 51 and 50 kg respectively with 'Williams'. However, Morse and Robinson (1996b - in press) achieved an average bunch mass of 30 to 35 kg in the ratoons at Komatipoort. This they believe compared favourably with bunch masses obtained in the tropics. In trials conducted with 'Robusta' and 'Valery' in Jamaica, Walker (1970) recorded bunch masses of 23 to 26 kg, while Holder and Gumbs (1983) working with 'Williams' in Honduras, recorded an average mass of 28 kg. One would expect smaller bunches from the hotter sites due to mean temperatures which are frequently much higher than the 22-24°C regarded as the optimum for net assimilation rate and in turn, for high bunch mass potential (Turner and Lahav, 1983). As stated above however, the localities that experience high temperatures compensate for the reduced bunch mass by producing leaves at a faster rate with a consequent shorter cycle interval.

### *3.1.3.2 Harvest Index*

A practical harvest index was calculated from the mean bunch mass (kg) for each cultivar divided by the mean height (m) of that cultivar. True harvest index is dry mass (bunch) ÷ dry mass (whole plant) x 100. A more practical indicator was needed due to the difficulty of obtaining whole plant dry mass. Bunch mass ÷ pseudostem height is a rough harvest index, proposed by Turner and Hunt (1984).

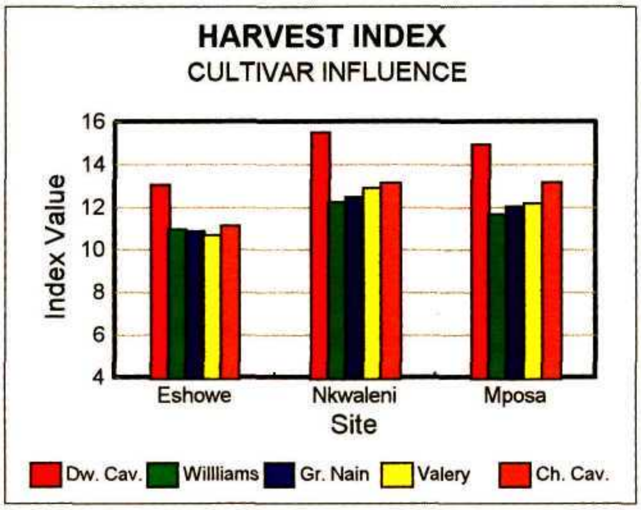


**Figure 13** : Harvest index (bunch mass ÷ pseudostem height) for five cultivars at three sites.

The harvest index is a measure of the biological efficiency of a plant and based on this characteristic alone 'Dwarf Cavendish' outperformed all other cultivars at all three sites (Fig.13). It outperformed the next best cultivar, 'Chinese Cavendish' by 17 % (Eshowe), 18 % (Nkwaleni) and 14 % (Mposa). The respective harvest indices of 'Dwarf Cavendish' at Eshowe (13.1 kg $m^{-1}$), Nkwaleni (15.5 kg $m^{-1}$) and Mposa (15.0 kg $m^{-1}$) compare somewhat poorly with that achieved by 'Dwarf Cavendish' in trials in North Queensland, Australia, where Daniells and O'Farrell (1988) calculated an index of over 19 kg $m^{-1}$. This was due to extremely good bunch weights under ideal semi-tropical conditions. Robinson *et al.* (1993a) also established that 'Dwarf Cavendish' had the greatest biological efficiency, although Turner and Hunt (1984) rated 'Williams' higher (12.1 compared to 10.5 kg $m^{-1}$ for 'Dwarf Cavendish'),due to much larger bunches from 'Williams'.

Robinson *et al.* (1993a) contend that measurements of biological efficiency such as bunch mass ÷ pseudostem height should be treated with caution. Since 'Dwarf Cavendish' is very short (Fig. 5), it will invariably have a high harvest index, but this does not compensate for bunch characteristics that are far from ideal. The short pseudostem also causes bunches emerging in winter to become "choked" in the neck of the plant.

### *3.1.3.3 Finger Length*

The central finger on the upper whorl of the third hand was measured on every data bunch. Results are summarized in Fig.14.

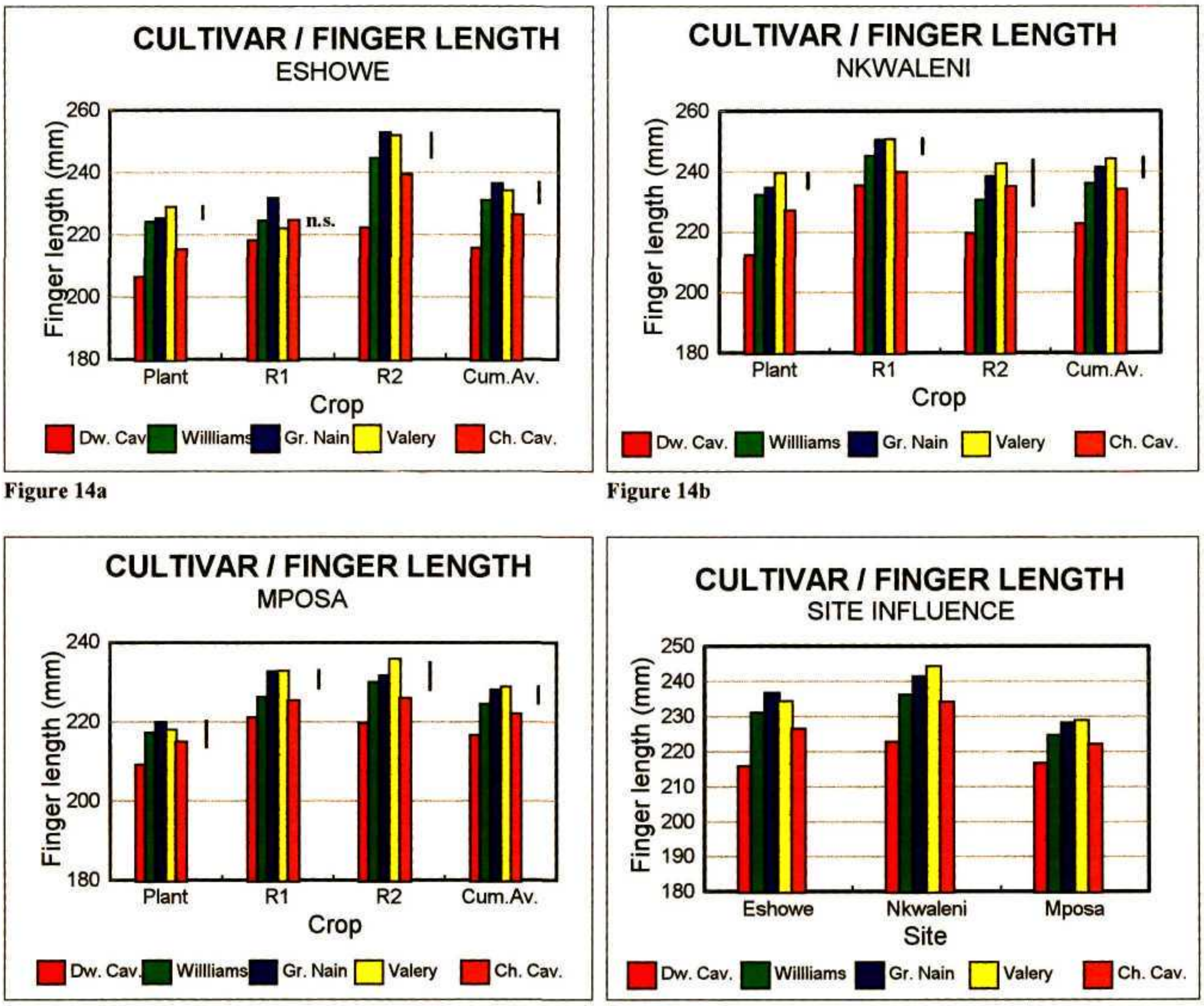


**Figure 14a**

**Figure 14b**

**Figure 14c**

**Figure 14d**

**Figure 14:** Finger length of five cultivars over three crop cycles at three sites with the respective cumulative averages at each site compared. Vertical bars represent LSD at P = 0.05 and n.s. represents non significance.

Finger length is discussed, together with all the other bunch component differences, after Tables 4 to 6 in section 3.1.3.4.

### *3.1.3.4 Bunch Component Differences*

These differences were measured on every data plant and comprised measurements of the number of hands per bunch, the number of fingers on the 3rd hand, the mass of third hand and stalk mass.

**Table 4. Bunch Component Differences Between Five Cultivars Over Three Crop Cycles: ESHOWE**

| Crop Cycle | Cultivar | No. of Hands $Bunch^{-1}$ | Stalk Mass (kg) | Stalk as % of Bunch | Mass of 3rd Hand (kg) | No. of Fingers on 3rd Hand | Mass $Finger^{-1}$ (g) |
|---|---|---|---|---|---|---|---|
| Plant | 'Dwarf Cavendish' | 9.79 | 2.30 | 8.57 | 3.00 | 19.61 | 153.2 |
| | 'Williams' | 10.03 | 2.63 | 8.60 | 3.31 | 19.21 | 172.5 |
| | 'Grand Nain' | 9.49 | 2.53 | 8.77 | 3.29 | 18.08 | 181.7 |
| | 'Valery' | 9.99 | 2.59 | 8.55 | 3.36 | 18.81 | 178.8 |
| | 'Chinese Cavendish' | 9.31 | 2.50 | 9.15 | 3.14 | 18.82 | 166.5 |
| | LSD (P=0.05) | 0.44 | 0.20 | n.s. | 0.19 | 0.78 | 3.1 |
| R1 | 'Dwarf Cavendish' | 10.67 | 2.34 | 7.85 | 3.04 | 20.60 | 147.9 |
| | 'Williams' | 10.53 | 2.17 | 7.20 | 3.14 | 19.53 | 160.3 |
| | 'Grand Nain' | 10.60 | 2.29 | 7.35 | 3.15 | 18.87 | 168.3 |
| | 'Valery' | 10.27 | 2.12 | 7.35 | 2.88 | 18.53 | 154.2 |
| | 'Chinese Cavendish' | 10.33 | 2.40 | 8.27 | 3.04 | 19.27 | 158.3 |
| | LSD (P=0.05) | n.s. | n.s. | 0.40 | n.s. | n.s | 5.6 |
| R2 | 'Dwarf Cavendish' | 10.67 | 2.20 | 7.44 | 3.10 | 20.75 | 148.8 |
| | 'Williams' | 10.46 | 2.25 | 7.04 | 3.38 | 19.82 | 170.3 |
| | 'Grand Nain' | 10.52 | 2.20 | 6.77 | 3.48 | 19.36 | 179.5 |
| | 'Valery' | 9.91 | 2.04 | 6.98 | 3.26 | 18.73 | 173.9 |
| | 'Chinese Cavendish' | 10.37 | 2.34 | 7.48 | 3.30 | 19.95 | 165.3 |
| | LSD (P=0.05) | n.s. | n.s. | 0.44 | n.s. | 0.72 | 5.6 |
| Cum. Av. | 'Dwarf Cavendish' | 10.38 | 2.28 | 7.95 | 3.05 | 20.32 | 150.0 |
| | 'Williams' | 10.33 | 2.35 | 7.61 | 3.28 | 19.52 | 167.7 |
| | 'Grand Nain' | 10.19 | 2.34 | 7.63 | 3.31 | 18.76 | 176.5 |
| | 'Valery' | 10.09 | 2.25 | 7.63 | 3.17 | 18.71 | 168.9 |
| | 'Chinese Cavendish' | 9.96 | 2.41 | 8.30 | 3.16 | 19.35 | 163.4 |
| | LSD (P=0.05) | n.s. | n.s. | 0.22 | n.s. | 0.68 | 2.9 |

**Table 5. Bunch Component Differences Between Five Cultivars Over Three Crop Cycles: NKWALENI**

| Crop Cycle | Cultivar | No. of Hands Bunch$^{-1}$ | Stalk Mass (kg) | Stalk as % of Bunch | Mass of 3rd Hand (kg) | No. of Fingers on 3rd Hand | Mass Finger$^{-1}$ (g) |
|---|---|---|---|---|---|---|---|
| Plant | 'Dwarf Cavendish' | 10.36 | 2.26 | 7.75 | 3.17 | 19.10 | 165.6 |
| | 'Williams' | 10.15 | 2.47 | 7.46 | 3.70 | 18.67 | 197.8 |
| | 'Grand Nain' | 10.37 | 2.50 | 7.39 | 3.75 | 18.69 | 200.5 |
| | 'Valery' | 10.33 | 2.66 | 7.71 | 3.80 | 18.47 | 206.0 |
| | 'Chinese Cavendish' | 9.81 | 2.35 | 7.62 | 3.47 | 18.69 | 185.3 |
| | **LSD (P=0.05)** | n.s. | 0.25 | n.s. | 0.24 | n.s. | 9.0 |
| R1 | 'Dwarf Cavendish' | 10.16 | 2.38 | 7.15 | 3.67 | 19.55 | 187.6 |
| | 'Williams' | 10.07 | 2.33 | 6.93 | 3.67 | 18.66 | 196.9 |
| | 'Grand Nain' | 10.13 | 2.45 | 6.94 | 3.84 | 18.67 | 205.9 |
| | 'Valery' | 10.32 | 2.48 | 7.17 | 3.79 | 18.81 | 201.6 |
| | 'Chinese Cavendish' | 9.49 | 2.29 | 7.29 | 3.56 | 18.37 | 193.3 |
| | **LSD (P=0.05)** | 0.45 | n.s. | n.s. | 0.18 | n.s. | 7.2 |
| R2 | 'Dwarf Cavendish' | 10.41 | 2.36 | 6.89 | 3.45 | 19.05 | 180.5 |
| | 'Williams' | 9.38 | 2.12 | 6.47 | 3.45 | 17.49 | 197.3 |
| | 'Grand Nain' | 10.09 | 2.28 | 6.56 | 3.63 | 18.40 | 197.2 |
| | 'Valery' | 10.00 | 2.27 | 6.59 | 3.57 | 17.00 | 199.5 |
| | 'Chinese Cavendish' | 9.72 | 2.22 | 6.90 | 3.43 | 18.66 | 184.1 |
| | **LSD (P=0.05)** | n.s. | n.s. | n.s. | n.s. | n.s. | 8.6 |
| Cum. Av. | 'Dwarf Cavendish' | 10.30 | 2.33 | 7.27 | 3.43 | 19.23 | 177.9 |
| | 'Williams' | 9.87 | 2.31 | 6.97 | 3.61 | 18.29 | 197.3 |
| | 'Grand Nain' | 10.20 | 2.41 | 6.97 | 3.74 | 18.58 | 201.3 |
| | 'Valery' | 10.20 | 2.46 | 7.16 | 3.72 | 18.40 | 202.5 |
| | 'Chinese Cavendish' | 9.67 | 2.29 | 7.27 | 3.49 | 18.57 | 187.6 |
| | **LSD (P=0.05)** | 0.35 | n.s. | 0.24 | 0.16 | 0.63 | 5.1 |

**Table 6. Bunch Component Differences Between Five Cultivars Over Three Crop Cycles : MPOSA**

| Crop Cycle | Cultivar | No. of Hands Bunch$^{-1}$ | Stalk Mass (kg) | Stalk as % of Bunch | Mass of 3rd Hand (kg) | No. of Fingers on 3rd Hand | Mass Finger $^{-1}$ (g) |
|---|---|---|---|---|---|---|---|
| Plant | 'Dwarf Cavendish' | 10.85 | 2.22 | 7.19 | 3.23 | 20.19 | 160.0 |
| | 'Williams' | 10.55 | 2.28 | 7.33 | 3.35 | 19.42 | 172.2 |
| | 'Grand Nain' | 10.54 | 2.37 | 7.51 | 3.38 | 19.09 | 176.7 |
| | 'Valery' | 10.75 | 2.34 | 7.61 | 3.31 | 19.19 | 172.2 |
| | 'Chinese Cavendish' | 10.47 | 2.31 | 7.65 | 3.24 | 19.62 | 165.0 |
| | **LSD (P=0.05)** | n.s. | n.s. | n.s. | n.s. | 0.68 | 11.0 |
| R1 | 'Dwarf Cavendish' | 10.70 | 2.64 | 8.29 | 3.30 | 20.37 | 161.8 |
| | 'Williams' | 10.53 | 2.67 | 8.56 | 3.26 | 19.87 | 164.0 |
| | 'Grand Nain' | 10.61 | 2.79 | 8.65 | 3.41 | 19.69 | 173.0 |
| | 'Valery' | 10.59 | 2.75 | 8.36 | 3.41 | 19.29 | 176.5 |
| | 'Chinese Cavendish' | 10.35 | 2.88 | 8.83 | 3.36 | 19.80 | 169.3 |
| | **LSD (P=0.05)** | n.s. | n.s. | n.s. | n.s. | n.s. | 7.9 |
| R2 | 'Dwarf Cavendish' | 9.69 | 2.09 | 7.85 | 2.98 | 19.36 | 153.9 |
| | 'Williams' | 9.45 | 2.14 | 7.97 | 3.06 | 18.37 | 166.6 |
| | 'Grand Nain' | 9.71 | 2.25 | 7.84 | 3.22 | 18.68 | 172.5 |
| | 'Valery' | 9.73 | 2.30 | 8.03 | 3.19 | 18.30 | 174.3 |
| | 'Chinese Cavendish' | 9.69 | 2.32 | 8.43 | 3.03 | 18.86 | 160.6 |
| | **LSD (P=0.05)** | n.s. | n.s. | 0.30 | n.s. | 0.65 | 8.7 |
| Cum. Av. | 'Dwarf Cavendish' | 10.42 | 2.31 | 7.77 | 3.17 | 19.98 | 158.6 |
| | 'Williams' | 10.18 | 2.36 | 7.95 | 3.22 | 19.21 | 167.7 |
| | 'Grand Nain' | 10.28 | 2.47 | 7.99 | 3.33 | 19.15 | 174.1 |
| | 'Valery' | 10.36 | 2.47 | 8.00 | 3.30 | 18.93 | 174.3 |
| | 'Chinese Cavendish' | 10.17 | 2.50 | 8.31 | 3.21 | 19.41 | 165.0 |
| | **LSD (P=0.05)** | n.s. | 0.14 | 0.30 | n.s. | 0.5 | 6.5 |

Finger length is an extremely important bunch component since it influences bunch mass potential and is one of the most important determinants of "quality" in grading of the fruit. Cultivar differences in finger length proved to be significant for all crop cycles and sites with the exception of the R1 at Eshowe. Overall, 'Valery' had the longest fingers at Nkwaleni (244mm) and at Mposa (229mm) and was 2mm shorter than 'Grand Nain' at Eshowe (237mm) (Fig. 14). The average mass of fingers was calculated from the mass of the third hand divided by the number of fingers on the third hand. In most instances there were significant differences either in the mass of the third hand or the number of fingers, and this translated into significant differences for the average finger mass in every crop and every site (Tables 4 to 6). Of interest in the data presented in these Tables, is that on average 'Dwarf Cavendish' had the most hands per bunch as well as the most fingers per hand at all three sites. However the average finger mass was significantly less than all of the other cultivars and this detracts significantly, both in terms of cultivar productivity as well as grading of the fruit. The lower finger mass of 'Dwarf Cavendish' is reflected in the short fingers of this cultivar (Fig. 14). Overall 'Valery' had the heaviest finger mass at Nkwaleni and Mposa while 'Grand Nain' fingers significantly outweighed all other cultivars at Eshowe. Again this is reflected in the data presented in section 3.1.3.3 under cultivar finger length. What is interesting to note at the Eshowe site is that 'Williams' had an average finger mass that was 5.5 % lighter than that of 'Grand Nain'. Notwithstanding this 'Williams' still had the most hands per bunch and more fingers per hand than 'Grand Nain', and these two factors gave this cultivar the heaviest bunches.

Trials conducted at Burgershall over four cropping cycles (Robinson *et al.,*1993a) resulted in 'Valery' producing the longest fingers. It was on the grounds of this characteristic that 'Valery' was released to the industry in 1988, together with 'Chinese Cavendish' and 'Grand Nain'. It was identified as a cultivar, which, because of its relatively long fingers, had potential for export - should such marketing ever be considered. The ranking order of cultivars based on finger length (Fig. 14) was similar to the order based on pseudostem height (Fig. 5) with 'Dwarf Cavendish' having the shortest fingers followed by 'Chinese Cavendish'. This ranking order was also similar to that determined by Morse and Robinson (1996b- in press).

Another interesting feature is the stalk (peduncle) mass which is expressed as a percentage of the bunch mass. On average 'Chinese Cavendish' had a significantly heavier stalk mass, relative to the bunch mass, at all three sites. At both Eshowe and Mposa this was 8.3 % of the bunch mass. Although at Nkwaleni

'Chinese' also had the heaviest stalk relative to bunch mass, this was lower at 7.3 %. There is no physiological reason why stalks should comprise a lower percentage of the bunch mass at Nkwaleni and such differences must be attributed to the harvesting techniques of the labour forces at the different sites.

### *3.1.3.5 Cultivar Productivity*

The total bunch mass produced by each cultivar over all three densities was divided by the average cycle time (days) of that cultivar and multiplied by 365 to determine the overall productivity (t $ha^{-1}$ $an^{-1}$). This is the formula described by Robinson & Nel (1989b). Results are summarised in Fig.15.

