PRODUCTION EVALUATION OF *OPUNTIA ROBUSTA* AND *O.FICUS-INDICA* CULTIVARS IN THE CENTRAL FREE STATE

By

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Declaration

I declare that the thesis hereby submitted by me for the partial fulfilment of the requirement of the degree M.Sc. (Agric.) (Grassland Science) at the University of the Free State is my own independent work and has not previously been submitted by me at another University/Faculty. I furthermore cede copyright of the thesis in favour of the University of the Free State.

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CHAPTER 1

Introduction

Developing countries of the world are facing huge challenges in providing enough food for their ever-escalating populations of people and animals. In the arid and semi-arid regions of Southern Africa, where annual rainfall ranges from 150 to 300 mm, food scarcity is not uncommon (De Kock 1965). The stock industry suffers major losses as a result of shortage of food during droughts in these areas. Harsh winters, aggrevated by drought add further pressure to the ailing plants. There is therefore, an important feed gap in this so-called bridging up season. According to Le Houérou *et al.* (1983) this feed gap is related more to the quality than the quantity of feed available. Fodder shrubs, such as cactus ear are adapted to filling this gap, as they are usually green throughout the year. The planting of fodder shrubs such as *Opuntia* species is a strategy to alleviate the effect of drought on animal production systems and has great potential to improve productivity in these arid and semi-arid areas (Brutsch 1979; De Kock 1967; Pimienta-Barrios 1993; Russell and Felker 1985; Oelofse 2002). The main reason for this is that it has a Crassulacean acid metabolism (CAM) pathway (Oelofse 2002), which makes it a few times more efficient in water-use requiments than C_4-plants (Russell and Felker 1985). Rainfall is the most limiting environmental factor in the drier areas (Snyman 1998). It is, therefore, important that when water is available it must be taken up as rapidly and as efficiently as possible. The cactus pear plant is outstanding due to its shallow and extensive root system (Hill 1995; Ramakatane 2003; Snyman 2003). The cactus pear plants can utilise the drier areas to their full potential (De Kock 1965; Snyman 2003).

Rather than depending on government to provide drought-aid, at huge costs to taxpayers, livestock farmers need to be better prepared to overcome drought conditions. One way to lessen the devastating effect of drought is to establish drought-tolerant fodder crops such as the cactus pear (*Opuntia spp)* in arid and semi-arid areas (Brutsch 1997). The plant's attributes make it an ideal "drought insurance", as it is adapted to withstand severe drought conditions and still produce fodder at low costs (Potgieter 1993). Changing climatic conditions, including global warming, dictate the growing need for developing arid-zone crops. Cactus plants show great adaptability to infertile soils and tolerate temperatures of up to 50-55°C although temperatures close to 40°C for two or three consecutive days damage the fruits at maturity (Potgieter 1995). They can therefore provide diversification and sustainable agricultural systems in dry and infertile lands, where common crops often fail (Schirra 1996).

The search for appropriate plant species able to grow successfully and produce in arid areas has long been a concern for farmers living in harsh environments. Cactus pear is a good option because it fits most requirements of a drought tolerant crop and can also fill gaps in the fodder flow planning during certain periods of the season. However, with renewed interest in this plant, there is a growing demand for better selection (Oelofse 2002). Cactus pear requires low inputs and is therefore, capable of establishing a sustainable system that will increase the efficiency and economic viability of small and medium sized farms of low-income farmers (Pimienta-Barrios *et al.* 1993: Oelofse 2002). The value of spineless cactus pear in subsistence agriculture has been well documented (Barbera 1995, Brutsch 1979, 1993, 2000).

Cactus pear *(Opuntia spp)* is a drought–resistant food and feed crop. In many areas cactus pear fruit is an important food source for satisfying the nutritional needs of the local, mainly poorer populations, for about three to four months of the year. The knowledge of its chemical composition, nutritional value and effects on human health has lead to a recent increase in the consumption of cactus pear. For the smaller farmers, cultivation of cactus pear can be profitable due to the low investment needed. There is scope for increased production on commercial scale for local and export markets of cactus pear fruit. Prices obtained for prickly pear fruit on the national fresh produce markets of South Africa compare very favourably with those of more common fruits, such as apple, peach and orange (Brutsch 1994). Cactus pear fruits represent a very important food source in satisfying the nutritional needs of populations in various countries, especially those in South America (such as Bolivia, Brazil, Chile, Columbia) and Mexico (Schirra 1996). Cactus pear fruits may also be used in a wide range of products made at home, in small enterprises or on an industrial scale such as jams, gelatine, syrup, dry fruit, candies and juice concentrates. Increasing knowledge of environmental influence on fruit productivity and quality will also allow a more profitable product (Brutsch 1979: Le Houèrou 1992; Mizrahi and Nerd 1999; Pimienta-Barrios *et al.* 1993)

Cactus pear plants differ with respect to yield, quality and also in sensitivity to biotic and abiotic factors, which may affect growth and productivity (Pimienta-Barrios 1990). According to Barbera *et al.* (1993), productivity of *Opuntia ficus-indica* is extremely variable from country to country. Although the aboveground productivity of *O. ficus-indica* can be substantially high, partitioning of dry matter into fruits and cladodes has not been reported on in South Africa (Garcia de Cortazar 1991). Increasing knowledge of environmental influences on fruit productivity and quality of this plant will allow more profitable production (Brutsch 1997; Le Houèrou 1992; Pimienta *et al.* 1993; Mizrahi and Nerd 1999; Pimienta-Barrios 1993; Oelofse 2002). Although cactus pear species can survive in drought prone areas, different species and cultivars are adapted to different habitats, have different production systems, different nutritive values and need different management practices. For this reason it is essential that the establishment and management of cactus pear plantations be adapted to the prevailing conditions, to ensure that the maximum value is obtained from the plant. The aim with this study was therefore, to evaluate the productivity of *Opuntia ficus-indica* (Green-pad cactus) and *Opuntia robusta* (Blue-pad cactus) varieties. The study explores the practical potential of the two species of cactus pear for the semi-arid areas and determines if they are different in terms of fodder and fruit production. The information generated by this study could be of great use to both commercial and subsistence farming communities who are considering cactus pear production.

CHAPTER 2

Literature review

2.1. Ethnobotany

2.1.1 The role of the cactus pear

The oldest record of the use of cactus pear for human nutrition is found in excavations of the cactus-rich valleys of Tehuacan in the state of Puebla, Mexico. These date back to 6500 BC (Smith 1967). Cacti and their products played a great role in the economic, social and religious life of the Nahuatls (Bravo 1978). In one of the few preserved pictographic writings of the time, the *Codex Mendoza,* there is an eagle perched on an *Opuntia*. This is also the coat of arms of modern-day Mexico. Numerous pre-Hispanic place names, encompassing the world *Nochtli*, indicate the wide spread of cactus pears, e.g. *Nocheztlan, Nochtepec* and *Xoconochtli* (Hoffmann 1983).

2.1.2 Genesis of the use of cactus pears

Since 1520, Mexican *Opuntias* were taken to Europe and then, from the Mediterranean, spread further to Africa, Asia and still further to Australia (Hoffmann 1983). The use of wild cactus pear communities dates back 25 000 years, to when man arrived in the territory now known as Mexico. These first settlers were hunters and gatherers, who used the cactus plant (fruits, nopalitos and mature cladodes) in their diet

2.1.3 The role of cactus pear in religion and traditional medicines

As in many other cultures, plants in ancient Mexico made their way into religion. Due to the vast number of species and dense populations, cacti have played an important role (Bravo 1978). The thorns for cactus species served for self-sacrifice at a temple dedicated to the god *Huitzinahuac*. Shoots from cactus plants were fastened as amulets to windows and doors to drive off evil spirits. Cactus plants, being hallucinogenic, are an important feature in customary rites in the sacred places. The traditional medicine of the Seri was water, mixed with juice from the cactus pear: this formed the basis of a drink against diarrhoea. A tea made from the roots of *Opuntia Bigelovi Engelm* acts as a diuretic (Meyer and McClaughlin 1981). In Mexico, pregnant women having difficulty in giving birth are given a drink made from the peeled, ground joints of the cactus pear. The application of the cut cladodes to burns and swellings is a widely accepted practice (Hoffmann 1983).

2.1.4 Forage and fodder cactus pears

Griffiths (1905) reported that during the United States Civil War, freighters loaded with cotton were pulled by oxen to the only safe port of export at the Southern tip of Texas (Brownsville). The route passed through extensive stands of spiny *Opuntias*. The teamsters scorched the cactus by burning, and chopped or slashed it with an axe, spade or machete to feed to the oxen. Due to the high water content of cactus, the oxen only had to drink water once a week in winter and two or three times a week in summer. In the early twentieth century, pressurised backpack "white gasoline" pear burners were used in Texas to singe the spines from prickly pear so that cattle would eat it (Pluenneke 1990). Also "cactus pear" is the same as "prickly pear" but is preferred because prickly pear has a negative connotation. Spineless cactus pear is reported to have been introduced for the first time in South Africa more than 300 years ago and were used mostly as life fences and to protect crops against wild animals (De Kock 1970).

2.2 Ecology and environmental requirements

2.2.1 Ecology

The majority of *Opuntia* species have originated from the dry, interior plateaux of Mexico and the Southwestern U.S.A. However, some are believed to be native to Canada and others from Patagonia. These areas have the following climatic conditions in common: relativly mild winters, a pronounced dry period usually coinciding with the winter months, predominantly summer rains and a mean annual rainfall which ranges from 180 mm to 650 mm (Brutsch 1979). Climatic factors that control the growth of *O. ficus-indica* are rainfall (either lack or excess), atmospheric humidity, winter temperature and the natural drainage of the soil (Monjauze and Le Houérou 1965).

2.2.2 Climatic requirements

Cactus pears are known around the world as unusual looking plants coming from hot, dry and hostile desert areas.

2.2.2.1 Rainfall

The absolute minimum requisite for rain-fed cultivation is 200 mm per year provided the soil is sandy and deep. On silty and loamy soils the minimum requisite is 300 to 400 mm mean annual precipitation. Drainage is an important ecological factor; cactus pear, like most cacti, is very sensitive to lack of oxygen in the root zone and cannot therefore, withstand prolonged water logging. Clay soils that may be temporarily saturated, poorly drained or water logged are not suitable for cactus pear production (Pimienta-Barrios 1994).

2.2.2.2 Frost damage

According to Le Houérou (1971) *Opuntia ficus-indica* species and clones can be severely damaged by frost while *Opuntia robusta* (Monterey and Chico) species and clones can be slightly damaged by cold temperatures. Most cacti grow in arid and semi-arid zones with high temperatures, and are among the most tolerant of all plant species to high temperatures, tolerating 50 to 55°C. Although spineless cacti are reasonably resistant to cold and can withstand temperatures as low as −10°C when in a hardened stage, it is desirable to establish plantations when possible on the northern or northeastern slopes in the Southern Hemisphere (De Kock 1980).

2.3 Soil requirements

Cactus pears show great adaptability to various soil conditions as they can grow in poor infertile desert soil and tolerate a wide pH range. Cactus pears also do well on a variety of soil types, but for optimum growth and production, it is better to plant them in good soils unless they are being used entirely for reclamation (Nobel 1986).

2.4 Site selection and planting

2.4.1 Site selection

The site should be preferably flat, but slopes up to 3% can be handled with simple soil and water conservation practices such as contour planting (Brutsch and Zimmermann 1993).

2.4.2 Planting

2.4.2.1 Pre-planting operations

Land clearing is very important for the good establishment of *Opuntias*. The soil should be ploughed to a depth of 600 to 800 mm, to ensure good drainage, as well as water storage and eradication of perennial weeds. Weeds compete strongly with cactus pear during the early stages following planting. The soil should be cross-ripped with a chisel plough to improve drainage. Together with pre-planting operations, there is pre-planting fertilisation (Brutsch and Zimmermann 1993). Fertilisation will be discussed in detail later in the study.

2.4.2.2 Selection of planting material

Only cladodes that are more than a year old are used for planting a successful establishment. The pads need not be allowed to wilt for a few weeks before planting. As soon as wounds resulting from severence dry off and are healed (calloused) cladodes can be planted (Brutsch and Zimmermann 1993).

2.4.2.3 Propagation material

Planting material should be collected from robust, productive and healthy plants. The pads can be collected at the end of the growing season and subjected to slight dehydration to allow suberization of the joints. Collected pads must be of medium to large size. After collection cladodes must be stored in shade for two weeks. Cladode portions can be used when planting material is in short supply but the smaller the portion the longer time the new shoot will require to reach full size. The smallest portion that can be planted should have at least 2-3 areoles on each surface (Brutsch and Zimmermann 1993).

2.4.2.4 Land preparations

When cactus pears are to be planted in areas that are predominantly grassland, it is desirable to till the soil with a plough or disc to eliminate competition between the grasses and newly established spineless plants. Elimination of perennial weeds or shrubs and tilling of the soil are very important to facilitate formation (Brutsch and Zimmermann 1993).

2.4.2.5 Planting time

The best planting time is in spring, from September to October. At this stage the cladodes are well developed and they are ready to sprout. The plants should be well established before the first frost and will then be able to withstand the cold winter. Planting should be done after risk of frost is over. Freezing temperatures damage cactus pear, a safe lower limit temperature would be 5°C for most cultivars. Tender cladodes are generally highly susceptible to frost damage and they can start emerging 2-3 weeks after planting (Inglese 1995).

2.4.2.6 Planting methods

Besides placing cladodes upright into the soil when planting, there are various other methods of planting the cladodes.

2.4.2.6.1 Laying the cladodes flat on the ground

Laying the cladodes flat on the ground with a stone or a spadeful of soil. This method requires less labour and is suitable where soil tillage is impossible. In this way the cladodes will develop more slowly. New growth takes place from the rim of the cladodes and the resultant stems are weakly jointed to the original cladodes, these stems are weak and often break off easily (Inglese 1995).

2.4.2.6.2 Planting cladodes on their edge

Planting cladodes on their edges in loose soil or against the side of a furrow is another method that can be decided on. In this case a single furrow-plough or a sub-soilercan be used to make the furrow. The point where the pad was cut off should be kept above the surface of the soil as this is where fungi, which cause rotting can enter the cladodes. This method results in strong plants, which also develop rapidly. The plants utilise rainwater collected in the furrows. This method, however, requires more labour than the first method (Inglese 1995).

2.4.2.6.3 Planting double cladodes

The quickest growth and development is obtained when double cladodes are planted. More cladodes, time and labour are required for this method (Inglese 1995).

2.4.3 Spacing

Between the rows the spacing could be 3.0 to 4.5 m and 1.5 to 2 m within the rows (Ingles 1995).

2.4.4 Fertilisation

Fertilisation is necessary at planting if the soil is low in phosphate and potash. These deficiencies can in most cases be supplemented with 50 to 100 kg super phosphate and 50 to 100 kg of potassium chloride per hectare. If the soil is poor in nitrogen, 50 kg of ammonium sulphate per hectare can be applied. Fertilisation should be based on soil analysis. Late summer application of N fertiliser to cactus pears could induce an additional flush of floral buds in autumn (Nerd *et al.* 1993).

Chemical fertilisers can be applied during the rainy season. Providing half of the nitrogen fertiliser early in the season and the rest 45 days later is advisable. The fertiliser must be spread along the rows and slightly covered with soil (Nerd, Mesika and Mizrahi 1993). Nitrogen fertilisers can be applied at the rate of 100 to 200 kg per hectare (Flores-Valdez 1992). To ensure high yields it is necessary to apply manure (broadcast or ploughed in) prior to planting. For better results the manure can be supplemented with synthetic fertilisers. Chemical fertilisers are a quick source of nutrients, while manure represents a slow release supply (Flores-Valdez 1992).

2.5 Management practices

2.5.1 Pruning

The objectives of pruning change with the age of the plant. Pruning and training systems include formative pruning, production pruning and renewal pruning (Inglese *et al.* 1994b).

2.5.1.1 Formative pruning

The first year after planting, new cladodes developing downwards, horizontally or from the basal portion of the parent cladode must be removed. To develop a vase, no more than two upright cladodes should be selected on the parent cladode. Recommendations for formative pruning include the removal of damaged cladodes and fruits, which compete with plant growth during its development (Inglese *et al.* 1994a).

2.5.1.2 Production pruning

One of the objectives of pruning fruiting plants of cactus pear is to expose as many cladodes to the sunlight as possible. Cladodes that develop in the inner shaded portion of the canopy are less productive than exposed outer cladodes (Inglese *et al.* 1994a). The opacity and thickness of the cladodes make pruning essential to facilitate light penetration into the canopy. Hidden cladodes, which develop in dense canopy, as well as cladodes that touch the ground are easily parasitised by cochineal and are difficult to reach with pesticide sprays. The reduction of canopy density by pruning makes cultural practices such as fruit thinning, *scozzolatura* and harvesting easy to practice and help to improve fruit quality. The closer the planting space, the higher the pruning intensity and frequency. No more than two daughter cladodes should be retained on the cladode to maximise development and reduce wind damage (Inglese *et al* 1994a). A summary of mean cladode yield, mean cladode mass and mean number of cladodes needed to be pruned per plant of cactus pear are presented in Table 2.1.

Table 2.1 Mean cladode yield per plant, mean cladode mass and mean number of cladodes that needed to be pruned per plant of cactus pear (*Opuntia ficus-indica* (L.) Mill.] (Oelofse 2002).

Cultivar	Cladode (kg plant $^{-1}$)	Cladode mass (kg)	Number of cladodes pruned (plant $^{-1}$)
Skinners Court	63.36	2.80	22.9
Nudosa	63.61	1.36	47.0
Gymno Carpo	63.02	1.16	56.6
Morado	78.84	1.18	72.5
Zastron	71.18	1.17	65.6
Malta	51.95	1.10	53.0
Algerian	63.48	1.23	56.3
Turpin	107.01	1.05	107.6
Meyer	102.05	1.14	91.9
Roedtan	77.09	1.09	72.0

2.5.1.3 Renewal pruning

Rejuvenation of debilitated plants can be achieved by heading back to 3 to 4 year-old scaffolds (Mulas and D'hallewin 1990). Heavier pruning can be practised to stimulate growth in weak plants, heading back to lignified cladodes. The plant resumes fruiting 2 to 3 years after pruning, depending on the pruning intensity. According to Mulas and D'hallewin (1990), to improve the effect of pruning, the plants can be fertilised with urea (60 kg ha^{-1}) soon after pruning. Pruning principles and recommendations can be summarised as follows:

- remove inner cladodes and those oriented downwards, horizontally or close to the ground,
- avoid the development of a dense canopy, which increases the risk of cochineal infestation, reduces light interception and hampers pest control, fruit thinning and fruit harvest,
- leave no more than two daughter cladodes on a parent cladode, in order to maximise cladode growth,
- remove cladodes developing from fertile parent cladodes,
- avoid pruning during rainy or cold periods,
- avoid summer planting, unless for summer growth and
- control plant height at 2 to 2.5 m (Inglese *et al.* 1994a).

2.5.1.4 Pruning time

Pruning should not be carried out during the rainy season in order to prevent the development of cladode putrid rot and scabies (Inglese *et al* 1994a). In South Africa, Wessels (1988) suggested pruning from May to July, after fruit harvest, when the plant is no longer actively growing.

2.5.1.5 Fruit thinning

Thinning times must be from two weeks before bloom or two weeks after set. Cladodes with more than ten fruits show irregular or delayed ripening, which decreases harvest efficiency. Earlier thinning requires more time because of the small size of the flower buds, whereas removing fruits, three or four weeks after set would reduce the effectiveness of thinning (Inglese *et al.* 1994a). Reasons why farmers should thin fruits include improved fruit size, improved internal quality, easy picking process and to prevent broken plants due to too much fruit set. When fruits are thinned at the right stage, there are relatively less seeds in relation to pulp. Fewer seeds enhance the eating quality of the fruits and improve consumer reaction. Research concerning the thinning of cactus pear showed that optimum fruit size and quality are obtained when about 9 to 12 fruits are left per cladode (Brutsch 1992). The fruit yield and mass obtained from different cultivars with different plant width and height are presented in Table 2.2.

Table 2.2 Plant height, width, fruit yield and fruit mass (Oelofse 2002).

Cultivar	Plant width (cm)	Plant height (cm)	Fruit yield (t ha^{-1})	Mean fruit mass (g)
Skinners Court	251.0	203.0	4.97	185.08
Nudosa	224.0	175.0	14.58	235.84
Gymno Carpo	217.0	175.0	30.67	170.81
Morado	223.0	207.0	19.60	145.68
Zastron	242.0.	223.0	17.96	136.68
Malta	222.0	175.0	23.22	169.75
Algerian	221.0	173.0	24.98	161.88
Turnip	223.0	186.0	28.67	181.19
Meyers	231.0	194.0	26.72	176.39
Roedtan	208.0	181.0	23.66	171.74
Average	226.2	189.2	21.50	173.50
LSD (P = 0.05)	25.836	10.8508	3.3766	24.6436

2.5.2 *Scozzolatura* (Removal of the reproductive buds to delay fruit ripening)

Late fruit production of cactus pear is obtained by forcing the plant to produce a second bloom. This involves taking away flowers and cladodes of the spring flush. In a second bloom, bigger fruits, with a lower fruit-to-flesh ratio than summer ones ripen from the beginning of October to the end of November in the Northern Hemisphere and from the beginning of March to the end of April in the Southern Hemisphere. The spring flush removal (S.F.R) takes place between the end of May and the last week of June in the Northern Hemisphere, and in October in the Southern Hemisphere, when the main bloom occurs. Removal time affects reflowering rate, fruit development and ripening time (Barbera *et al.*1995, Brutsch and Scott 1991). The pre-bloom removal results in the highest re-flowering rate, while removing the spring flush after petal shedding reduces re-flowering by up to 50 to 70%. Proper scheduling of S.R.F removal could extend the fruit harvest period. This could be useful for overcoming harvest and market problems related to the poor storage performance of the fruit. The number of cladodes produced after *scozzolatura* is 10 to 40% lower than for the spring flush. In light soil with low water content, irrigation should be applied at the moment of S.F.R to improve re-flowering (Inglese *et al.* 1994a).

2.6 Weed control

Weed control is essential for sustainable production of cactus pear. Weeds compete with the shallow root system of the cactus pear for nutrients, particularly during the early stages of plant development. Young plantations can be lost completely if weed control is not properly managed. Weed control is the main factor influencing *Opuntia* production costs (During the initial growth stage, the growth of cactus can be severely retarded by grass and other herbaceous vegetation). According to Santos and Albuquerque (2001), horses can be admitted to the spineless cactus plantation, as they will eat most forage but not the cactus. After the cacti reach a height of more than 1 m, livestock can be admitted at the rate of 1 cow per hectare. Once planted, *Opuntia* can serve as a nurse plant for many weed species, so periodic weeding becomes an integral element in crop management (Santos and Albuquerque 2001). Maintain the plot free of perennial weeds and shrubs to eliminate competition with *Opuntia*. Soil cultivation should be restricted to the minimum in order to avoid damaging the cactus pear's superficial root system. To avoid any damage to the roots and to preserve soil structure, weeds can be mowed and left as mulch on the soil to retain moisture and smother weed growth. In summer the soil should be lightly worked with a superficial scraper or a rotating hoe, in order to reduce water loss. Successful chemical weed control can be attained by use of Paraquat and Glyphosate (Felker 2001). Glyphosate at 20 g l^{-1} is not phytotoxic to *Opuntia* (Felker and Russell 1988).

2.7 Irrigation

Irrigation is not normally practiced in South Africa (Van der Merwe *et al.* 1997). Basin irrigation is not suitable as it enhances leaching of nutrients because of the high permeability of the soil in which cactus pear grows. Localised micro-sprinklers, which cover a fairly large soil surface area with small volumes, are suitable for the characteristic cactus pear root system. Drip irrigation can also be profitably practised, but it results in nutrient leaching and root rot if not properly managed (Nerd *et al.* 1991).

2.8 Harvesting

Cactus pear fruits can be manually picked with thick gloves and glasses to avoid injuries from glochids. It is recommended to start picking early in the morning, when glochids are wet and stick to the fruit. In South Africa fruits are handled with a picking glass and cut with grape-scissors. The cut must include a thin layer of the cladode to prevent rapid loss of fruit weight and preserve storage ability (Barbera *et al.*1992a). The harvesting period for different cultivars differs, the main harvesting period could be from January to March at Fort Hare, (E. Cape) (Brutsch 1979). The main harvesting period of the fruits for some cultivars as well as the fruit characteristics is presented in Table 2.3.