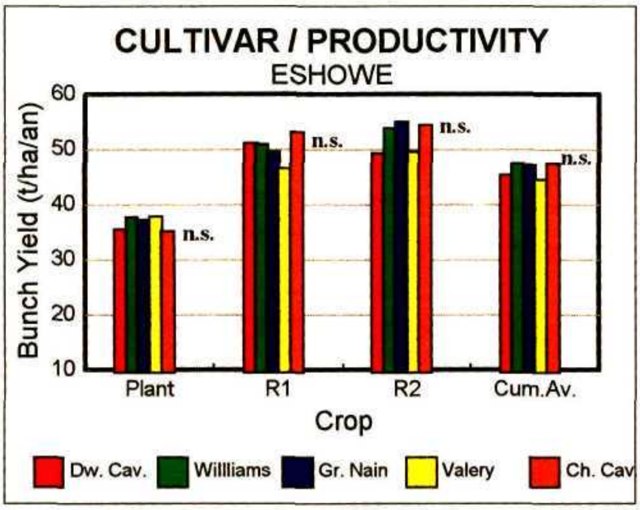


**Figure 15a**

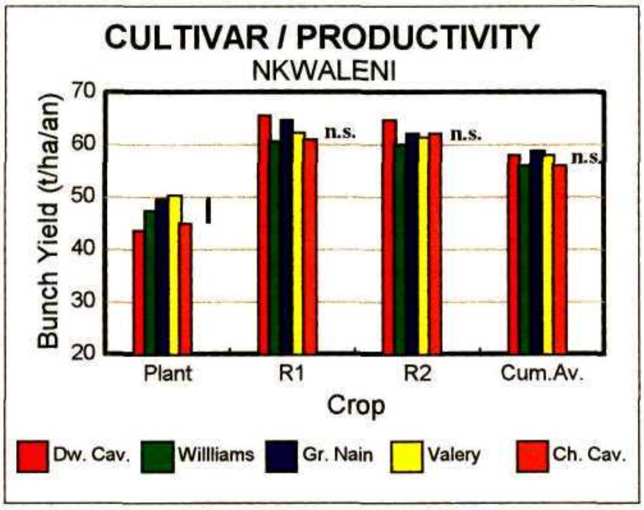


**Figure 15b**

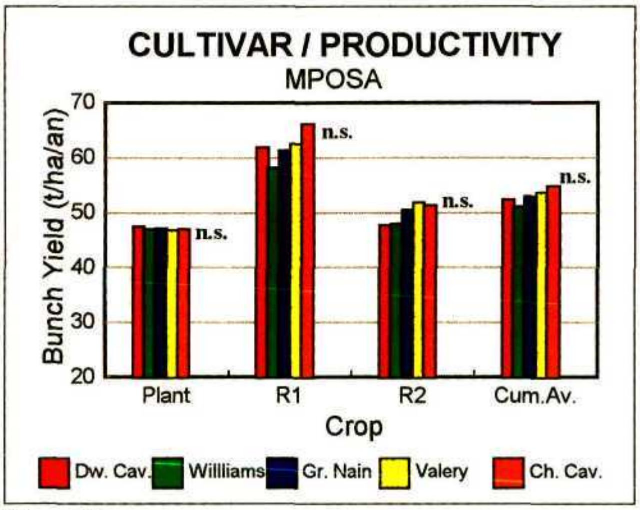


**Figure 15c**

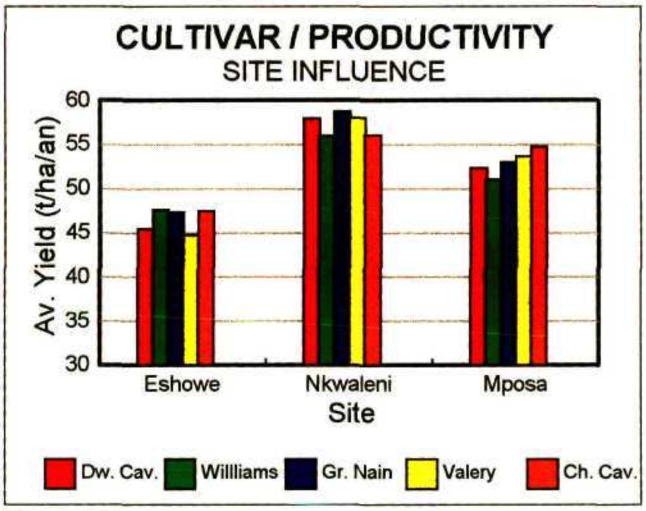


**Figure 15d**

**Figure 15:** The productivity of five banana cultivars expressed as bunch yield in tonnes $ha^{-1}$ $an^{-1}$ over three crop cycles and three sites, with the cumulative averages at each site compared. Vertical bars represent LSD at P = 0.05 and n.s. represents non-significance.

In the plant crop at Nkwaleni, 'Valery' (50.3 t ha$^{-1}$ an$^{-1}$) significantly outproduced 'Chinese' (45.0 t ha$^{-1}$ an$^{-1}$) and 'Dwarf Cavendish' (43.7 t ha$^{-1}$ an$^{-1}$). Also, 'Grand Nain' (49.6 t ha$^{-1}$ an$^{-1}$ ) significantly outproduced 'Dwarf Cavendish' (43.7 t ha$^{-1}$ an$^{-1}$ ). Other than this, there were no significant differences in productivity between cultivars (Fig.15). This once again shows how similar the Cavendish sub-group cultivars are in respect of overall productivity. On a national basis, trials at Komatipoort (Morse and Robinson, 1996b - in press), Levubu and the KwaZulu Natal South Coast (Robinson *et al.,* 1994c) have compared Cavendish sub-group cultivars, including the five tested in the current study, with non-significant differences in all instances. At Komatipoort, Morse and Robinson (1996b - in press) found that 'Grand Nain' (Central America) was significantly lower yielding than 'Chinese Cavendish' and 'Grand Nain' (Israel) in the R2 cycle only. However, Cavendish cultivars are more likely to show significant differences if tested over more than two or three cycles. Thus, it was only at Burgershall that Robinson *et al.* (1993a) established, over a four cropping cycle trial, that 'Grand Nain' and 'Chinese Cavendish', with a joint annual yield of 58 t ha$^{-1}$, significantly out-yielded 'Williams'(53 t ha$^{-1}$) and 'Dwarf Cavendish'(43 t ha$^{-1}$). Notwithstanding the non-significant results achieved at three of the four other trial sites in South Africa, results between cultivars were sufficiently different, or there were certain favourable characteristics pertinent to a particular cultivar, to enable firm recommendations to be made.

Similar non-significant results have been obtained in other subtropical areas, such as those measured by Galan Sauco *et al.* (1991;1995) in the Canary Islands. They evaluated the performance of 'Williams' and 'Grand Nain' against the traditionally produced 'Dwarf Cavendish'. 'Grand Nain' produced the highest annual bunch yield of 73 t ha$^{-1}$ at a density of 2 000 plants ha$^{-1}$ in the second ratoon cycle. The corresponding annual bunch yields for 'Dwarf Cavendish' and 'Williams' were 72 and 67 t ha$^{-1}$ respectively. Yields were therefore similar, but there was a significant improvement in finger length with 'Grand Nain' which supported the choice of this cultivar as a valid substitute for the traditional 'Dwarf Cavendish'.

At Eshowe (Fig. 15a) overall best performance over three cycles was achieved by 'Williams' (47 t ha$^{-1}$ an$^{-1}$) closely followed by 'Grand Nain' (46.8 t ha$^{-1}$ an$^{-1}$) and 'Chinese Cavendish' (46.4 t ha$^{-1}$ an$^{-1}$). It is quite conceivable that as this plantation ages, 'Chinese Cavendish' could well outperform 'Williams' as a result of quicker cycling, just as occurred at Burgershall (Robinson *et al.,* 1993a) and at Komatipoort (Morse and Robinson 1996b - in press). At Nkwaleni (Fig. 15b) overall best performance was from 'Grand Nain' (58.7 t ha$^{-1}$ an$^{-1}$), closely followed by 'Valery' (57.9 t ha$^{-1}$ an$^{-1}$) and 'Dwarf Cavendish' (57.6 t ha$^{-1}$ an$^{-1}$). 'Williams', considered over all densities, only just outperformed 'Chinese Cavendish'. 'Dwarf Cavendish', with its faster cycling could improve on its performance with increasing plantation age. In the tropics of Puerto Rico, Irizarry *et al.* (1989) evaluated four AAA Cavendish sub-group cultivars over a three year period, in four locations. 'Grand Nain' was consistently the most productive cultivar, with annual ratoon yields of up to 60 t ha$^{-1}$ marketable fruit being recorded. Based on international as well as local performance (Robinson *et al.*,1993a; Morse and Robinson, 1996b- in press) 'Grand Nain' should feature well in many South African localities, as at Nkwaleni. At Mposa (Fig. 15c) the best performance was from 'Chinese Cavendish' (54.2 t ha$^{-1}$ an$^{-1}$) followed by 'Valery' (53.3 t ha$^{-1}$ an$^{-1}$). Whereas bunch mass potential is clearly evident after two ratoon cycles, the short cycling cultivars ('Chinese Cavendish' and 'Dwarf Cavendish' ) became progressively more productive as the plantation aged. This is an extremely important factor when it is realised that commercial plantations usually continue for ten or more years.

Overall, cultivar productivity increased dramatically from the plant crop to the R1 at Eshowe ( +37 %), Nkwaleni (+33 %) and Mposa (+32 %). This increase was marginally maintained in the R2 at Eshowe (+4.2 %) and Nkwaleni (-1.2 %). However at Mposa there was a substantial 20 % reduction in the R2 yield, primarily as a result of insufficient irrigation water (Fig 15). This trend is not normal because productivity usually increases for three or more cycles in a vigorous plantation. The difference in production between plant and ratoon crops will however, vary according to cultivar, pest and disease load and other environmental factors such as soil fertility and seasonal effects, as well as management level (Daniells *et al.*, 1985).

A comparison of site productivity (Fig. 15d) reveals a situation where the intermediate Nkwaleni site, on average, outproduced the cooler Eshowe site by 23 % and the hotter Mposa site by 8 %. The Mposa site, with more effective heat units (Table 1), should theoretically have a higher production potential and the relatively inferior performance there must be attributed to an insufficiency of irrigation water, particularly during the R2. If each of the trials had functioned optimally, the production could have been more closely related to heat units experienced. However, since each of the trials experienced insufficient irrigation water at different stages, comparisons between sites must be regarded with extreme caution.

### 3.1.4 Economic Returns

Gross margins were determined by firstly deducting stalk mass (Tables 4-6) from the production figures discussed in Figures 15 a-c to arrive at total fruit mass. This figure was reduced, in turn, by a factor of 10 % to account for downgrading and wastage. An average value of R1 510 per tonne was assigned to the crop (average Durban market prices, May 1995 to April 1996) and all production, harvesting, transport and marketing costs were deducted. Results are summarised in Fig.16.

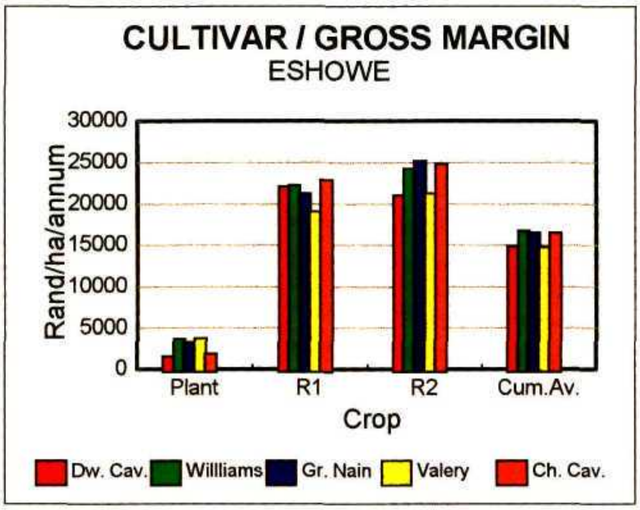


**Figure 16a**

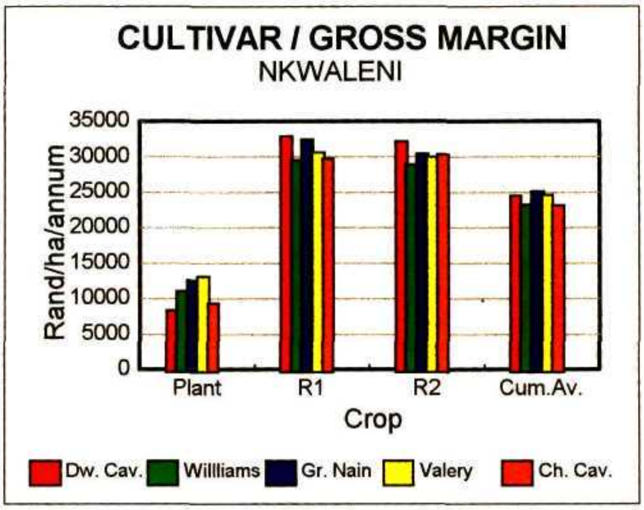


**Figure 16b**

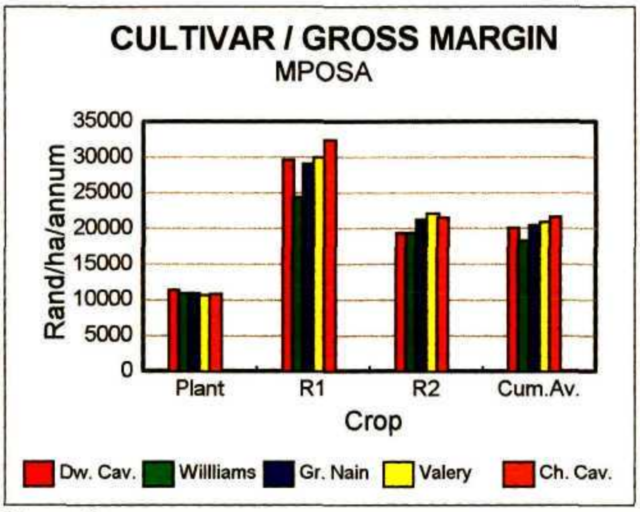


**Figure 16c**

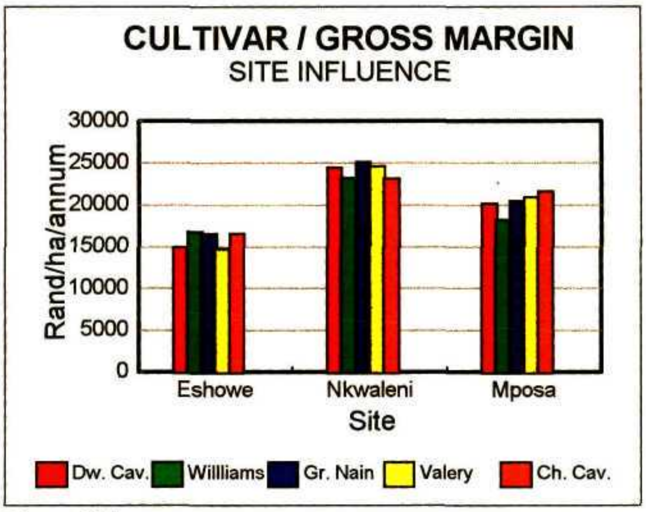


**Figure 16d**

**Figure 16:** Gross margins ha$^{-1}$ an$^{-1}$ (gross income - variable costs) for five cultivars, over three crops cycles, at three sites, with the respective cumulative averages at each site compared.

The ranking order of cultivar profitability (Fig.16) was virtually identical to that of cultivar productivity shown in Figs. 15 a - c. The only variation was due to stalk mass between the cultivars, particularly in respect of 'Chinese Cavendish' having a higher stalk mass to bunch mass ratio than the other cultivars (Tables 4 to 6).

Profitability in the plant crop was greatly reduced due to the full write off of establishment costs. Establishment costs varied according to density. Including interest (19.2 %) on operating capital the establishment and post-plant variable costs for 1 666 plants $ha^{-1}$ were R15 374; for 2 105 plants $ha^{-1}$ it was R18 774, and for 2 500 plants $ha^{-1}$ it was R21 805. Pre-plant allocatable costs that were constant, irrespective of density, amounted to R3 829. In order to make valid comparisons between sites, unit costs were applied uniformly. In addition transport to market costs were based on a distance of 160 km at R1 per tonne per km.

Monetary returns were good. Over the three crop cycles the gross margin achieved on average exceeded R15 000 $ha^{-1}$ $an^{-1}$ at Eshowe, and ranged between R20 000 and R25 000 $ha^{-1}$ $an^{-1}$ at both Nkwaleni and Mposa. When this is compared to the R2 500 to R3 000 $ha^{-1}$ $an^{-1}$ gross margin realised by the average sugar cane producer, there is sufficient justification to support and indeed promote an industry that has the potential (in selected situations where resources warrant) to improve the income of the North Coast farmers. It must be stressed, however, that the production levels achieved were significantly higher than what is being achieved commercially. This is despite the fact that each of the trial blocks was managed as part of an integral commercial banana plantation. The fact remains though that reliable bench mark norms have been established with regard to the production potential in each of the three Bioclimatic Regions studied. Furthermore, the trials were conducted during a prolonged period of drought, when irrigation water was often insufficient.

### 3.1.5 Individual Plant Performance

The cumulative performance of every data plant was expressed on the basis of fruit yield per hectare per annum and the top ten plants from each site were identified. Results are summarised in Table 6A. The objective of identifying the plants with superior performance at the three sites, is to take some or all of those listed, bulk them up and evaluate them further.

**Table 6A: Top Ten individual plant performances for each of three sites. Fruit Production per mat over three crop cycles is expressed on a t ha$^{-1}$ an$^{-1}$ basis.**

| ESHOWE | | | NKWALENI | | | MPOSA | | |
|---|---|---|---|---|---|---|---|---|
| CULTIVAR | DENSITY | t ha$^{-1}$ an$^{-1}$ | CULTIVAR | DENSITY | t ha$^{-1}$ an$^{-1}$ | CULTIVAR | DENSITY | t ha$^{-1}$ an$^{-1}$ |
| 'Dwarf Cav.' | 2500 | 69.8 | 'Chinese Cav.' | 2500 | 85.4 | 'Chinese Cav.' | 2500 | 75.6 |
| 'Chinese Cav'. | 2500 | 67.9 | 'Dwarf Cav.' | 2500 | 82.9 | 'Williams' | 2500 | 75.5 |
| 'Dwarf Cav.' | 2500 | 64.6 | 'Chinese Cav.' | 2500 | 82.8 | 'Grand Nain' | 2500 | 74.9 |
| 'Chinese Cav.' | 2500 | 63.9 | 'Chinese Cav.' | 2105 | 82.0 | 'Chinese Cav.' | 2500 | 74.1 |
| 'Williams' | 2105 | 62.7 | 'Valery' | 2500 | 80.3 | 'Chinese Cav.' | 2500 | 73.4 |
| 'Dwarf Cav.' | 2500 | 62.7 | 'Williams' | 2500 | 78.2 | 'Chinese Cav.' | 2500 | 71.8 |
| 'Williams' | 2500 | 62.2 | 'Dwarf Cav.' | 2500 | 77.7 | 'Dwarf Cav.' | 2105 | 71.7 |
| 'Williams' | 2500 | 61.8 | 'Williams' | 2500 | 77.4 | 'Valery' | 2500 | 70.9 |
| 'Dwarf Cav.' | 2500 | 61.6 | 'Chinese Cav.' | 2500 | 77.3 | 'Grand Nain' | 2500 | 70.6 |
| 'Williams' | 2500 | 61.6 | 'Williams' | 2500 | 76.5 | 'Chinese Cav.' | 2105 | 70.4 |

Interestingly, certain 'Dwarf Cavendish' plants (mats) performed exceptionally well at the Eshowe site and this cultivar took four of the top ten places, with 'Williams' also occupying four of the top ten and 'Chinese Cavendish' the remaining two (Table 6A). Nine of these plants were planted at 2 500 plants ha$^{-1}$ and only one was planted at 2 105 ha$^{-1}$. This is logical, because productivity of the individual plants was enhanced by the higher plant density. This was also the case at Nkwaleni , whereas at Mposa there were two plants at the lower density that featured amongst the top ten performers. At the Nkwaleni site four 'Chinese Cavendish' plants rated in the top ten, whereas at Mposa there were five 'Chinese Cavendish' plants in the top ten. All in all, eleven (37 %) 'Chinese Cavendish' plants featured out of the top thirty at all three sites. The top performing plant (mat) at each site out-yielded the overall average by :- Eshowe - 61.5 %; Nkwaleni - 60.2 % and Mposa - 55.2 %.

The possibility exists that some of the high performing plants listed may be somaclonal variants (natural mutations occurring during *in vitro* multiplication) and thus have superior genes. Gross and Simmonds (1954) state that the mutation rate of stable banana clones in the field, where sucker propagation is used, is very low (1 or 2 in a million). Consequently the chances of identifying superior mutants from sucker propagation are rather slim. However, somaclonal variation can be significant (5 to 10 % and higher) when plants are produced in large numbers during *in vitro* multiplication (Stover and Buddenhagen, 1986; Robinson ,1996). Although this can be commercially problematic, in that it generally leads to inferior plants, there is still considerable scope for selecting a superior mutant clone. The origin of somaclonal variation in *Musa* shoot tip cultures may be explained by three mechanisms (Novak, 1992). These are:- 1) genetic changes already present in the tissue of the explant, 2) mutagenic action of the tissue culture media, and 3) variations due to stresses of the tissue culture environment. The first two factors are responsible for genetic changes which revert to the normal characteristic in the field. These variations allow for both non-mutagenic and mutagenic breeding possibilities.

The objective of identifying plants with superior performance at the three sites, is to further evaluate those listed and to determine if their superior performance was genetically or environmentally induced.

## 3.2 PLANTING DENSITIES

Three densities, *viz.* 1 666, 2 105 and 2 500 plants ha$^{-1}$, constituted the sub-plots of this trial. Each cultivar main plot was split into three density sub-plots as outlined above. The results obtained from each density are therefore based on the average performance of all five cultivars at that specific density.

### 3.2.1 Morphological Results

The effect of density on the morphology of a plant can be quite pronounced and a knowledge of this effect can be useful in determining management options.

#### *3.2.1.1 Plant Height*

The height of every data plant was measured from soil level to the neck of the inflorescence axis at the stage of inflorescence emergence. Results are summarised in Fig.17.

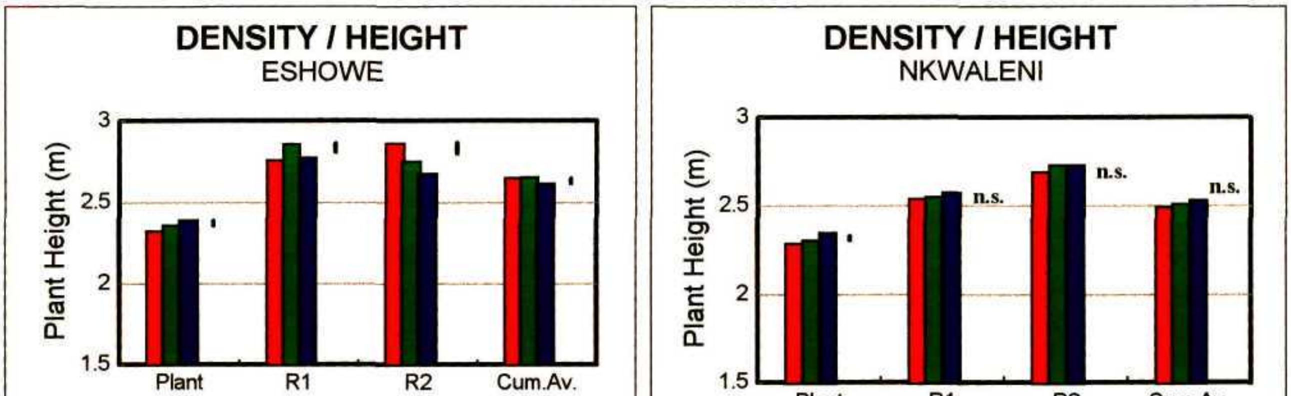


**Figure 17a** **Figure 17b**

**Figure 17c** **Figure 17d**

**Figure 17:** Variation in pseudostem height at three plant densities over three crop cycles at three sites, with averages at each site. Vertical bars represent LSD at P = 0.05 and n.s. represents non-significance.