Table 2.3 Fruit characteristics of five promising cactus pear cultivars [*Opuntia ficus-indica (L)* Mill] (Brutsch 1979) at Fort Hare, E. Cape.

Cultivar	Main harvesting period in E. Cape	Mean fruit mass (g)	External colour	Internal colour
Algerian	End Jan. – end Mar.	88	Red	Red
Blue Motto	Early Feb. – end Mar.	109	Light green	Yellow/Khaki
Gymno Carpo	End Jan. – end Mar	102	Yellow	Yellow
Malta	Early Feb. – end Mar.	85	Yellow	Yellow
Morado	End Jan. – end Mar	97	Light green	White
Skinners Court	Early Feb. – end Mar.	107	Light green	Light green/white

Cladodes for "nopalitos" in Mexico should be harvested 30 to 60 days after sprouting, when they weigh between 80 to180 g and are 150 to 200 mm long. Some producers harvest by pulling and twisting the "nopalitos" off, however, this can produce injuries and rotting. Most farmers use a knife to harvest cladodes. Nopalitos should not be cut at the base as this causes rotting. Cutting at the joint between the supporting cladode and the "nopalitos" helps to delay deterioration (Cantwell 1992; Corrales1992). Mature pads can be collected at the end of the growing season. The number of cladodes to be harvested varies with cultivar and age of the plant. During the first year, 2-4 cladodes per plant can be collected. In order to obtain constant yield, the plants are left with only two branches ("rabbits") oriented along the broad-bed. It is more efficient to collect and store them close to the livestock yard until needed (Cantwell (de Trojo) 1992; Corrales 1992).

2.9 Storage

Nopalitos should be stored at 5 °C to 10 °C to avoid yellowing and inward curving due to loss of water. Proper storage reduces respiration rate and increases post-harvest shelf life from less than one week at 20°C to three weeks at 5°C. Cactus stems lose their brilliant shiny appearance and become dull green in colour with time following harvesting. Visual quality can be maintained for about two weeks if storage takes place at 10°C and for three weeks at 5° C. After one week at 20° C and two weeks at 15°C, the vestigial leaf senesce, blacken and abscise (Cantwell 1992).

2.10 Uses

Cactus parts can be used in many different ways, with only the important ones discussed.

2.10.1 Cactus pear as fruit crop

Cactus pears have the wellknown glochids (Gibson and Nobel 1986), which are removed before the fruit can be peeled. The major components of the fruit pulp are 85% water, 10-15% carbohydrates and 0.25-0.03% of vitamin C (Gurrieri *et al.* 2000). Cactus pear fruits can be used in a variety of ways such as:

- strained into deserts,
- used in beverages,
- used in syrup, jelly and candies,
- seeds are dried and used in soup or ground and used in sweet cakes and
- the fruit is peeled and eaten fresh. The common name of the fruit is "tuna" in Latin America, *Ficodindia* (Indian fig) in Italy, *Tzabbar* in Israel and *Sabar* in Arab countries (Brutsch and Zimmermann 1993).

In the developing nations, where cactus pear is consumed by only a small section of the population, it can be considered a luxury item. But in Mexico and North Africa, it makes substantial contribution to the diet of peasant populations during the summer months, and also at other times, if processed. It is, therefore, an important commodity. In South Africa the fruit is already known to a wide cross-section of the population. There is a good market for the fruits in large centres such as Pretoria, Johannesburg and Bloemfontein (Brutsch 1979). The fruit contains a large number of seeds. The seed is hard coated (De Kock 1980). The negative aspects of the fruit can be listed as follows; the unpleasant glochids on the fruit which have to be carefully removed before the fruit can be handled and eaten, the thick outer cover (peel) which accounts for more waste (inedible fraction) than in most other fruits, severe constipation resulting from eating large quantities of the fruit at any one time and the large number of seeds (Brutsch 1979). According to Oelofse (2002), the ripening times of fruits of different cactus pear cultivars differ. Most fruits ripening in January. The dates of the basic phenological stages of each cactus pear cultivar in Limpopo province are summarised in Table 2.4.

Table 2.4 Dates of the basic phenological stages of cactus pear [*Opuntia ficus-indica* (L.) Mill.] cultivars evaluated in the 1999/2000 season at Limpopo province (Oelofse 2002).

Cultivars	Reproductive budbreak	Vegetative budbreak	50% Anthesis	50% Fruit ripening
Skinners Court	Week 2 in July	Week 3 in August	Week 3 in October	Week 2 in January
Nudosa	Week 2 in August	Week 2 in August	Week 4 in October	Week 4 in January
Gymno Carpo	Week 2 in August	Week 2 in August	Week 3 in October	Week 3 in January
Morado	Week 2 in August	Week 3 in August	Week 4 in October	Week 3 in January
Zastron	Week 2 in July	Week 4 in August	Week 4 in October	Week 1 in January
Malta	Week 1 in August	Week 3 in August	Week 3 in October	Week 2 in January
Algerian	Week 1 in August	Week 4 in August	Week 3 in October	Week 2 in January
Turpin	Week 2 in August	Week 3 in August	Week 3 in October	Week 2 in January
Meyers	Week 3 in August	Week 3 in August	Week 4 in October	Week 3 in January
Roedtan	Week 2 in August	Week 2 in August	Week 4 in October	Week 3 in January

Size, percentage flesh, colour, total soluble solids (TSS) and seed content are the main parameters characterising fruit quality. Fruit size depends on seed number (Barbera *et al.* 1992c), cladode load (Barbera *et al.* 1993b), water availability, (Barbera 1984) and ripening time (Barbera *et al.* 1992c). The most sought after fruits, on the international markets are yellow-orange (peel and flesh colour). Sugar content plays a decisive role in defining fruit quality, because consumers favour sweet fruits (Barbera *et al.* 1992b). Fruit yield varies considerably with ecological conditions, the care given to the crop and the nature of the clone and cultivar (Monjauze and Le Houérou 1965). The minimum criteria for cactus pear varieties evaluated for fruit production are summarised in Table 2.5.

Table 2.5 Minimum criteria for cactus pear varieties evaluated for fruit production (Potgieter and Mkhari 1989).

Characteristics	**Minimum criteria**
Fruit yield potential	
Year 2	1 t ha^{-1}
Year 3	2.5 t ha^{-1}
Year 4	4 t ha^{-1}
Year 5	7 t ha^{-1}
Year 6	10 t ha^{-1}
Year 7	15 t ha^{-1}
Year 8	20 t ha^{-1}
Fruit mass	>140.0 g
TSS	>13^{0}Brix
Pulp percentage	>50 %
Peel thickness	<6 mm

One of the major constraints limiting the consumption of cactus pears is the presence of the thick, hard seed in the flesh (Pimienta 1990). Empty rudimentary seeds, caused by early failure of embryo growth, are common in cactus pears and allow flesh development. The ratio of empty to normal seed is one of the most important parameters that define fruit quality (Pimienta and Engleman 1985). The fruit size depends on the number of fecundate and aborted seeds. It has, however, not been established why the seeds abort (Archibald 1935: Barbera *et al.* 1994).

2.10.2 Cactus pears as animal feed

Fresh cladodes provide dependable sources of food and drink for livestock and poultry. Brutsch and Zimmermann (2000) pointed out that the cladodes, when supplemented with cottonseed meal, offer all the water and nutrition for animal needs. If cladodes make up more than 50% of animal's feed, they will, however develop diarrhoea. A wide variety of animals such as sheep, pigs, horses, ostriches and circus elephants can be raised on cactus cladodes. When fed to dairy stock, the cladodes impart a distinctive flavour to milk and butter, and these products are often highly desired (Brutsch and Zimmermann 2000).

Cactus pears may be planted on the contour in the veld to enable the grazing animals to utilise both the veld and the cactus plants. During periods of drought, the succulent cladodes enable the animals to make better use of the dry veld. When planted on the contour the plants also serve as windbreaks, reduce run-off and in this way conserve the soil and water (Brutsch and Zimmermann 2000). Cactus cladodes can be fed to livestock as fresh forage or stored as silage for later feeding (Castro *et al.* 1977).

Plantings of spineless cacti for use as fodder (i.e. harvested) or as forage (i.e. directly browsed by livestock or wildlife) have been developed in Sicily and North Africa since the mid-19th century with the purpose of stabilising the fodder resource in the arid and semi-arid zones where feed shortage has always been a sub-permanent limiting factor in livestock production. The establishment of fodder cacti is thus a kind of drought-insurance in dry regions (Guastella 1913; Cottier 1934; Abramo 1935; Musmara 1937; Cordier 1947).

Cactus pear plantations can be utilised in three different ways, namely, (i) as part of the daily feed ration e.g. in dairy operations, (ii) as supplementary feed from the end of the growing season to the onset of the next growing season, when rangelands are chronically deficient in green forage, protein, carotene and phosphorus and lastly, (iii) as buffer feed reserve for times of acute scarcity, in the event of prolonged droughts which may last 1 to 3 years (Le Houérou 1982; 1986; 1989a,c). Cactus feed i.e. cladodes aged 1-3 years, is high in water (75-85%) in summer and early Autumn and (85-90%) in winter and spring; it is also rich in sugars, pro-vitamin A and vitamin C, but poor in nitrogen (3-4%) (Monjauze and Le Houérou; 1965). The digestibility of cactus pears also decreases with age. When fed as an exclusive diet fresh cactus pads cause diarrhoea after about six weeks for cattle and eight weeks for sheep. Their use as a single feed for emergency survival rations should thus not exceed these periods. The diarrhoea can easily be prevented and cured by adding to the cactus the equivalent of approximately1% of the animal live-weight in dry roughage, straw or hay (Cordier 1947).

The harvesting of fodder using the cut-and-carry method reduces or prevents wastage. There is more risk in overuse in plantations where direct grazing is allowed. Cladodes are given to herded animals either in the evening when returning to the pen or in the morning before being set out to graze. The glochids present in spineless cacti are softened by saliva and become harmless in the mouth and further down in the digestive tract. The stand is exploitable after 4-5 years and fully-grown after 7-8 years. When rationally managed, some remain productive for more than 50 years (Barbera 1984).

For fodder production a distinction can be made between blue-cladode cactus and green-cladode cactus. In the past only the blue-pad type was recommended for fodder production. Over the last few years, research has shown that some of the green-cladode types could also be used as fodder plants. The blue-cladode cactus may have many advantages over the green-cladode type. The most important advantage is that they are resistant to cochineal and more drought resistant. The blue-cladode type of cactus pear is however less palatable and yields less than the green-cladode type. There are three recognised cultivars of the blue-cladode cactus namely, Robusta, Monterey and Chico. Robusta and Monterey yield more, while Chico is more cold resistant (De Kock 1980).

Opuntia plants are highly efficient in the use of water and withstand dry periods and extreme heat. These traits make them highly promising for soils poor in nutrients and with limited water supply (Silva and Acevedo 1985). In relation to the management of stock feeding, it was determined that the use of cactus pear cladodes in the feeding of growing sheep improves the efficiency of drinking water by 3o%. On the other hand, the high productive potential of the cactus pear (*Opuntia ficus-indica*), under water deficient conditions, makes it an important feeding resource in Mediterranean zones where it can be used to supplement dairy and meat-producing livestock, fed mainly on rangeland (Azócar and Rojo 1991; Azócar 1992; Azócar *et al.* 1996; Ben Salem *et al.* 1996; Santana 1992).

Santana (1992) reported a yield (fresh) of 106.9 to 205.0 ton per hectare per year (approximately 16 to 31 ton ha^{-1} $year^{-1}$ of dry matter), according to the geographical zone, type of soil, fertiliser application, plant population and association to other crops. In Chile, recorded yields of cladodes ranged from 13 ton per hectare per year of dry matter in not very dense crops that only covered 30% of the land to 28-30 ton per hectare per year in simulated conditions of density, watering and good fertilisation. Advantages of the cactus pear include high biomass yield, high palatability and nutritive value, evergreen habit, drought resistance, salinity tolerance and soil adaptability (Monjauze & Le Houérou 1965; Le Houérou, 1992). This species has a high ash (260 g kg^{-1} DM) and water contenr (926 g kg^{-1} fresh weight), and low crude protein (58 g kg^{-1} DM). Ben Salem *et al.* 1996 Monjauze & Le Houérou 1965; Le Houérou (1992) reported that drinking water consumption by sheep is substantially reduced as the level of cactus pear increases.

2.10.3 Cactus pear as vegetable

The nutritional value of "nopalitos" (diced young cladodes) is similar to that of many vegetables, they contain mostly water (88-95%), some carbohydrates (3-7%), and minerals (about 1.3%, mainly Ca). Like most vegetables, nopalitos are low in proteins (about 1%) and fibre (about1%, which is still more than twice that of lettuce) (Rodríquez-Félix and Cantwell 1988). Nopalitos are less nutritious than spinach, but more nutritious than lettuce (Cantwell 1991).

2.10.4 Cactus as industrial crop

Cactus pear is very important as an industrial crop.

2.10.4.1 Cochineal

Cactus pear is an important industrial crop for the production of red dye from cochineal insects. The carminic acid can be used as a biological stain for microscopy as well as a dye for fabrics and foods (Nobel 1994).

2.10.4.2 Processed food

Nopalitos can be sold as processed food, including pickled nopalitos, various salads, and cooked dishes. Fruits can be processed into fruit juices, concentrates, jams and jellies. *Queso de tuna* (cheese of cactus pear) is also produced. *Miel de tuna* ((honey of cactus) is another popular fruit product (Ingles *et al.* 1993).

2.10.4.3 Medicinal products

Cactus pears are reported to improve the glucose control in humans, can reduce the blood sugar levels and increase insulin activities under hyperglycaemic conditions. The sap from the cactus cladodes can be used in first aid and cosmetics similar to the *Aloe vera* plant. A portion of the cladodes is cut, crushed and the juice squeezed onto a cut, burn or bruise. Ground or pureed young cladodes are used as a laxative and also as a remedy for diabetes. In Central Africa, the sap from the cladodes also serves as a mosquito repellent (Inglese *et al.* 1993).

2.10.5. Uses of cactus pears to combat desertification

Cactus pear, as drought and erosion tolerant plant, can be used to slow and direct sand movement, enhance the restoration of the vegetation cover and avoid the water destruction of the land terraces built to reduce run-off. The cactus pear plant can be used in combination with cement barriers or cut palm leaves to stop wind erosion and sand movement. It will fix the soil and enhance the restoration of the vegetative plant cover (Brutsch and Zimmermann 1993).

2.10.6 Anti-erosion hedges

Cactus pears are often used as defensive live hedges for the protection of gardens and orchards throughout North Africa and parts of Italy and Spain. Cactus pear hedges play an important role in landscape organisation when established in double rows. Cactus hedges also play a major role in erosion control and land-slope partitioning, particularly when established along contours. Moreover, hedges are physical obstacles to run-off, favouring silting and thus preventing regressive erosion (Monjauze and Le Houérou 1965). Another role of cactus pear plantation is for runoff and erosion control and watershed management. Planting cactus pear in degraded arid and semi-arid lands is one of the easiest, quickest and fastest ways of rehabilitating them (Le Houérou 1982). Recently, a cactus cladode extract was tested to improve water infiltration (Sáenz *et al.* 2004).

Chap ter 3

Study area and experimental procedures

3.1 Location

This study was conducted on the farm named Welgegund (28° 53' S; 26° 56' E) near a small town called Verkeerdevlei, 90 kilometres northeast of Bloemfontein.

3.2 Climate

The Glen weather station was used in this study to represent the climate of the experimental plot because it has data of more than 70 years. Other climatic data used in this study was obtained from a new weather station put up on January 2001 near the study area. Long-term data used was obtained from Glen weather station and the national climatological weather database of the Institute for Soil, Climate and Water of the Agricultural Research Council (ARC).

3.2.1 Temperatures

Extreme temperatures beyond optimum are bound to affect production potential of different plants. According to Botha (1964), the average maximum temperatures for Glen are 23.8°C, 20.2°C and 17.5°C for April, May and June respectively over the long-term (Table 3.1). The average minimum temperatures are 7.4°C, 2.4°C and -1.3°C over the long-term for Glen for April, May and June respectively (Botha 1964). The monthly average maximum temperatures for April, May and June of 16.3°C, 20.1°C and 26.3°C in the 2001/2002 growing season and 27.1°C, 20.4°C and 17.9°C in the 2002/2003 growing season respectively, recorded during the study were not abnormal (Figure 3.1). During the study, the recorded average monthly minimum temperatures of –0.4°C, -3.3°C and -0.1°C in 2001/2002 growing season were below the long-term levels. During the 2002/2003 growing season the monthly minimum temperatures of 10.1°C, 2.1°C and

2.9°C for April, May and June were recorded. These records were not unusual when compared to the long-term readings (Table 3.1).

Table 3.1 The long-term average temperatures of Glen for the different months (National climatological weather database of the Institute for Soil, Climate and Water 1922 - 1990).

Month	Average maximum temperature (°C)	Average minimum temperature (°C)	Average temperature (°C)	Average grass minimum temperature (°C)
July	17.3	-1.6	7.7	-4.4
August	20.4	0.7	10.5	-2.3
September	24.5	4.8	14.4	2.1
October	27.1	9.2	18.0	5.9
November	28.1	11.7	19.9	8.8
December	30.0	13.9	21.9	11.1
January	30.6	15	22.7	12.2
February	29.7	14.6	22.0	12.1
March	27.2	12.3	19.7	9.8
April	23.8	7.4	15.5	4.7
May	20.2	2.4	11.4	0.0
June	17.5	-1.3	7.9	-3.8

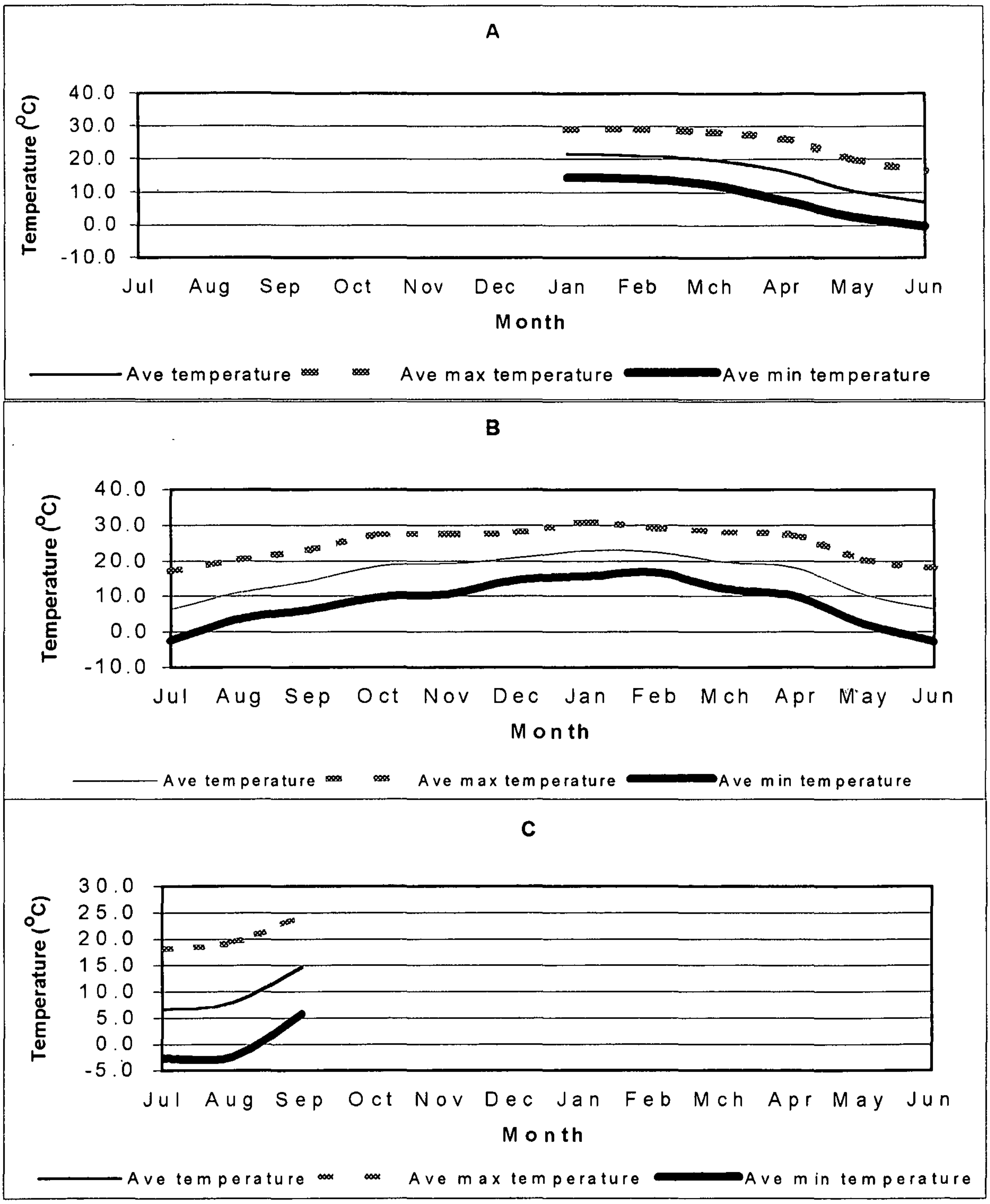

Figure 3.1 Average temperatures (°C) at Weigegund for the 2001/2002 (A), 2002/2003 (B) and 2003/2004 (C) growing seasons.

3.2.2 Rainfall

The experimental site is located in a summer rainfall area. The probability of rainfall higher than 50% is expected from October to April. The highest rainfall of 85.2 mm occure in March. The highest average raindays of 10.1 is also in March. The total rainfall of 677 mm recorded during the 2001/2002 growing season (Figure 3.2) was higher than the long-term means (547.5 mm) for Glen (Table 3.2 and Figure 3.2). The total rainfall of 93.7 mm recorded for April, May and June during the first season of the study (2001/2002) was also higher than the long-term means for the same months. During the 2002/2003 growing season, the total rainfall of 484.1 mm was lower than the long-term levels for Glen. The total rainfall of 5.3 mm for April, May and June received during the 2002/2003 growing season was far lower than the long-term means.for the same months.