Over all densities, there was a substantial overall increase in pseudostem height from the plant crop to the Rl (Fig 17). This was from 2.4 to 2.8 m at Eshowe, 2.3 to 2.6 m at Nkwaleni and 2.2 to 2.5 m at Mposa. For the R2 the pseudostem height was maintained at Eshowe, increased upon at Nkwaleni, and decreased at Mposa. Robinson and Nel (1988b) reported a substantial increase in pseudostem height from the P to the R1, with slight but continuous increases in height up to the R4 cycle. Daniells *et al.* (1985) and Daniells *et al.* (1987) also showed similar results and reasoned that the progressive increase in ratoon plant stature compared with the plant crop must be related to the fact that the parent plant is nourishing the following sucker. This beneficial effect is obviously absent in a plant crop situation. It is clear that optimum plantation density can be determined accurately only when morphological and phenological stability is reached after four or more cropping cycles.

The effect of density varied between crop cycles and sites. At all sites there was an increase in plant height with an increase in density in the plant crop, and this was significant at both Eshowe and Nkwaleni (Fig. 17). However, only at Nkwaleni was the same trend maintained with the following ratoons. Daniells *et al* (1985) established small increases in pseudostem height in both the P and R1, with increasing density. They attributed this to an increase in internode length in the P and an increase in the number of leaves, with increasing density, in the R1. At both Eshowe and Mposa the density of 2 105 plants ha$^{-1}$ produced the tallest plants in the R1 and this changed even further in the R2, with the lowest density (1 666 plants ha$^{-1}$) producing the tallest plants. These results suggest that the change of height order at Eshowe and Mposa is related to the reducing vigour of the plants at the higher densities. This was indirectly a climatic effect at Eshowe and the result of insufficient irrigation at Mposa. This proves what Robinson (1993e) found at Levubu i.e. that in a plantation of low vigour (for whatever reason) the higher densities are detrimental to individual plant performance due to the increased competition enhancing the effects of low vigour. Daniells *et al.* (1987) reasoned that the greater plant size in the R1 contributed to greater inter-plant competition compared with the plant crop, particularly with increasing density. This competition resulted in reduced vigour and overall performance, especially at the cooler Eshowe site.

The influence of site on pseudostem height was dealt with in section 3.1.1.2.

### *3.2.1.2 Pseudostem Index*

Measurements were taken of the pseudostem height, as outlined above (section 3.2.1.1), and the pseudostem circumference 300 mm above the soil level at flowering stage on every data plant (Table 7). The pseudostem index was then calculated by dividing the height by the circumference. Results are summarised in Fig. 18.

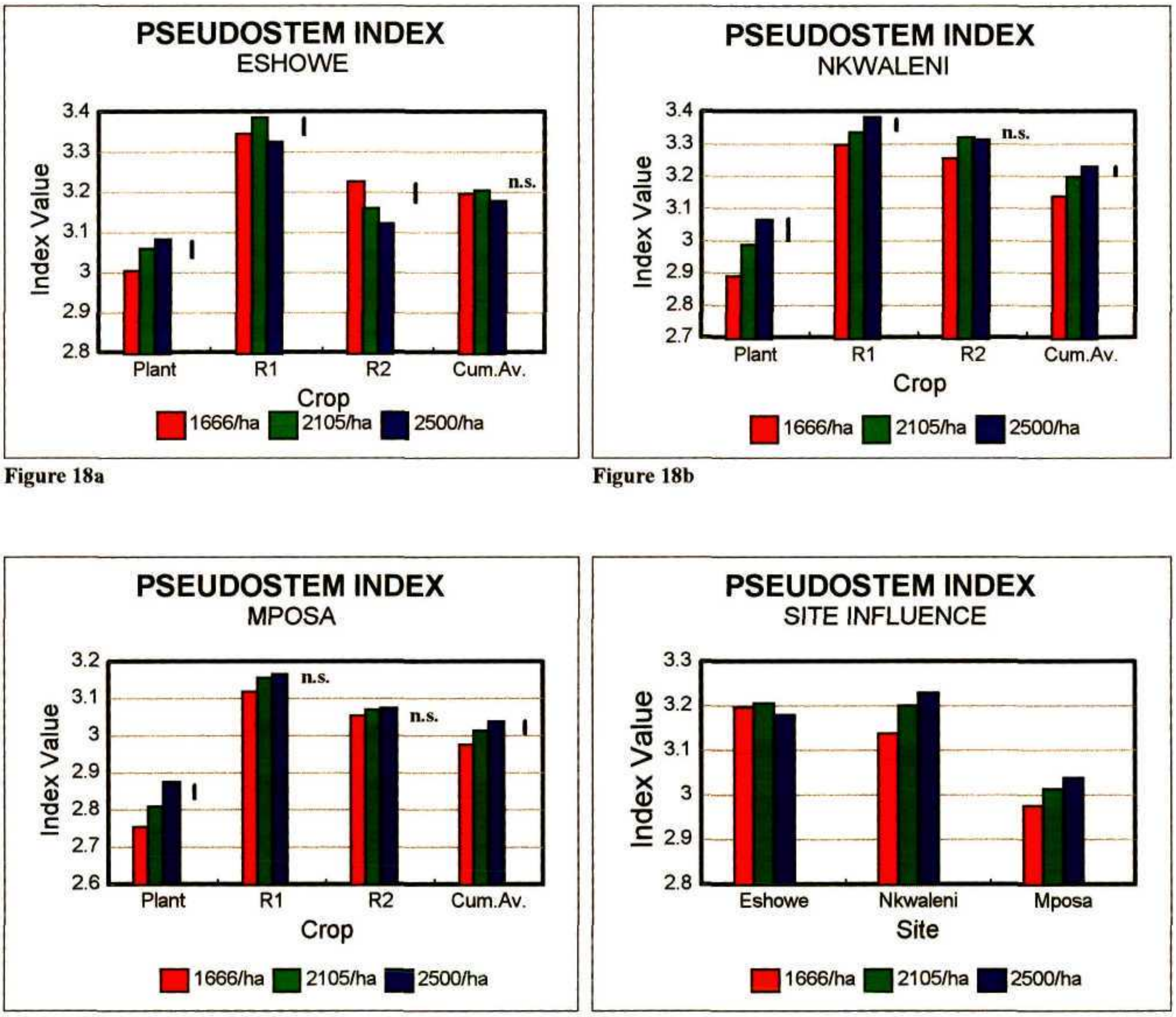


**Figure 18a**

**Figure 18b**

**Figure 18c**

**Figure 18d**

**Figure 18:** Variation in pseudostem index (height ÷ circumference) at three plant densities over three crop cycles at three sites, with averages at each site. Vertical bars represent LSD at P = 0.05 and n..s. represents non significance.

The effect of density on pseudostem index (Fig. 18) was essentially a function of height, particularly at the Eshowe site, where the ranking order was identical to that of pseudostem height (Fig. 17). This order also changed in accordance with the reducing plant vigour and consequent reduction in plant height, which was brought about as a result of the increasing inter-plant competition at higher densities, particularly at the cooler Eshowe site (Fig. 18a). At Mposa the index was influenced to a greater degree by stem circumference, that reduced significantly with increase in density (Table 7), than the other two sites (Fig. 18c). Fundamentally though, the pseudostem index reflected a pattern similar to that of pseudostem height and this substantiates the results presented in section 3.1.1.3, where it was established that plant stability against wind appears to be directly related to pseudostem height rather than stem circumference.

Table 7 illustrates that density had no significant effect on the overall stem circumference measurements at both Eshowe and Nkwaleni, although there were slight reductions with an increase in density. At Mposa this difference was significant, yet represents a difference of less than 3 % over all crops. There was also a reduction of 3.6 % of the average pseudostem circumference over all densities from the R1 to the R2 at Mposa. This once again illustrates the reduction in plant vigour at Mposa in the R2. Increasing density had the effect of reducing circumference by 4 % in the R2 at Mposa. This is far less than the 9 % reduction measured by Daniells *et al.* (1985) in their R1. Their difference in density though, ranged from 930 to 3 980 plants ha$^{-1}$, a far greater spread. They found that for every 1 % reduction in pseudostem circumference, the cross sectional area of the pseudostem reduced by about 2 %, with a proportional reduction in bunch mass potential, and this is borne out by the overall reduction in bunch mass in the R2 at Mposa (Fig. 24c).

**Table 7: Cumulative average pseudostem circumference at flowering(m) of 3 planting densities, over 3 crop cycles at 3 sites.**

| DENSITY | ESHOWE | NKWALENI | MPOSA |
|---|---|---|---|
| 1 666 plants ha$^{-1}$ | 0.828 | 0.793 | 0.799 |
| 2 105 plants ha$^{-1}$ | 0.828 | 0.785 | 0.794 |
| 2 500 plants ha$^{-1}$ | 0.823 | 0.784 | 0.778 |
| LSD ( P = 0.05) | n.s. | n.s. | 0.010 |

### *3.2.1.3 Leaf Area Index*

Leaf measurements were carried out at harvest on all the leaves of two randomly selected plants from each treatment combination (sub-plot). The average leaf area per plant was then used to determine the leaf area for each plant at flowering and this was related to soil surface area to determine the maximum LAI for every sub-plot. Measurements were conducted in the P and R1 at all sites and in the R2 at Nkwaleni. Results are summarised in Fig. 19.

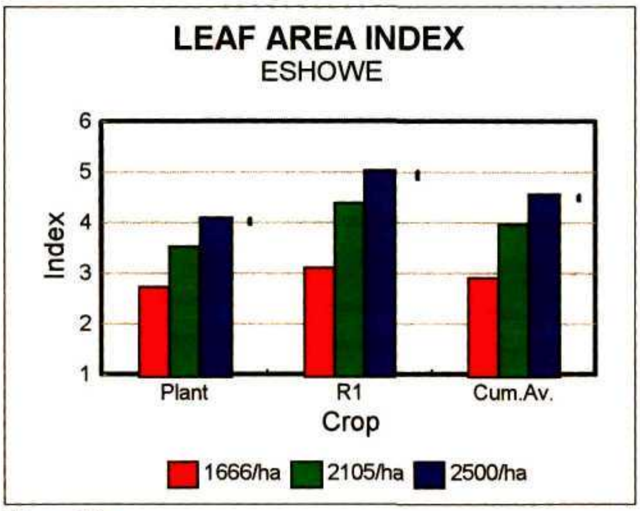


**Figure 19a**

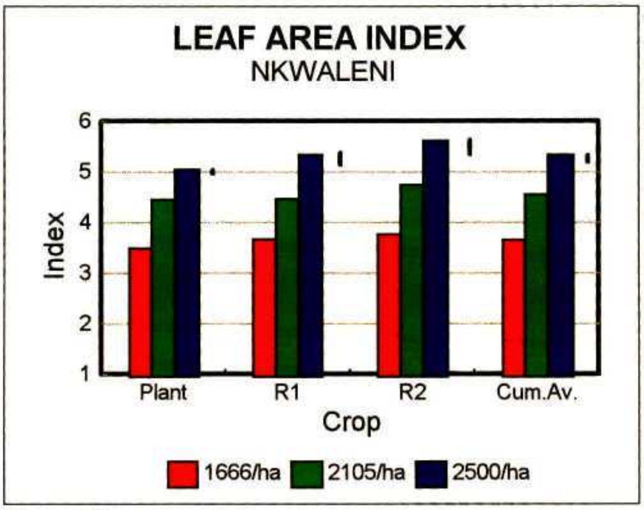


**Figure 19b**

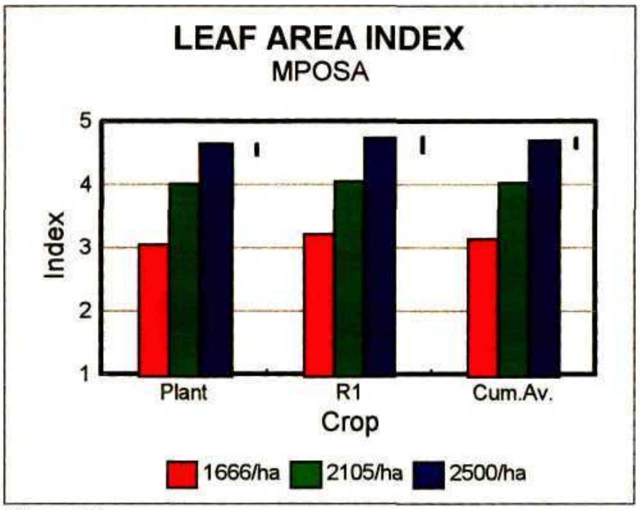


**Figure 19c**

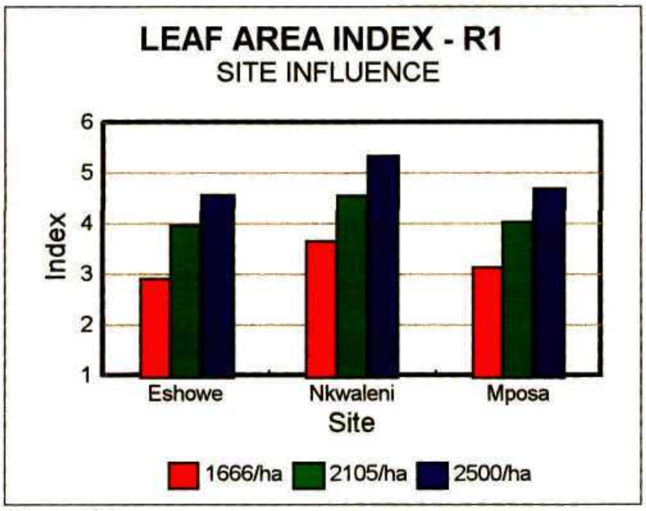


**Figure 19d**

**Figure 19:** Variation in leaf area index (L x W x 0.83 x maximum number of functional leaves at flowering ÷ ground area) at three plant densities over two/three crop cycles at three sites. Sites are compared on the R1 LAI. Vertical bars represent LSD at $P = 0.05$.

The ranking order of LAI relative to density was the same for all crops and sites, with an increase in LAI according to an increase in density, and all differences being significant. In the R1 there was a 66 % increase in LAI from the lowest to the highest density at Eshowe, a 46.9 % increase at Nkwaleni and a 49.7 % increase at Mposa. Robinson and Nel (1988b) recorded a virtual doubling in ratoon LAI when comparing densities of 1 000 and 2 222 plants ha$^{-1}$, which was a somewhat greater density range than the trials under review, and from a much more vigorous plantation.

At each site there was an increase in overall LAI at flowering from the P to R1. At Eshowe this was 20.2 %, at Nkwaleni 11.8 % and at Mposa 3.5 %. The respective increases in plant height from the P to R1 was Eshowe - 18.4 %, Nkwaleni - 10.5 % and Mposa - 14 %. With the exception of the Mposa site this increase in LAI appeared to be strongly correlated to an increase in pseudostem height, which supports the findings of Morse and Robinson (1996a - in press).

The maximum LAI recorded at each site in the R1 was at 2 500 plants ha$^{-1}$, *viz.* Eshowe - 5.1, Nkwaleni - 5.4 and Mposa - 4.8. It should be borne in mind that this represents the average LAI of all five cultivars at the highest density. As already illustrated in section 3.1.1.4, the difference in LAI between cultivars was as much as 28 % and the LAI of certain cultivars at the high density was a lot higher than that listed.

As stated earlier in section 3.1.1.4, Turner (1982) and Stover (1984) recommended that an optimum density should provide a canopy cover that reduces light transmission to about 10 %, and Turner established that the optimum LAI for 'Williams' in New South Wales was 4.5. Robinson and Nel (1989b) achieved maximum production at an LAI of 6 but maximum economic returns were achieved at an LAI of 5. Morse and Robinson (1996a- in press) also established an optimum LAI of between 5 and 6 at Komatipoort and this equated to densities that were approximately 15 % higher than those recommended for the cooler Burgershall district. Based on the above theory, the optimum densities at both Eshowe and Nkwaleni would be 2 500 plants ha$^{-1}$ and a slightly higher density would be required at Mposa in order to reach an LAI of 5-6. However, Robinson (1993e) demonstrated clearly that one cannot simply compensate for reduced vigour by increasing the density until a satisfactory LAI is reached. The plants then become so weak and stunted that they are commercially worthless. In the case of Mposa therefore, a density lower than 2 500 plants ha$^{-1}$ would be recommended in order to enhance individual plant vigour. If at all possible, the cause of the lack of vigour should be rectified.

### 3.2.2 Phenological Results

Inter-plant competition becomes more pronounced with increasing plant density and one of the effects of high density on the phenology of a plant is to slow down the developmental cycle. Various parameters were accordingly monitored.

#### *3.2.2.1 Leaf Emergence Rate*

New leaf emergence was recorded on five data plants from each subplot for the duration of the three cropping cycles, at the three sites. The cumulative average monthly LER for each density and site averaged over all cultivars, is reflected in Figs. 20a - c.

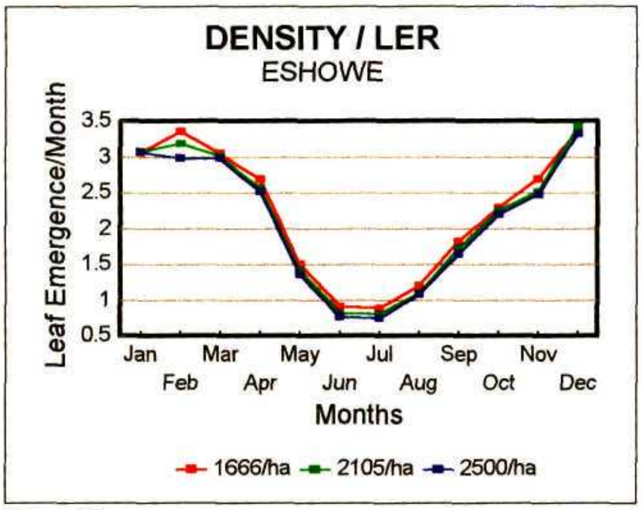


**Figure 20a**

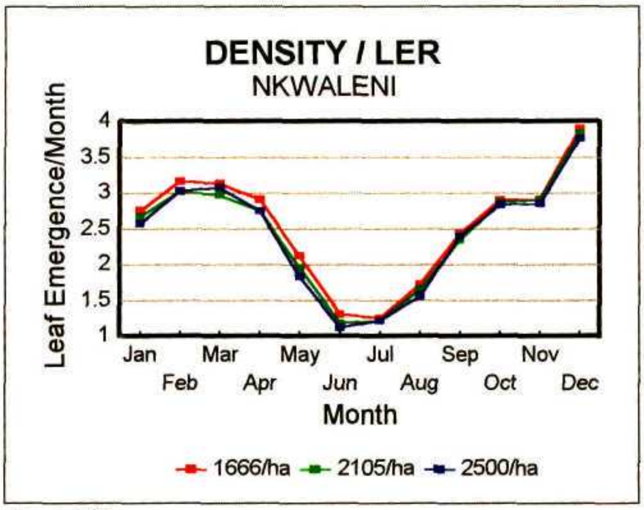


**Figure 20b**

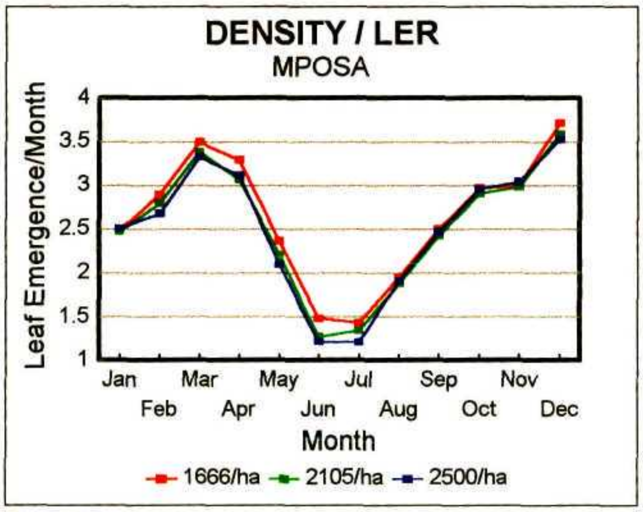


**Figure 20c**

**Figure 20:** Seasonal variation in LER at three plant densities at three sites. Data are the cumulative average of 3 crop cycles, averaged over five cultivars.

The pronounced influence of season (temperature) was once again reflected in the leaf emergence rate in all three densities at all three sites (Fig.20). The reasons for this seasonal effect have been elucidated in section 3.1.2.1. and are valid for this section as well. A comparison of the influence of site on monthly leaf emergence has been omitted from this section, as it would be identical to Fig. 8d.

What is interesting to note, is the small yet distinct influence of density on the monthly leaf emergence rate (Fig. 20). These differences were significant in 9 of the 12 months at Eshowe and in 6 of the 12 at both Nkwaleni and Mposa. It is evident therefore, that as the density increased and inter-plant competition became more pronounced, the vegetative development of the plant was reduced. It is also apparent from Table 8 that this slowdown was greater at the cooler site of Eshowe, where the difference in annual LER between the high and low density is 1.7 leaves compared with 1.5 at Nkwaleni and Mposa. The difference in annual LER was significant between all densities at Eshowe and was non-significant only between the mid and high densities at Nkwaleni and Mposa.

When comparing density extremes from 1 000 to 2 222 plants ha$^{-1}$, Robinson and Nel (1989e) recorded an annual LER difference of almost five fewer leaves in the R1, and over five leaves in the R2. In comparing even greater density extremes from 1 333 to 3 333 plants ha$^{-1}$, Robinson and Nel (1989e) recorded an annual LER difference of over 8 leaves. Morse and Robinson (1996a - in press) found no significant differences between densities when comparing monthly LER, but established an annual decrease of 2 to 3 fewer leaves per annum between 2 005 and 2 618 plants ha$^{-1.}$

**Table 8. Cumulative Average Annual Leaf Production : Eshowe, Nkwaleni and Mposa.**

| **Density** | **Eshowe** | **Nkwaleni** | **Mposa** |
|---|---|---|---|
| 1 666 plants ha$^{-1}$ | 26.98 | 30.61 | 31.64 |
| 2 105 plants ha$^{-1}$ | 26.04 | 29.46 | 30.36 |
| 2 500 plants ha$^{-1}$ | 25.26 | 29.10 | 30.10 |
| LSD ($P = 0.05$) | 0.27 | 0.52 | 0.46 |

It is evident that with increasing density, a reduction in LER results in an extension of the vegetative cycle of the plant. This reduction in LER at higher density is, *inter alia,* associated with lower growing temperatures induced by increased shading. Plant development rate and ambient temperature are highly correlated in banana plantations (Kuhne *et al.*, 1973 ; Robinson, 1981).

### *3.2.2.2 Internal Pseudostem Temperature*

Although this did not form part of the overall evaluation of density , due to the fact that no other physiological measurements were taken, the author felt it would be interesting to record the effect of density on pseudostem temperature in relation to growth and development.

Internal pseudostem temperatures were measured on a clear sunny day, in early March 1995, on two 'Grand Nain' data plants from each density, in each of five replications, at Nkwaleni. The average of ten readings for each density is plotted on an hourly basis in Fig. 21. Seven of the thirteen hourly measurements exhibited significant differences at the 5 % level.

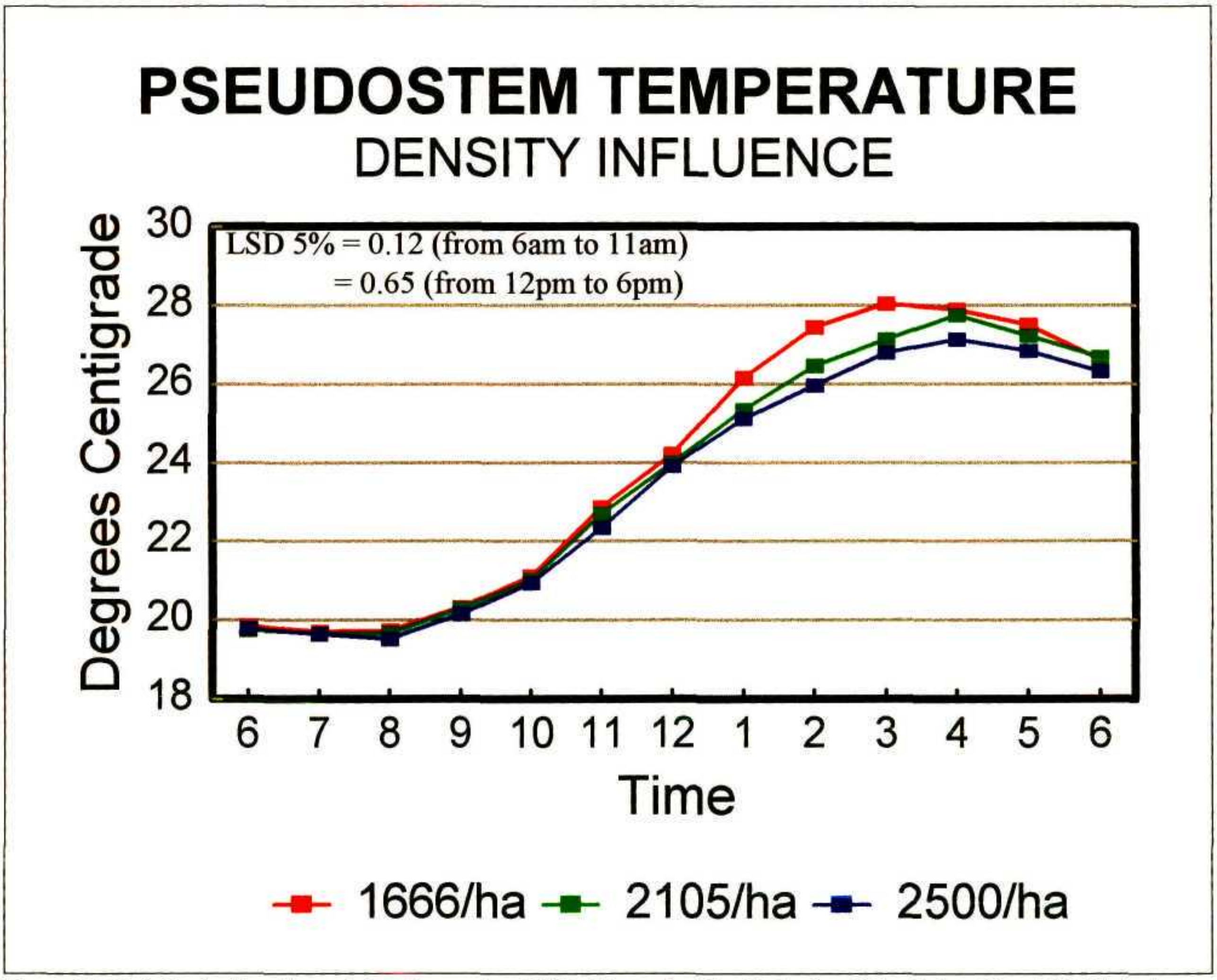


**Figure 21**: Variation in diurnal pseudostem temperature ( $^0$C ) at three plant density levels at Nkwaleni on 'Grand Nain' plants. Readings commenced at 6 am and ended at 6 pm.

From approximately 10h00 onwards the effect of density on internal pseudostem temperature was observed, with a maximum difference between low and high density occurring at 14h00 to 15h00. The temperatures at 14h00 and 15h00 in the low density were 27.44 and 28.03°C respectively, with the respective temperatures in the high density being 1.48 and 1.24°C lower.

Kuhne *et al.* (1973), Robinson (1981) and Eckstein (1994) have all demonstrated the correlation between LER and ambient temperatures in a plantation. With increasing light penetration at lower densities the ambient and internal plant temperatures increase with a consequent increase in growth and development. When comparing 1 000 against 2 222 plants ha$^{-1}$, Robinson and Nel (1988b) recorded internal pseudostem temperature reductions of ± 3°C in summer and ± 4 °C in winter, with the higher density. In comparing 2 005 to 2 818 plants ha$^{-1}$ at Komatipoort, Morse and Robinson (1996a -in press) found that as the temperature decreased in the winter months, the lowest density had a slightly higher LER than the highest density, with the converse being true in summer. They attributed this to the fact that in winter, the lowest density allowed in more radiation to warm the pseudostems and soil, compared with the high density. In summer however, the maximum temperatures at Komatipoort are often too high for optimum LER and this problem is exacerbated at low densities. Eckstein (1994) recorded a maximum internal pseudostem temperature difference of 4.2°C when comparing plants growing in full sun and those growing in the shade of windbreaks, again pointing to the improved plant development potential of those plants with greater exposure to sunlight. In his trial, Eckstein established that plants growing in the shade produced 1.87 and 3.4 more leaves before flowering than plants in the sun, for the plant crop and R1 respectively.

Based on the preceding discussion, it is obvious that the cooler internal pseudostem temperatures, which are induced by the cooler microclimate created by planting at higher densities (Fig. 21), are partially responsible for a reduction in the leaf emergence rate (Fig. 20) as well as an increase in the total number of leaves produced (Fig.22), thereby contributing to the longer cycle intervals experienced at higher plant densities (Fig. 23).

### *3.2.2.3 Total Leaf Production*

The number of new leaves produced were counted on a monthly basis until flower emergence on five data plants per sub-plot, and a cumulative total was derived. In the case of the plant crop, the total number of leaves present at establishment was added to the total. Again, this is strictly speaking a morphological feature, but has been dealt with in this section due to its close association with LER and vegetative cycle time. Results are summarised in Fig. 22.

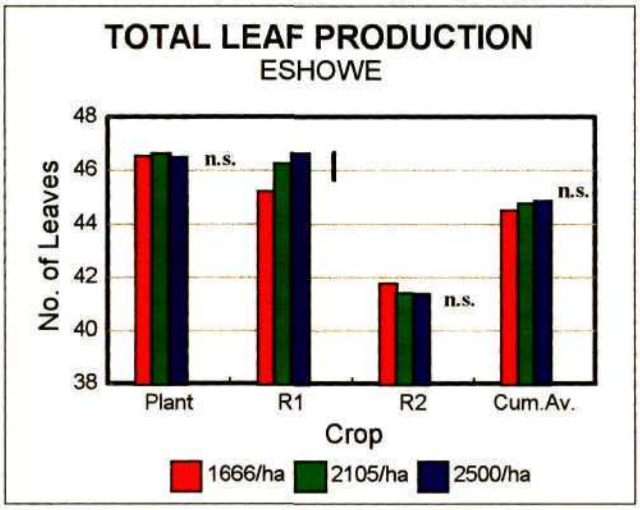


**Figure 22a**

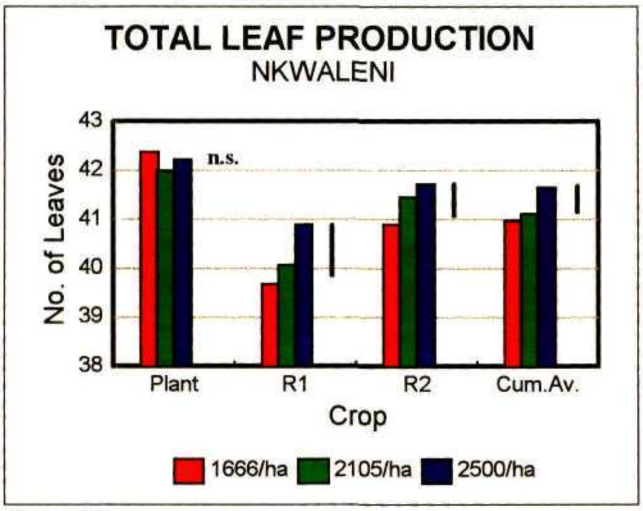


**Figure 22b**

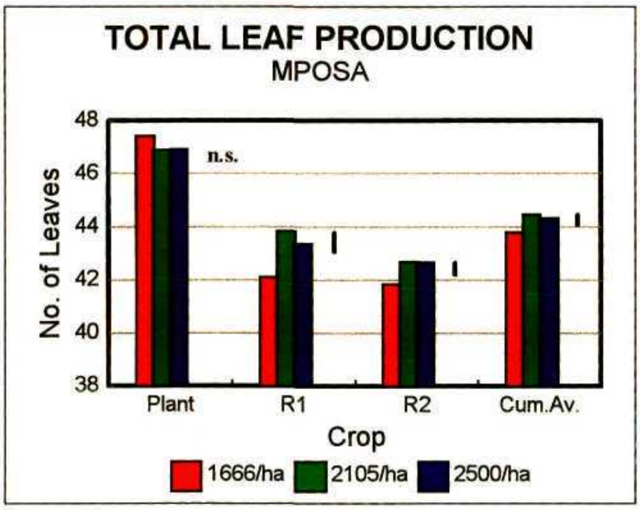


**Figure 22c**

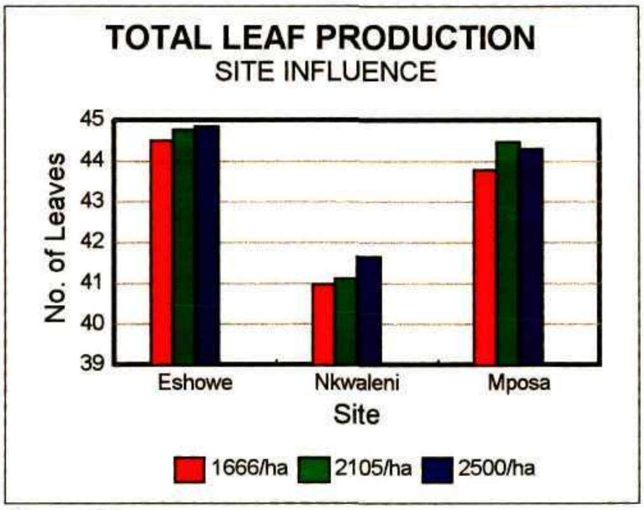


**Figure 22d**

**Figure 22:** Variation in total leaf production per plant at three plant densities over three crop cycles at three sites, with averages at each site. Vertical bars represent LSD at P = 0.05 and n. s. represents non-significance.

The ranking order between densities, with regard to total leaf production in the plant crop cycle, varied at the three sites and was not significant. In the ratoons however the higher densities, in the main, produced more leaves than the lower densities, with the most pronounced pattern emerging at Nkwaleni (Fig. 22).

The mean total leaf production for the R1 and R2 at Eshowe, with increasing density from 1 666 to 2 105, to 2 500 plants ha$^{-1}$, was 43.5, 43.8 and 44.0 respectively. The corresponding figures for Nkwaleni were 40.3, 40.8 and 41.3 . For Mposa they were 42.0, 43.3 and 43.2. These differences were not as great as those recorded in the R2 by Robinson and Nel, (1986b), where plants at the density of 2 222 plants ha$^{-1}$ produced 6½ more leaves than those at the density of 1 000 plants ha$^{-1}$, and which contributed to an extension of the R2 vegetative cycle (from sucker emergence) of almost seven months at the higher density. This difference in total leaf production between densities, reduced to 2.9 leaves in the R3 (Robinson and Nel 1988b), where , over all densities, leaves grew more slowly and more leaves were produced per plant. This phenomenon was ascribed partly to the larger R2 canopy leaf area shading the R3 suckers to a greater extent than which the smaller R1 canopy leaf area shaded the R2 suckers (refer to the influence of shading on pseudostem temperatures in section 3.2.2.2). In comparing 1 333 and 3 333 plants ha$^{-1}$ Robinson and Nel, (1989e) recorded 2.2 more leaves on plants at the higher density in the R1. This phenomenon of increasing plant densities producing more leaves, has also been observed by other international researchers, such as Daniells *et al.* (1985) and may be described as probably being a compensatory mechanism due to leaves at high density being shaded and less efficient.

Considered in conjunction with the slower LER at higher densities (Fig. 20), the greater total number of leaves produced with increasing density (Fig. 22) contributed to an extension of the vegetative and consequently full crop cycle at the higher plant densities (Fig 23).

The variation in total leaf production experienced between crop cycles and sites was dealt with in section 3.1.2.2

### *3.2.2.4 Crop Cycle Intervals*

The date of planting and the harvest date of every data plant was recorded to provide the average planting-to-harvest interval (plant crop cycle). The harvest date of successive crops was related to the previous harvest date for each plant and averaged to provide a harvest to harvest interval for each density (ratoon crop cycles). Results are summarised in Fig. 23.

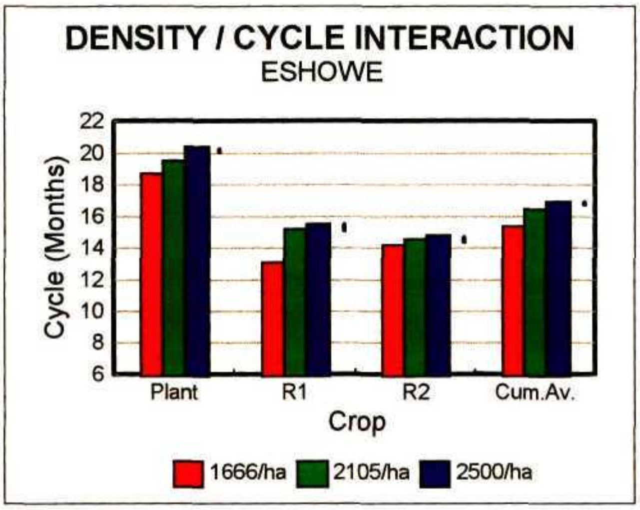


**Figure 23a**

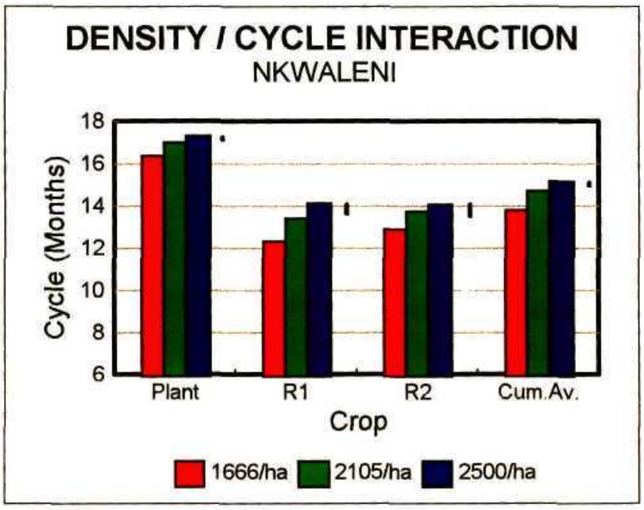


**Figure 23b**

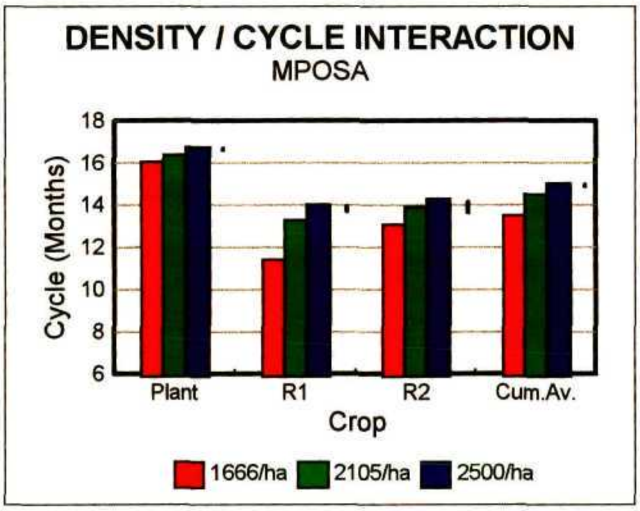


**Figure 23c**

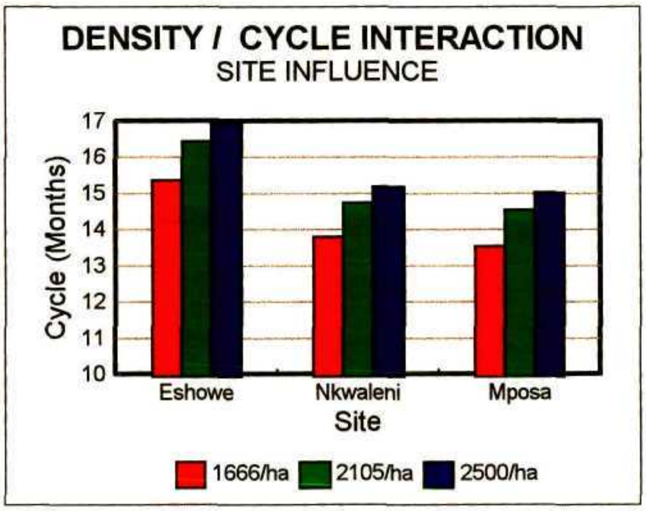


**Figure 23d**

**Figure 23:** Variation in cycle duration (months) at three plant densities over three crop cycles at three sites, with averages at each site. Vertical bars represent LSD at P = 0.05.

For all crops and all sites there were significant differences between densities, with higher densities experiencing longer cycle times (Fig. 23). A comparison of the R1 cycle duration (months) in the order of low to high density was as follows:- Eshowe - 13.1, 15.2, 15.6 ; Nkwaleni - 12.3, 13.4,14.1 ; and Mposa - 11.4, 13.3, 14.0. This clearly illustrates and confirms the claim by Robinson and Nel (1988b) that crop-to-crop cycle time is extremely sensitive to plant density. This extension of cycle time in association with increasing density has been widely reported (Chattopadhyay *et al.,* 1980; Chundawat *et al.,*1983; Daniells *et al.,* 1985; Robinson and Nel ,1988b; Robinson *et al.,* 1993b; Morse and Robinson 1996a - in press).

In the hot Komatipoort district, Morse and Robinson (1996a -in press) measured an average extension in cycle time of 8½ days as the density increased from 2 005 to 2 339 to 2 618 plants ha$^{-1}$. The highest density took 402 days per cycle (13.2 months), and the lowest density 385 days per cycle (12.66 months). In comparing 2 222 plants ha$^{-1}$ with an extremely high density of 6 666 plants ha$^{-1}$ in the cooler Burgershall district, Robinson *et al.* (1993b) experienced an extension of cycle time of 126 days in the plant crop. An increase of this magnitude is not normally associated with a tissue culture plant crop due to the fact that the competitive effects are really only found from the R1 onwards ( Daniells *et al.,*1985). However a density of 6 666 plants ha$^{-1}$ is excessively high and the competitive effects were experienced almost immediately. This high density could not be considered for ratooning purposes. Robinson and Nel (1986b) recorded a total R1 delay of 1.6 months when the density of 'Williams' was increased from 1 250 to 1 666 plants ha$^{-1}$, but a delay of only nine days in the plant crop cycle. The corresponding delays, when comparing 1 000 with 2 222 plants ha$^{-1}$, were 4.9 months and 27 days respectively, thereby confirming that an extension of cycle interval as a result of increasing competition, generally only reaches substantial proportions after the plant crop cycle.

The crop cycle (H-H) is a vital component of the annual yield potential (t ha$^{-1}$ an$^{-1}$) of a banana plantation and comprises the vegetative (H-E) cycle as well the bunch emergence-to-harvest (E-H) cycle. The vegetative component (H-E) is a function of both the LER and the total number of leaves produced (as outlined in sections 3.2.2.1 and 3.2.2.3), both of which are influenced by the plantation micro-climate (section 3.2.2.2), and this has a profound effect on the H-H interval. When the low plant density of 1 666 was compared with the high density of 2 500 plants ha$^{-1}$, the average annual production of 1.7 more leaves at Eshowe and 1.5 more at Nkwaleni and Mposa (Table 8), coupled with the overall trend towards fewer total leaves produced (Fig. 22) led to significant reductions in cycle intervals at the low density in all crops and sites (Fig. 23). The cycle interval also differed significantly between a number of other density/crop/site combinations. The other component of the crop cycle is the E-H interval, the results of which were presented in section 3.1.2.3. Reference to the models presented in that section (Fig. 10) indicate that the E-H interval was at its fastest during an early summer flower emergence and slowest during an early winter emergence. Emergence-to-harvest differences between 1 666 and 2 500 plants ha$^{-1}$ for a summer and winter emergence respectively were:- Eshowe 11.4 and 2.6 days; Nkwaleni 13.7 and 3.9 days; and Mposa 8.3 and 3.4 days. The longer E-H cycling time was associated with the higher density. The actual E-H intervals in summer and winter respectively, for plants at a density of 1 666 plants ha$^{-1}$, were:- Eshowe- 117 and 201 days; Nkwaleni- 94 and 181 days; Mposa- 104 and 180 days.

The extremely long E-H interval with an early winter emergence is symptomatic of the virtual total quiescence of the plant during the winter period. Robinson (1992) contends that as a result of this reduced growth potential in winter, sub-optimal management will not have a major impact on the productivity of the plant. Conversely, when growth potential during the summer period is at its maximum, this can be reduced considerably by sub-optimal management, with particular reference to irrigation, fertilization, de-suckering and weed control.

Other phenomena evident in Figs. 23 a to d are:-

1) The disparity between the different crop cycles, with the plant crop having a far longer cycle than that of the ratoons. As explained in section 3.1.2.4 this was due to the fact that the plant crop cycle was based on date of planting to date of harvest, whereas ratoon cycles were based on date of harvest of one crop to date of harvest of the following crop. By date of harvest of the plant crop, the R1 sucker is already well developed and the impression is gained that the R1 cycle interval is a lot shorter than that of the plant crop, when in actual fact the opposite can be true (Robinson and Nel, 1985).

2) Influence of site on cycle time. The overall average cycle times for Eshowe, Nkwaleni and Mposa were:- 16.2, 14.6, and 14.4 months respectively. The faster cycle times were evident in sites with a greater number of heat units, which supports the claim of Robinson *et al.* (1990) that warmer sites favour faster leaf emergence rate and consequently produce a shorter cycle time.

### 3.2.3 Yield Components

Yield components include bunch mass, "harvest index", finger length, stalk mass, number of hands per bunch, number and mass of fingers on the third hand and overall productivity.