Table 3.2 The long-term rainfall characteristics of Glen for the different months (National Climatological weather database of the Institute for Soil, Climate and Water 1922 - 1990)

Month	Average rainfall	% Reliability	Average raindays 1914 –1964 (Botha 1964)
July	8.7	20.63	2.1
August	11.8	18.13	2
September	19.1	20.68	2.6
October	47.1	51.15	5.5
November	64.3	52.41	8.2
December	66.5	51.55	8.1
January	81.8	58.01	9.8
February	82.4	57.81	9.6
March	85.2	56.15	10.1
April	52.3	51.34	6.4
May	19.3	36.01	4.6
June	9.5	27.82	2.0

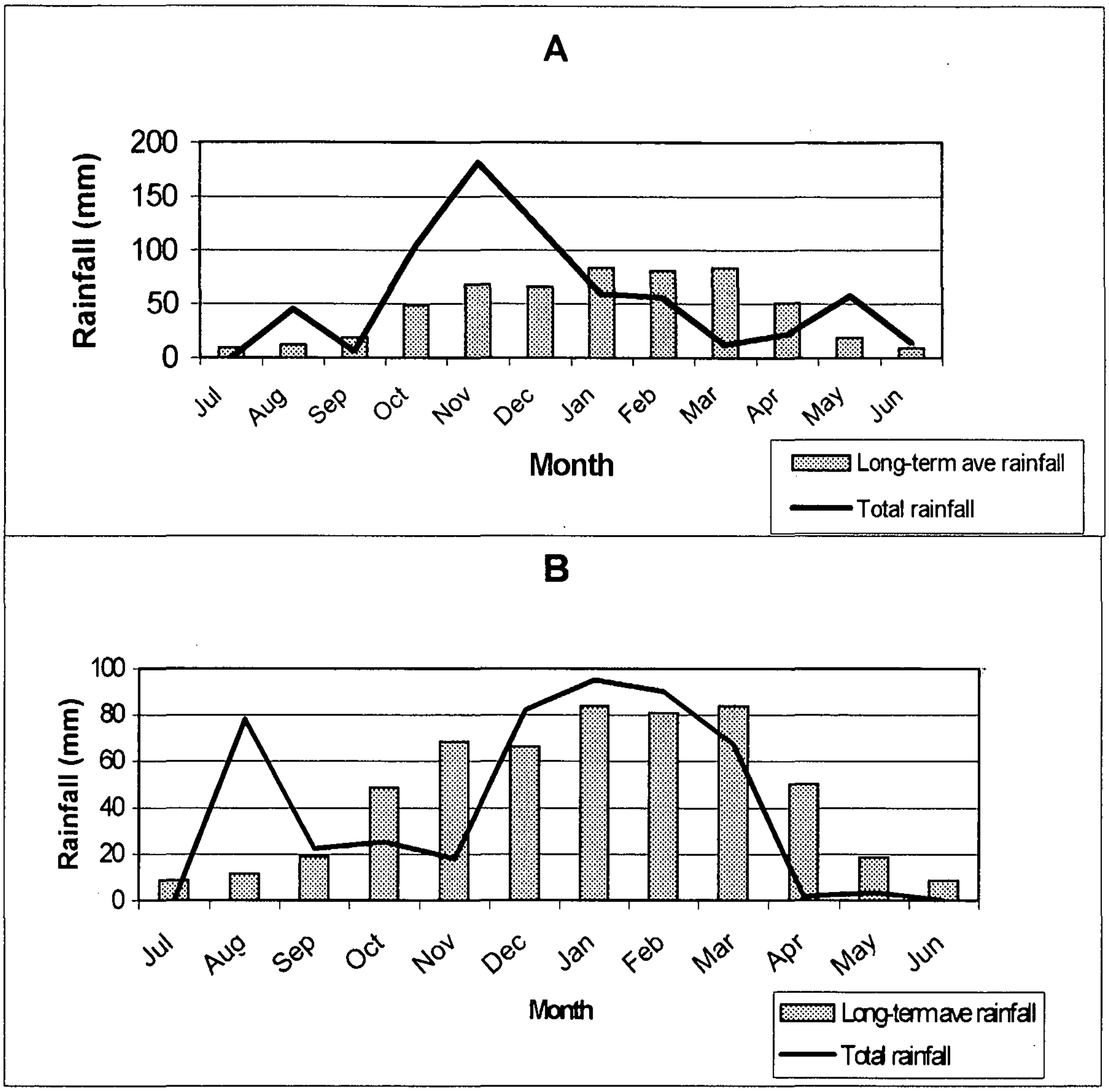

Figure 3.2 Long-term rainfall (mm) for Glen and total rainfall (mm) at Welgegund for the 2001/2002 (A) and 2002/2003 (B) growing seasons.

3.3 Soil

The soil in the study area was a sandy loam of the Valsrivierform (Aliwal family–11220) (Soil Classification Working Group 1991). The average soil texture for 0-300 mm, 300-800 mm and deeper than 800 mm were 32%, 54% and 56% clay respectively. The decrease in sand percentage, phosphorus and zinc and increase in clay percentage, electrical conductivity (EC), pH, Ca, Mg, K and Na with depth of the soil is not unusual (Table 3.3). Soil samples for laboratory analysis were collected from the three different horizons (0 – 300, 300 – 800 and >800 mm). Samples for analysis were obtained from Block A and Block B using a soil auger. The different blocks will be discussed in detail under the experimental layout (Fig. 3.3). According to Wessels (1988), the optimal levels of macro-elements in the soil for cactus plants should be 150 mg kg^{-1} for K, 12-15 mg kg^{-1} for P and 80-100 mg kg^{-1} for Mg. The values for K and Mg (Table 3.3) were above the recommendations while P was low compared to the record provided by Wessels (1988). Table 3.3 presents the percentage clay, percentage sand, electrical conductivity, soil acidity level, calcium, magnesium, potassium, sodium, phosphorus and zinc at different depths.

Table 3.3 Laboratory soil analysis for sand, clay, electrical conductivity (EC), soil acidity level (pH), calcium (C), magnesium (Mg), potassium (K), sodium (Na), phosphorus (P) and zink (Zn) for different depths in the experimental site at Welgegund.

Depth (mm)	**Clay** %	**Sand** %	**EC** mSm^{-1}	**pH** mg kg^{-1}	**Ca** mg kg^{-1}	**Mg** mg kg^{-1}	**K** mg kg^{-1}	**Na** mg kg^{-1}	**P** mg kg^{-1}	**Zn** mg kg^{-1}
Profile (0 -300)	32.00	68.00	12.50	4.40	761.50	324.50	350.00	31.00	9.52	0.45
Profile (300 – 800)	54.00	46.00	19.00	5.95	1823.50	920.50	106.00	96.50	1.04	0.38

(>800)	56.00	44.00	61.00	7.65	9298.50	1430.50	144.00	232.00	0.18	0

3.4 Experimental procedure

The experiment was a randomised block design consisting of three treatments (fodder, fruit and scozzolatura) and 11 cultivars, replicated twice on sixty-six plots. Each plot consisted of 20 plants, planted in two rows of which 10 plants were randomly selected, marked and used as data plants. The field experimental layout is illustrated in Figure 3.3. The plant density was 1 000 plants per hectare. The numbers represent different treatment combinations that are presented in Table 3.4.

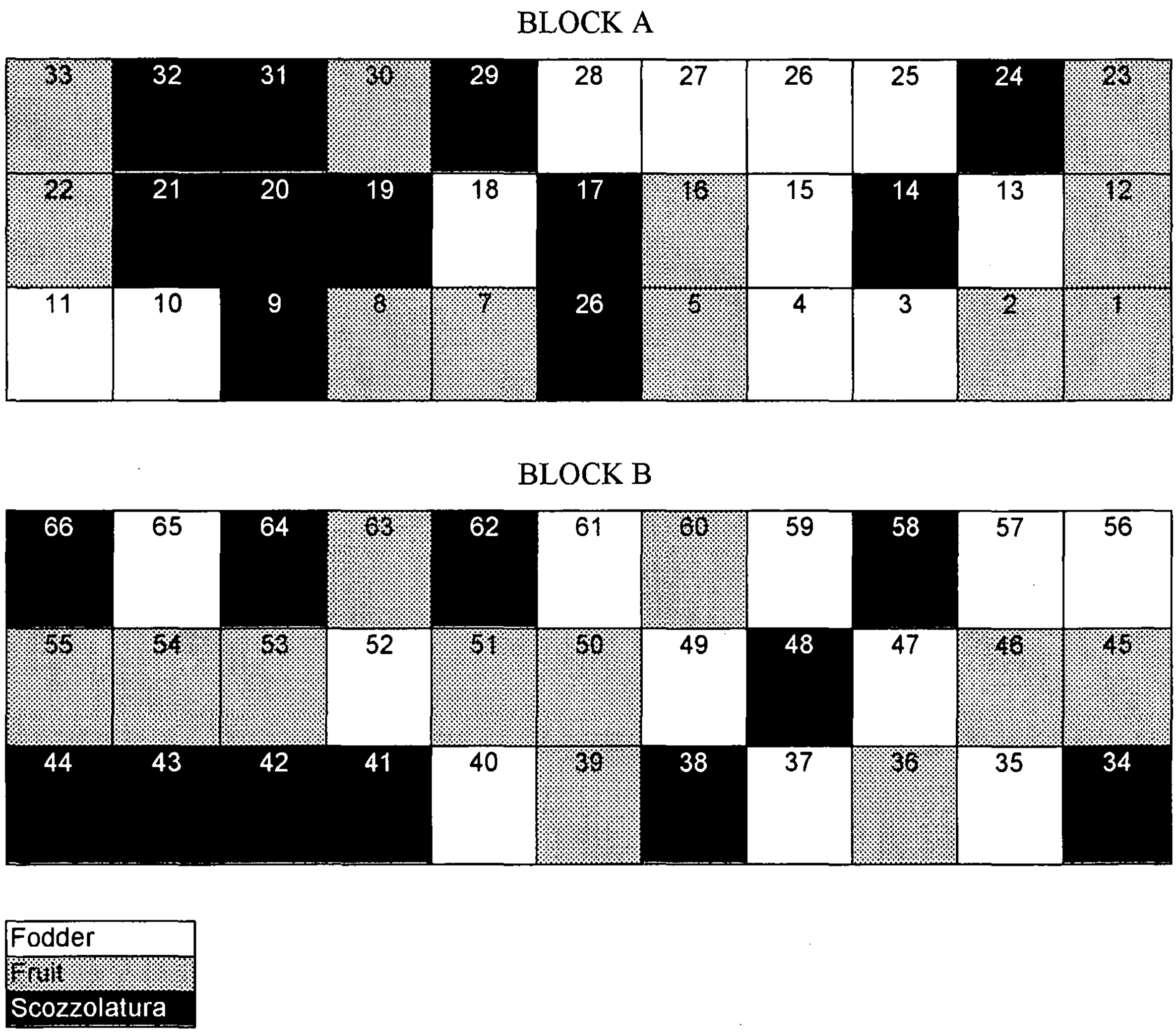

Figure 3.3 Experimental layout of the different treatments in two blocks.

Table 3.4 The different treatment combinations

Block A		Block B		Treatment combinations		
Plot	Treatment combination	Plot	Treatment combination	Treatment combination	Cultivar	Treatment
1	24	1	25	1	Nudosa	Fruit
2	18	2	29	2	Nudosa	Fodder
3	2	3	3	3	Nudosa	Scozzolatura
4	20	4	32	4	Gymno Carpo	Fruit
5	9	5	22	5	Gymno Carpo	Fodder
6	7	6	15	6	Gymno Carpo	Scozzolatura
7	3	7	20	7	Morado	Fruit
8	33	8	31	8	Morado	Fodder
9	28	9	16	9	Morado	Scozzolatura
10	17	10	28	10	Zastron	Fruit
11	5	11	4	11	Zastron	Fodder
12	30	12	6	12	Zastron	Scozzolatura
13	14	13	9	13	Algerian	Fruit
14	31	14	2	14	Algerian	Fodder
15	26	15	1	15	Algerian	Scozzolatura
16	27	16	8	16	Roedtan	Fruit
17	16	17	30	17	Roedtan	Fodder
18	32	18	12	18	Roedtan	Scozzolatura
19	22	19	17	19	Tormentosa	Fruit
20	25	20	18	20	Tormentosa	Fodder
21	19	21	21	21	Tormentosa	Scozzolatura
22	21	22	27	22	X 28	Fruit
23	15	23	5	23	X 28	Fodder
24	13	24	26	24	X 28	Scozzolatura
25	23	25	13	25	Sicilian fig	Fruit
26	29	26	23	26	Sicilian fig	Fodder
27	8	27	33	27	Sicilian fig	Scozzolatura
28	11	28	11	28	Van As	Fruit
29	4	29	7	29	Van As	Fodder
30	6	30	24	30	Van As	Scozzolatura
31	1	31	10	31	Monterey	Fruit
32	10	32	14	32	Monterey	Fodder
33	12	33	19	33	Monterey	Scozzolatura

3.5 Collection of plant material

Plant material (one-year-old cladodes) used (Fig. 3.4) during the study was collected on the 8th of August 2001 from Guillemberg (Polokoane) in the Limpopo province. Cladodes from different cultivars were numbered as a way of identification (Fig. 3.5). Cladodes were washed with Parathion to reduce possible incidences of infection before planting.

Figure 3.4 The one year old cladodes used as planting material

Figure 3.5 Numbering of cladodes from different cultivars

3.6 Cultivars and treatments

Two *Opuntia* species used in this study were *Opuntia ficus-indica* and *O. robusta.* The ten cultivars for the first-mentioned species were Algerian, Gymno Carpo, Morado, Nudosa, Roedtan, Sicilian Indian fig, Tormentosa, Van As, X28 and Zastron. Monterey was the only cultivar used for *O. robusta*. The cultivars used in this study were selected on the basis of their adaptability and production potential according to research and literature. *Opuntia ficus-indica* is believed to produce higher cladode production than *O. robusta*. It can be used either for fruit or cladode production. *Opuntia robusta* is traditionally a fodder plant compared to *O. ficus-indica.*

- In the fodder treatment all the cladodes (previous seasons' cladodes) were pruned in winter. The idea was to stimulate production of more cladodes than fruits.

- Fruit treatment involved minimum pruning of cladodes to keep the plant in shape and keep it below 2 m height as tall cactus plants would make harvesting difficult.

- In the scozzolatura treatment all the reproductive buds were removed during the first flush. In winter the pruning was performed in the same way as the fruit treatment. The main aim of scozzolatura treatment was to produce a late crop and stimulate vegetative growth.

3.7 Liming and fertilisation

Liming to raise the soil pH, as per laboratory analysis used during the study was 4 tonnes (Dolomite lime) per hectare. Superphosphate added at 300 kg per hectare, while 75 kg per hectare of N-fertiliser was applied before establishment. It was only possible during the study to fertilise the plants at establishment because a long period of drought made it impossible to carry out topdressing.

3.8 Planting and spacing

Cladodes were planted on the 18th October 2001 on a deeply tilled and well-disced soil. Each plot consisted of 2 rows with 20 plants (of which only 10 were used as data plants). The cladodes were spaced 5m apart between rows and 2m apart within the row (Fig. 3.6). The cladodes were planted upright, one-third into the soil (Fig 3.7). The row direction was North-South.

Figure 3.6 The spacing of cladodes in the field during planting

3.9 Weeding

A tractor drawn disc cultivator was used to remove the weeds between the rows to reduce competition for water and nutrients. Chemical weed control in the third season of the study was done using glyphosphate. To ensure that the chemical did not reach the plants, the cactus plants were covered before spraying the herbicide.

3.10 Data collection

Collection of data was carried out mostly in the second growing season (2002/2003) because the plants were allowed to establish in the first season (2001/2002) while in the winter of 2003 they were killed by frost. The relationship between growing season, plant age and activities are summarised in Table 3.5. Data collection can be divided into three parts, namely: vegetative measurements, reproductive measurements and laboratory measurements. It was not possible to calculate means from the data because of the big difference in the production between the second and third seasons. After the plants have matured (3 years) the production difference would be constant based on age of the plants and climatic conditions.

3.10.1 Vegetative measurements

Vegetative measurements comprised plant width, plant height, number of cladodes on the plant before pruning, number of cladodes removed by pruning, cladode percentage dry matter content, cladode fresh mass, cladode dry mass, cladode dry yield, phenology and frost damage. Only 10 data plants per treatment or plot were chosen randomly for each measurement from the total of 20 plants planted.

3.10.1.1 Plant width

This measurement was carried out to monitor horizontal vegetative plant development and enable the recommendation of a specific within-row planting distance for the climatic region. A measuring tape was held horizontally alongside the plant in the row so that the end of the measuring tape was in line with the starting point of the plant and the measurement was taken. The operation was carried out in winter prior to pruning.

Table 3.5 The relation between growing season, plant age and activity at welgegund

Growing season	Months										
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
1/7/01 - 30/6/02				Plant date				Remove buds				
1/7/02 – 30/6/03		Vegetative data Frost damage	Reproductive data Frost damage		Reproductive data			Harvest fruit	Harvest fruit			
				1 Year old								
1/7/03 – 30/6/04		Frost damage		Frost damage								
				2 Years old								

3.10.1.2 Plant height

This measurement is necessary to indicate the vertical vegetative growth rate of cultivars in the same climatic region. A measuring tape was placed next to the plant and the height from the soil to the highest point of the plant was measured.

3.10.1.3 Number of cladodes on the plant prior to pruning

This measurement is an indication of the relative comparative vegetative growth rate of the different cultivars. All the cladodes per plant (except the primary cladode) were counted in winter before pruning. However, cladodes of different cultivars may not be of same size.

3.10.1.4 Number of cladodes removed by pruning

This practice is performed in order to determine how many cladodes are removed as fodder for livestock or for purposes of plant material. After pruning in winter, all the cladodes pruned per plant were counted.

3.10.1.5 Cladode mass

This measurement is used to determine individual cladode mass where the average cladode mass per plant was calculated after weighing all pruned cladodes.

3.10.1.6 Cladode dry mass yield

The measurement is calculated to determine what the cladode yield (kg ha $^{-1}$) could be. The values were calculated by multiplying the cladode dry mass yield (kg) per plant with the number of plants per hectare.

3.10.1.7 Percentage frost damage

The values expressed as percentage were obtained by observing and noting the damage caused by frost on cladodes and used to indicate difference in frost damage between cactus pear cultivars. The percentage damage to plants was based on whether the damage was 25%, 50%, 75% or 100%. Frost damage was observed and recorded three times on 2nd August 2002, 4th October 2002 and 14th October 2003.

3.10.2 Reproductive measurements

Reproductive measurements cover the following: phenology, number of fruits per plant and fruit yield per plant. The average fruit measurements of only 10 data plants per treatment were taken. The plants were randomly chosen from the total of 20 plants planted in each treatment or plot.

3.10.2.1 Phenology

The time is determined when flower and leaf buds form, when flowering occures and fruit development, in a given climatic region. The average date, expressed asn weeks of the month, was observed and noted. Flower and leaf buds can be easily distinguished when they are approximately 5 mm long.

3.10.2.2 Removal of the buds

Removal of the flowering buds from all the plants in the first year of plant development was performed on the 18th November 2002. All the reproductive buds were removed during the first flush. This was done to ensure a better establishment.

3.10.2.3 Number of fruits

This measurement is used to determine fruit yield (plant $^{-1}$) for the different cultivars. The number of fruits per plant was obtained by counting the fruits during harvesting. The operation was performed on the 28th January 2003 for all other cultivars except X28 and Zastron. Zastron's fruits were harvested on 6th March 2003 because the fruits ripened later in the season.

3.10.2.4 Fruit yield

The value is useful in determining the fruit yield per plant or per hectare for each cultivar. The average fruit mass per plant was determined and then multiplied by number of plants per hectare (1 000) to obtain fruit yield per hectare.

3.10.2.5 Laboratory measurements

Laboratory measurements include fruit mass, fruit width, fruit length, flower- end depth, peelability index, peel thickness, pulp mass, T.S.S (Brix %), number of mature seeds, number of aborted seeds, mass of dried developed seeds, mass of dried aborted seeds and peel mass.

3.10.2.6 Fruit mass

The value is useful in determining fruit-yield and quality analysis. A laboratory electronic scale was used to obtain the weight of individual fruit from the different cultivars. The average fruit mass per plant and per cultivar was calculated with and without peel.

3.10.2.7 Fruit width

A Vernier caliper was used to measure the width of individual samples of harvested fruits from different cultivars. This value is useful in determining the size and shape of the fruit.

3.10.2.8 Fruit length

A Vernier caliper was used to measure the length of individual samples of harvested fruit from the different cultivars. This value is useful in determining the size and shape of the fruit.

3.10.2.9 Flower-end depth

The back-end of a Vernier calliper was used to measure the depth of the bell of the flower (calyx end) on the individual sample of fruits. This value is a genetic characteristic of cultivars, but is also influenced by environmental conditions e.g. the longer the fruit-developing period, the shallower the calyx end depth.

3.10.2.10 Peelability index

This measurement determines the difference in ease of peel removal of different cactus pear cultivars. It has a bearing on fruit quality and marketing potential. The peel of a fruit was cut with a knife and removed from the pulp. The peelability index was categorised as good or poor.

3.10.2.11 Peel thickness

The measurement is necessary in order to determine the proportion of the peel to the pulp. Individual peel thicknesses of the different cultivars were determined using the Vernier caliper. The peels were measured around the center of the fruit.

3.10.2.12 Peel mass

This measurement gives an indication of the ratio of peel mass to edible pulp mass. Individual peel masses of the different cultivars were determined using the laboratory-electronic scale.

3.10.2.13 Percentage dry material content of cladodes

This measurement is necessary in order to determine the dry material yield. The fresh wet mass of a sample of cladodes was determined before it was dried in an oven at 100°C. From these differences, the dry matter yields were calculated.

3.1.2.14 Cladode fresh mass

This measurement is necessary to determine the mass of plant material removed annually with pruning. During pruning the mass of all pruned cladodes from the different cultivars was obtained using a Digital platform scale. The fresh mass yield was expressed in kilograms.

3.10.2.15 Peel and pulp colour

The measurement is required to determine the difference in peel and fruit colour of the different varieties. The fruit colour may determine marketing potential of a specific variety. When the peel has been separated from the pulp, the colour of both peel and pulp was determined visually.

3.10.2.16 Total soluble solids (TSS)

Total Soluble Substances provide an indication of the sugar content of fruits from different cactus pear cultivars. In this study TSS, in Brix %, from individual cactus pear cultivars was determined using a hand refractometer. The average TSS of only 10 fruits from each treatment was taken.

3.10.2.17 Number of developed seeds

When seeds from fruits of different cactus pear cultivars had been separated from the pulp using a juice extractor and dried, developed seeds were separated from the aborted seeds and counted. The number of seeds is an indication of fruit quality. The seeds from only 10 fuits per treatment were taken for the seed measurement.

3.10.2.18 Number of aborted seeds

The number was obtained by separating the dry aborted seeds from developed seeds and counting them to obtain the number. The number is an indication of fruit quality.

3.10.2.19 Mass of mature and aborted seeds.

Dried developed and aborted seed mass from each fruit was obtained by using the laboratory electronic scale.

Chapter 4

Evaluation of cactus pear cladodes

4.1 Introduction

Cactus pear is used worldwide either as a dry-land pasture or as a cash crop. However, little horticultural research has been devoted to its productivity under different environmental conditions and management systems (Inglese 1992). Cactus pear is increasingly commercialised and there is therefore, a need to evaluate different characteristics to improve the farmer's selection of cultivars and productivity (Oelofse 2002). On the other hand, *Opuntia* production is extremely variable, because yield depends on orchard design and management rather than on prevailing environmental constraints (Pimienta 1990; Barbera *et al.* 1991). Differences in planting material, related to root and canopy development, often account for discrepancies in yield potential during the first four to five years after planting (Barbera *et al.* 1991). The production potential of selected cactus pear cultivars was Therefore, evaluated for two and three year old plants in this study.

4.2 Results and discussions

Encompassed under this heading are plant height and width, number of cladodes on the plant before pruning and number removed by pruning, cladode mass and cladode dry matter content, cladode yield and frost damage. Cladodes were not evaluated in the first growing season (2001/2002) because the plants were still young. No pruning took place IN the first growing season, the plants were only allowed to grow and establish well. Unfortunately, over the third growing season (2003/2004) the plants were killed by frost and only A few measurements were carried out. Most of the records in the present study were, therefore, obtained in the second season (2002/2003).

4.2.1 Plant height and width

The plant height and width measurements displayed in Figures 4.1 and 4.2 were obtained in the second growing season (2002/2003) of plant development. In the third growing season, it was impossible to carry out height and width measurements because the plants were killed by frost. This will be discussed in detail under point 4.2.7. The treatments did not differ significantly ($P>0.05$) from each other in terms of height and width (Fig. 4.1). The P-values and least significant differences (LSD) for the different treatments and cultivars ($P\leq0.05$ level of significance) are presented in Table A.1.

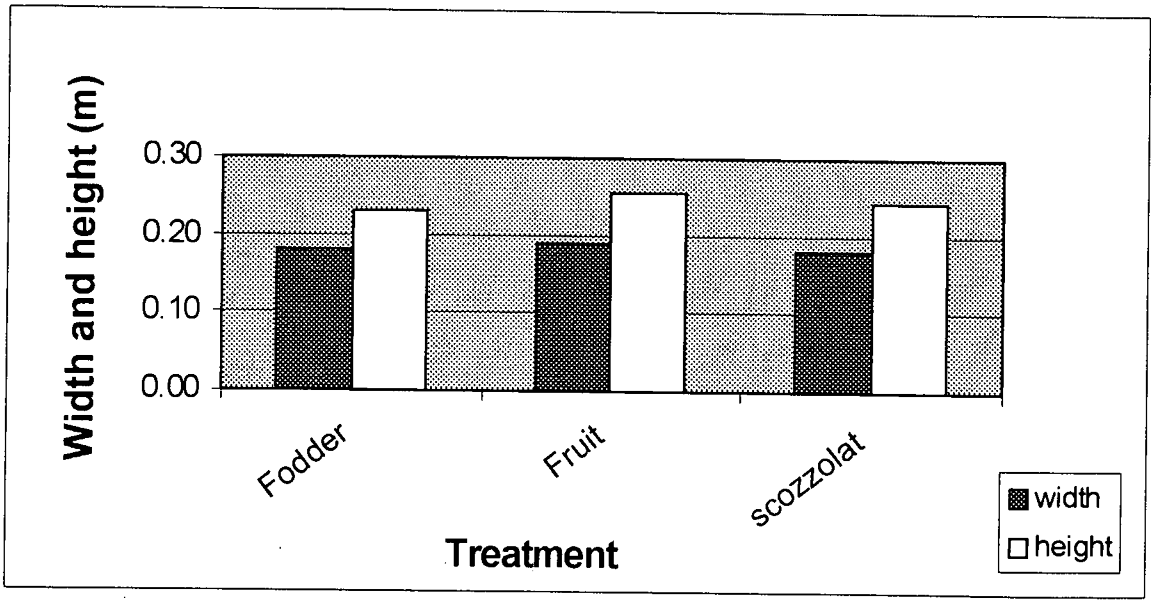

Figure 4.1 Average plant width (m) ($LSD_{0.05} = 0.022$) and height (m) ($LSD_{0.05} = 0.0285$) for the different treatments determined for two-year-old plants.