#### *3.2.3.1 Bunch Mass*

Bunches were harvested from every data plant at a finger maturity of ¾ round and were weighed on an electronic scale to an accuracy of 0.02 kg. Data were averaged to provide the bunch mass for each density, crop and site. Results are summarised in Fig. 24.

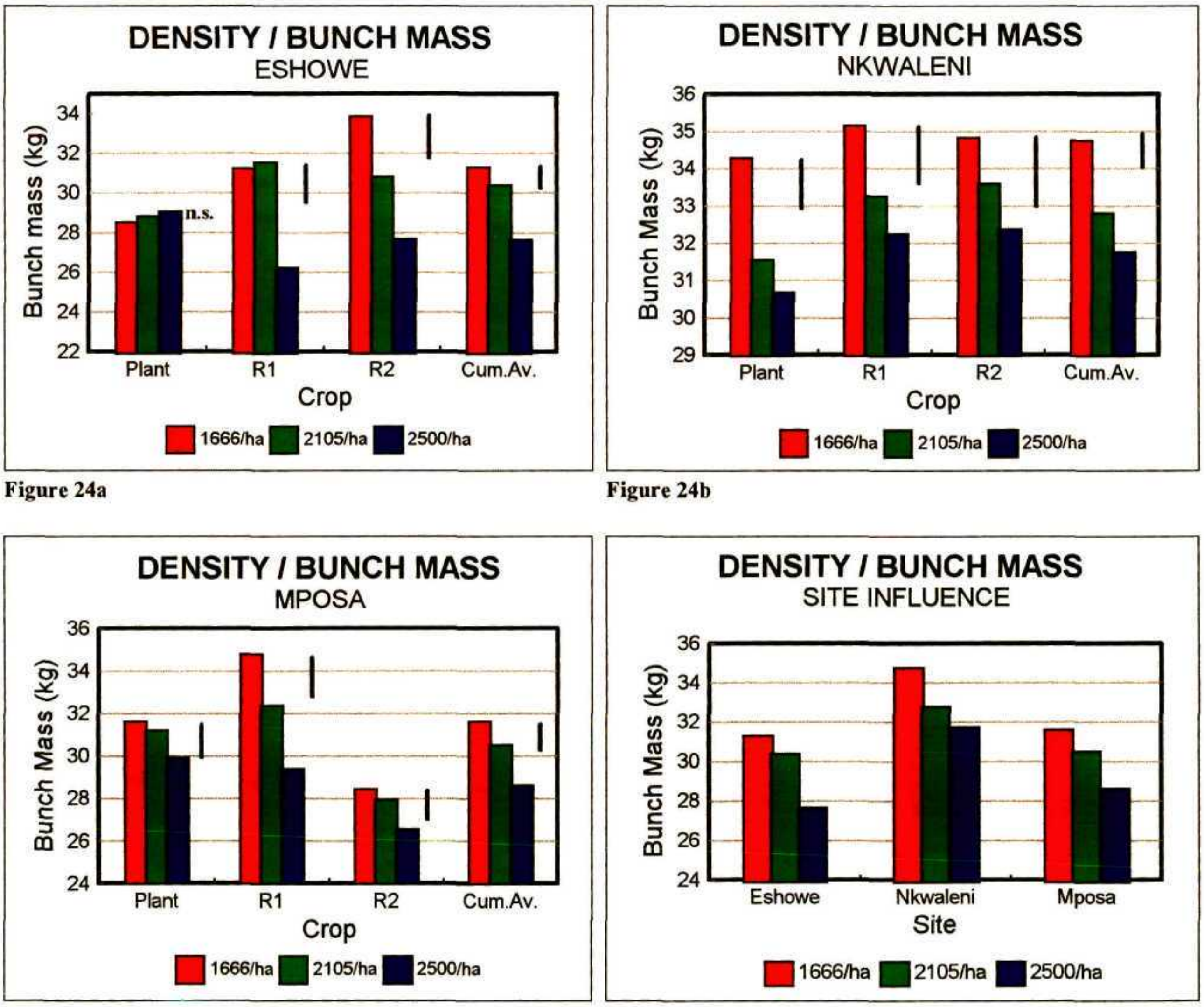


**Figure 24a**

**Figure 24b**

**Figure 24c**

**Figure 24d**

**Figure 24:** Variation in mean bunch mass (kg) at three plant density levels over three crop cycles at three sites, with averages at each site. Vertical bars represent LSD at P = 0.05 and n. s. represents non-significance.

With the exception of the P and R1 cycle at Eshowe, increasing plant density had a significant negative effect on the bunch mass in all crops and sites (Fig.24). The cumulative average bunch mass for each site, ranging from low to high density was:- Eshowe- 31.3, 30.4 and 27.7 kg; Nkwaleni- 34.8, 32.8 and 31.8 kg and Mposa- 31.6, 30.5 and 28.6 kg. The respective differences in the R2 at Eshowe were 33.9, 30.8 and 27.7 kg. These figures highlight the significant negative effect of increasing density on the bunch mass of an individual plant. This trend has been observed by numerous researchers, both in the tropics (Echeverri-Lopez and Garcia-Reyes, 1981 ; Irizarry *et al.,* 1981; Obiefuna *et al.,*1982; Chundawat *et al.,* 1983; Mustaffa, 1988; Anil *et al.*, 1994) as well as in the subtropics (Daniells *et al.,* 1985; Robinson and Nel, 1989b ; Robinson *et al.,* 1993b). In a comparison of 2 222 and 6 666 plants ha $^{-1}$, Robinson *et al.*( 1993b) established a reduction in average bunch mass from 28.5 to 25.5 kg in the plant crop. This 10.5 % reduction in bunch mass is unusual in a plant crop, and is attributed to severe plant-to-plant competition which prevented normal fruit filling. The result was smaller bunches with a large proportion of undersized, unmarketable fruit and a high proportion of "choked" bunches.

At Eshowe there was a 1.9 % increase in bunch mass when increasing the density from 1 666 to 2 500 plants ha$^{-1}$ in the plant crop compared to a 16 % decrease in the R1 (Fig.24a). The corresponding figures for the P and R1 at Nkwaleni were decreases of 10 % and 8.2 %, and at Mposa there were decreases of 5.3 % and 15 %. Daniells *et al.* (1985) reported a 15.7 % decrease in bunch mass in the plant crop, when increasing density from 930 to 3 980 plants ha $^{-1}$ but a much greater decrease from 53.7 to 30.9 kg (43 %) in the R2. They attributed this to the greater size of ratoon plants and thus greater inter-plant competition than in the plant crop and therefore a somewhat different response to density. This phenomenon possibly explains the lack of negative effect of density on bunch mass in the plant crop at Eshowe. Additionally, the variations observed in response to density may best be explained by the findings of Robinson and Human (1988) and Robinson and Nel (1989b), who observed that bunch mass was greatly influenced by season of flowering. Since density treatments induced a spread of flowering there was a dual effect on the bunch mass of plants at a specific density. Plants at the high density in Eshowe may thus have flowered at a more suitable time than the low density plants in the plant crop.

The effect of site on the overall bunch mass as well as the variation in the different crop cycles has been dealt with in section 3.1.3.1.

### *3.2.3.2 Harvest Index*

A practical harvest index was calculated by dividing the mean bunch mass (kg) for each density by the mean height (m) of that density (kg m$^{-1}$). True harvest index is dry mass (bunch) ÷ dry mass (whole plant) x 100. A more practical indicator was needed due to the difficulty of obtaining whole plant dry mass. Bunch mass ÷ Pseudostem height is a rough harvest index proposed by Turner and Hunt (1984). Results are summarised in Fig. 25.

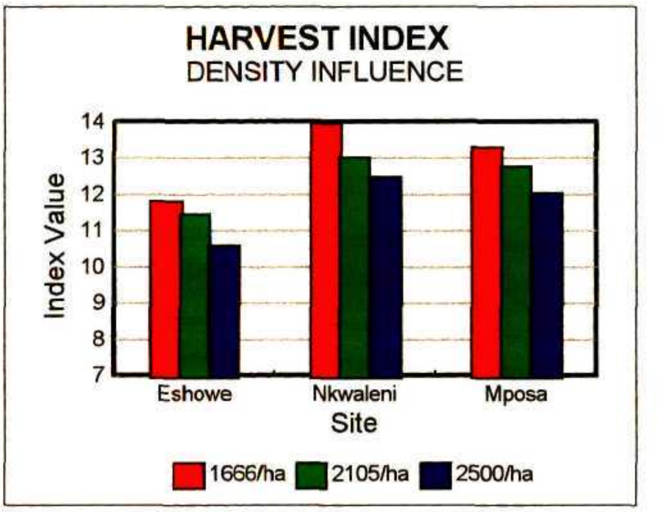


**Figure 25:** Variations in Harvest Index (Bunch mass ÷ pseudostem height) according to 3 densities at 3 sites.

Density had a distinct negative effect on the biological efficiency of plants which were planted at higher densities (Fig.25). Overall (combining all cultivars and crops) Nkwaleni had the highest harvest index (13.95 kg m$^{-1}$) at 1 666 plants ha$^{-1}$. The corresponding value for the highest density was 10.4 % less at 12.5 kg m$^{-1}$. At Mposa, the harvest index at 1 666 plants ha$^{-1}$ was 13.03 kg m$^{-1}$, and at Eshowe it was 11.82 kg m$^{-1}$, with the corresponding values for the highest density being 9.4 % and 10.4 % less than the harvest index of the lowest density.

Decreased bunch mass resulting from increase in density (Fig. 24) had the greatest effect on the harvest index. The plant height component (Fig. 17) had an effect on the index value in certain ratoon crops, but overall had a minimal effect compared to bunch mass. The harvest index is an indication of the amount of plant dry matter in the fruit and in the pseudostem. The higher the ratio the more dry matter there is in the fruit. Theoretically therefore, plants at lower densities have a greater biological efficiency due largely to their greater bunch mass. For further discussion on harvest index refer to section 3.1.3.2.

### *3.2.3.3 Finger length*

The central finger on the upper whorl of the third hand was measured on every data bunch. Results are summarised in Fig. 26.

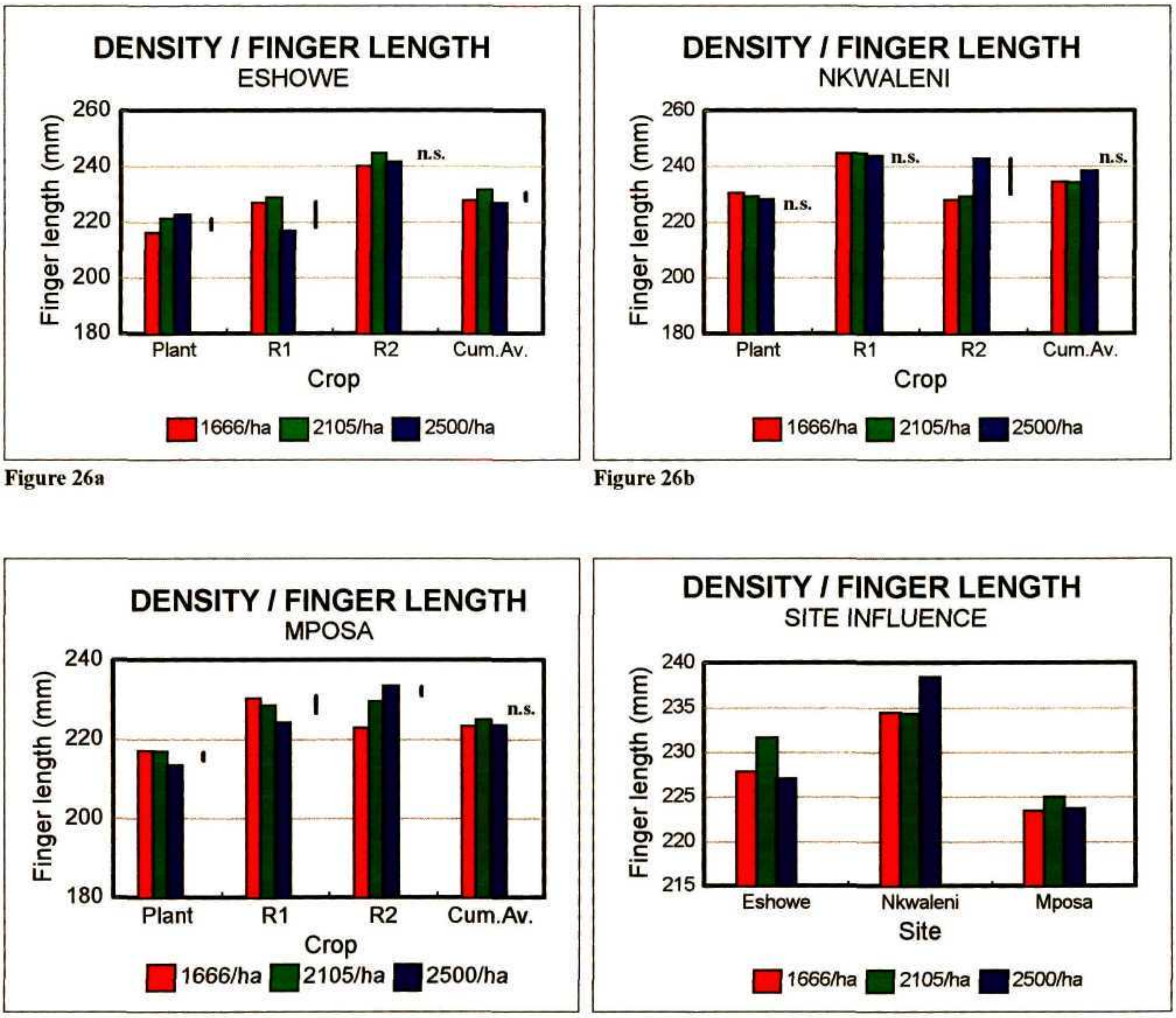


**Figure 26a** **Figure 26b**

**Figure 26c** **Figure 26d**

**Figure 26:** Variations in finger length (mm) at three plant density levels over three crop cycles at three sites, with averages at each site . Vertical bars represent LSD at P = 0.05 and n. s. represents non-significance.

For a discussion of these and other bunch component results refer to section 3.2.3.4.

### *3.2.3.4 Bunch Component Differences*

These differences were measured on every data plant and comprised measurements of the number of hands per bunch, the number of fingers on the third hand, the mass of the third hand and bunch stalk mass. Results are summarised in Tables 7 to 9.

**Table 7. Variations in bunch components at three plant densities over three crops: ESHOWE**

| Crop Cycle | Density | No. of Hands Bunch$^{-1}$ | Stalk Mass (kg) | Stalk as % of Bunch | Mass of 3rd Hand (kg) | No. of Fingers on 3rd Hand | Mass Finger $^{-1}$ (g) |
|---|---|---|---|---|---|---|---|
| Plant | 1666 ha$^{-1}$ | 9.52 | 2.60 | 9.12 | 3.24 | 18.80 | 172.4 |
| | 2105 ha$^{-1}$ | 9.71 | 2.52 | 8.74 | 3.24 | 18.90 | 171.3 |
| | 2500 ha$^{-1}$ | 9.94 | 2.42 | 8.33 | 3.18 | 19.00 | 167.8 |
| | **LSD ( P=0.05)** | 0.16 | 0.08 | 0.23 | n.s. | n.s. | 3.1 |
| R1 | 1666 ha$^{-1}$ | 10.48 | 2.49 | 7.97 | 3.21 | 19.30 | 166.9 |
| | 2105 ha$^{-1}$ | 10.96 | 2.41 | 7.64 | 3.16 | 19.80 | 158.9 |
| | 2500 ha$^{-1}$ | 10.00 | 1.89 | 7.21 | 2.79 | 19.00 | 147.6 |
| | **LSD (P=0.05)** | 0.47 | 0.16 | 0.31 | 0.16 | 0.77 | 5.6 |
| R2 | 1666 ha$^{-1}$ | 11.00 | 2.46 | 7.25 | 3.50 | 20.40 | 171.0 |
| | 2105 ha$^{-1}$ | 10.38 | 2.15 | 6.95 | 3.32 | 19.80 | 167.6 |
| | 2500 ha$^{-1}$ | 9.78 | 2.01 | 7.23 | 3.10 | 18.90 | 164.0 |
| | **LSD (P=0.05)** | 0.40 | 0.13 | 0.28 | 0.16 | 0.49 | 5.6 |
| Cum. Av. | 1666 ha$^{-1}$ | 10.33 | 2.51 | 8.11 | 3.31 | 19.50 | 170.1 |
| | 2105 ha$^{-1}$ | 10.32 | 2.36 | 7.78 | 3.24 | 19.50 | 166.0 |
| | 2500 ha$^{-1}$ | 9.92 | 2.11 | 7.59 | 3.02 | 18.90 | 159.8 |
| | **LSD (P=0.05)** | 0.19 | 0.08 | 0.15 | 0.08 | 0.32 | 2.8 |

**Table 8. Variations in bunch components at three plant densities over three crops: NKWALENI**

| Crop Cycle | Density | No. of Hands Bunch$^{-1}$ | Stalk Mass (kg) | Stalk as % of Bunch | Mass of 3rd Hand (kg) | No. of Fingers on 3rd Hand | Mass Finger$^{-1}$ (g) |
|---|---|---|---|---|---|---|---|
| Plant | 1666 ha$^{-1}$ | 10.32 | 2.62 | 7.62 | 3.80 | 19.01 | 200.1 |
| | 2105 ha$^{-1}$ | 10.10 | 2.42 | 7.66 | 3.51 | 18.65 | 188.5 |
| | 2500 ha$^{-1}$ | 10.19 | 2.30 | 7.47 | 3.42 | 18.52 | 184.5 |
| | **LSD (P=0.05)** | n.s. | 0.13 | n.s. | 0.12 | 0.37 | 4.6 |
| R1 | 1666 ha$^{-1}$ | 10.17 | 2.47 | 7.02 | 3.83 | 19.08 | 200.9 |
| | 2105 ha$^{-1}$ | 9.94 | 2.41 | 7.23 | 3.69 | 18.75 | 196.7 |
| | 2500 ha$^{-1}$ | 9.99 | 2.27 | 7.04 | 3.60 | 18.61 | 193.6 |
| | **LSD (P=0.05)** | n.s. | 0.14 | n.s. | 0.13 | n.s. | 5.0 |
| R2 | 1666 ha$^{-1}$ | 10.75 | 2.49 | 7.02 | 3.79 | 19.91 | 190.5 |
| | 2105 ha$^{-1}$ | 10.52 | 2.39 | 6.96 | 3.69 | 19.44 | 190.0 |
| | 2500 ha$^{-1}$ | 10.20 | 2.23 | 6.79 | 3.62 | 18.91 | 191.5 |
| | **LSD (P=0.05)** | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| Cum. Av. | 1666 ha$^{-1}$ | 10.41 | 2.53 | 7.22 | 3.81 | 19.32 | 197.2 |
| | 2105 ha$^{-1}$ | 10.18 | 2.41 | 7.28 | 3.63 | 18.95 | 191.6 |
| | 2500 ha$^{-1}$ | 10.12 | 2.27 | 7.10 | 3.54 | 18.69 | 189.8 |
| | **LSD (P=0.05)** | n.s. | 0.10 | n.s. | 0.12 | n.s. | 3.0 |

**Table 9. Variations in bunch components at three plant densities over three crops : MPOSA**

| Crop Cycle | Density | No. of Hands Bunch$^{-1}$ | Stalk Mass (kg) | Stalk as % of Bunch | Mass of 3rd Hand (kg) | No. of Fingers on 3rd Hand | Mass Finger $^{-1}$ (g) |
|---|---|---|---|---|---|---|---|
| Plant | 1666 ha$^{-1}$ | 10.69 | 2.35 | 7.43 | 3.39 | 19.76 | 172.0 |
| | 2105 ha$^{-1}$ | 10.62 | 2.33 | 7.44 | 3.32 | 19.46 | 170.6 |
| | 2500 ha$^{-1}$ | 10.60 | 2.24 | 7.50 | 3.18 | 19.28 | 165.1 |
| | LSD (P=0.05) | n.s. | 0.11 | n.s. | 0.14 | 0.32 | 6.2 |
| R1 | 1666 ha$^{-1}$ | 10.68 | 2.94 | 8.46 | 3.62 | 20.17 | 179.2 |
| | 2105 ha$^{-1}$ | 10.73 | 2.78 | 8.60 | 3.36 | 20.03 | 167.7 |
| | 2500 ha$^{-1}$ | 10.26 | 2.52 | 8.55 | 3.07 | 19.21 | 159.8 |
| | LSD (P=0.05) | 0.32 | 0.17 | n.s. | 0.14 | 0.54 | 5.4 |
| R2 | 1666 ha$^{-1}$ | 10.01 | 2.36 | 8.30 | 3.06 | 19.30 | 158.5 |
| | 2105 ha$^{-1}$ | 9.78 | 2.25 | 8.07 | 3.12 | 18.78 | 165.9 |
| | 2500 ha$^{-1}$ | 9.18 | 2.05 | 7.71 | 3.11 | 18.06 | 172.4 |
| | LSD (P=0.05) | 0.30 | 0.11 | 0.23 | n.s. | 0.46 | 4.8 |
| Cum. Av. | 1666 ha$^{-1}$ | 10.46 | 2.55 | 8.06 | 3.36 | 19.74 | 169.9 |
| | 2105 ha$^{-1}$ | 10.37 | 2.45 | 8.04 | 3.26 | 19.42 | 168.1 |
| | 2500 ha$^{-1}$ | 10.01 | 2.27 | 7.92 | 3.12 | 18.85 | 165.8 |
| | LSD (P=0.05) | 0.20 | 0.94 | n.s. | 0.10 | 0.31 | 3.8 |

The effect of plant density on finger length varied greatly between crop cycles and sites with no distinct pattern emerging. Overall fingers at Eshowe were longest (232 mm) at a density of 2 105 plants ha$^{-1}$. Those at Nkwaleni were longest (238 mm) at the highest density and at Mposa the longest fingers (225 mm) were produced at a density of 2 105 plants ha$^{-1}$ (Fig. 26). These inconsistent results contrast with the findings of Robinson and Nel (1989b) who established that finger length generally declined quite significantly with an increase in density in the R2 and R3. However, their increase in finger length in the R2 when density increased from 1 666 to 2 222 plants ha$^{-1}$ was attributed to a large proportion of bunches at the 1 666 density flowering in October/November when bunch mass potential was low and fingers more stunted. This seasonal effect on bunch mass potential in the subtropics is quite possibly the cause of the variations experienced in the finger length at the different densities in this trial. Daniells *et al.* (1987) found a very slight reduction in finger length with increase in density from 1 736 to 2 825 plants ha$^{-1}$, but also experienced certain inconsistencies, which could probably be explained by seasonal variations.

Other components of bunch mass also failed to produce consistent trends throughout the study. For example, there were significantly more hands per bunch at the higher densities in the P cycle at Eshowe (Table 7), and a significant increase in finger mass with increase in density in the R2 cycle at Mposa (Table 9). These inconsistencies were most probably induced by seasonal variation, as was experienced by Robinson and Human (1988) and Robinson and Nel (1989b). However when the cumulative average figures for the three crop cycles are considered, the overall trend was for a reduction in the bunch components with an increase in plant density. Thus, the number of hands per bunch resulting from the highest densities, decreased by 4, 2.8 and 4.3 % at Eshowe, Nkwaleni and Mposa, respectively. Similarly, a reduction in the number of fingers per hand when comparing the highest to the lowest density, was 3.1, 3.3 and 4.5 % for Eshowe, Nkwaleni and Mposa respectively. The corresponding figures for the third hand mass resulted in reductions of 8.8, 7.1 and 7.1 % respectively and the reduction in individual finger mass was 6.1, 3.8 and 2.4 % for Eshowe, Nkwaleni and Mposa, respectively. (Tables 7-9).

If one discounts the increase in finger mass that was associated with an increase in density in the R2, at both Nkwaleni and Mposa which, in turn, was associated with seasonally later bunch emergence, then the overall deduction from the data presented is that bunch development (third hand mass and finger mass) appeared to be influenced by density to a greater extent than was bunch initiation (number of hands and fingers). There was as much as an 11.8 % decrease in finger mass in the R1 at Mposa when comparing the high density with the low density. Components determined at bunch initiation are evidently influenced more by seasonal factors than by density changes. This trend was also established by Robinson and Nel (1989b), who worked with a maximum of 2 222 plants ha$^{-1}$. In instances where bunch components, which are determined at initiation, were more substantially affected by density than in the current review, the density being evaluated was invariably higher. For example, Irizarry *et al.* (1975) found significantly fewer plantain fingers per bunch at high density, but this was at a very high density of almost 4 444 plants ha$^{-1}$.

The stalk mass, when expressed as a percentage of the bunch mass, was lower at the high density compared to the low densities, with differences being significant in all crops at Eshowe. At Nkwaleni and Mposa the reduction in stalk mass with increase in density was significant in most instances, but when expressed as a percentage of bunch mass this difference was only significant in the R2 at Mposa (Tables 7-9). The somewhat minor effect of density on stalk mass is reflected in the mass of marketable fruit used in determining the gross margins (Fig. 28).

The variability in results achieved (due to season) was similar to that experienced in the trial of Robinson and Nel (1989b) at Burgershall, although in both instances the overall trend is towards a decrease in the bunch component identifier with an increase in plant density. Daniells *et al.* (1987) also experienced a certain degree of variability, but the overall decline in bunch mass was attributed to fewer fingers per bunch (-18 %) rather than a decline in finger mass (-5 %). This response was also reflected in the third hand finger length which only declined slightly at the higher densities .

The significant reduction in bunch mass with increase in density (Fig. 24) may be attributed to an overall decrease in the number of hands per bunch and fingers per hand, as well as a reduction in the mass of both hands and fingers and these trends may be influenced by both seasonal effects at flower initiation, as well as the direct effect of density itself.

### *3.2.3.5 Effect of Plant Density on Productivity*

The total bunch mass produced at each density was divided by the average cycle time (days) and multiplied by 365 to achieve the overall yield per hectare per annum. Results are summarised in Fig.27.

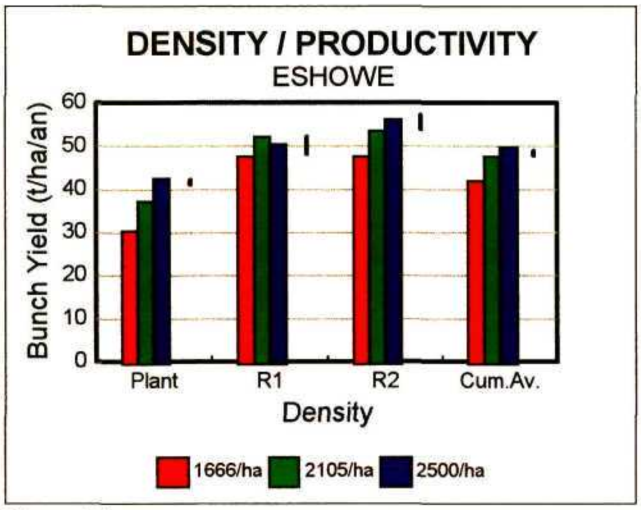


**Figure 27a**

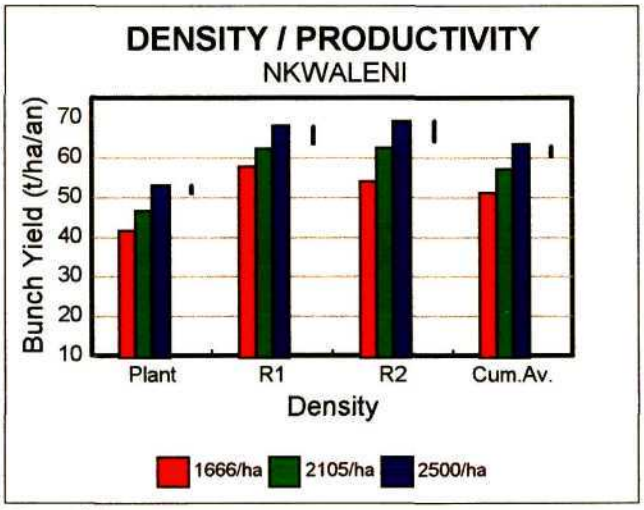


**Figure 27b**

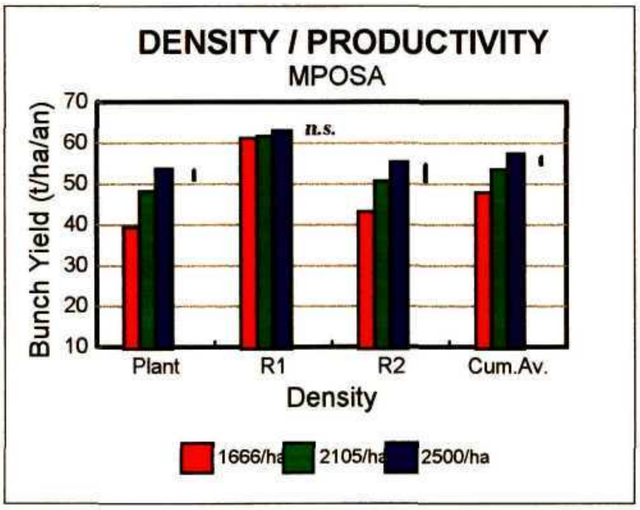


**Figure 27c**

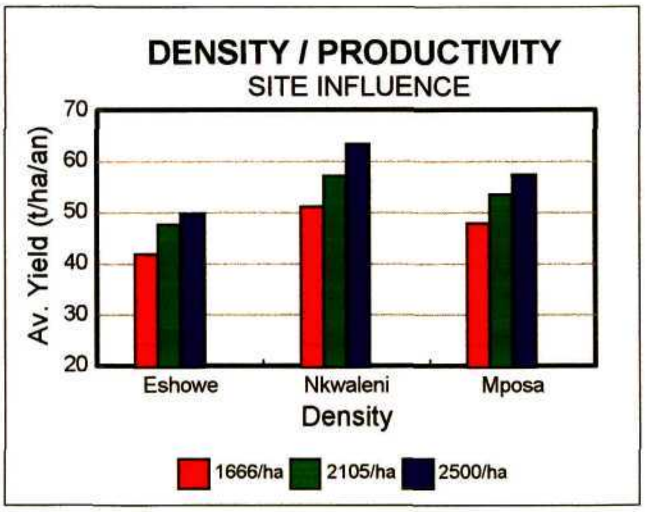


**Figure 27d**

**Figure 27:** Variations in productivity (t $ha^{-1}$ $an^{-1}$) at three plant density levels over three crop cycles at three sites, with averages at each site. Vertical bars represent LSD at $P = 0.05$ and n.s. represents non-significance

With the exception of the R1 cycle at Mposa, all crops and sites exhibited significant increases in productivity with an increase in density. In every instance, except the 2 500 density in the R1 at Eshowe there were overall increases in productivity with an increase in plant density (Fig. 27).

Numerous researchers world-wide have established that, despite reduced bunch component values, the unit area productivity at higher plant densities is greater than at lower densities (Lichtemberg *et al.,* 1986; Arango-Bernal, 1987; Daniells *et al.,* 1987; Sandrini *et al.,* 1991; Bose *et al.,* 1992; Anil *et al.*, 1994) Locally, researchers have established similar trends (Robinson and Nel, 1989b; Robinson *et al.*, 1993b; Morse and Robinson, 1996b- in press). Generally, most of these researchers established optimum densities ranging from 2 000 to 2 500 plants ha$^{-1}$ for Cavendish type cultivars. However, the optimum density varies tremendously according to cultivar, locality and number of crop cycles analysed. Singh and Kashyap (1992) and Robinson *et al.* (1993b) both established maximum productivity in the plant crop at 5 555 plants ha$^{-1}$. However, Robinson (1995b) showed that as the high density trial continued into the ratoons, the productivity of the high densities declined dramatically, even after halving the population, and after three cycles the recommended density for maximum economic returns was down to 2 222 plants ha$^{-1}$. These findings confirmed that productivity could increase almost linearly with increasing density in the plant crop but that interplant competition in the ratoons severely curtailed productivity of the ultra high densities.

At all three sites, highest cumulative production was achieved at the highest density of 2 500 plants ha$^{-1}$ after three crops. Even at the cooler Eshowe site, the cumulative average production of 49.8 t ha$^{-1}$ an$^{-1}$ at 2 500 plants ha$^{-1}$ was 4.4 % higher than that at 2 105 plants ha$^{-1}$. The respective high density yields at Nkwaleni and Mposa were 64.0 and 57.4 t ha$^{-1}$ an$^{-1}$ , which was 11.2 % and 7.2 % higher than the intermediate density at each site (Fig.27). In the R1 cycle the 2 105 density produced the highest annual yield at Eshowe and it appeared that the higher density would fail to perform in future ratoons. However, the higher density regained its superiority in the R2 and overall, was the density with the highest production. The deviation in the R1 could well have been induced by seasonal influences on bunch mass, although the significant reduction in bunch mass in the R2 with an increase in density (Fig. 24), leads one to believe that future ratoons could well see a reversal of the productivity in favour of the lower plant densities. Based on density alone, the highest cumulative production at Nkwaleni and Mposa was achieved at 2 500 plants ha$^{-1}$ but it is also debatable if this could continue for another ratoon or two.

The increase in productivity in the ratoons relative to the plant crop has been reported on in section 3.1.3.5. and is due, both to the increase in bunch mass, as well as to the reduction in cycle time. However, this is not so pronounced in the R2 relative to the R1, suggesting increased inter-plant competition which may start to adversely affect higher density plantations in the R3 or R4 cycle.

### 3.2.4 Economic Returns

The optimum density is that at which annual gross margin per hectare is maximized over the entire plantation life (Robinson, 1996). The marketable yields were determined by deducting the stalk mass (Tables 7 to 9) from the production figures presented in Fig. 27 a-d, to arrive at fruit mass. This figure was further reduced by a factor of 10 % to account for blemished fruit and wastage. An average value of R1 510 per tonne was assigned to the crop (average Durban market prices, May 1995 - April 1996) and all production, harvesting, transport and marketing costs were deducted. Gross margin was determined by deducting variable production costs from gross income and this is shown in Fig. 28.

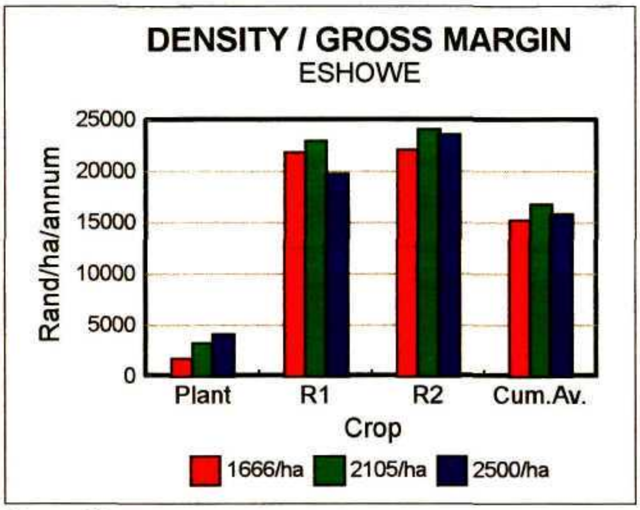


**Figure 28a**

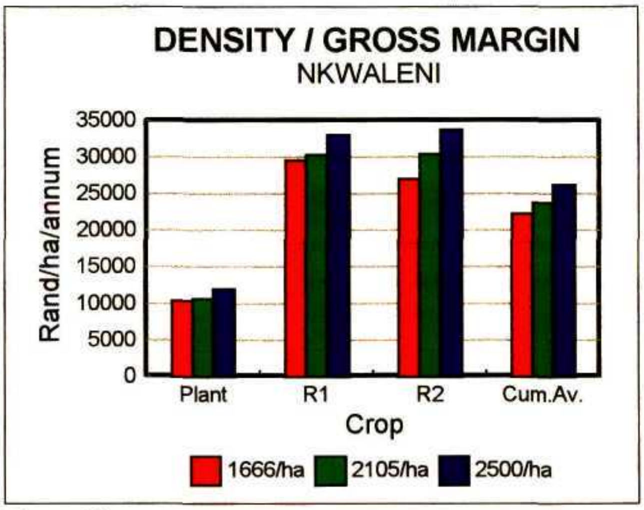


**Figure 28b**

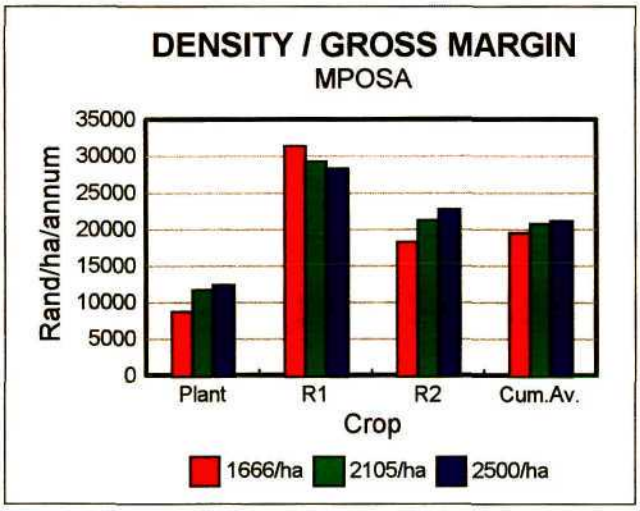


**Figure 28c**

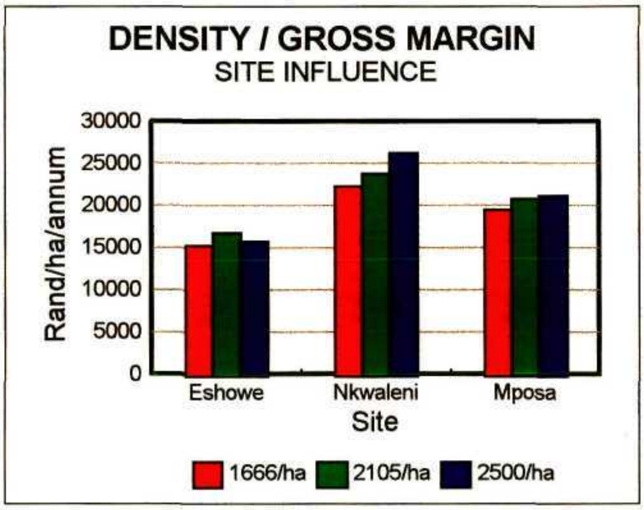


**Figure 28d**

**Figure 28:** Gross margins (gross income-variable costs) for three densities over three crop cycles at three sites, with the respective cumulative average at each site compared.

Unlike the economic returns for cultivars, where the ranking order for gross margin was virtually identical to that of cultivar productivity (Fig. 16), the plant densities that yielded the highest economic returns were not necessarily those that provided highest productivity. This is because there are a number of costs related to an individual plant that will substantially increase the cost per hectare with an increase in density. Examples are planting material, fertilizer, pesticides, fungicides, bunch covers, props and labour. In the plant crop, the variable costs at high density amounted to R5 391 more than that at low density. This amount excludes harvest labour costs. Consequently highest economic returns for Eshowe were achieved at the intermediate density of 2 105 plants ha$^{-1}$ for all ratoon crops, as well as the cumulative average, and not at 2 500 plants ha$^{-1}$ which had the highest productivity. The average annual gross margins at Eshowe for the low, medium and high densities were R15 236, R16 777 and R15 833 ha$^{-1}$ for the three crop cycles (Fig. 28a). At Nkwaleni, the greatest economic returns were achieved at a density of 2 500 plants ha$^{-1}$ over all crops. The average annual gross margins for the low, medium and high densities were R22 290, R23 806 and R26 257 ha$^{-1}$ respectively (Fig. 28b). At Mposa the highest gross margin was achieved at the high density in the plant crop, the low density in the R1 and again at the high density in the R2. The average annual gross margins for the low, medium and high densities were R19 502, R20 781 and R21 192 ha$^{-1}$ (Fig. 28c) , thus favouring the high density overall. It is clear that gross margin analyses should be used to determine density choice and not productivity alone.

Density studies with 'Chinese Cavendish' at Burgershall (Robinson, 1995b) showed that, although highest gross income occurred at 5 555 plants ha$^{-1}$ in the plant crop, the highest gross margin was jointly achieved at much lower densities of 2 777 and 3 333 plants ha$^{-1}$. After two crop cycles, the highest average gross margin was realised from the 2 777 regime and this level was also the most productive after three cycles. Robinson, however, contended that it was unlikely that 'Chinese Cavendish' could sustain an economic advantage at the 2 777 density for more than three or four cycles, and since commercial plantations last for 8 to 10 cycles, he recommended that 2 222 plants be regarded as the optimum in the long term. Based on the same economic criteria, a density of 1 666 ha$^{-1}$ is recommended for 'Williams' at the cooler Burgershall, and not the density of 2 222 plants ha$^{-1}$ which gave the highest productivity. Morse and Robinson (1996b- in press) achieved maximum economic returns over three crop cycles with a density of 2 618 plants ha$^{-1}$. This was based on an average production from six different Cavendish cultivars in a hot area. Thus, data from this study as well as from the literature, clearly show that highest economic returns are most likely to be achieved from a higher density in a hot area, and from a somewhat lower density in a cool area (Fig. 28b)

## 3.3 CULTIVAR / DENSITY INTERACTION

Whilst the two treatments dealt with in the previous sections (cultivars and densities), were evaluated separately, it is the interaction of these treatments that determines what cultivar should be grown at what density in each area. The two treatments have been dealt with in detail above and this section only deals with the productivity and economic returns achieved as a result of the interaction between the two treatments.

### 3.3.1 Effect of Density on Cultivar Productivity

The total bunch mass produced by each cultivar/density treatment was divided by its average cycle time (days) and multiplied by 365 to achieve the overall productivity (t $ha^{-1}$ $an^{-1}$).

***3.3.1.1 Effect of Density on Cultivar Productivity: Eshowe*** Results are summarised in Fig.29.

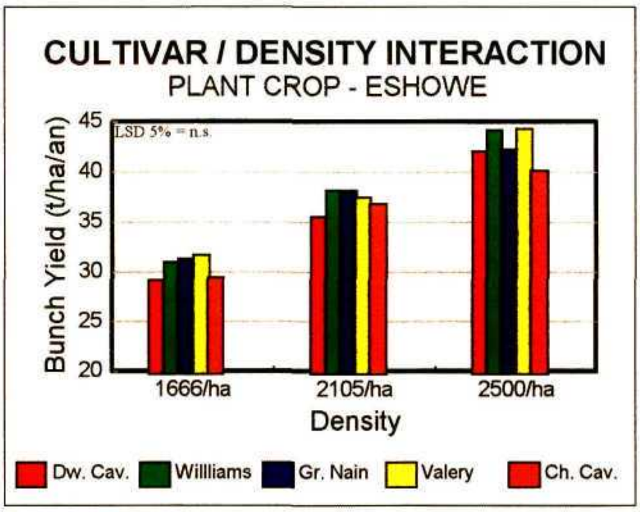


**Figure 29a**

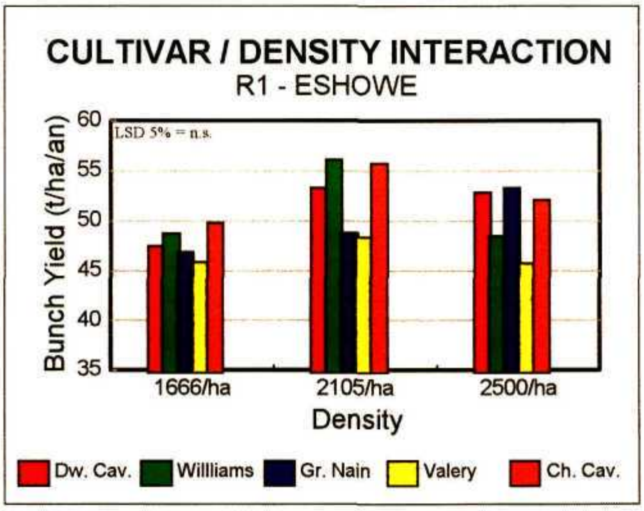


**Figure 29b**

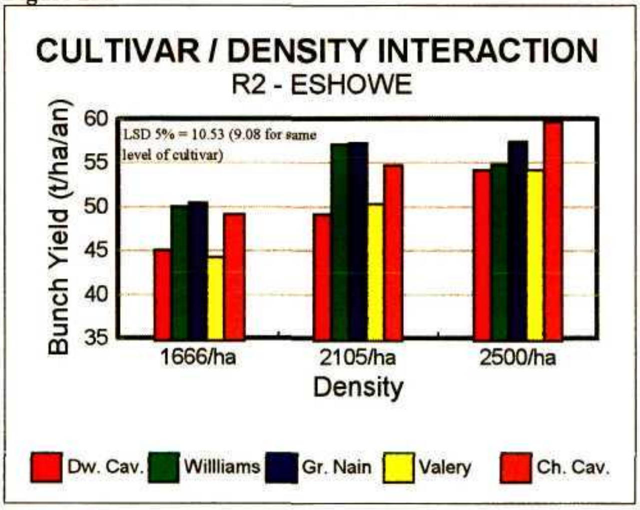


**Figure 29c**

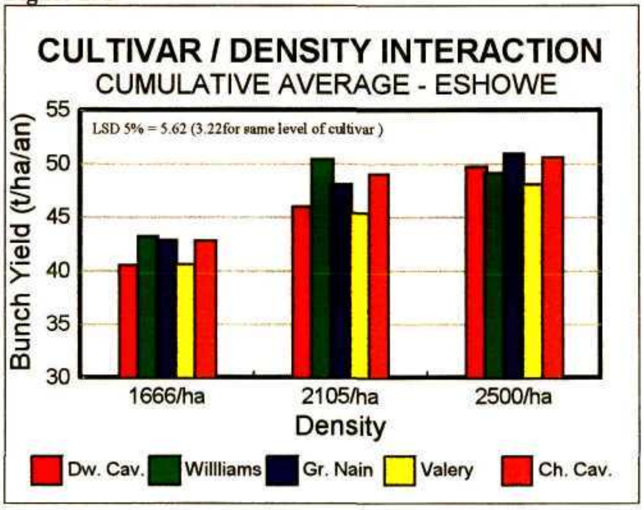


**Figure 29d**

**Figure 29:** The productivity of five cultivars, expressed as bunch t $ha^{-1}$ $an^{-1}$ at three plant densities over three crop cycles at Eshowe, with the cumulative averages presented in d.