Such results were expected because after only two years of establishment, the treatments should not show an effect. However, a significant difference ($P<0.05$) existed between some cultivars in terms of height and width (Fig. 4.2). Although the greatest plant widths attained by Roedtan, Morado and Algerian were not significantly ($P>0.05$) different from each other, they were greater ($P<0.05$) compared to Gymno Carpo, X28, Monterey and

Tormentosa. The lowest average width of 0.12 m was recorded for Tormentosa with the highest average width of 0.26 m recorded for Morado in this study. The greatest height attained by Zastron was significantly higher ($P<0.05$) than Van As, Sicilian Indian fig, Gymno Carpo, X28 and Tormentosa. The lowest height attained by Tormentosa was only not significant ($P>0.05$) when compared to Gymno Carpo, Monterey and X28. All cultivars grew more in height than width, with the exception of Zastron which grew more in width. The lowest average height of 0.16 m per plant was recorded for Tormentosa, while the highest average width of 0.33 m was recorded for Zastron in this study.

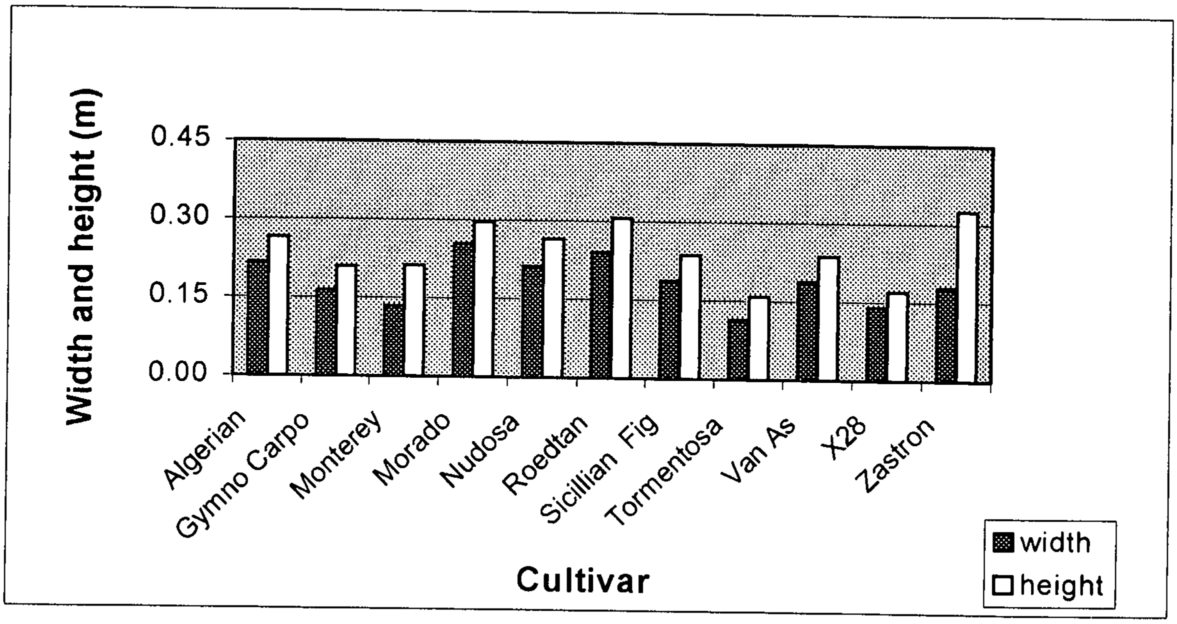

Figure 4.2 Average plant height (m) (LSD $_{0.05}$ = 0.0746) and width (m) (LSD $_{0.05}$ =0.0665) for the different cultivars for two year old plants.

In view of the results reported by Oelofse (2002), who evaluated among other variables, plant height and width of ten cactus pear cultivars (5 years old) including Nudosa, Gymno Carpo, Morado, Zastron, Algerian, and Roedtan, Zastron, Morado and Roedtan attained greater height and width than other cultivars (Nudosa, Gymno Carpo and Algerian). This report is in agreement with the observations in the present study. In the present study all eleven cactus pear cultivars under consideration attained more height (0.16 – 0.26 m) than width (0.16 – 0.33 m) which is not in harmony with the findings of

Olelofse (2002) who reported more growth in width (2.08 – 2.51 m) than height (1.73 – 2.23 m) in all cultivars. As one could expect from five-year-old plants, Oelofse (2002) reported far higher growth in height and width than those recorded in this study. Unfortunately, there is limited literature available on the growth performance of young cactus plants (1 - 3 years) to substantiate the findings reported in this study.

4.2.2 Number of cladodes on the plant before pruning

It was only possible to monitor this parameter twice during the study. In the first year the plants had developed only 2 cladodes on average and as such no exact counts or pruning were done. Over the first season the plants were only allowed to establish without any pruning. The average number of cladodes on the plant before pruning during the second season (Fig. 4.3) did not differ significantly ($P>0.05$) between the treatments. However, there was a significant difference ($P<0.05$) between cultivars both in the second and third seasons (Fig. 4.4). The highest number of cladodes per plant before pruning attained by Zastron in the second year was higher ($P<0.05$) than those in all other cultivars, except Morado, Roedtan, Algerian and Nudosa. The lowest number of cladodes per plant before pruning, attained by Tormentosa was significantly lower ($P<0.05$) than in all other cultivars, except for Monterey and X28. In the third year of plant development, Roedtan attained a higher number of cladodes per plant ($P<0.05$) when compared to Monterey, Tormentosa, Gymno carpo, Zastron, Algerian and X28 (Fig 4.4). The lowest number of cladodes per plant was recorded for Monterey. Lack of literature about performance of young cactus plants (1 – 3 years) makes it difficult to compare the results obtained in this study.

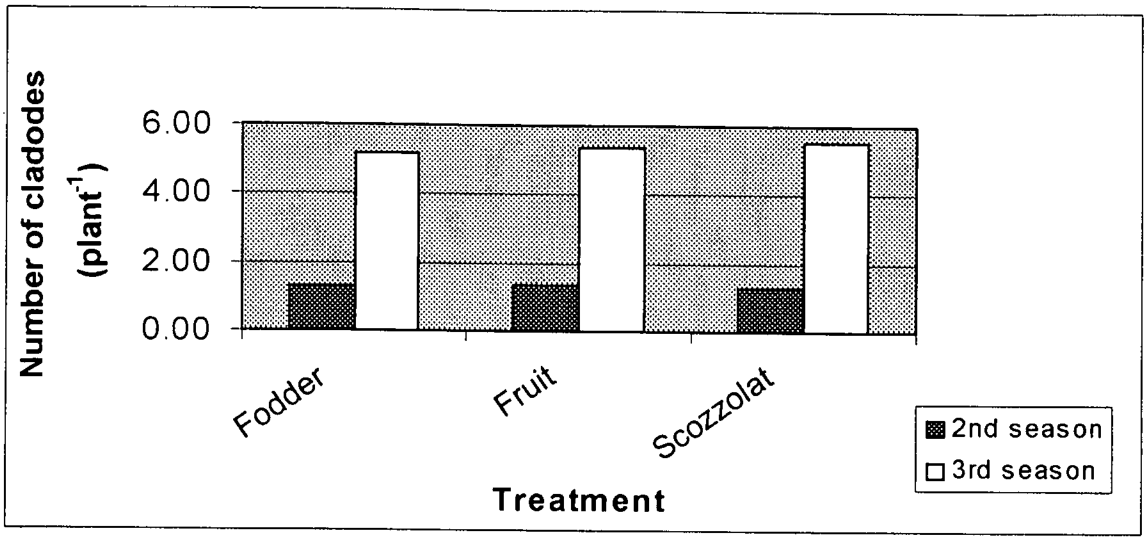

Figure 4.3 Average number of cladodes (plant^{-1}) in the second ((LSD $_{0.05}$ = 0.1239) and third season (LSD $_{0.05}$ = 0.152) before pruning.

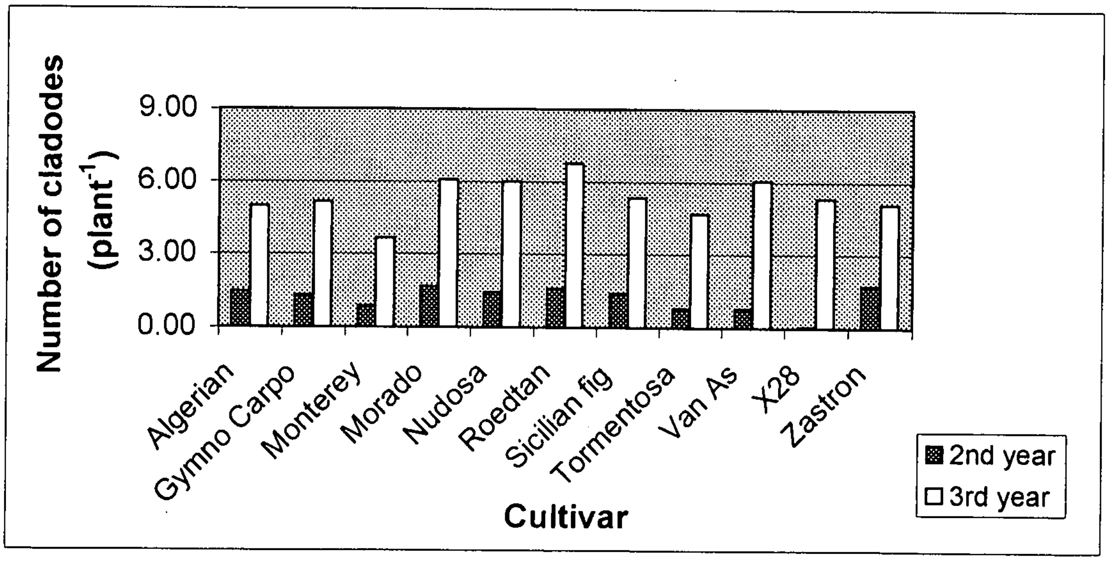

Figure 4.4 Average number of cladodes (plant^{-1}) in the second (LSD $_{0.05}$ = 0.4381) and third year (LSD $_{0.05}$ = 0.9692) before pruning for the different cultivars

It is not surprising that Roedtan, Morado, Van As and Nudosa attained higher average numbers of cladodes before pruning (Figure 4.4) because these cultivars did not suffer as much frost damage relative to Zastron, Tormentosa, Algerian, Gymno Carpo and Van As during the winter of 2002 (Figure 4.14). Roedtan, Morado and Van As also suffered relatively less frost damage from the late frost (4th October 2002). This is discussed in detail under point 4.2.7.

4.2.3 Average number of cladodes per plant removed by pruning

It was only possible to monitor this parameter once in 2002/2003 because in the first season (2001/2002) the plants were still developing while in the third season (2003/2004) all the cultivars were killed by frost. The average number of cladodes per plant removed by pruning differed non-significantly (P>0.05) between the treatments. At a young stage of plant development (1 – 3 years) there should be no difference between treatments with similar management. The difference between treatments was expected later beyond the third year when management differs according to each treatment.

The relative difference between the treatments shown in Figure 4.5 was not expected. The observed discrepancy should have been made possible by the higher individual contribution of certain cultivars over others in different treatments. The total average number of cladodes per plant recorded for the fruit treatment (1.37) was largely due to the contribution of Roedtan (12%), Zastron (11%), Algerian, Morado, Sicilian Indian fig and Nudosa (10% each). Algerian and Morado contributed 9% each, Monterey 7% and X28 6%. Under fodder treatment, the attained total average number of cladodes removed by pruning (1.30) was largely due to the contribution of Roedtan (12%), Zastron (11%), Algerian, Morado, Nudosa and Sicilian Indian fig (10% each). Other cultivars' contributions were 9% for Van As, 8% for Gymno Carpo and 6% for Tormentosa and X28 each. Under Skozzolatura, the total average number of cladodes (1.26) removed by pruning was largely the combined contribution of Roedtan, Morado and Zastron (33%) and Sicilian Indian fig (10%). Algerian and Gymno Carpo contributed 9% each and Monterey and X28 7% each. Under the three treatments (fodder, fruit and skozzolatura) the contributions of Roedtan, Zastron, Morado and Nudosa was superb. The combined contribution of the above mentioned cultivars was higher in fruit and fodder treatments (43%) than in skozzolatura (42%).

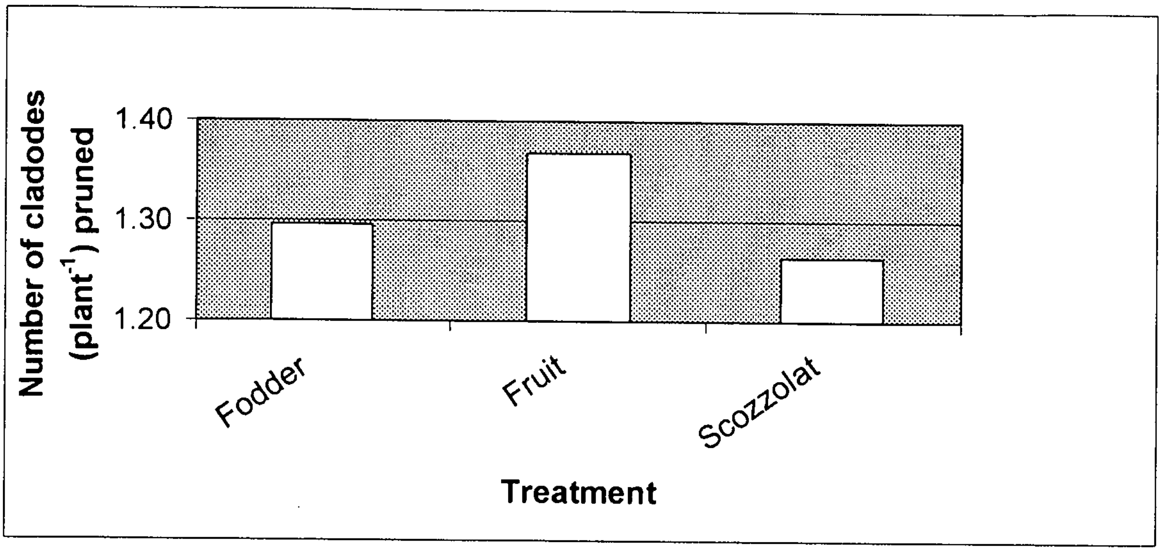

Figure 4.5 Average number of cladodes removed by pruning ($LSD_{0.05}$ =0.2284) for each treatment determined for two-year-old plants.

The number of cladodes per plant differed significantly (P<0.05) between some cultivars (Figure 4.6). Morado and Roedtan had a higher number of cladodes removed by pruning than other cultivars. However this was only significant (P<0.05) when compared with Tormentosa, Monterey and X28. In view of the findings recorded by Oelofse (2002), on the number of cladodes pruned from 5 year old plants, Morado and Roedtan attained higher values than Zastron, Algerian, Roedtan, Nudosa, Gymno Carpo and other cultivars. The values were 72.5, 72, 65.6, 56.6, 56.3, 47 and 22.9 cladodes per plant for Morado, Roedtan, Zastron, Gymno Carpo, Algerian and Nudosa respectively. Such findings agree with the present study. Roedtan and Morado had a higher average number of cladodes removed by pruning (Figure 4.6), as these cultivars together with Nudosa and Van As, did not suffer as much frost damage in comparison to Zastron, Tormentosa, Algerian, Gymno Carpo and Van As during the winter of 2002 (Figure 4.14). Roedtan, Morado and Van As also suffered relatively less frost damage from the late frost (4th October 2002). This is discussed in detail under point 4.2.7. The lower average number of cladodes removed by pruning recorded for Nudosa compared to Roedtan, Morado and Van As, could be associated with the relatively high late frost damage (2.33%) recorded on 4 October 2002 (Figure 4.14). Roedtan, Morado, Van As and Nudosa suffered almost equal frost damage during winter 2002 and attained an almost equal average number of cladodes before pruning.

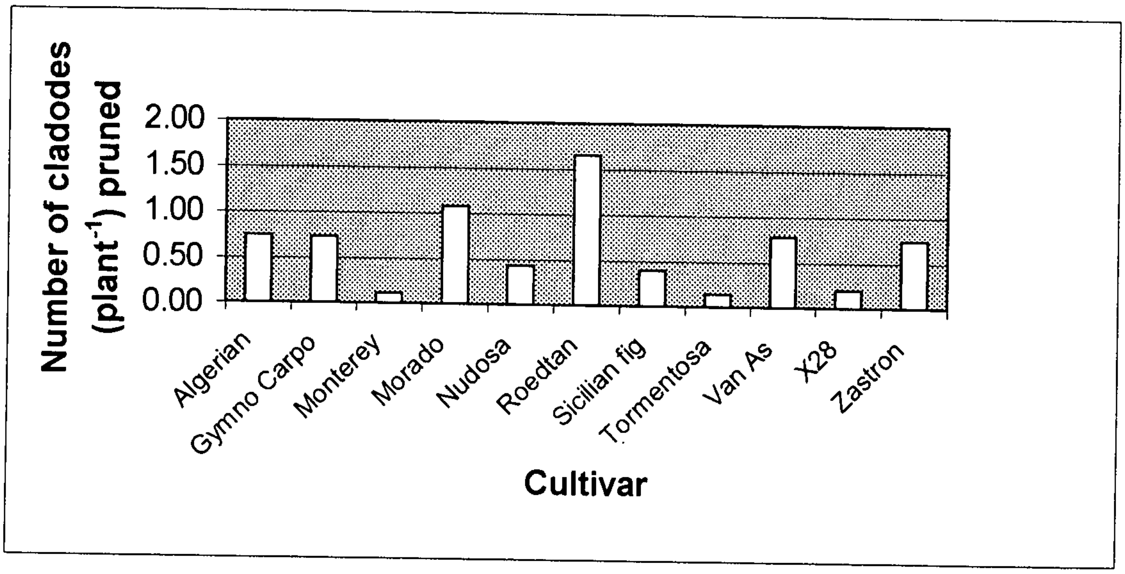

Figure 4.6 Average number of cladodes per plant removed by pruning ($LSD_{0.05}$ = 0.4925) for each cultivar.

4.2.4 Average cladode fresh mass

The cladode fresh mass per plant was determined only in the second season (2002/2003). In the first season (2001/2002) it was not evaluated because the plants were still young. It was impossible to evaluate cladode fresh mass for the third growing season (2003/2004) because the plants were killed by frost. The treatments did not differ significantly ($P>0.05$) from each other in terms of the average cladode fresh mass (Fig. 4.7). Slightly higher values, although non-significant ($P>0.05$) were obtained for scozzolatura than for other treatments. The contribution of the different cultivars to the overall cladode fresh mass recorded for scozzolatura was as follows: 0.07g (19%) for X28, 0.05g (14%) for

Monterey and Nudosa (each), 0.03g (8%) for Morado, Roedtan, Tormentosa and Sicilian Indian fig (each), 0.02 (5%) for Algerian, Gymno Carpo and Zastron (each), and 0.025 (6%) for Van As. The cultivars X28, Montery and Nudosa were responsible for higher cladode fresh mass attained by scozzolatura over fodder and fruit treatments.

The different cultivars differed significantly ($P<0.05$) in terms of average cladode fresh mass (Fig. 4.8). Roedtan attained the highest ($P<0.05$) cladode mass compared to other cultivars. Morado also had a significantly high ($P<0.05$) cladode fresh mass than Monterey, Nudosa, Sicilian Indian fig, Tormentosa and X28. The lowest cladode mass, recorded for Tormentosa, was only significant ($P<0.05$) when compared to Roedtan, Morado, Gymno Carpo and Algerian. Oelofse (2002) reported a higher cladode mass for five-year-old plants (1.09 – 2.8 kg) than those reported in the present study. These discrepancies could be due to the difference in age of the plants considered in the different studies. Oelofse (2002) also recorded 1.36, 1.23, 1.18, 1.17, 1.16, 1.09 kg fresh cladode mass per plant for Nudosa, Algerian, Morado, Zastron, Gymno Carpo and Roedtan respectively. Although Roedtan attained the highest cladode mass in the present study among all cultivars, it recorded the lowest mass compared to other cultivars according to Oelofse (2002). Surprisingly, Nudosa, which was not prominent in the present study in terms of cladode fresh mass, performed excellently according to Oelofse (2002). Roedtan and Morado recorded higher average cladode mass per plant because they were not affected as much by frost as Zastron, Tormentosa, Algerian and Gymno Carpo in winter during 2002/2003 growing season. They also suffered the least late frost damage together with Monterey and Van As (Figure 4.14).

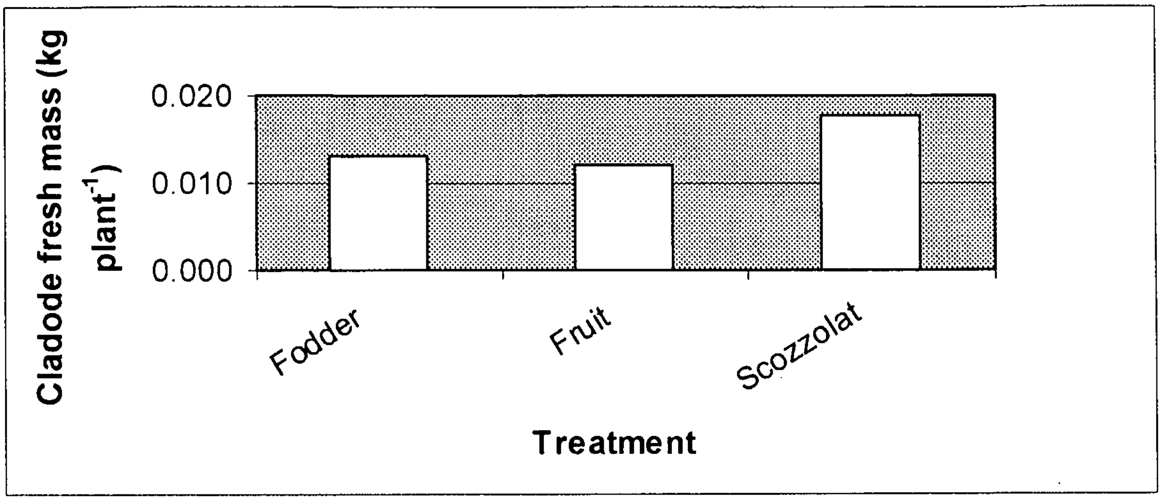

Figure 4.7 Average cladode fresh mass (kg plant $^{-1}$) (LSD $_{0.05}$ = 0.0067) for different treatments determined for two year old plants.