### *3.3.1.2 Effect of Density on Cultivar Productivity : Nkwaleni*

Results are summarised in Fig.30 and discussed in section 3.3.1.3, together with the results from Eshowe and Mposa.

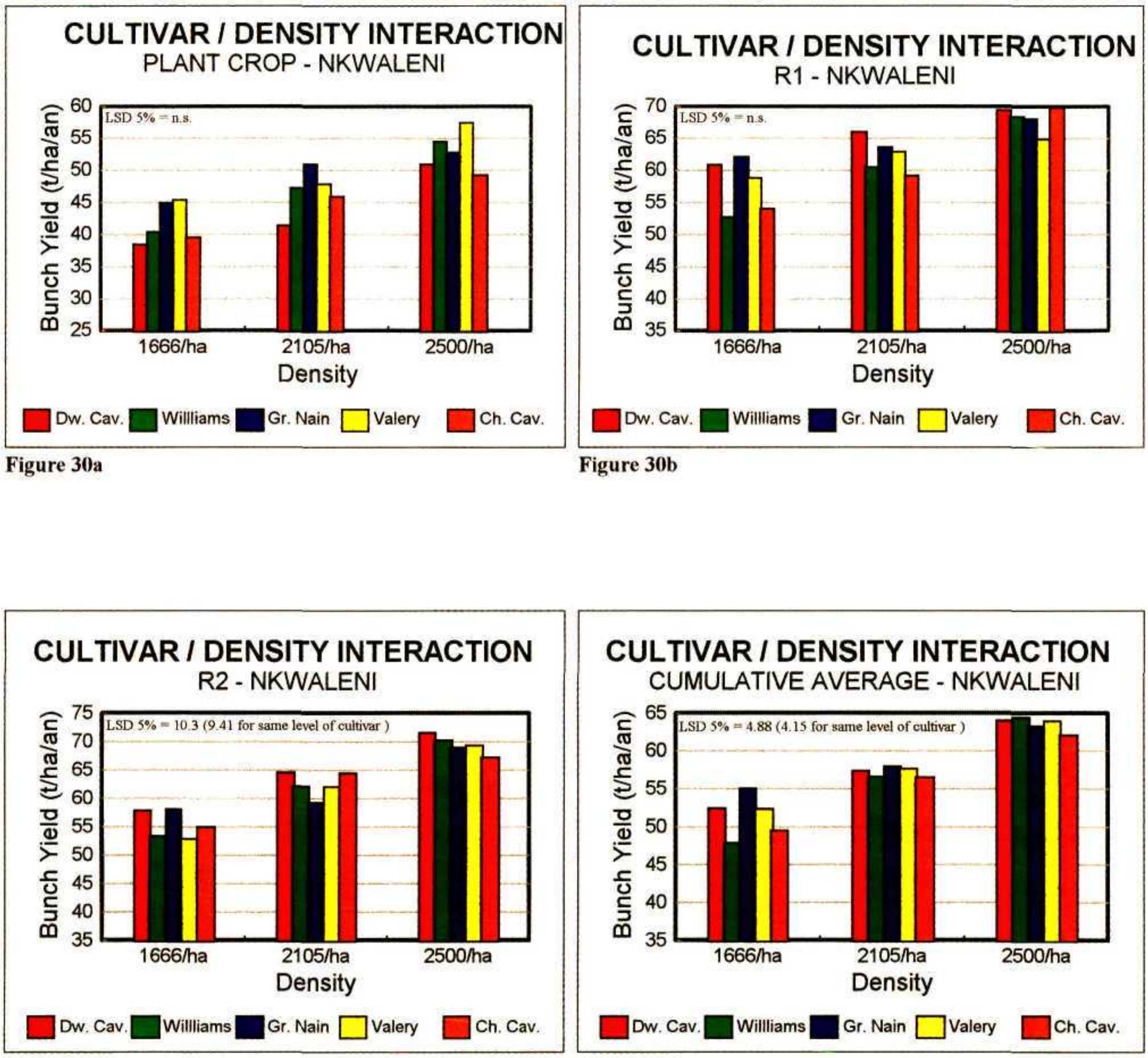


**Figure 30a**

**Figure 30b**

**Figure 30c**

**Figure 30d**

**Figure 30:** The productivity of five cultivars, expressed as bunch t ha$^{-1}$ an$^{-1}$ at three plant densities over three crop cycles at Nkwaleni, with the cumulative averages presented in d.

### *3.3.1.3 Effect of Density on Cultivar Productivity : Mposa*

Results are summarised in Fig. 31.

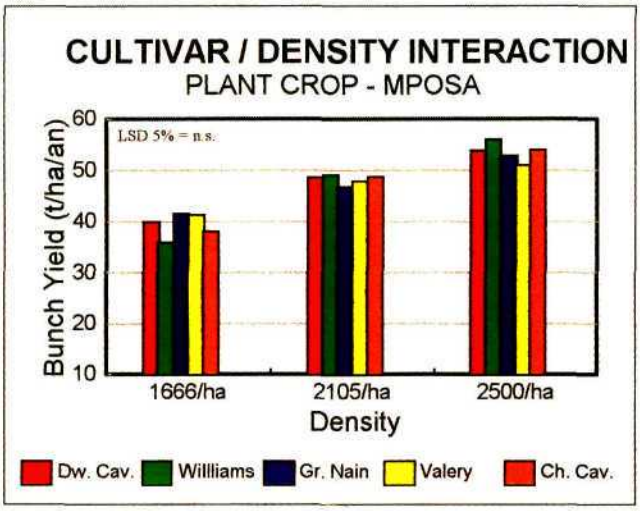


**Figure 31a**

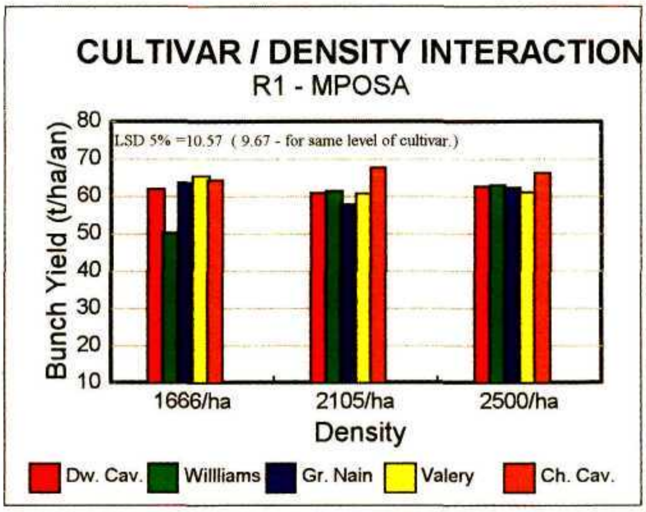


**Figure 31b**

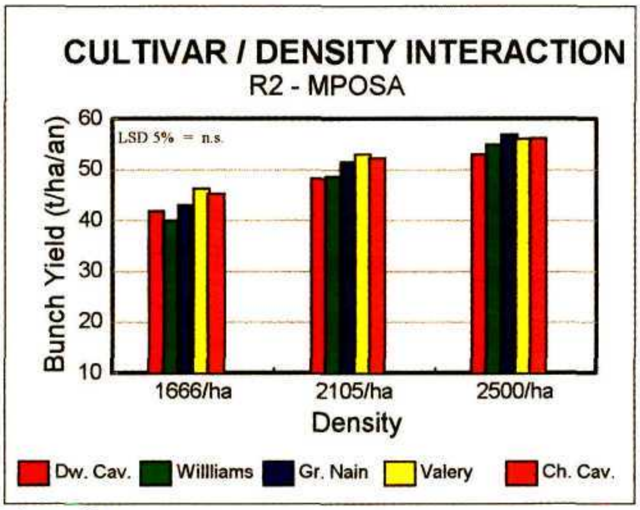


**Figure 31c**

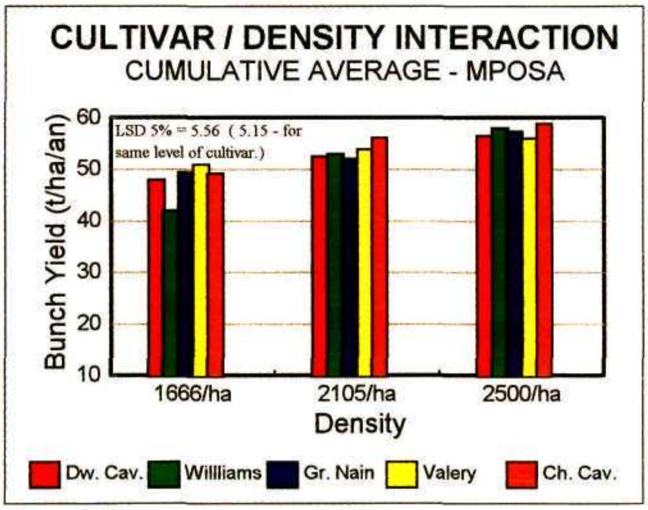


**Figure 31d**

**Figure 31:** The productivity of five cultivars, expressed as bunch t ha$^{-1}$ an$^{-1}$ at three plant densities over three crop cycles at Mposa, with the cumulative averages presented in d.

The most significant trend observed in the plant crop was that of increasing productivity with an increase in density at all sites (Figs. 29-31). This was purely the result of additional plants per unit area. The competitive effects such as reduced bunch mass and longer cycling, only became evident from the R1 onwards and did not significantly affect the performance of individual plants, in the plant crop. This phenomenon has been dealt with in section 3.2.3.

At Eshowe the performance of 'Valery' in the plant crop was good at all density levels. What is important however is that this cultivar then performed poorly in the ratoons, relative to the other cultivars, indicating that it should not be recommended in the cooler area (Fig.29). By contrast, Morse and Robinson (1996 a; b- in press) found that 'Valery' performed well in the hot Komatipoort district, relative to its poorer performance at the cooler Burgershall site. 'Chinese Cavendish' had a relatively poor start in the P cycle, but due to quicker cycling, performed well in the ratoons, particularly at the higher densities. 'Grand Nain' planted at 2 500 plants $ha^{-1}$ was the overall top performer (51.0 t $ha^{-1}$ $an^{-1}$), closely followed by 'Chinese Cavendish' at the same density (50.7 t $ha^{-1}$ $an^{-1}$ ), which in turn was slightly ahead of 'Williams' at 2 105 plants $ha^{-1}$ (50.5 t $ha^{-1}$ $an^{-1}$ ). However, these differences were relatively small and other characteristics, particularly economic returns, should be considered prior to a decision being taken on the recommended combination. At Nkwaleni there was a consistently poor performance from 'Williams' at the low density, yet it performed well at the highest density and in fact, was the top performer after three cycles with 64.4 t $ha^{-1}$ $an^{-1}$. This was closely followed by 'Dwarf Cavendish' (64 t $ha^{-1}$ $an^{-1}$ ) and 'Valery' (63.9 t $ha^{-1}$ $an^{-1}$) at the same high density. Again, mean yield differences were small (Fig.30). At Mposa, 'Williams' performed equally poorly at the lowest density (42.1 t $ha^{-1}$ $an^{-1}$ ), yet was the second highest producer after 'Chinese Cavendish' at the highest density (58 and 58.9 t $ha^{-1}$ $an^{-1}$ respectively) (Fig.31).

The relatively poor performance of 'Williams' at low densities and its good performance at the higher densities in both of the hotter sites, suggests that 'Williams' is fairly susceptible to heat exposure. At the higher densities a cooler microclimate is created ( section 3.2.2.2 ) and 'Williams' is apparently better adapted physiologically, to such a microclimate. When one considers the overall poor performance of 'Williams' at both Nkwaleni and Mposa (section 3.1.3.5), this masks the fact that 'Williams' was the best and second best performer respectively at 2 500 plants $ha^{-1}$. 'Valery' had consistently good performance at the low and medium density at Mposa and this gives credence to the claim by Morse and Robinson

(1996 a; b- in press ) that 'Valery' performs well in a hot climate. 'Dwarf Cavendish' performed well at Nkwaleni at the highest density and rated reasonably well at Mposa at the higher densities. This better performance by 'Dwarf Cavendish' in the hotter areas is also supported by Morse and Robinson (1996 a; b).

### 3.3.2 Economic Returns

The marketable yields were determined by deducting the stalk mass from the production figures presented in Figs. 29-31 to arrive at fruit mass. This figure was further reduced by a factor of 10 % to account for blemished fruit and wastage. An average value of R1 510 per tonne was assigned to the crop (average Durban market prices, May 1995 - April 1996) and all production, harvesting, transport and marketing costs were deducted. Gross margin was determined by deducting variable production costs from gross income and this is shown in Fig. 32.

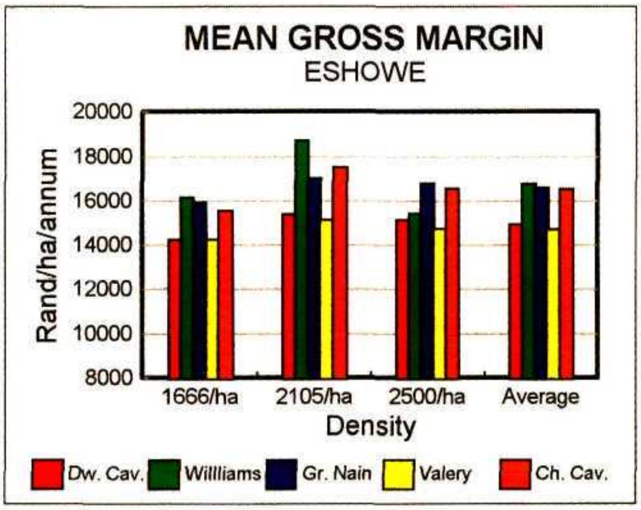


**Figure 32a**

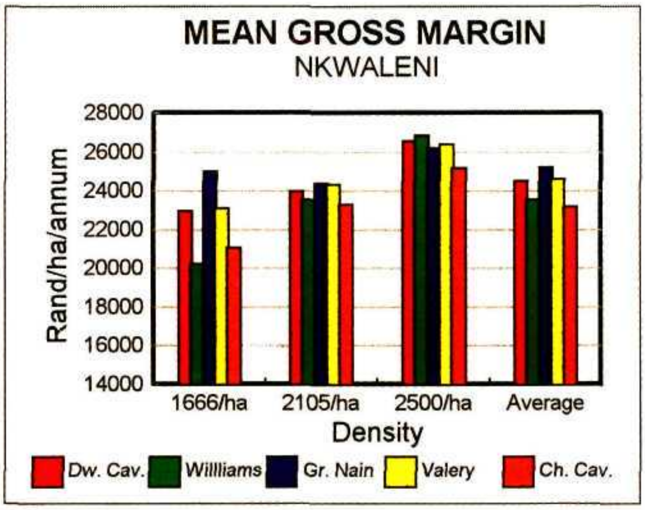


**Figure 32b**

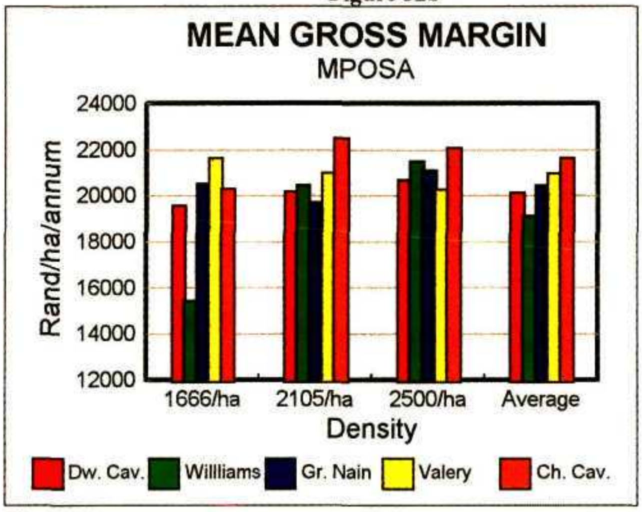


**Figure 32c**

**Figure 32:** Mean annual gross margins (gross income - variable costs) for five cultivars at three plant densities at three sites.

The ranking order of cultivar profitability within a specific plant density was virtually identical to that of productivity. The performance between densities varied according to the increase in costs with an increase in density.

At Eshowe the highest annual gross margin per hectare (R18 730 ) was made from 'Williams' at 2 105 plants ha$^{-1}$ followed by 'Chinese Cavendish' (R17 526) and 'Grand Nain' (R17 032) at the same density (Fig. 32a). Although the highest production was from 'Grand Nain' at 2 500 plants ha$^{-1}$ (Fig. 29), the gross margin was almost R2 000 less than that from 'Williams' at the intermediate density and, given the strong likelihood of declining production at the higher densities (section 3.2.3.5), the recommended combination is 'Williams' at 2105 plants ha$^{-1}$. It is highly likely that the quick cycling 'Chinese Cavendish' will outperform 'Williams' in future ratoons and if markets do not discriminate against the somewhat poorer fruit quality, this cultivar could be considered at the intermediate density.

At Nkwaleni the highest annual gross margin per hectare (R26 884) was made from 'Williams' at 2 500 plants ha$^{-1}$ followed by 'Dwarf Cavendish' (R26 590) and 'Valery' (R26 418) at the same density (Fig.32b). Of interest is that 'Grand Nain' at 1 666 plants ha$^{-1}$ realised a gross margin of R25 022 , only R1 862 less than 'Williams' at the high density. Based on the data from three crop cycles the recommended combination for Nkwaleni is 'Williams' at 2 500 plants ha$^{-1}$, but if one accepts that declining vigour at the high density in future ratoons will favour the lower densities, then 'Grand Nain' with it's superior fruit and overall good productivity, should be considered at a lower density.

At Mposa, 'Chinese Cavendish' at 2 105 plants ha$^{-1}$ produced the highest annual gross margin per hectare (R22 527), followed by the same cultivar at the high density (R22 090) and in turn by 'Valery'(R21 635) at 1 666 plants ha$^{-1}$ (Fig. 32c). If this plantation had not suffered from a lack of vigour (due to insufficient irrigation) it is likely that the higher density would have realised the greatest economic returns. The good overall performance of 'Chinese Cavendish', coupled with it's relatively short stature, renders this the number one choice of cultivar. Based on an assessment of the data from three crop cycles this cultivar is recommended at a density of 2 105 plants ha$^{-1}$.

# OVERALL DISCUSSION AND CONCLUSIONS

Due to the nature of these trials, each of the two treatments (main plots and sub-plots) is dealt with independently and the cultivar/density interaction must be viewed as the synthesis of the two treatments. The latter must ultimately be regarded as the most important component of the trials and any recommendations for a particular area should be based on a gross margin evaluation of this interaction.

## 1. CULTIVARS

Numerous cultivar trials have been conducted in recent years, both in tropical and subtropical countries (Turner, 1995) and the emphasis has been on distinguishing between cultivars and selection within the Cavendish sub-group. No one cultivar has outperformed the others in all the different sites tested, giving credence to Robinson *et al.*'s (1994c) claim that cultivar trials must be conducted locally in each and every production area.

In Australia, Turner and Hunt (1984) and Daniells and O'Farrell (1988) established that 'Williams' was significantly superior to all other cultivars evaluated. In the tropics of Puerto Rico 'Grand Nain' was consistently the most productive cultivar (Irizarry *et al.* 1989). In the Canary Islands (Galan Sauco *et al.*, 1991;1995) and Burgershall, South Africa, (Robinson *et al.*, 1993a) 'Grand Nain', together with 'Chinese Cavendish' in the latter locality, proved to be superior. In other South African trials, cultivar performance varied between production sites with 'Williams' proving superior at Levubu and the KwaZulu-Natal South Coast (Robinson *et al.* 1994c) and 'Chinese Cavendish' and 'Grand Nain' (Israeli) outperforming the rest at Komatipoort (Morse and Robinson 1996b - in press). Robinson (1996) states that, on the basis of numerous worldwide trials, 'Grand Nain' should eventually become the premier export cultivar from Central American countries as well as the main commercial cultivar in subtropical countries.

Turner (1995) defines productivity as the mass of fruit produced per unit area per unit time ($t\ ha^{-1}\ an^{-1}$). The two basic components of productivity are therefore:-

1) mean bunch mass and 2) number of bunches harvested in a year for any given density. Any comparison between cultivars must concentrate primarily on the components of productivity,

since that ultimately determines the economic returns. The trials in question have been planned, not only to evaluate the productivity of the five cultivars, but in addition, to evaluate the morphological characteristics and bunch component characteristics, all of which have a bearing on the selection of an ideal cultivar for a particular locality.

Robinson *et al.*(1993a) and Robinson *et al.* (1994c) recommended that cultivar trials be conducted over at least four cropping cycles so that cultivars with inherent short cycling, such as 'Chinese Cavendish', can be fully evaluated on a cumulative basis in the long term. Due to time and cost constraints, very few credible national or international cultivar trials are carried beyond the third cropping cycle (Turner and Hunt, 1984; Daniells and O'Farrell, 1988 ; Morse and Robinson, 1996b - in press). The author therefore feels justified in using the results from the three crop cycles and basing cultivar recommendations thereon. However the author also acknowledges that density trends could change in subsequent ratoons, and for commercial purposes, these trials should ideally be allowed to continue.

**Eshowe:** At the Eshowe site, 'Williams' (47 t $ha^{-1}$ $an^{-1}$) was the overall best producer, very closely followed by 'Grand Nain' (46.8 t $ha^{-1}$ $an^{-1}$) and 'Chinese Cavendish' (46.4 t $ha^{-1}$ $an^{-1}$). Contrary to most studies 'Grand Nain' (2.82 m) was actually the tallest cultivar, being just slightly taller than 'Williams' (2.81 m) and significantly taller than 'Chinese Cavendish' (2.62 m). If wind proves to be a problem in a specific locality or aspect one would have to consider the shorter 'Chinese Cavendish'. In reality though, the standard recommendation is to double prop every plant, which to a large extent negates the problem of lodging. However, being shorter with lighter bunches, 'Chinese Cavendish' also facilitates easier handling and management than 'Williams' and in addition has a faster cycling time than all other cultivars and actually outproduced 'Williams' in the R1 and R2. A detraction from 'Chinese Cavendish' is that finger length is 4 mm shorter than that of 'Williams' which is a quality disadvantage. There was also evidence of "choke throat" in a number of plants with winter emerging bunches. Despite this it must be regarded as a serious contender for the number one cultivar choice, particularly in areas that are prone to excessive wind. 'Dwarf Cavendish' on the other hand cannot be considered due to serious "choke throat". 'Valery', notwithstanding the longer fingers, cannot be considered due to it's poor performance in the ratoons. Overall, it also realised the lowest gross margin.