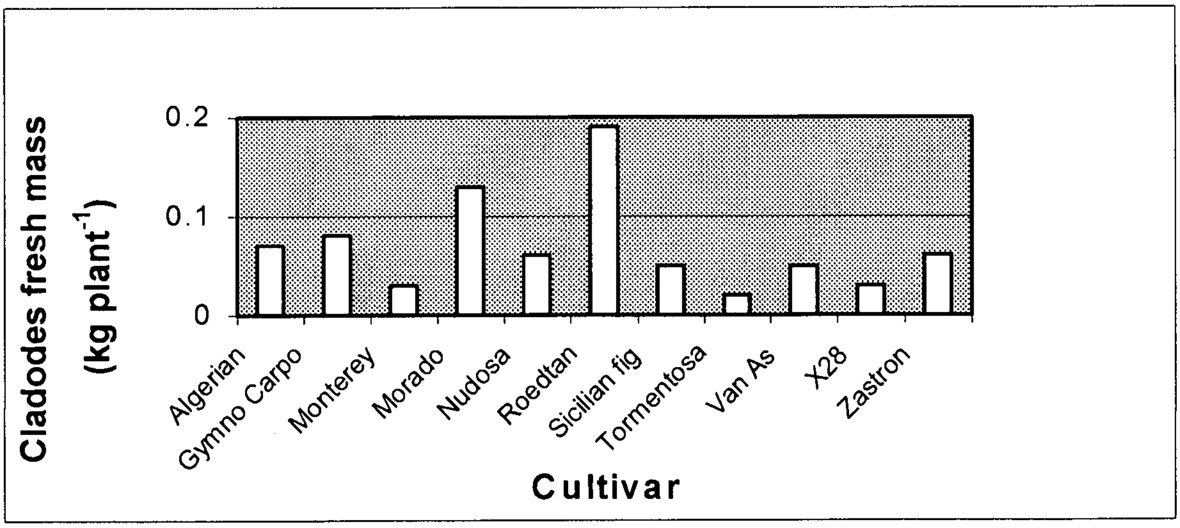

Fig 4.8 Average cladode fresh mass (kg plant $^{-1}$) (LSD $_{0.05}$ = 0.0518) for different cultivars determined for two-year-old plants.

4.2.5 Average cladode dry mass percentage

This parameter was recorded in the second season (2002/2003) after the establishment of the plants. In the first season (2001/2002) no data was collected because the plants were too young. It was impossible to obtain data in the third season (2003/2004) because the plants were killed by frost. The average cladode percentage dry matter per treatment (Fig 4.9) did not differ significantly (P>0.05). The observed difference between treatments, although not significant (Fig. 4.9) is questionable because the three treatments received similar treatments.

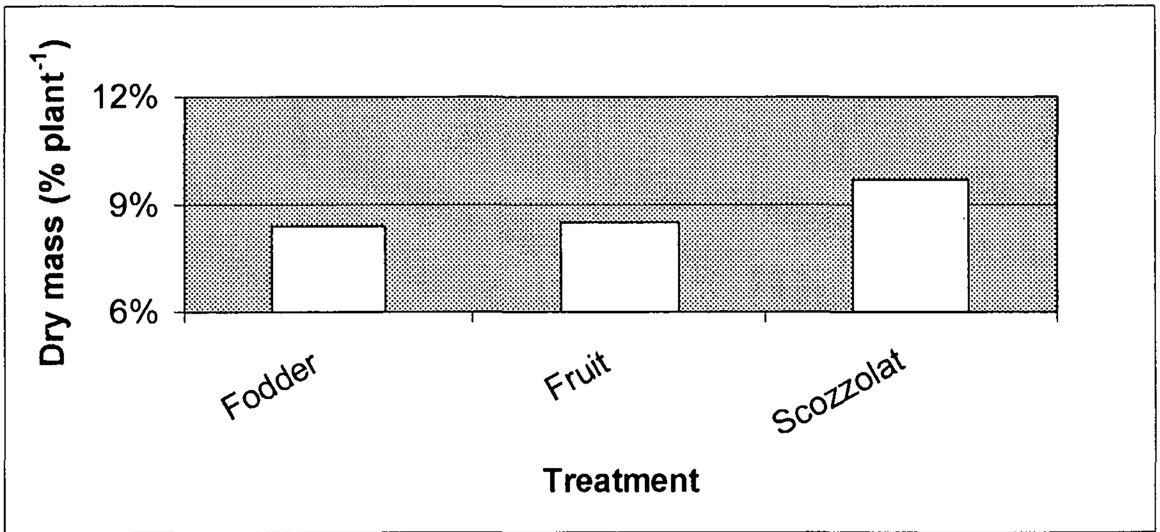

Figure 4.9 Average cladode dry mass (% plant $^{-1}$) (LSD $_{0.05}$ = 2.27) for different. treatments determined for two year old plants

The different cultivars' contribution to the total percentage dry mass recorded for Scozzolatura was 12%, 11%, 11%, 10%, 10% 10%, 9%, 9%, 9%, 5% and 4% for Zastron, Monterey, Morado, Nudosa, Roedtan, X28, Gymno Carpo, Sicilian Indian fig, Van As, Algerian and Tormentosa respectively. It seems that all the cultivars except Algerian and Tormentosa made a considerable contribution to the cladode dry mass yield under Scozzolatura. Under fodder and fruit treatments, all the cultivars contributed relatively equally to the total percentage dry mass.

Different cultivars did not differ significantly (P>0.05) in terms of cladode percentage dry matter content (Figure 4.10). Cladode dry matter content of 8.01 and 7.96% recorded by López-García *et al.* (1997) agreed with that of Algerian, Monterey, Sicilian indian fig and X28. In this study a higher percentage dry mass for Gymno Carpo, Morado, Nudosa, Roedtan, Van As and Zastron was recorded compared to that obtained by López-García *et al.* (1997).

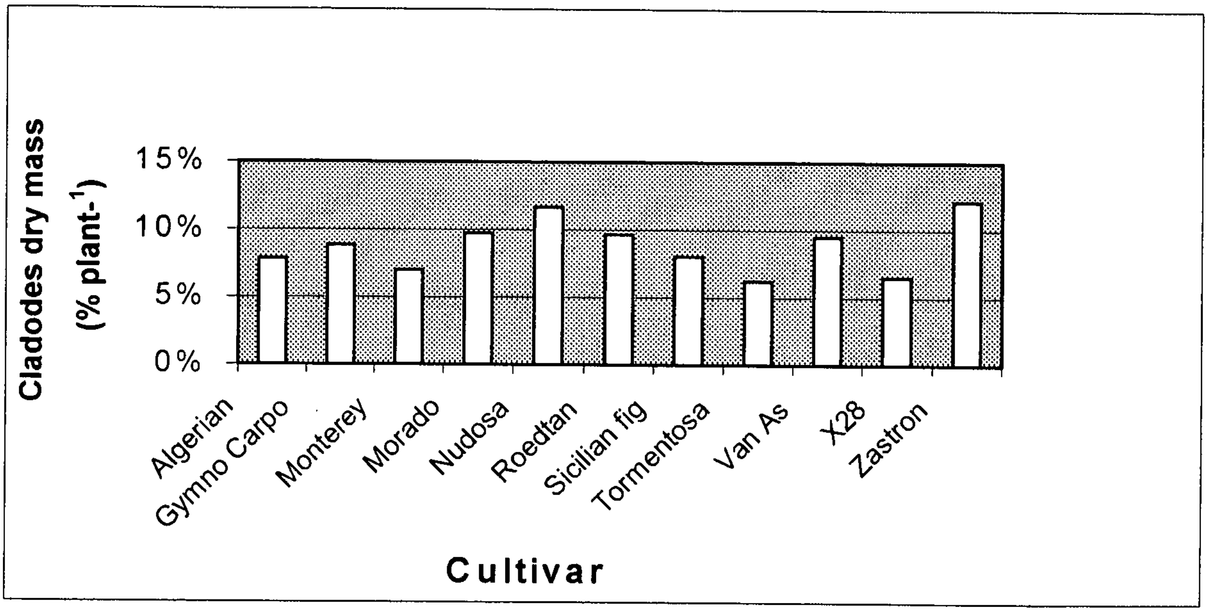

Figure 4.10 Average cladode dry mass (% plant $^{-1}$) (LSD $_{0.05}$ = 6.3856) for different cultivars determined for two year old plants.

4.2.6 Average cladode dry mass yield

The average cladode dry mass yield was measured in the second season (2002/2003). In the first season (2001/2002), no data was gathered to allow plants to become well establish. It was impossible to obtain data on dry mass yield of cladodes in the third growing season because all the cultivars were severely damaged following severe frost, except the mother cladodes. This record is well presented in 4.2.7.

The average dry mass yield per treatment did not differe significantly (P>0.05) between treatments (Fig. 4.11). The different cultivars' contribution to the total dry mass yield recorded for scozzolatura was 12%, 11%, 11%, 10%, 10% 10%, 9%, 9%, 9%, 5% and 4% for Zastron, Monterey, Morado, Nudosa, Roedtan, X28 Gymno Carpo Sicilian Indian fig, Van As, Algerian and Tormentosa respectively. It seems that all the cultivars except Algerian and Tormentosa made a considerable contribution to the cladode dry mass yield under Scozzolatura. Under fodder and fruit treatments, all the cultivars contributed relatively equally to the total percentage dry mass yield.

In contrast, some of the cultivars differed significantly (P<0.05) in terms of cladode dry mass yield. Cladode dry mass yield attained byr Roedtan was higher (P<0.05) than that of all other cultivars except that of Morado. Low cladode dry mass yields for Monterey and Tormentosa was only significantly (P<0.05) different from those of Morado and Roedtan. Morado, Algerian and Gymno Carpo recorded relatively higher dry mass values than all other cultivars, except Roedtan. This parameter was not documented in most research work on cactus pear. De Kock (1998) recorded a 3.27 (t ha^{-1}) cladode dry mass yield for 2920 mature plants (t ha^{-1}) or 1.1 (kg ha^{-1}) for each plant. By comparison, the cladode dry mass yields attained in the present study were low. It is logical that low dry mass values were recorded here as only a small cladodes (Fig. 4.4) were produced and consequently few cladodes were pruned (Fig.4.6) per plant (from which dry mass was derived).

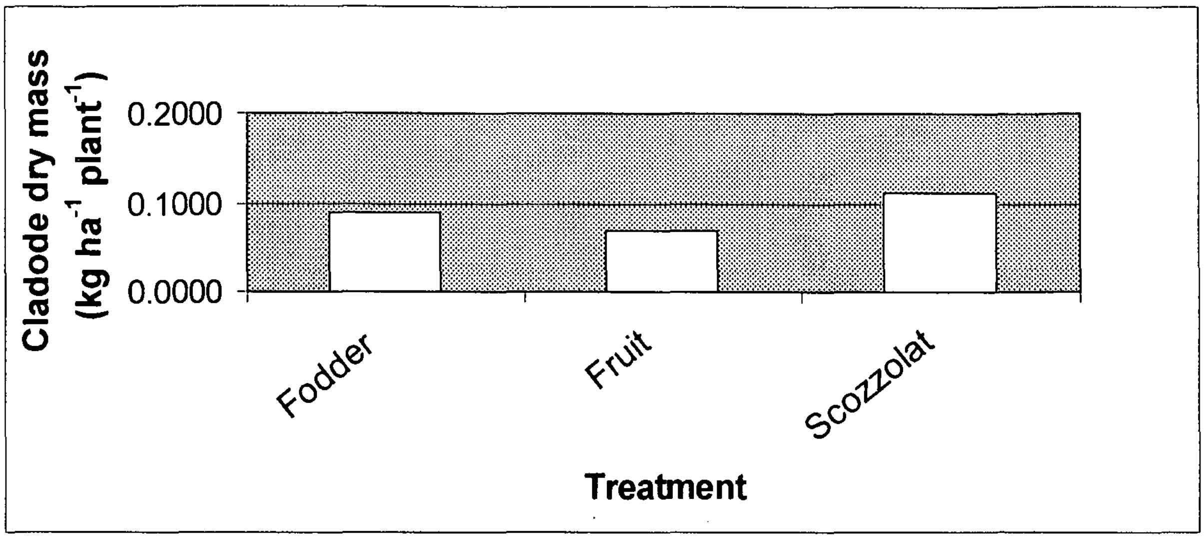

Figure 4.11 Average cladode dry mass per plant (kg ha $^{-1}$) for each treatment (LSD $_{0.05}$ = 0.1200) determined for two-year-old plants.

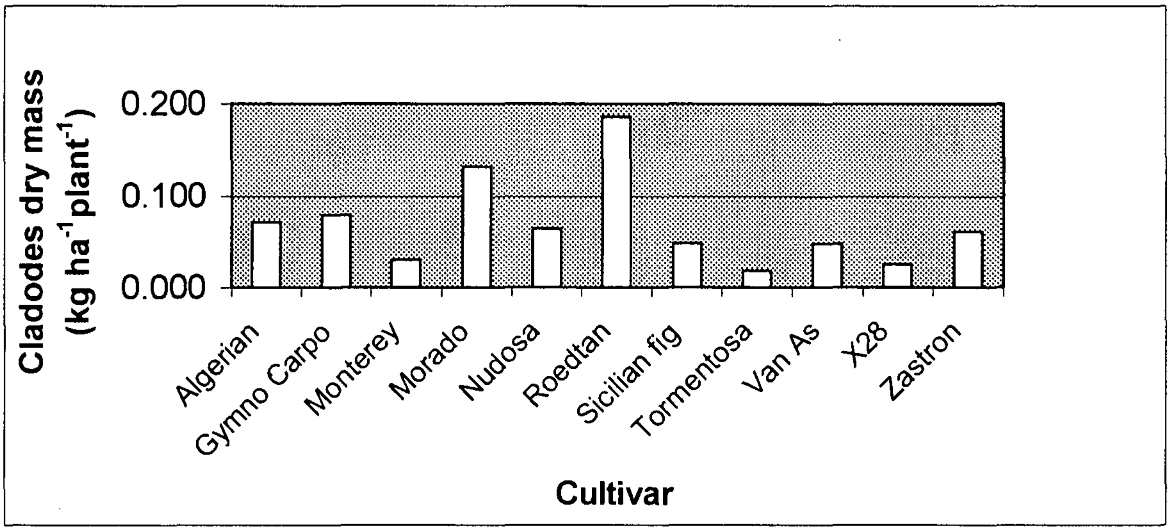

Figure 4.12 Average cladode dry mass per plant (kg ha^{-1}) for each cultivar (LSD $_{0.05}$ = 0.1200) determined for two-year-old plants.

Higher average dry mass (plant kg ha^{-1}) recorded for Roedtan and Morado was due to the fact that these cultivars did not suffer much frost damage during winter 2002. They also did not suffer more damage from late frost when compared to other cultivars except Van As and Monterey (Figure 4.14).

4.2.7 Frost damage

Figures 4.13 and 4.14 illustrates the average percentage frost damage per plant for the different treatments and cultivars observed on different dates (2/8/02, 4/10/02 and 14/9/03). The treatments did not differ significantly ($P>0.05$) in terms of percentage frost damage. However, there was a significant ($P<0.05$) difference between some cultivars in terms of frost damage. Zastron suffered more ($P<0.05$) frost damage than other cultivars in the (2002/2003) growing season (2nd October 2002). Monterey attained the lowest ($P<0.05$) frost damage compared to all other cultivars, except Zastron, Algerian and Tormentosa at the first observation date (2/8/02). Nudosa suffered the most frost damage. However, this was significant ($P<0.005$) when compared to all other cultivars except Zastron and Sicilian fig at the second observation date (4/10/02). Zastron also suffered more frost damage, which is significant when compared to all other cultivars except Nudosa, Sicilian Indian fig and Monterey (Fig. 4.14). At the third observation date (14/9/03), Monterey recorded the lowest ($P<0.05$) percentage frost damage compared to other cultivars. All other cultivars, which were not significantly different ($P>0.05$) were dead (except the mother cladode) when the last observation was carried out (2003/2004 growing season). Algerian, Sicilian Indian fig, Van As and X28 suffered higher frost damage (100%) than other cultivars. Tormentosa and Roedtan (98%), Nudosa (97%), Morado (96%) Gymno Carpo (95%) and Zastron (85%) were also greatly affected by the frost.

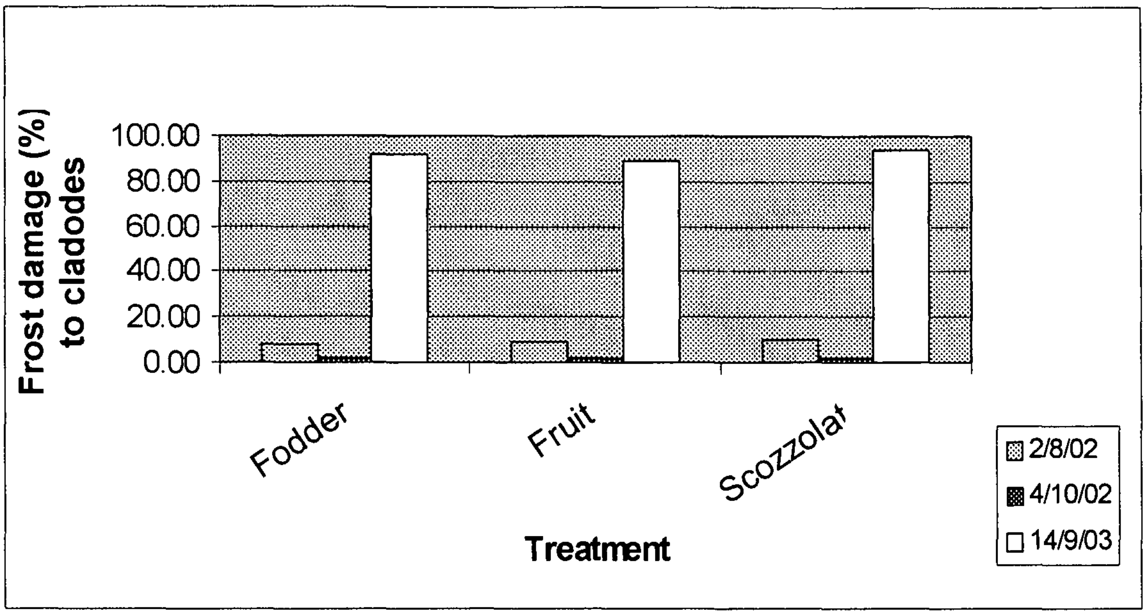

Figure 4.13 Average frost damage (%) to cladodes measured at different dates (LSD $_{0.05}$ = 2.3312), October (LSD $_{0.05}$ = 1.186) and (LSD $_{0.05}$ = 6.649) for each cultivar.

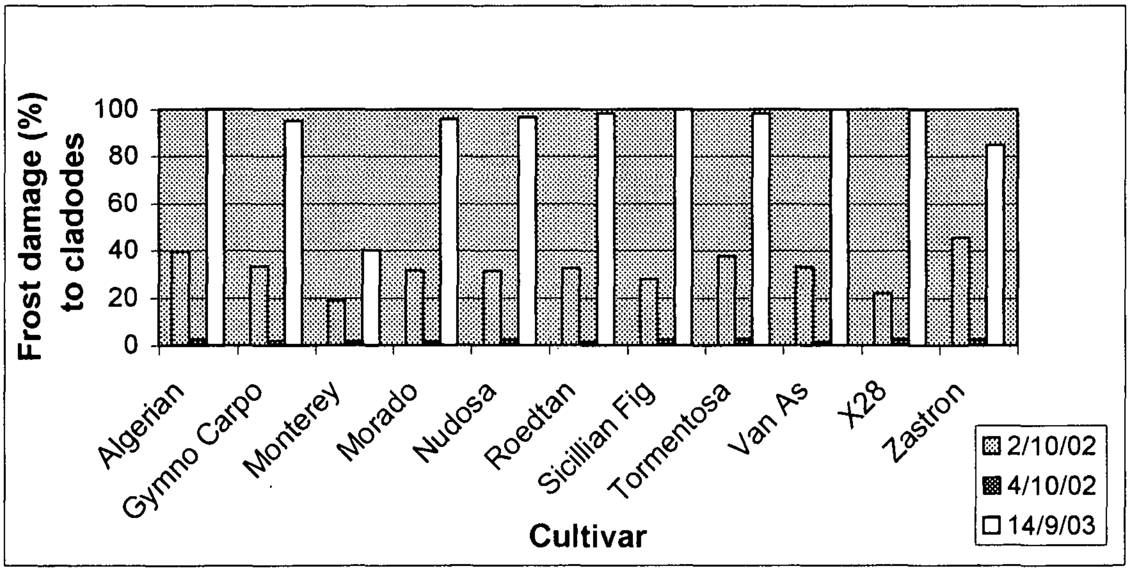

Figure 4.14 Average frost damage (%) to cladodes measured at different dates (LSD $_{0.05}$ = 17.007), (LSD $_{0.05}$ = 1.6329) and (32.0101) for each cultivar.

Opuntia cultivars are generally irreversibly injured at temperatures between -5 and –10 °C (Russell and Felker 1987: Nobel and Loik 1993). In *Opuntias*, the lack of freezing resistance is probably not due to the lack of tolerance to cold temperature *per se*, but the range of day to night temperatures, from 28°C down to –12°C in a single day, which does not allow the plant to properly acclimatise (Gregory *et al.* 1993). Successive nights of low temperatures (Figures 5.16) of –0.86 to –3.3 °C, -2.08 to –2.67 °C, -0.61 to –1.37°C, -0.37 to –4.65°C, -3.15 to –4.79°C, and –0.61 to –0.12°C for 5 days (7-12/5/2002), 2 days (9-11/6/2002) 4 days (16-20/6/2002), 6 days (24-30/6/2002) and 6 days 2-8/7/2002 respectively were very injurious to the cactus pear cladodes in this study. Another incidence of a drop in temperatures (-0.12°C) and (-2.06°C) on the 2nd and 4th October of the same season, when young plants had resumed growth is believed to have aggravated the degree of damage suffered by plants during winter.

Low night temperatures of –0.61 to –3.55°C for 4 days (27-31 May 2003), -0.2 to –8.07°C for 25 days (4 to 30 June 2003), –0.94 to –6.25°C for 20 days (01 to 21 July 2003), -0.61 to –3.55°C for 4 days (7 to11 August 2003), -0.2 to –9.63°C for 6 days (14 to 20 August 2003), and –1.36 to –8.05°C for 7 days (22 to 29August 2003) should have been too much for the young cactus pear plants to withstand (Fig. 4.16). Nine out of the 11 cactus pear cultivars under study were killed in the winter preceeding the third growing season. The remaining two cultivars also suffered high frost damage (Monterey 40% and Zastron 85%) where only some of the mother cladodes survived (Figure 4.16).

The reason why cactus pear cultivars were killed in the present study can be debated, as there are successful cactus pear plantations in the central Free State and in the karoo. It is believed that low temperatures did not single-handedly cause the death of the cactus pear plant. A long spell of drought for 4 months (April, May, June and July) in 2002/2003 growing season could have a bearing on that as well (Figure 3.2). A long period of drought coupled to successive nights of low temperatures below zero experienced several times during the study (Figures 5.14), could have been too harsh for the young plants to survive. Also high average maximum temperatures of 28.1, 30.1, 29.3 and 28.1 for December, January, February and March respectively recorded in 2002/2003 growing season, could have been detrimental to young cactus plants (Fig. 5.15). The 4.40 mm rainfall recorded over three months (April, May and June) in 2002/2003 growing season could have been inadequate to allow young plants to attain full development and production. That amount of rainfall was far below the long-term levels (77.8mm) for the same months. Of the 4.40 mm rainfall recorded for three months, 20% was received in April while 80% was received in May. No rainfall was recorded in June and July. The monthly summary of climatic data at the experimental site over 2001/2002 to 2003/2004 growing seasons is presented in Table A.2

When cultivation was carried out (3 times over the study period) to remove weeds between the rows, it is believed that the disc implement cut some of the roots. Cut roots were bound to reduce the capacity of the plants to take up water efficiently (Inglese and Pace 2000). With some roots reduced, young cactus plants could find it hard to survive a long period of drought Van der Merwe *et al.* 1997. It is well known that the cactus pear plant is shallow-rooted. The cactus pear roots can spread horizontally up to 4 to 8 m from the mother plant (Hills 1995; Drennan and Nobel 1998). According to Ramakatane (2003), the root spreading can be as far as 1.5 to 1.7 m from the plant after only the first season of planting. Given the long period of drought, Successive cold winter nights (third season 2003/2004) (Brutsch 1997) and probable cutting of roots by cultivation, it is possible that the plant available water was inadequate and as such plants stood no chance of survival. The study was planned to continue beyond the third season after establishment but unfortunately, it had to be terminated when most of the cultivars, except the mother cladodes of some cultivars, died.

Figure 4.15 Water stressed one-year old cactus pear cladodes.