'Grand Nain' produced fingers with a cumulative average length of 237 mm, 5.5 mm longer and 5.5 % heavier than 'Williams. 'Grand Nain' and 'Chinese Cavendish' also had an overall LAI that was slightly (2 % and 12 % respectively) less than that of 'Williams', indicating that they could be planted at a slightly higher density. All things considered, there would be no justification to recommend a wholesale change from the industry standard, 'Williams'. If producers were to become reliant on markets that demanded longer finger length then a move to 'Grand Nain' would have to be considered. 'Chinese Cavendish' could also be considered for specific sites where wind is problematic.

**Nkwaleni:** At the Nkwaleni site, overall best performance was from 'Grand Nain' (58 t $ha^{-1}$ $an^{-1}$) and 'Valery' (57.9 t $ha^{-1}$ $an^{-1}$), closely followed by 'Dwarf Cavendish' (57.6 t $ha^{-1}$ $an^{-1}$). 'Dwarf Cavendish' was in fact the best performer in the two ratoon cycles, due largely to a very quick cycling interval. The advantages of this short cultivar (2.06 m) compared with 'Grand Nain' (2.76 m) have been elucidated in the preceding chapter. The major disadvantages, which mitigate against its acceptance as a cultivar are its shorter fingers (at 222 mm almost 20 mm shorter than 'Grand Nain') and the tendency to "choke" in winter. It should also be borne in mind that the trial site was situated on a mid-slope, some distance up from drainage lines where the incidence of "choke throat" would have been much worse. This phenomenon was evident in a number of plants within the'Dwarf Cavendish' group, yet not at all in others, giving reason to believe that there could be room for selection of superior plants, particularly within this cultivar. A 'Dwarf Cavendish' plant at Nkwaleni had the distinction of producing the heaviest bunch recorded during the trials - (58 kg). On the basis of data gleaned from the "cultivar plots" which were combined over all densities, there is no hesitation in recommending 'Grand Nain' as the number one choice of cultivar for the Nkwaleni site, which is representative of the "Valley Bushveld" Bioclimate. Although finger length, at 242 mm, is ± 3 mm shorter than that of 'Valery', it has highly acceptable fingers. It also outproduced 'Valery' in both the R1 and R2 cycles, giving reason to believe that it's performance in future ratoons should be better than that of 'Valery'.

**Mposa:** At the Mposa site, best overall performance was from'Chinese Cavendish' (54.2 t $ha^{-1}$ $an^{-1}$) followed by 'Valery' (53.3 t $ha^{-1}$ $an^{-1}$). At 222 mm 'Chinese Cavendish' had fingers that were almost 7 mm shorter than that of 'Valery'. However, the overriding consideration at this site, which is representative of the "Coastal Lowlands", with its attendant problem of wind, is the height of the cultivar. At 2.29 m 'Chinese Cavendish' was 240 mm shorter than 'Valery'. With an LAI (R2) that is 7 % less than 'Valery' and 10 % less than 'Grand Nain', 'Chinese Cavendish' could be planted at a higher population, which would assist in providing mutual stability. At high density the wind tends to be forced over the plantation and not through it. With the threat of losing significant production potential as a result of leaf shred (Eckstein, 1994), the need to overcome such wind damage by whatever means, must be investigated. Therefore, 'Chinese Cavendish', despite shorter finger length, is the recommended cultivar for the "Coastal Lowlands".

The cultivar recommendations made here are based solely on the performance of the five cultivars averaged over three density levels. It is imperative therefore, that any final recommendations with regard to cultivars should take cognisance of the cultivar/density interaction discussed later on in this section.

## 2. PLANT DENSITY

The choice of density is an extremely complex issue and no general recommendations can be made to suit all situations. Robinson (1996) states that it is vitally important that the appropriate planting density be chosen because it is one of the major determinants of annual yield per hectare and once chosen, it cannot easily be adjusted at a later stage. The optimum density varies according to each particular locality, cultivar, soil type and management level. Because floral initiation and therefore harvesting, can occur at any time of the year (Turner, 1970), an evaluation of banana yield must take into account the crop-to-crop cycle interval. Numerous researchers such as Daniells *et al.*(1985) and Robinson and Nel (1988b) have demonstrated how susceptible this cycle interval is to changes in density. Since the crop-to-crop cycle of bananas is not specifically annual, unlike most other horticultural tree crops, the optimum density for either high yield or good fruit quality involves a compromise between several components. A high density will induce a longer crop cycle, smaller bunches and smaller fruit size, but total yield per hectare will increase due to the greater number of bunches. However, input costs per hectare increase with increasing density and the optimum density is that at which gross margin per hectare per annum is maximised over the entire plantation life (Robinson, 1995a; 1996).

At the cooler Eshowe site, the reduced heat units had a marked effect on the morphology as well as the phenology, with plants being taller, having a slower leaf emergence rate and producing more leaves per plant than those at Nkwaleni and Mposa. The resultant negative effect on cycling time is significant with Eshowe experiencing far longer vegetative as well as E-H cycle intervals than either of the other two warmer sites. Increasing the density exacerbated this problem by reducing leaf emergence rate, increasing the number of leaves produced and increasing both the vegetative as well as the E-H cycles, giving rise to longer crop-to-crop cycles. This trend was observed at all three sites, but was particularly problematical at the cooler Eshowe site.

Bunch mass was reduced significantly with increasing density at all three sites. However, the percentage reduction attributed to the effect of density (5 to 15 %) was not nearly as great as that reported on by Daniells *et al.* (1985). The range of density evaluated in their trial was far greater (930 to 3 980 plants ha$^{-1}$). Over all cycles and trial sites the trend was for a reduction in the bunch component identifier, with an increase in density. There were deviations from this trend, which could be attributed to season of flower initiation (Robinson and Nel, 1989b) but overall, the number of hands, number of fingers per bunch and mass of third hand was reduced with increased density. The high degree of shading at the higher densities reduces the photosynthetic capacity of each plant to a level which can inhibit fruit filling and development (Eckstein, 1994).

Despite the overall increase in cycle time, and smaller bunches and fingers that were associated with increased density, the overall productivity at all sites was maximised at the highest density, due simply to the greater number of bunches produced per hectare. This was in accordance with the findings of numerous researchers world-wide (Obiefuna *et al.*, 1982; Chundawat *et al.*, 1983; Venero, 1985; Daniells *et al.*, 1985; Robinson and Nel, 1989b; Robinson *et al.*, 1993a). However, in accordance with Robinson's (1995a; 1996) definition of optimum density, the economics of the various treatments was evaluated with interesting results. At Eshowe, where maximum average productivity (49.84 t ha$^{-1}$ an$^{-1}$ ) was achieved at a density of 2 500 plants ha$^{-1}$ over three cycles, the highest economic returns were realised at a lower density of 2 105 plants ha$^{-1}$. This corresponds to an overall LAI of 4.35 in the R1, which is essentially what Turner (1982) recommended as the optimum LAI for 'Williams' in New South Wales, but is less than the 5 recommended by Robinson and Nel (1989b) and Morse and Robinson (1996a - in press). At Nkwaleni, maximum productivity (64.0 t $ha^{-1}$ $an^{-1}$ ) as well as maximum economic returns (R26 257) were realised at a density of 2 500 plants $ha^{-1}$, with a corresponding LAI of 5.3 and 5.6 in the R1 and R2 respectively. Similarly, Mposa realised production (57.4 t $ha^{-1}$ $an^{-1}$) and maximum economic returns at the highest density, with a corresponding LAI of 4.8 in the R1. Although the highest density out-yielded all other densities in all crops, the cumulative average gross margin was only marginally higher than that of the intermediate density (R21 192 compared to R20 781). With increase in plantation age it is highly likely (Robinson, 1995a) that the productivity of the high density will decline further, particularly as this site has already exhibited reduced vigour. This will then shift the gross margin return in favour of the intermediate density or lower.

It should be borne in mind that the density treatments and their results are averaged over five cultivars that can vary quite substantially in terms of morphology, phenology and production. It is therefore imperative that the interaction of cultivars with densities is assessed before any firm recommendations can be made for a particular locality.

## 3. CULTIVAR/DENSITY INTERACTION

One could well conclude that the objective of evaluating cultivars and densities, as set out above, had been adequately covered and satisfactory results achieved. However, as was observed in section 3.3 the interaction of cultivar and density, in certain instances, was significant. For example, the overall performance of 'Williams' cultivar at both of the hotter sites was poor, when considered over all three densities. It was in fact the worst performer at Mposa and the second worst performer at Nkwaleni. However, the reason for this is evident in section 3.3, which clearly illustrates the extremely poor overall performance of 'Williams' at the low density (46.9 and 42.1 t $ha^{-1}$ $an^{-1}$ ) at Nkwaleni and Mposa respectively. This poor performance at the low density had the effect of reducing the overall performance of 'Williams' at these two sites and masked the fact that it performed well at the higher densities.

**Recommendations:-**

**Eshowe:-** When cultivars were considered independently, 'Williams' was the overall best producer at this relatively cool site. The highest density achieved the greatest production although highest gross margins were achieved at the intermediate density. When cultivar/density interaction is considered, the best cumulative average production was achieved by 'Grand Nain' (51.03 t ha$^{-1}$ an$^{-1}$ at 2 500 plants ha$^{-1}$), closely followed by 'Chinese Cavendish' at the same density, which in turn, was closely followed by 'Williams' (50.5 t ha$^{-1}$ an$^{-1}$) at 2 105 plants ha$^{-1}$. This good performance by 'Williams' at a lower density resulted in it realising an annual per hectare return of almost R2 000 more than the top producing 'Grand Nain' at 2 500 plants ha$^{-1}$. The results achieved in the evaluation of the interaction substantiate the results achieved with the independent evaluation of cultivars and densities. The highest annual net income per hectare (R18 730) was achieved by 'Williams' at 2 105 plants ha$^{-1}$, and based on the assessment of three crop cycles, this is the combination that is recommended for the cooler Bioclimatic Group 2 site. Given the likelihood of the quick cycling 'Chinese Cavendish' outperforming 'Williams' in future ratoons, this cultivar could be considered at the intermediate density.

**Nkwaleni:**- 'Grand Nain' was the overall top producing cultivar. Highest production as well as highest gross margin was achieved at a density of 2 500 plants ha$^{-1}$. One would therefore be inclined to recommend the above combination. However, when the cultivar/density interaction was evaluated, it would appear that 'Williams' is physiologically better adapted to the cooler microclimate that is created at high density, and consequently was the best producer (64.4 t ha$^{-1}$ an$^{-1}$) and money generator (R26 884), at 2 500 plants ha$^{-1}$. 'Dwarf Cavendish' out-yielded 'Williams' in both ratoons at this density level and coupled with it's shorter stature, would appear to be a strong contender for first choice cultivar. However, the negative characteristics, such as reduced finger length and "choke throat" mitigate against it's acceptance. 'Williams', at 2 500 plants ha$^{-1}$ would therefore, be the first choice combination in Bioclimatic Group 10. Both 'Valery' and 'Grand Nain' , which realised marginally less (R466 and R668 ha$^{-1}$ an$^{-1}$) and which have longer and heavier fingers than 'Williams', would also be acceptable alternatives at the higher density.

**Mposa:**- 'Chinese Cavendish' was the top producing cultivar. Highest production was achieved at a density of 2 500 plants ha$^{-1}$, and the greatest economic returns were also realised at this density. One would therefore be inclined to recommend 'Chinese Cavendish' at 2 500 plants ha$^{-1}$. However, when the cultivar/density interaction is evaluated, the highest economic return was made from 'Chinese Cavendish' at 2 105 plants ha$^{-1}$, even though production at the higher density was greater. Of interest, is that this combination realised only R892 ha$^{-1}$ an$^{-1}$ more than 'Valery' at the low density regime. Robinson and Nel (1989g) demonstrated that in a plantation of mediocre vigour, maximum gross margin was realised at a very low density of 1 333 plants ha$^{-1}$. If one is aware of restrictions on the optimal development and consequently the vigour of plants, one could consider opting for a combination of 'Valery' at the low density. The better performance by 'Valery' in hot areas (which is enhanced at low density) is supported by the findings of Morse and Robinson (1996b - in press). The longer finger length of 'Valery' would improve the overall quality of fruit produced. However, one of the biggest problems facing producers in the "Coastal Lowlands" is that of wind, and such a combination should, ideally, only be considered in select, protected sites. With it's short stature, 'Chinese Cavendish' at 2 105 plants ha$^{-1}$ is the generally recommended combination for Bioclimatic Group 1.

**Comments pertinent to the trials:-** The prolonged drought that coincided with virtually the entire trial period, resulted in each site suffering from insufficient irrigation at stages. Consequently plants produced below their potential. One of the initial objectives was to quantify the production potential at each site and relate this to heat units experienced, but the sub-optimum performance, coupled with inadequate climatic data recording, rendered this impossible. As stated in section 2.1, on-farm co-operative trials are not ideal from a research point of view, as high density plantations require an above-average level of management, if an acceptable level of vigour is to be maintained in the ratoons. Given the co-operative nature of the trials, it is inevitable that certain cultural practices such as de-suckering were sub-optimal. However, the author is of the opinion that the benefits of such trials, particularly insofar as they enable access to a range of Bioclimatic Groups, plus the benefits of using these trials for demonstration purposes, far outweighs the negatives. Restrictions on financial resources and manpower limited the duration of these trials to three cropping cycles. It is evident from the data reviewed that the quick cycling cultivars, such as 'Chinese Cavendish', only come into their own later on in the ratoons. If any trials of this nature are conducted in the future it should be with a view to continuing through to a minimum of the R3 crop. An immediate research requirement emanating from these trials, is the need to evaluate the individual plants that performed exceptionally well, to establish whether or not they are somaclonal variations with superior genetic material.

# SUMMARY

Over the past decade, there has been a gradual yet significant expansion of the banana industry on the North Coast of KwaZulu-Natal, with an estimated 1 200ha currently planted to bananas. The North Coast is a new production area, with farmers diversifying from sugarcane into bananas in a quest to maximise economic returns. Being a new production area, the responsibility lay with the Department of Agriculture to provide both an extension service, as well as production norms established by research trials. With the release of three new cultivars to the banana industry in 1988, the choice of correct cultivars for specific areas became a topic of intense debate. One of the most important components of banana productivity and consequently profitability, is the correct choice of population density. This is one of the major determinants of annual yield per hectare and once chosen, cannot easily be adjusted at a later stage, hence the requirement for correct choice of population density at planting. It became evident that the most important research requirements for the North Coast banana growers were correct choice of cultivar and population density.

The North Coast, particularly north of Richards Bay, has some of the best banana production potential in the country (Wolstenholme, 1976) and it is likely that the steady expansion witnessed over the past decade will continue. The banana industry on the North Coast has expanded rather haphazardly into three diverse Bioclimatic zones. A decision was consequently taken to address the dearth of production norms on the North Coast by establishing three identical cultivar/density split plot trials in each of Phillips' (1973) Bioclimatic Groups 1, 2 and ten. Trials were established on a co-operative basis on private farms at Mposa (1), Eshowe (2), and Nkwaleni (10) in late 1991 and early 1992. Five cultivars ('Dwarf Cavendish', 'Williams', 'Grand Nain', 'Valery' and 'Chinese Cavendish') were established at three densities of 1 666, 2 105 and 2 500 plants ha$^{-1}$. Final harvesting took place in October 1996 after three full crop cycles had been monitored. The trials were affected to some extent by prolonged drought and periods of inadequate irrigation water.

The three major components of the trials, *viz.* cultivars, densities and the interaction of the two, are discussed independently.

**1. Cultivars**

The relative pseudostem heights of the five cultivars were much the same at the three different sites, with 'Grand Nain' being the tallest, followed, in order, by 'Williams' and'Valery',which were all significantly taller than 'Chinese Cavendish', which in turn, was significantly taller than 'Dwarf Cavendish'. This contrasts with the findings of international research in which 'Valery' is generally far taller than 'Williams', and which in turn, is taller than 'Grand Nain'. All cultivars were tallest at the cooler Eshowe site, followed by the warmer Nkwaleni site, with the shortest plants occurring at the hot Mposa site. The cultivar ranking order for psuedostem height was virtually identical to that of Leaf Area Index, indicating that as plant height increases so the LAI increases for a given density, provided leaf number is constant.

Leaf emergence rate was highest in the shorter 'Dwarf' and 'Chinese Cavendish' cultivars than in the taller 'Grand Nain', 'Williams' and 'Valery', although cultivar differences were non-significant in most months. The effect of season on LER was substantial. At the cooler Eshowe site, LER for the R2 in January was seven times greater than in July. At the warmer Nkwaleni site it was 4.4 times greater and at the hot Mposa site there was a four-fold increase in LER between summer and winter. This clearly illustrated the seasonal influence of temperature on the phenology of the banana plant as well as the influence of site. The seasonal and site influences were also reflected in the E-H interval which, for November and May bunch emergence at Eshowe, were 118 and 204 days respectively. At Mposa, the intervals for the same two months of bunch emergence were shorter at 105 and 184 days respectively. When the faster LER of 'Chinese Cavendish' was coupled with a lower total leaf production, particularly in the R1 and R2, this contributed to significantly faster crop cycle intervals for this cultivar. At both Eshowe and Mposa, 'Chinese Cavendish' had the shortest average cycle interval and was only slightly longer than that of 'Dwarf Cavendish' at Nkwaleni.

At all three sites, the three taller cultivars, 'Grand Nain', 'Williams' and 'Valery', generally produced heavier bunches than the shorter 'Dwarf' and 'Chinese Cavendish'. This was the result of longer and heavier fingers on the bunches of tall cultivars, which more than countered the greater number of hands and fingers on 'Dwarf Cavendish' bunches. However, when the crop cycles were factored into the productivity equation (t $ha^{-1}$ $an^{-1}$), the shorter 'Chinese Cavendish', with it's faster cycle interval, was the best performing cultivar at Mposa. Relatively quick cycling enabled 'Dwarf Cavendish' to outproduce all the other cultivars in the R1 and R2 at Nkwaleni, and this feature favoured 'Chinese Cavendish' in the ratoons at Eshowe. The overall best performance over three cycles at Eshowe was achieved from 'Williams' (47 t $ha^{-1}$ $an^{-1}$), closely followed by 'Grand Nain'(46.8 t $ha^{-1}$ $an^{-1}$) and 'Chinese Cavendish'(46.4 t $ha^{-1}$ $an^{-1}$). At Nkwaleni the highest production was from 'Grand Nain'(58.7 t $ha^{-1}$ $an^{-1}$), closely followed by 'Valery' (57.8 t $ha^{-1}$ $an^{-1}$) and 'Dwarf Cavendish'(57.5 t $ha^{-1}$ $an^{-1}$). At Mposa 'Chinese Cavendish' (54.2 t $ha^{-1}$ $an^{-1}$) was the best performer followed by 'Valery'(53.3 t $ha^{-1}$ $an^{-1}$). Differences between all five cultivars over three crop cycles at each site were non-significant.

### 2. Densities

Over all densities and sites, there was a substantial overall increase in pseudostem height from the plant crop to the R1, with a continuation of this trend in the R2 at Nkwaleni. At Eshowe and Mposa there was a decline in plant height in the R2, particularly at the higher densities. This suggests that in these plantations of mediocre vigour (due to insufficient irrigation), the higher densities were detrimental to individual plant performance due to the increased plant-to-plant competition enhancing the effects of reduced vigour. The effect of density on pseudostem index (height ÷ circumference) was virtually identical to that on plant height, indicating that density had very little effect on circumference, with the exception of the R2 at Mposa, where the plants lacked vigour. Increasing density had the effect of significantly increasing LAI at all sites, with a 66 % increase in LAI from the lowest to highest density in the R2 at Eshowe.

Density had a small, yet distinct influence on the monthly LER with this difference proving significant in most months. Consequently, this influence was also significant on the annual leaf production at all three sites, indicating that as density increased and inter-plant competition became more pronounced, so the vegetative development of the plant was restricted. Increasing density had the effect of reducing internal pseudostem temperature which also contributed to a reduction in the vegetative development of plants at high density. Coupled with a greater total leaf production and slower E-H interval, the reduced vegetative development of plants at higher densities had the effect of significantly increasing crop-to-crop cycle intervals.

Increasing density had a significant negative effect on bunch mass, third hand mass and finger mass. Despite reduced bunch component values and longer cycle intervals at high density, the mean unit area productivity at higher densities was significantly greater than that at lower densities for all three sites. This was due solely to the greater number of plants per hectare. Although highest productivity was achieved at the highest densities, this did not necessarily translate into the highest gross margins at each site. The highest gross margin was indeed achieved at the highest density of 2 500 plants ha$^{-1}$ at both Nkwaleni and Mposa, but was achieved at the intermediate density of 2 105 plants ha$^{-1}$ at the cooler Eshowe site.

### 3. Cultivar/Density Interaction

There were certain substantial interactions, notably with 'Williams', in the two warmer sites of Nkwaleni and Mposa. The relatively poor performance of 'Williams' at the low densities and good performance at the higher densities at both of these sites, leads one to believe that 'Williams' is fairly susceptible to heat exposure and consequently benefits from the cooler microclimate created at higher densities. The poor performance of 'Williams' at low density at both Nkwaleni and Mposa contributed to an overall poor performance and masked it's good performance at higher densities. In fact, 'Williams' achieved the highest gross margin at the high density of 2 500 plants ha$^{-1}$ at Nkwaleni and, based on the evaluation over three cycles, is the recommended combination for Bioclimatic Group 10. At the cooler Eshowe site the best returns were realised from 'Williams' at a density of 2 105 plants ha$^{-1}$ and this is the recommended combination for Bioclimatic Group 2. At Mposa, the highest gross margin was achieved from 'Chinese Cavendish' and this is the recommended combination for Bioclimatic Group 1.

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# APPENDICES

### Appendix 1: Disk 1-5

Eighty nine files comprising raw data of all morphological, phenological and yield component measurements. Spreadsheet links allow for cross referencing and calculations of averages. Accessible through Quatro Pro Dos Wq1. Files are zipped with the programme PK zip.

### Appendix 2: Disk 6

Files comprising the analysis of mean data contained in disks 1-5. Accessible through Genstat 5.

### Appendix 3: Disk 7

Programme for the analysis of the relationship between time of bunch emergence and harvest. Accessible through Genstat 5.

### Appendix 4: Disk 8

Ten files comprising graphs and spreadsheet data pertaining to all the graphs presented in the manuscript. Accessible through Quatro Pro 6 and 7.

### Appendix 5: Disk 9

Three files comprising the economic analysis of mean productivity for cultivars, densities, and their interaction, at the three sites. Accessible through Quatro Pro 7.