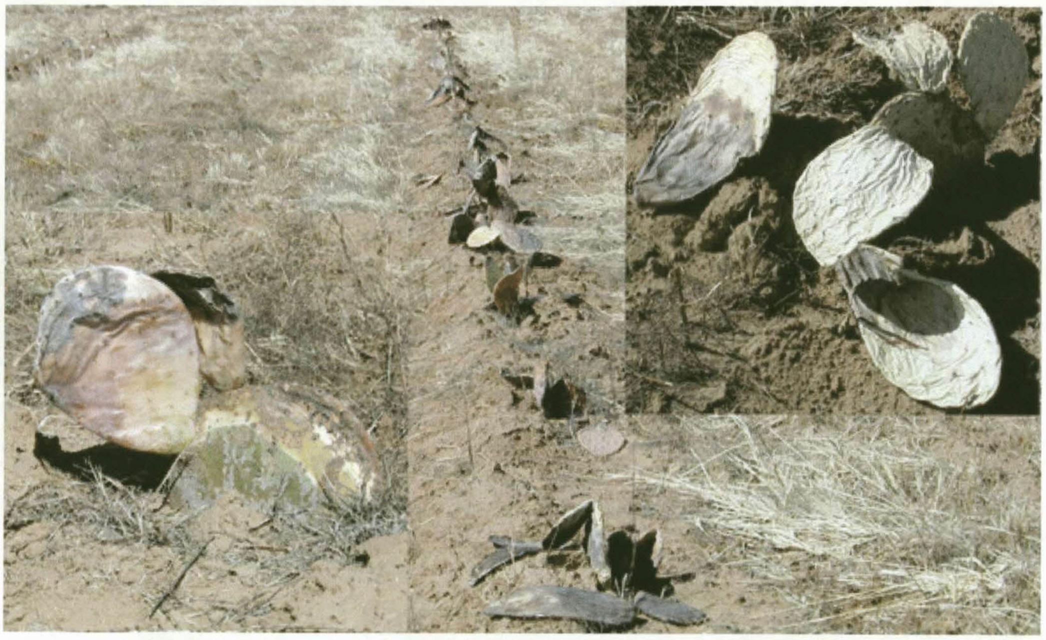

Figure. 4.17 Cactus pear plants killed by frost in the 2003/2004 growing season.

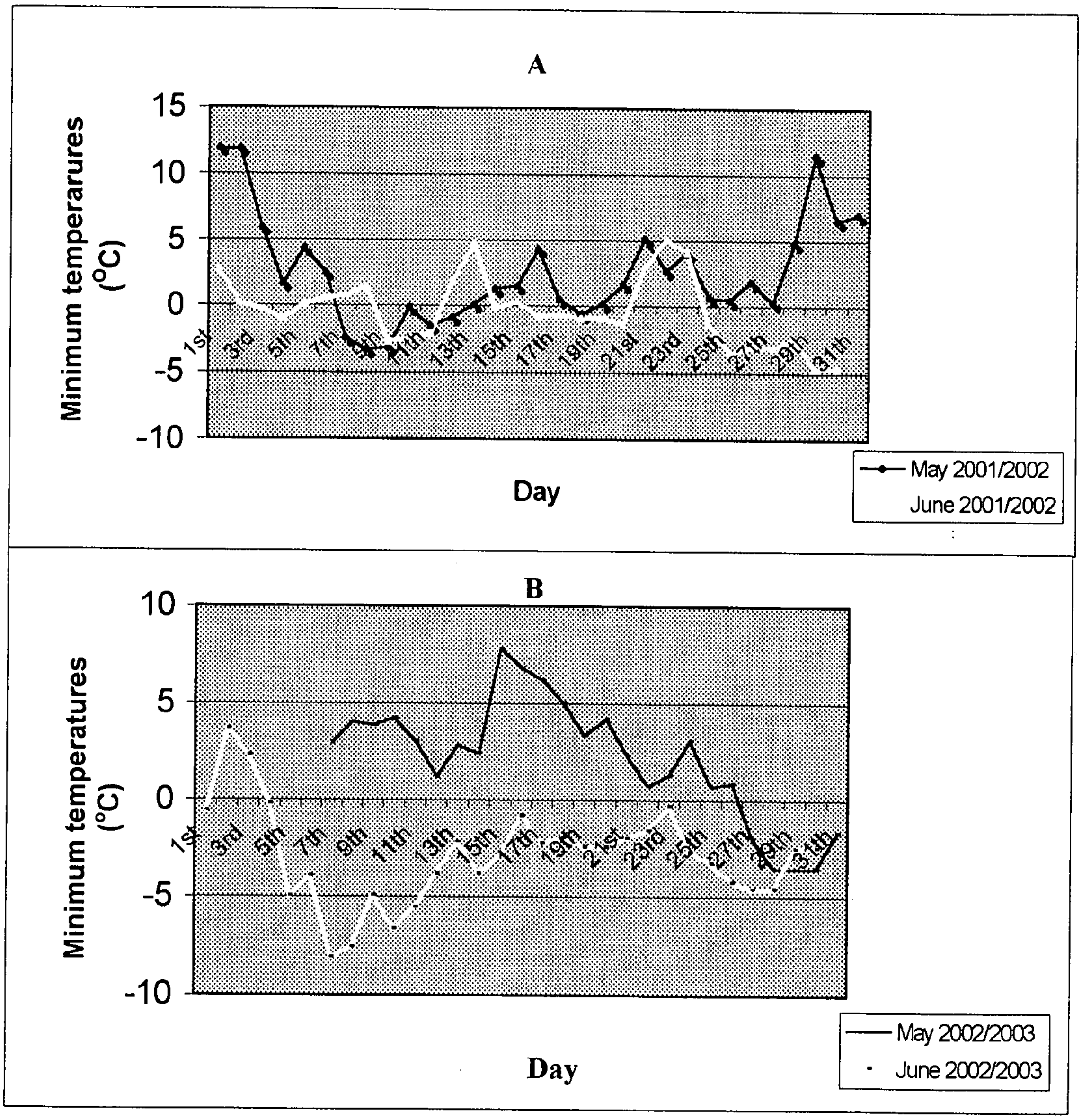

Figure 4.16 The daily temperatures (^{O}C) for May and June in 2001/2002 season (A) and 2002/2003 season (B) at Welgegund.

4.2.8 Conclusions and recommendations

Conclusions

This study has demonstrated that all the cultivars studied are able to attain more growth in height than width in the young stage of development (1 – 3 years). It was evident that the studied cactus pear cultivars would be killed by frequent successive nights of temperatures below freezing point. Frost damage to young cactus pear could impact negatively on both vegetative and reproductive yields. The findings about the cactus pear cultivars based on their individual performance on different vegetative characteristics are shown in Table 4.1.

This study was intended to continue beyond the third season but this was impossible because the young plants of most cultivars were killed by frost in the third year. It is therefore necessary that more research on performance and survival of young cactus pear plants be carried out. In any endeavour to engage in cactus pear production for different purposes, it is imperative that the site selected be not prone to heavy frost. A combination of low temperature and soil-water stress could be detrimental to young cactus pear plants. When mechanical weeding is carried out, great care should be taken to avoid cultivating near the plants and consequently cutting the roots. The best method of weed control is therefore chemical. This is very important during droughts as cactus plants in the arid and semi-arid areas need to have a well-spread and developed root system in order to take up small rain showers in the most efficient way. Timely weeding is necessary to avoid competition between weeds and young cactus plants in the drier areas. Further research work is a necessity to improve cold resistance characteristics in adapted cactus pear cultivars. Another problem is the lack of data on young plants (1 to 3 years old). Most findings are based only on full-grown plantations and there is, therefore, a need for information on the performance of different cultivars over the first years of growth. It would be wrong to reach a conclusion that cactus pear plantations can not be successful in the Central Free State, or similar cold areas, whereas there are a lot of succssful fodder and fruit plantations of cactus pear in the Free State. The success of cactus pear (especially young plants) is a function of both management and climatic conditions. Perhaps the whole dynamics of cactus pear plant development is not properly understood.

Table 4.1 Performance summary for the different cultivars.

Cultivar	Height	Width	Cladode number	Cladodes pruned	Cladode fresh mass	Cladode dry mass	Cladode dry mass yield	Frost damage
Algerian	++	+++	++	+	++	++	++	-
Gymno Carpo	+	+++	++	+	++	+++	+	+
Monterey	+	+	+	-	±	+	-	-
Morado	+++	++++	+++	++	+++	+++	++	-
Nudosa	++	+++	+++	±	+	++++	±	-
Roedtan	+++	++++	++++	++++	++++	+++	++++	-
Sicilian fig	++	++	++	±	+	++	±	-
Tormentosa	±	±	+	-	±	+	-	-
Van As	+	++	+++	+	+	+++	+	-
X28	±	+	++	-	±	+	±	-
Zastron	++++	++	++	+	+	++++	±	±

Key

Excellent	++++	Good	++	Poor	±
Very good	+++	Satisfactory	+	Very poor	-

Surplus vegetative growth is only beneficial where one is looking at feeding it to livestock (or as a source of planting material). For fruit production, it is important to have a balance – fruit production plus new cladodes which will bear the following season.

Chapter 5

Evaluation of cactus pear fruits

5.1 Introduction

There is increasing interest in the major markets for the fruit of cactus pear where it competes with some of the better known traditional fruits in the different regions of southern Africa. Although cactus pears are already known to a broad cross-section of the population in southern Africa, demand for good quality fruits can be expected to increase rapidly (Brutsch and Zimmermann 1993). Mindful of this fact, it is imperative to direct efforts to broaden the database about the crop.

5.2 Results and discussion

Included under results and discussion are phenological stages, number of fruits produced, mass of fruits, total soluble solids, pulp colour, peelability index, harvest period, seed number and seed weight.

5.2.1 Phenology

Basic phenological stages such as budbreak and 50% anthesis are presented in Table 5.1. for the different cultivars It was only possible during the study to monitor this parameter in the second season of plant development (2002/2003). In the first season (2001/2002) the plants were too young to monitor phenological stages while in the third season (2003/2004) all the plants were killed by frost, leaving only the mother cladode. The last-mentioned problem is discussed fully in chapter 4. All the cultivars had a slightly later budbreak when compared to the results reported by Oelofse (2002). Oelofse (2002) reported early budbreak (week 2 in July – week 4 in August) as compared to the results in this study (Table 5.1). The 50% anthesis for Monterey, Nudosa, Sicilian Indian fig, Van As and Zastron started later than Algerian, Gymno Carpo, Roedtan, Tormentosa and

X28. The 50% anthesis for Algerian, Gymno Carpo, (week 3 in October) reported by Oelofse (2002) occurred a week earlier than what was reported in this study for the same cultivars. The discrepancies on both budbreak and 50% anthesis between the results of Oelofse (2002) and that of the present study for different cultivars could be attributed to the late frost, which befell the latter (4th October 2002) and preceeding climatic conditions.

Table 5.1 Basic phenology stages of different cactus pear cultivars for two-year-old plants.

Bud break	Cultivar	50% Anthesis
Week 2 in September	Gymno Carpo	Week 4 Oct. – Week 3 Nov.
Week 2 in September	Monterey	Week 3 Nov.
Week 2 in September	Morado	Week 3 Nov.
Week 2 in September	Nudosa	Week 3 Nov.
Week 2 in September	Roedtan	Week 4 Oct. – Week 3 Nov
Week 2 in September	Sicilian Indian fig	Week 3 Nov.
Week 2 in September	Tormentosa	Week 4 Oct. – Week 3 Nov
Week 2 in September	Van As	Week 3 Nov.
Week 2 in September	X28	Week 4 Oct. – Week 3 Nov
Week 2 in September	Zastron	Week 3 Nov.
Week 2 in September	Algerian	Week 4 Oct. – Week 3 Nov.

5.2.2 Number of fruits

The average number of fruits per plant for each treatment and average number of fruits per plant for each cultivar are presented in Figures 5.1 and 5.2. The P-values and least significant differences (LSD) for the different treatments and cultivars ($P \leq 0.05$ level of significance) are presented in Table A.1. The number of fruits per treatment differed significantly ($P<0.05$) from each other. The scozzolatura treatment recorded only few fruits per plant ($P< 0.05$) compared to fodder and fruit treatments (Fig. 5.1). The number of fruits per plant (0.8) under scozzolatura was largely (80%) the contribution of Sicilian

Indian fig. The remaining 20% of the total number of fruits per plant under scozzolatura were the contribution of Algerian and Nudosa. Number of fruits produced per plant under Sozzolatura was zero for other cultivars. The total number of fruits per plant under scozzolatura was only one. Such differences between treatments (Fig. 5.1) were not expected because all the treatments were managed in the same way in this study e.g. removal of the buds and pruning.

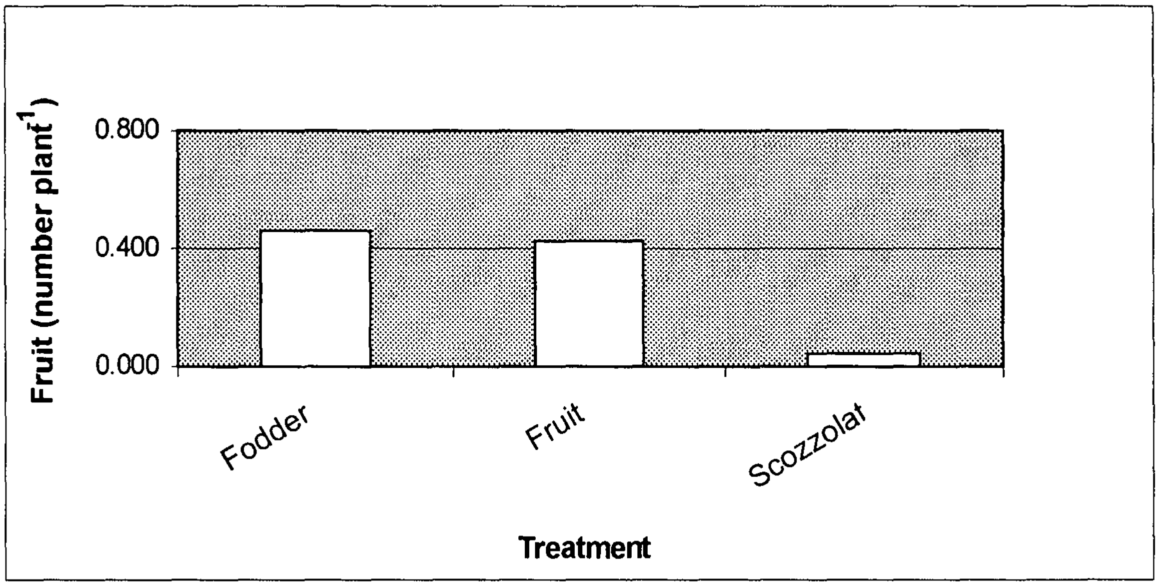

Figure 5.1 Number of fruits (plant^{-1}) for each treatment determined in two-year-old plants (**LSD $_{0.05}$ = 0.1408**)

A significantly higher ($P < 0.05$) number of fruits per plant was recorded for Morado and Roedtan than for all other cultivars while the lowest number of fruits was recorded for Zastron, Monterey and Nudosa (Fig. 5.2). Most research work on cactus pear does not include this parameter and therefore there is not much information with which to compare the recorded findings in this present study. The low number of fruits obtained in this study for the different cultivars could be attributed to the age of the plant (2 years) and late frost (4th October 2002). A sudden drop in temperature to below freezing point (refer to 5.2.7) that does not allow the young plants to acclimatise for successive nights, could have been too much for many developing buds to survive. If reproductive buds are reduced in number, fruit production will decrease. According to Gregory *et al.* (1993), a sudden drop in temperature (28°C to -12°C) does not allow the plants to acclimatise and express cold tolerance. A shortage in nutrients could also be associated with the low number of fruits obtained in this study. Fertiliser was applied only at planting during the study because topdressing could not be carried out due to the long spell of drought conditions.

Nobel (1988) reported that the number of fruits produced per cladode depends on the dry weight accumulation in the cladodes, which in turn depends on the net CO_2 uptake. For *O. ficus-indica*, cladodes with a higher than average dry weight tend to produce more fruits (García de Gartázar and Nobel 1992). However in this study the cladode dry mass percentage for both treatments and cultivars were not significantly different (Fig. 4.10).

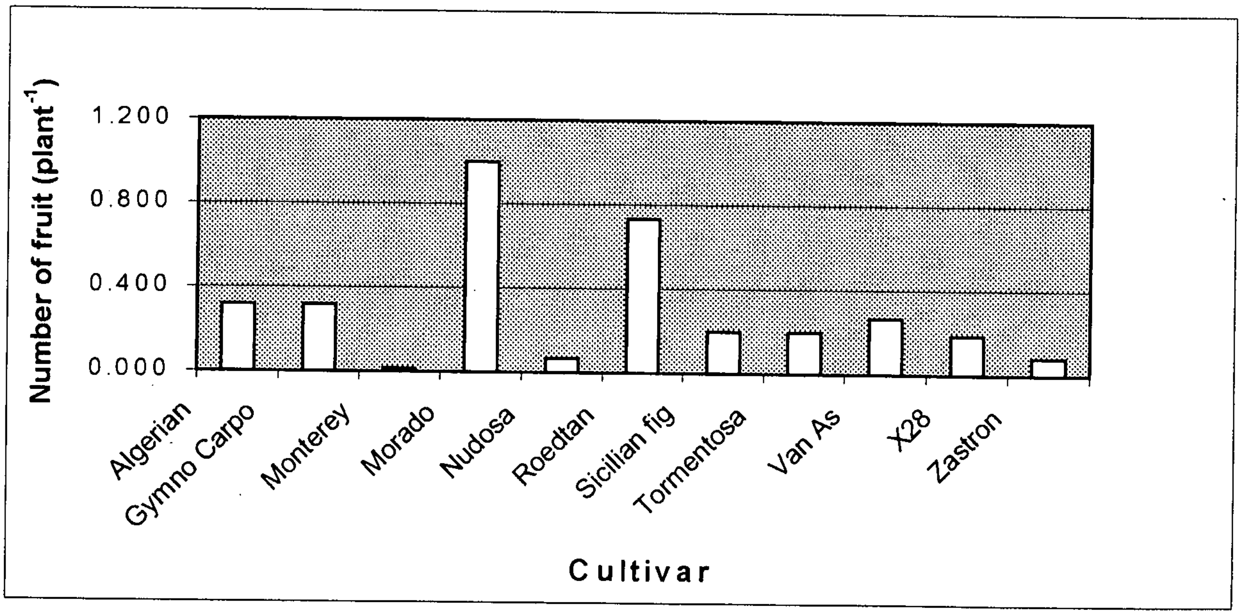

Figure 5.2 Number of fruits (plant^{-1}) for each cultivar determined from two-year-old Plants (LSD $_{0.05}$ = **0.2981)**

Zastron, Tormentosa, Algerian and Gymno Carpo were cactus pear cultivars that suffered relatively more frost damage than other cultivars during the winter of 2002 (Figure 4.14).

The damage by frost could have played a role in the low number of fruits produced by these concerned cultivars (Figure 5.2). Even though Monterey and X28 suffered relatively lower average frost damage during winter 2002 (Figure 4.14), they attained fewer numbers of fruits (Figure 5.2). It is not surprising that Roedtan and Morado attained the highest ($P < 0.05$) average number of fruits because these cultivars were not damaged as much as Zastron, Algerian, Tormentosa, Gymno Carpo and Van As by frost in winter 2002. Nudosa, which suffered frost damage equal to Morado, produced the lowest number of fruit (which was only more than Monterey's).

Some cultivars come into bearing more than others. One should therefore, not lay too much stress on the bearing of very young plants. Yield potential can change with time (Brutsch 1979). In this study, it was impossible to evaluate the number of fruits per plant for every cultivar during the first and third season. In the first season the developing plants were not allowed to produce fruits while in the third season the plants were killed by frost, leaving only the mother cladode.

5.2.3 Fruit mass

Evaluation of this parameter was only possible on two-year-old plants as discussed previously. Figures 5.3 and 5.4 illustrate the fruit mass per treatment and per cultivar respectively. The average fruit mass differed significantly between treatments. Scozzolatura treatment recorded significantly ($P<0.05$) lower fruit mass compared to the other treatments. Under the fodder treatment, Gymno Carpo and Sicilian Indian fig recorded more fruit mass. Under skozzolatura treatment Morado and X28 recorded the lowest ($P<0.05$) fruit mass. The differences illustrated in Figure 5.3 between treatments are hard to explain because the three treatments were managed in the same way. Such a difference could only be expected at a later stage when management changes as required for each treatment. The final fruit mass depends on the cultivar, seed number, fruit load and horticultural management such as thinning and irrigation (Barbera *et al.* 1997, Oelofse 2002). One-year-old fruiting cladodes are the main source of photosythetates for fruit growth in cactus pear (Barbera *et al.* 1997, Oelofse 2002). The ability of the cladode to support fruit growth depends on the previous year's fruit load and its light interception during the season (Barbera *et al.* 1997, Oelofse 2002). Higher mean fruit mass ($P<0.05$) for fodder over fruit and scozzolatura obtained with Gymno Carpo is questionable, because the plants were not allowed to bear fruit in the previous year in this study.

The highest fruit mass of 60.35 per plant recorded for Algerian, was significantly higher ($P<0.05$) than fruit mass obtained for Gymno Carpo, Zastron, Sicilian Indian fig and Monterey. Tormentosa also recorded higher ($P<0.05$) fruit mass per plant (54.23g) than Monterey, Sicilian Indian fig and Zastron. X28 also registered a relatively high average fruit mass per plant. In view of the findings by Brutsch (1979) Piemienta – Barrios and Muños (1995) Van der Merwe *et al.* (1997) and Oelefse (2002) who recorded 88 –109g, 84 –175g, 113 – 163g and 161.88 – 185.08g fruit mass respectively from mature cactus pear plants, the values reported in this study are very low. These discrepancies could be attributed to the age of the plants and shortage of nutrients. The plants were fertilised only once during establishment. Because of a long spell of drought (refer to 4.2.7) it was not possible to topdress the plants during the study. Also in view of the minimum criteria for (140.0g) cactus pear varieties evaluated for fruit production (Potgieter *et al.* 1989), the reported results on fruit mass in this study were very low.

According to Brutsch (1979), Algerian, which was dominant in this study in terms of average fruit mass per plant compared to other cultivars, produced the lowest values (88g) in their trials when compared to Morado (97g) and Gymno Carpo (102g). Piemienta–Barrios and Muños (1995) recorded a greater average fruit mass per plant for Morado (114g) and Nudosa (175g) than Algerian (110g). This data is contrary to the findings obtained in this study. Oelofse (2002) recorded lower fruit mass per plant for Algerian (161.88g) compared to that of Nudosa (236g), Gymno Carpo (171g) and Roedtan (171.74g). The results of Oelofse (2002) thus do not agree with those of this study. The results obtained in this study are however in agreement with those reported by Oelofse (2002) on the lowest fruit mass per plant obtained for Zastron. Fruit mass also depend on whether or not there was fruit thining or not. There was no fruit thining in the trial reported by Brutsch (1979).

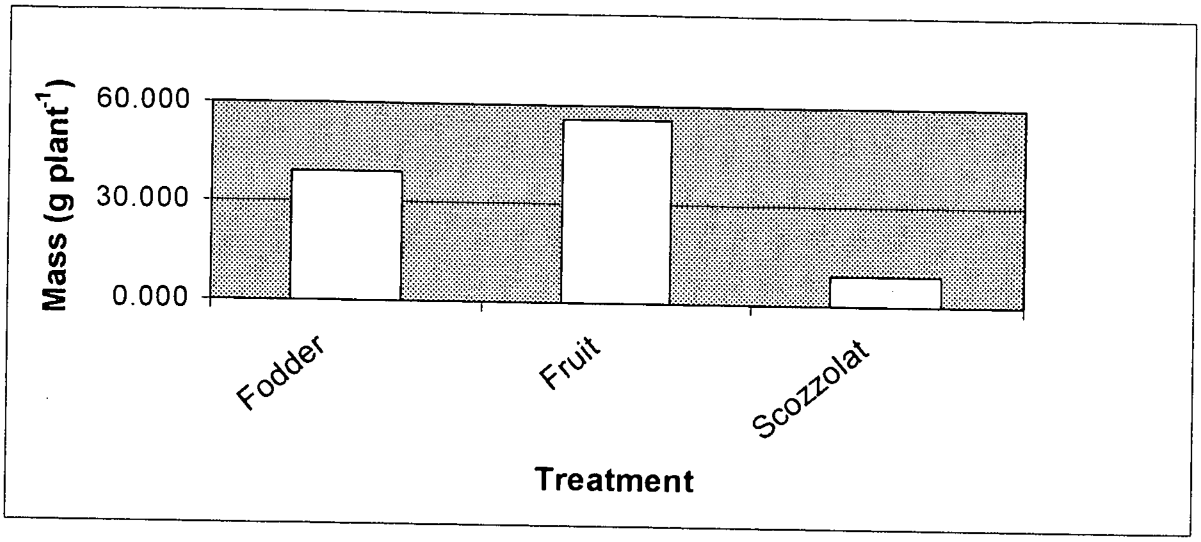

Figure 5.3 Average fruit mass for each (g plant^{-1}) treatment determined from two-year-old plants (**LSD $_{0.05}$ = 21**).

Most of the research work with which the findings of this study were compared, considered mature plants and such data on the performance of the young plant is lacking. Low average fruit mass from young cactus plants obtained in this study should not discourage further trials. More research work should be carried out regarding the performance of young cactus pear plants. Even though the results reported in the present study were disappointing, when compared with records presented by Brutsch (1979), Pimienta-Barrios and Muñoz (1995), Van der Merwe *et al.* (1997) and Oelofse (2002) for older plants, there are some good indications that cultivars such as Algerian, Morado, Tormentosa, Van As and X28 can produce desirable fruits in terms of the fruit mass per plant. However, the plants were too young to make meaningful predictions.

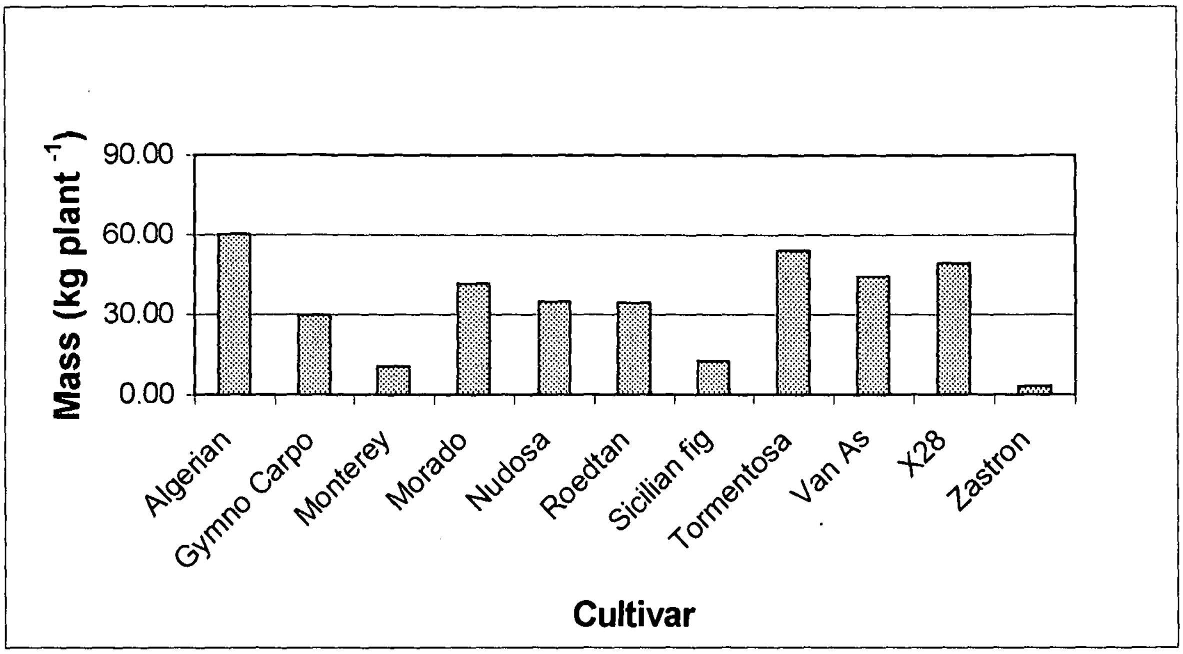

Figure 5.4 Average fruit mass (kg plant^{-1}) for each cultivar determined from the two-year-old plants (**LSD $_{0.05}$ = 27.2822**).

5.2.4 Fruit yield

Figures 5.5 and 5.6 illustrate the fruit yield per treatment and for the 11 cactus pear cultivars subjected to fodder, fruit and scozzolatura treatments. The difference between treatments in terms of fruit yield was significant ($P<0.05$). The differences would be expected later when management starts to differ depending on the requirements of a particular treatment. Morado contributed 58% percent of the total fruit yield recorded for fodder treatment while Tormentosa contributed 10%. The remaining 32% were shared by other cultivars. The total yield (76.8kg) obtained by the fruit treatment in this study was largely the contribution of Roedtan (30%) and Gymno Carpo (35%). The remaining 35% were shared by other cultivars. The total fruit yield obtained by the Scozzolatura treatment was due to just three cultivars namely: Algerian (7%), Nudosa (16%) and Sicilian Indian fig (77%). The other nine cultivars studied did not produce fruits under Scozzolatura.

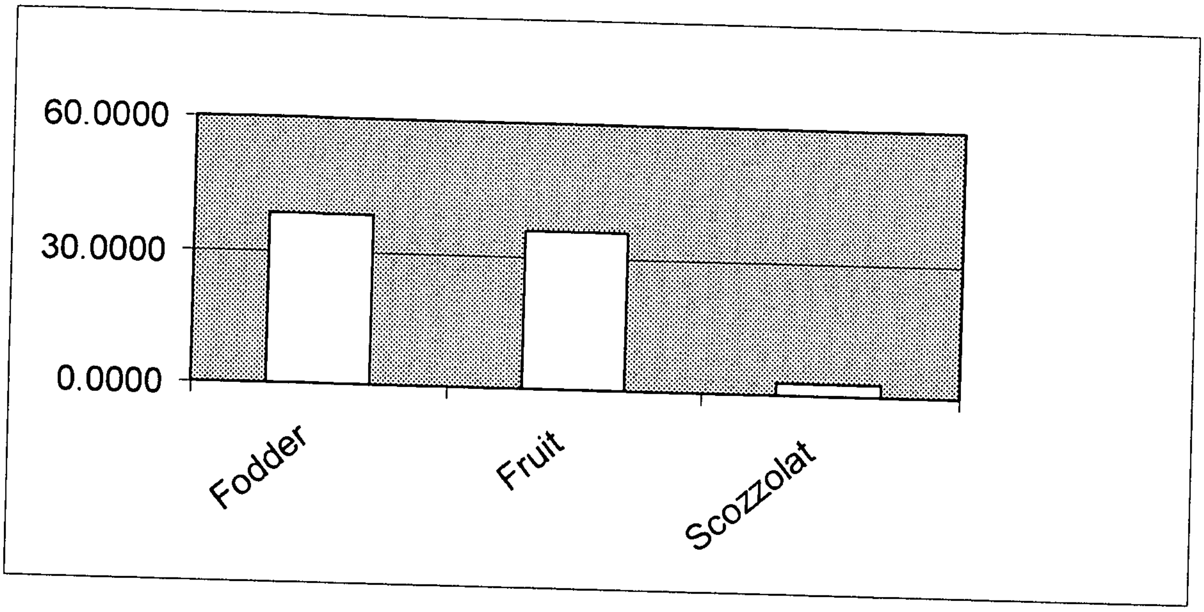

Figure 5.5 Fruit yield (kg ha^{-1}) for each treatment determined from two-year-old plants **(LSD 0.05 = 20.52)**.

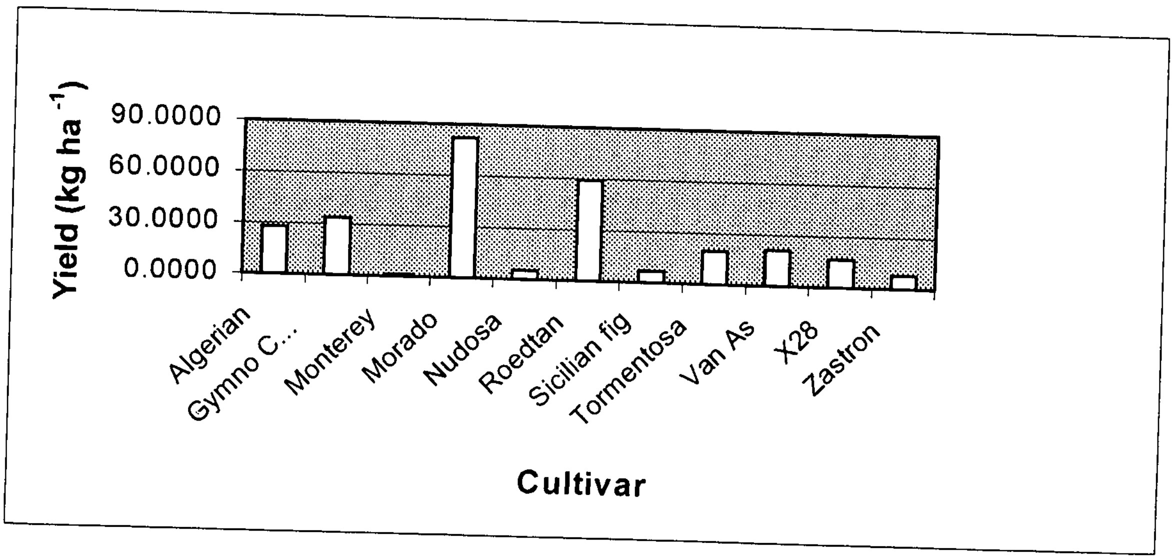

Figure 5.6 Fruit yield (kg ha^{-1}) per cultivar determined from two year old plants **(LSD $_{0.05}$ = 28.20)**

The values obtained from this study were low and not comparable with the fruit yield of 1.3, 3.1, 6.3, 15.6 and 7.5 t ha^{-1} reported for 2,3,4-15, 16-20 and 21-35 year old plants respectively (SAG 1976). These yields were moreover made possible by some irrigation and use of 12-kg goat manure per individual plant. Based on the minimum criteria (Potgieter *et al.* 1979) for cactus pear varieties evaluated for fruit production (1, 2.5, 4, 7, 10, 15 and 20 t ha^{-1} for 2, 3, 4, 5, 6, 7 and 8 year old plants respectively) the values obtained in the present study were disappointing. Van der Merwe *et al.* and Oelofse (2002) reported higher values of 4.3 – 13.2 and 4.97 –30.67 t ha^{-1} respectively for mature plants, than those reported in this present study. Such yields were, however, obtained from mature cactus pear plants. The discrepancies could be due to lack of irrigation, use of manure, age of plants, shortage of nutrients and very low minimum temperatures for successive nights, which injured cladodes during winter (as discussed previously). It was only possible during the study to monitor this parameter in the second season (2002/2003 growing season). No evaluation took place in the first (2001/2002) and third (2003/2004) growing seasons as discussed earlier.

5.2.5 Total Soluble Solids (TSS)

Figure 5.7 illustrates TSS values for the eleven cactus pear cultivars. It was only possible to monitor these parameters in the second season of the study (2002/2003). In the first growing season (2001/2002) the plants were not allowed to produce fruits, while in the third growing season (2003/2004) all the plants except some mother cladodes were killed by frost. In this study, Van As (15 Brix% TSS) and Tormentosa (15 Brix% TSS) recorded relatively higher TSS values than other cultivars. However, owever, this was only significant ($P > 0.05$) when compared to Monterey (9 Brix% TSS). Monterey recorded the lowest TSS values. According to Potgieter and Mkhari (1989) the minimum criteria for cactus pear varieties evaluated for fruit production potential should be more than 13 Brix% TSS. Based on this criterion, cultivars such as Gymno Carpo, Morado, Sicilian Indian fig, Tormentosa, Van As and X28 complied with the recommendations while the rest failed. Total Soluble Solids values for Algerian, Nudosa and Morado (Pimienta-Barrios and Muñuz-Urias 1995) are in agreement with the findings recorded in this study.

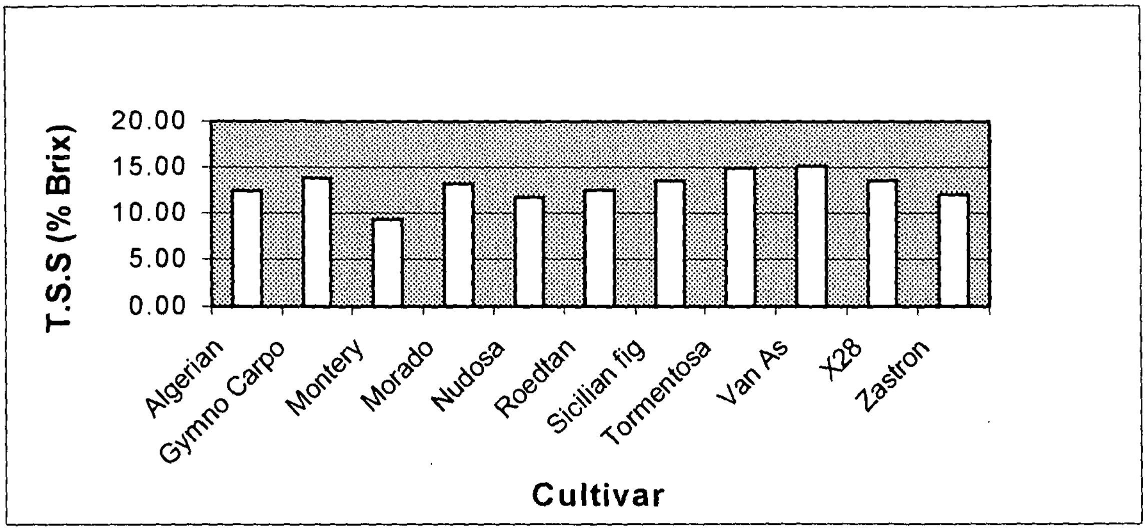

Figure 5.7 Total Soluble Solids % for the different cultivars (**LSD $_{0.05}$ = 4.7454**)

The Total Soluble Solids for Gymno Carpo was found to be higher than 13% Brix TSS in this study but less according to the results obtained by Pimienta-Barrios and Muñuz-Urias (1995) and Oelofse (2002). Oelofse (2002) recorded TSS values higher than 13% Brix for Zastron, Algerian and Roedtan while they reflected lower values in this study. Since the decision of when to collect fruits for TSS evaluation is subjective and the ripeness of the fruits is not uniform, this might explain the difference in TSS values reported above. The Total Soluble Solids is one of the parameters characterising fruit quality. It is generally recognised that during the final weeks of flesh development, optimum TSS values at harvest should be 13-15% (Barbera *et al.* 1992b, Kuti 1992).

5.2.6 Pulp colour, peelability index and harvest period

Table 5.2 presents pulp colour, peelability index (ease to peel the fruit) and harvest period of the 11 cactus pear cultivars under study.

Table 5.2 Pulp colour, peelability index, main harvest period and harvesting date for young cactus plants of different cultivars different cultivars.

Cultivar	Colour	Peelabity index	Main harvesting period	Harvesting date
Gymno Carpo	Orange	Good	End Jan. – begin Mar.	28/01/03
Monterey	Dark red	Poor	End Jan	28/01/03
Morado	Light green	Good	End Jan. – begin Mar	28/01/03
Nudosa	Red	Good	End Jan. – begin Mar	28/01/03
Roedtan	Orange	Good	End Jan. – begin Mar	28/01/03
Sicilian fig	Red	Good	End Jan	28/01/03
Tormentosa	Orange	Good	End Jan. – begin Mar	28/01/03
Van As	Light-green	Good	End Jan. – begin Mar	6/3/03
X 28	Orange	Good	End Jan. – begin Mar	28/01/03
Zastron	Light-green/white	Good	Begin Mar.	6/3/03
Algerian	Red	Good	End Jan.	28/01/03

It was only possible during the study to monitor these parameters in the second season of the study (2002/2003). The results (pulp colour) mostly match the descriptions reported by Oelofse (2002) and that reported by Brutsch (1994, 1997). Dark pink pulp colour of Algerian (Oelofse 2002, Pimienta-Barrios 1995) does however differ from the results presented in Table 5.2. Yellow fruit colour for Gymno-Carpo (Brutsch 1994) differs slightly from the results in Table 5.2. Figure 5.8 depicts different colours of fruits from five cactus pear cultivars. All cultivars except Monterey, whose peelability was described as poor (Table 5.2), were easy to peel according to the present study.

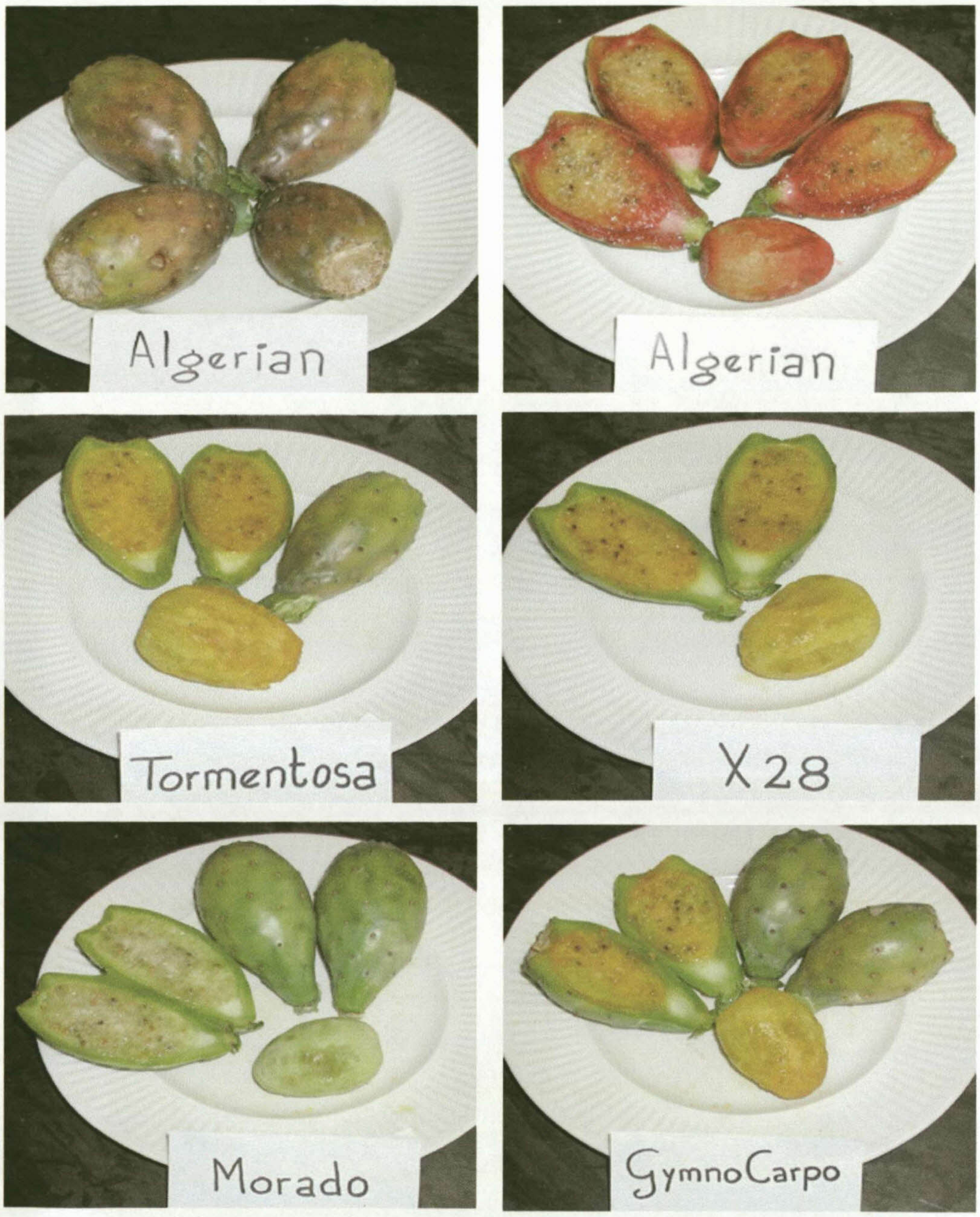

Figure 5.8 The different colours of fruits of some cactus pear cultivars

The main harvesting period corresponds with that reported in previous works (Brutsch 1994, 1997: Pimienta-Barrios and Muñoz-Urias 1995, Oelofse 2002). However, Oelofse (2002) whose description of a harvesting period for Zastron and Roedtan was the third week of January differed from the results presented in Table 5.2. The most appreciated fruits on the international market are yellow-orange (peel and flesh). Red-purple fruits, like Algerian are also appreciated. Green-clear or white cultivars as well as pink-orange ones are relevant only in regional markets and present major problems in handling and storage (Ingles Barbera 1992). The different colours of fruits of some cactus pear cultivars are shown in Figure 5.8.

5.2.7 Peel-thickness

Figures 5.9 and 5.10 illustrate peel-thickness per treatment and per cultivar for the 11 cactus pear cultivars. It was only possible during the study to monitor these parameters in the second season of the study (2002/2003). Peel-thickness was significantly ($P<0.05$) different between treatments. The fodder treatment attained higher peel thickness ($P<0.05$) than the other treatments. The Skozzolatura treatment recorded the lowest ($P<0.05$) peel-thickness. The recorded difference between treatments in terms of peel-thickness is questionable because the young cactus pear plants in this study received the same attention. Peel-thickness differences were significant ($P<0.05$) between some cultivars. Peel-thickness for Algerian and Nudosa was greaterr than that recorded for Gymno Carpo, Monterey, Roedtan and Sicilian fig. The thinner peel recorded for Monterey was significant when compared to that of all other cultivars except Roedtan and Zastron.

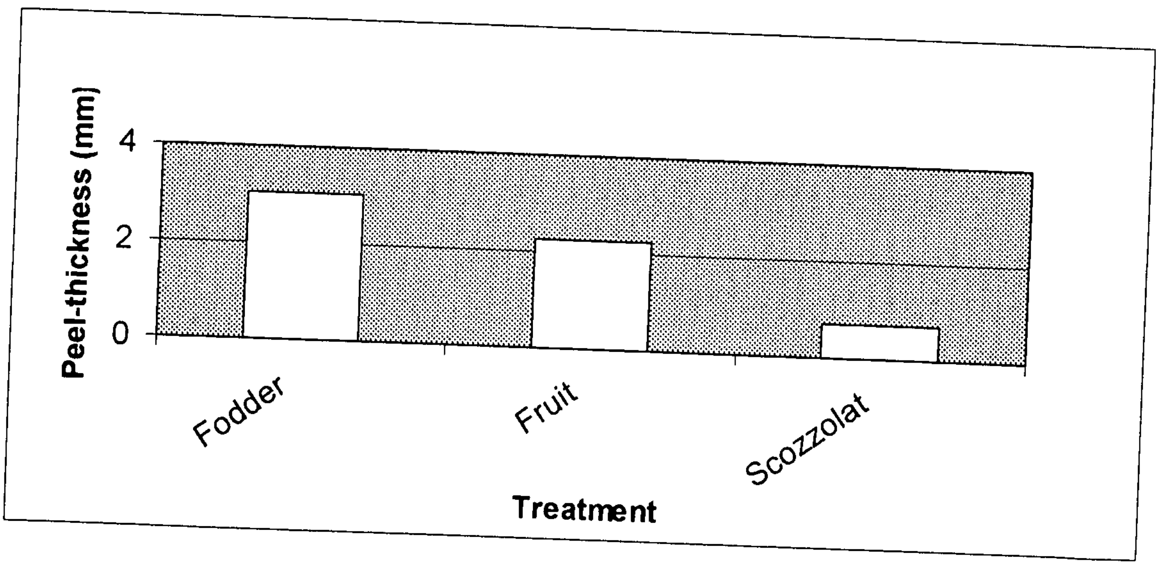

Figure 5.9 Peel-thickness for each treatment (**LSD $_{0.05}$ = 1.4688**).

All the cultivars evaluated in this present study conform to the requirements (<6mm) for fruit production according to the recommendations of Potgieter and Mkhari (2002) in terms of peel-thickness. The results presented in this present study (Figure. 5.10) are to some extenT different from 6.60, 6.41, 5.24, 2.89, 6.20 and 4.94 for Nudosa, Gymno Carpo, Morado, Zastron, Algerian, and Roedtan respectively reported by Oelofse (2002). Oelofse (2002) reported the lowest peel-thickness value for Roedtan compared to other cultivars. In the present study Roedtan, which produced lower peel-thickness, than all cultivars except Monterey (Figure 5.10) supported the findings of Oelofse (2002).

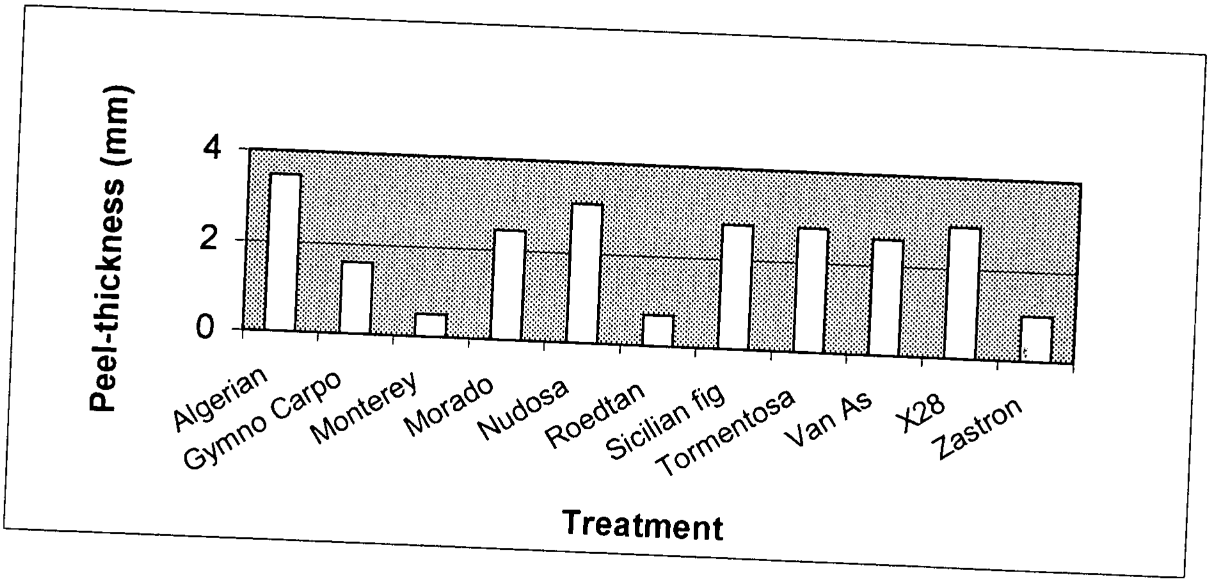

Figure 5.10 Peel-thickness (mm) for each cultivar determined from two-year-old plants (**LSD** $_{0.05}$ **= 1.534**)

5.2.8 Seed numbers and mass of cactus pear seeds

Table 5.3 presents average seed number and mass of seeds from the 11 cactus pear cultivars in the second season (2002/2003). Some cultivars differed in terms of number of fully developed seeds and mass of both fully developed and aborted seed. The number of aborted seeds did not differ significantly (P>0.05) between different cultivars. The mean mass of mature seeds for Van As was higher (P<0.05) than those recorded for the other cultivars. Roedtan produced more (P<0.05) aborted seed than other cultivars. The lowest mass of aborted seeds recorded for Morado was not significantly (P<0.05) different from that recorded for other cultivars excluding Roedtan. The findings provided in this present study could not be readily compared with results recorded by other researchers because most of the research did not include this parameter.

Table 5.3 Seed numbers and mass (g) of seeds for each cultivar from two-year-old plants.

Cultivar	**Mean number of seeds (fruit $^{-1}$)**		**Mean mass of seeds (g)**	
	Mature seeds	Aborted seeds	Mature seeds	Aborted seeds
Algerian	169	76	2.50	0.39
Monterey	200	72	2.50	0.10
Morado	127	17	1.60	0.33
Nudosa	175	66	2.30	0.77
Roedtan	106	45	1.80	0.44
Sicilian Indian fig	166	68	2.47	0.28
Tormentosa	88	40	1.50	0.31
Van As	208	67	3.17	0.41
X28	142	69	2.03	0.37
Zastron	176	61	2.80	0.28
Gymno Carpo	153	35.	2.90	0.27
LSD 0.05	**55.208**	**43.695**	**0.771**	**0.286**

One of the major constraints limiting the consumption of cactus pear is the presence of thick, hard seeds in the flesh. Empty aborted, caused by early failure of embryo growth, are common in cactus pears and allow flesh development (Pimienta-Barrios and Engleman 1985). The ratio between aborted and normal seeds is one of the most important parameters that define fruit quality (Barbera *et al.* 1992c). Lack of data in South Africa (Pimienta-Barrios 1990: Barbera *et al.* 1992a) regarding this parameter makes it impossible to compare findings reported in this present study. Seed size can vary by cultivar (Barbera *et al.* 1992a; 1992c) and by species (Nerd *et al.* 1990). More research work is needed to reduce seed number, seed size and increase the percentage of empty seeds.

5.2.9 Conclusions

This study has demonstrated that a prolonged winter or late frost could delay the phenological stages in some cultivars of young cactus pear plants. In this study, budbreak and 50% anthesis were delayed by at least a week compared to the findings of Oelofse (2002). If some reproductive buds are damaged by late frost, the number of fruits, and fruit yields produced by individual plants could be affected. The degree of frost damage to young cactus pear plants may lead to fewer fruit bearing cladodes, fewer fruits produced (plant $^{-1}$), and low fruit yield (plant $^{-1}$) or even death.

Based on minimum standards (<6mm) for fruit production according to Potgieter and Mkhari (2002) in terms of peel-thickness, all the cultivars studied possessed desirable traits for fruit production. In the Minimum Descriptor List for *Opuntia* spp. (http: //www.unifi.it/ueresgen29/netddase/s5/dls5.htm), only Tormentosa qualified to be categorised as cultivar producing a very few seed (< 100) while the other cultivars are considered to produce few seed (101 - 200). Van As falls under a medium (201 - 300) seed-producing cactus pear cultivar. Table 5.4 presents the findings about the cultivars individual performance on different reproductive characteristics.

The incidences of frost damage experienced during the study call for further research work to determine the minimum range of temperatures that could delay phenological stages in cactus pear. Also careful choice of site for the establishment of cactus pear plantations (not prone to severe frost) is necessary to avoid possible frost damage to developing buds. It needs to be determined whether fruits from young cactus plants (1-3 years) differ from the fruits obtained from mature plants in terms of peel thickness. This is necessary because the peel thickness recorded by Oelofse (2002) was higher compared to the data provided in this study.

Table 5.4 Performance summary of the different cactus pear cultivars

Cultivar	Number of fruits	Fruit mass	Fruit yield plant -1	Fruit yield ha -1	Peel thickness
Algerian	+	+	±	±	+
Gymno Carpo	+	±	±	±	+++
Monterey	-	-	-	-	++++
Morado	+++	±	++	++	++
Nudosa	-	±	-	-	+
Roedtan	++	±	+	+	++++
Sicilian fig	±	-	-	-	++
Tormentosa	±	+	±	±	++
Van As	+	±	±	±	++
X28	±	+	±	±	++
Zastron	-	-	-	-	++++

Key:

Exellent	++++	Good	++	Poor	±
Very good	+++	Satisfactory	+	Very poor	-

Chapter 6

General discussions and conclusions

Cactus pear is a multipurpose crop, which can be of great value in both developed and developing countries, because of its ability to utilise the full potential of arid areas The full potential of cactus pear has not however, been realized in southern Africa. Spineless cactus pear in South Africa is increasingly commercialised and there is a need to establish a database to assist the South African farmers in the selection of cultivars for production (Oelofse 2002). Cactus pear can be produced with great success on land presently deemed marginal for other crops (e.g.wheat, maize and sorghum). In light of the known variability of the rainfall precipitation regimes, it is hoped that cactus pears can also be successfully included into many rangeland management schemes in Southern Africa. There are vast areas of Sub-Saharan Africa where the cactus pear could be grown with ease and to good advantage, particularly when one bears in mind the all-too-frequent droughts.

This study clearly indicated that young (1-3 year's) cactus pear plants grow more in height than width. The cultivars that grow more in height than others also tend to achieve more growth in width with the exception of Zastron whose growth in width does not tally with growth in height. Prolonged minimum temperatures of–5 °C on successive nights can affect growth and therefore, height in young cactus plants. Frost damage leads to a decrease in both width and height

This study has demonstrated that more growth in height and width in young cactus plants is essential for the production of a larger number of cladodes on a plant before pruning (and therefore, number of cladodes removed by pruning), cladode yield and fruit yield. These results are of the few available for young cactus plants, because the available literature has concentrated on the fodder and fruit productions of full-grown plantations. Although this research project was planned for over a few years, the plants were unfortunately killed by frost after only three years. Therefore, there is no indication of difference between the different treatments (fodder, fruit and skozzolatura) that could be quantified. Studies such as this one need to be carried out in the future to get a clearer picture of the production potential of the different cultivars under different management practices. Because data was collected over only a two to three-year period, limited useful information on fodder and fruit productivity for different cultivars was obtained. All the cultivars studied showed the ability to produce more fodder than fruits. The study has shown that Roedtan and Morado are outstanding in terms of fodder and fruit production. Other promising cultivars for both fodder and fruit production were Algerian, Gymno Carpo, Nudosa and Van As. Monterey and Zastron did not posses desirable traits for fruit production. The individual performance of cultivars based on fodder and fruit production is summarised in Table 6.1.

Table 6.1 Performance summary of different cultivars in terms of fodder and fruit production based on two to three-year-old plants.

Cultivars	**Fodder**	**Fruit**
Algerian	++	+
Gymno Carpo	++	+
Monterey	+	-
Morado	+++	++
Nudosa	++	+
Roedtan	++++	++
Sicilian Indian fig	+	+
Tormentosa	+	+
Van As	++	+
X28	+	+
Zastron	++	-

Key:

Excellent	++++	Good	++	Poor	±
Very good	+++	Satisfactory	+	Very poor	-

In order to be successful in cactus pear production for fodder and fruits, it is very important to select areas that are not prone to severe frost. There is a need to topdress the plants with fertiliser every year if possible to improve production. Unfortunately the plants were not fertilised in either the second or the third season of the study. According to most researchers the cactus pear reacts possitively to fertilisers. Shortage of nutrients may affect both fodder and fruit production negatively. Weeding of the cactus pear field is very important to minimise competition for nutrients and moisture, during dry period. Mechanical weeding in cactus pear plantations, if done close to the plants, may damage the roots that spread near the surface of the soil. The best way to control weeds on a cactus pear field is therefore chemically. Further research work is required to select adapted cactus pear cultivars with high fodder and fruit production characteristics.

The commercial cultivation of spineless cactus for its fruit is a relatively recent undertaking in South Africa but has been shown to possess huge export potential (Oelofse 2002). As there has been an increasing interest in cactus pear for both fodder and fruit production over the last few years, more research needs to be carried out on the evaluation of different cultivars under different environmental conditions. Cactus pear can be beneficial to both developed and under-developed countries. According to the minimum descriptor list for *Opuntia* species for fruit production, only Tormentosa qualifies to be categorised as a cultivar producing very few seed (< 100 per fruit), while most the other cultivars produce few seed (101 – 200 per fruit). Van As produces a medium number of seeds (201 - 300)

The severe frost damage in 2003 greatly reduced the value of the trial since a second year of data was not possible and it is not possible to obtain reliable data from a single harvest season, particularly if it is the first (two-year-old plants). Irregular bearing is common in cactus pear plantings and important differences exist even between plants of the same cultivar in a particular season. Therefore, the limitations of this study must be borne in mind and meaningful comparisons with other studies are difficult.

Summary

The search for appropriate plant species able to produce with sustainably in arid and semi-arid areas, has been a concern for some farmers living in such harsh environments. Unfortunately there is a lack of information concerning the adaptability of different cactus pear cultivers under a range of environmental conditions. This includes the cultivation for both fodder and fruit production. Cactus pear could be introduced with great success on land presently deemed marginal for other crops. A study was therefore conducted to evaluate the production potential of ten cultivars of the green pad cactus pear species (*Opuntia ficus-indica*) and one blue pad cultivar of *O. robusta* over three growing seasons (2001/02 to 2003/04). The cultivars of *O. ficus-indica* included Algerian, Gymno Carpo, Morado, Nudosa, Roedtan, Sicilian Indian fig, Tormentosa, Van As, X28 and Zastron. The species *O. robusta* was represented by the cultivar Monterey. The experimental layout was a randomised block design with three treatments (fodder, fruit and scozzolatura), consisting of 11 cultivars replicated twice on 66 plots. Each plot consisted of 20 plants, of which 10 were used as data plants, planted in two rows. During the study vegetative, reproductive and laboratory measurements were evaluated for the different treatments and cultivars.

It was evident from this study that young cactus pear plants could be killed by a combination of frequent successive nights of temperatures below the freezing point (as low as –9°C) and water stress. Shortage of soil nutrients could also influence both fruit and fodder production in young cactus plants. Mechanical weeding near the cactus plants could damage the shallow and widespread roots thus reducing the ability of plants to cope with harsh drought. Therefore, chemical control of weeds is encouraged.

This limited study has revealed that Roedtan is the best cultivar for both fodder and fruit production while Morado is also ideal for production of both fodder and fruit. Other promising cultivars (although not as outstanding) for fodder production are Algerian, Gymno Carpo, Nudosa, Van As and Zastron. The same cultivars, except Zastron, can produce promising results in fruit production. Monterey, Sicilian Indian fig, Tormentosa

and X28 can produce satisfactory results in terms of fodder production. The same cultivars except Monterey can produce satisfactory results in terms of fruit production. The study has proved that Zastron and Monterey should be discouraged for fruit production. However, more in-depth research should be carried out to provide more information about the cultivars in the different arid environmental conditions of southern Africa.

In the minimum descriptor list for *Opuntia* species for fruit production, only Tormentosa qualifies to be categorised as having very few seeds (< 100), while most of the other cultivars have few seeds (101 - 200). The study has demonstrated that all other cultivars except Monterey are easy to peel. It needs to be established by research if there is a difference between young and mature cactus pear cultivars in terms of number of seeds produced per fruit. The limited information obtained from this study could benefit both commercial and subsistence farming communities living in drought threatened areas.

OPSOMMING

Die soeke na toepaslike plant spesies wat in staat is om suksesvol te groei en volhoubaar te produseer onder sulke strawwe omgewingstoestande, wat ariede en semi-ariede gebiede soms ondervind, is 'n groot probleem vir sekere boere. Die turksvyplant kan wel met groot sukses in hierdie sogenaamde marginale gebiede verbou word. Ongelukkig bestaan daar nog 'n groot leemte rondom die aanpasbaarheid van verskillende turksvykultivars vir verbouing onder verskillende omgewingstoestande. Dit sluit die verbouing vir beide voer- en vrugproduksie in. 'n Studie is gevolglik uitgevoer ten einde die produksiepotensiaal van tien kultivars van die groenblad turksvy spesie *Opuntia ficus-indica* en een bloublad kultivar van die spesie *O. robusta,* oor drie groeiseisoene (2000/01 tot 2002/03) te evalueer. Die kultivars vir *O. ficus-indica* het ingesluit Algerian, Gymno Carpo, Morado, Nudosa, Roedtan, Sicilian Indian fig, Tormentosa, Van As, X28 en Zastron. Hierteenoor is slegs die kultivar Monterey vir die spesie *O. robusta* ondersoek. Die proefuitleg was 'n ewekansige blok ontwerp met drie behandelings (voer, vrugte en skozzolatura), bestaande uit 11 kultivars wat twee keer herhaal is op 66 persele. Elke perseel het bestaan uit 20 plante, geplant in twee rye, waarvan 10 ewekansig gekies is as data plante. Tydens die studie is van vegetatiewe, reproduktiewe en laboratoriummetings vir die evaluering van die verskillende behandelings en kultivars gebruik gemaak.

Hierdie beperkte studie het getoon dat jong turksvyplante kan afsterf as gevolg van 'n kombinasie van opeenvolgende lae nagtemperature van laer as vriespunt (so laag as -0.9°C) asook waterstremming. 'n Tekort aan grondvoedingstowwe kan beide voer- en vrugproduksie van jong turksvyplante beïnvloed. Meganiese bewerking naby die turksvyplant mag die oppervlakkige en wydverspreide wortelstelsel beskadig en gevolglik die vermoë om droogtetoestande te weerstaan, verlaag. Daarom word chemiese onkruidbeheer eerder aanbeveel.

Die studie het bewys dat Roedtan die beste kultivar vir beide voer- en vrugproduksie is, terwyl Morado ook ideaal vir beide voer- en vrugproduksie is, alhoewel nie so uitstaande. Ander belowende kultivars vir voerproduksie is Algerian, Gymno Carpo, Nudosa, Van As en Zastron. Dieselfde kultivars, met die uitsondering van Zastron, kan ook as redelik belowende vrugproduksie kultivars beskou word. Monterey, Sicilian Indian fig., Tormentosa en X28 het redelik gevaar in terme van voerproduksie. Dieselfde kultivars met die uitsondering van Monterey kan ook redelik vaar in terme van vrugproduksie. Die studie het getoon dat die verbouing van Zastron en Monterey ontmoedig moet word vir vrugproduksie. Nog meer indiepte studies behoort in die toekoms uitgevoer te word rondom kultivar evaluasie onder verskillende omgewingstoestande van suidelike Afrika.

In die lig van die minimum vereistes gestel vir *Opuntia* spesies se vrugte, was dit slegs Tormentosa wat gekwalifiseer het as 'n kultivar met min (<100) sade in die vrugte geproduseer. Hierteenoor het al die ander kultivars misluk in terme van minimum sade per vrug (101-200) geproduseer. Die studie het ook getoon dat al die kultivars met die uitsondering van Monterey se vrugte baie maklik afskil. Die verskille in sade per vrug tussen jong en volwasse turksvyplante, vir verskillende kultivars in terme van aantal regverdig beslis verdere indiepte navorsing. Die resultate met hierdie studie verkry, kan van groot waarde wees vir beide ontwikkelde en ontwikkelende boerdery gemeenskappe.

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Appendix

Table A.1 The P-values and least significant differences (LSD) for the different treatments and cultivars ($P \leq 0.05$ level of significance).

Variable	P-Values		LSD	
	Treatment	Cultivar	Treatment	Cultivar
Width	0.9328	0.0205	0.022	0.665
Height	0.8889	0.0083	0.0285	0.0746
No. cladodes (2nd year)	0.8166	0.0069	0.1239	0.4381
No. cladodes (3rd year)	0.0391	0.0252	0.152	0.9692
No. cladodes pruned	0.7948	0.0011	0.2284	0.4925
Cladode fresh mass	0.947	0.2798	0.0067	0.0518
Cladode dry mass %	0.5626	0.5455	2.27	6.3856
Cladode dry mass (plant $^{-1}$)	0.8669	0.0102	0.0001	0.0001
Cladode dry mass (ha $^{-1}$)	0.87	0.0210	0.12	0.12
Frost damage % (2/8/02)	0.1441	0.0442	2.3312	17.007
Frost damage % (4/10/02)	0.0692	0.1302	1.186	1.6329
Frost damage % (14/9/03)	0.0339	0.0119	6.649	32.0101
No. fruits	0.0216	0.0005	0.1408	0.2981
Fruit mass	0.002	0.0096	21	27.2822
Fruit yield (plant $^{-1}$)	0.0298	0.0013	0.0171	0.0235
Fruit yield (ha $^{-1}$)	0.0336	0.0023	20.52	28.20
Peel thickness	0.0002	0.0057	1.4688	1.534

Table A.2 The monthly summary of climatic data for Welgegund (experimental site) over three growing seasons (2001/2002 to 2003/2004).

2001/2002 Growing season												
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Radiation							26.1	25.0	21.0	18.2	13.9	13.0
Average temperature							21.6	21.2	19.9	16.4	10.4	7.0
Average humidity							62.7	61.3	62.0	56.2	67.0	72.0
Average wind speed							2.3	1.8	1.5	1.4	1.5	1.4
Total rainfall	0.0	45.0	6.0	104.0	182.0	120.0	59.3	55.6	11.7	21.8	57.9	14.0
Average maximum temperature							29.1	29.2	28.4	26.3	20.1	16.3
Absolute maximum temperature							32.8	34.0	32.5	30.8	27.0	20.7
Average minimum temperature							14.4	14.1	12.3	7.5	2.6	-0.4
Absolute minimum temperature							7.8	8.7	2.1	-0.1	-3.3	-4.7
Average maximum humidity							91.1	91.2	91.5	86.6	93.7	96.6
Average minimum humidity							31.4	28.4	29.5	23.5	32.4	35.3
Average evaporation							5.7	2.7	4.9	3.8	2.5	2.0
Total cold units							0.0	0.0	0.0	7.5	172.0	256.5
Total heat units							362.6	336.2	319.6	207.4	61.1	0.4
Average rainfall Tweespruit	13.2	22	28	84	87.9	71.8	77.4	96.4	87.9	59.6	25.4	14.1
Average rainfall Glen	8.7	11.5	18.9	48.6	68.1	66.1	83.6	80.7	83.5	50.5	18.6	8.7
Cumulative Ave rainfall Glen	8.7	20.2	39.1	87.7	155.8	221.9	305.5	386.2	469.7	520.2	538.8	547.5
Cumulative rainfall Welgegund	0.0	45.0	51.0	155.0	337.0	457.0	516.3	571.9	583.6	605.4	663.3	677.3

2002/2003 Growing season												
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Radiation	15.0	14.9	19.5	24.5	27.2	23.6	27.7	22.7	22.4	18.6	14.1	14.2
Average temperature	6.3	11.2	14.3	18.5	19.3	20.9	22.8	22.4	19.7	18.0	10.5	6.3
Average humidity	58.5	64.8	60.8	47.9	47.0	64.7	57.2	65.9	61.9	62.5	64.2	55.4
Average wind speed	1.7	2.0	1.9	2.3	2.6	2.3	2.3	1.7	1.8	1.3	1.3	1.1
Total rainfall	0.1	78.3	22.6	25.3	18.1	82.2	95	89.9	67.3	1.8	3.5	0
Average max temperature	17.0	20.4	23.1	27.4	27.6	28.1	30.8	29.3	28.1	27.1	20.4	17.9
Absolute max temperature	24.9	24.8	29.2	34.4	33.5	34.7	35.6	35.7	33.5	30.3	25.1	22.6
Average min temperature	-2.6	3.6	6.1	9.7	10.6	14.6	15.5	16.6	12.0	10.0	2.1	-2.9
Absolute min temperature	-7.5	-3.7	0.6	-2.1	3.7	11.9	10.7	13.9	4.7	3.1	-3.6	-8.1
Average max humidity	89.6	90.8	91.4	81.6	78.5	91.4	89.6	93.7	91.7	93.3	92.2	85.7
Average min humidity	23.1	32.2	27.2	19.6	18.6	33.9	25.5	35.5	30.4	27.7	29.8	22.8
Average evaporation	2.6	2.8	3.8	5.4	6.2	5.2	6.3	4.9	4.7	3.8	2.5	2.4
Total cold units	180.5	158.5	80.5	15.5	14.0	0.0	0.0	0.0	24.5	3.5	135.0	112.5
Total heat units	5.3	71.4	145.0	261.6	269.3	350.3	397.0	358.1	309.3	170.5	48.1	3.9
Average rainfall Tweespruit	13.2	22	28	84	87.9	71.8	77.4	96.4	87.9	59.6	25.4	14.1
Average rainfall Glen	8.7	11.5	18.9	48.6	68.1	66.1	83.6	80.7	83.5	50.5	18.6	8.7
Cumulative average rainfall Glen	8.7	20.2	39.1	87.7	155.8	221.9	305.5	386.2	469.7	520.2	538.8	547.5
Cumulative rainfall Welgegund	0.1	78.4	101.0	126.3	144.4	226.6	321.6	411.5	478.8	480.6	484.1	484.1

2003/2004 Growing season												
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mch	Apr	May	Jun
Radiation	14.9	17.5	20.8									
Average temperature	6.5	8.0	14.8									
Average humidity	51.3	66.0	78.7									
Average wind speed	1.2	1.7	2.3									
Total rainfall	0.0	0	1.7									
Average max temperature	18.1	19.5	24.2									
Absolute max temperature	21.5	27.6	30.9									
Average min temperature	-2.8	-2.5	5.8									
Absolute min temperature	-6.3	-9.6	-1.9									
Average max humidity	80.5	93.1	99.6									
Average min humidity	23.0	28.4	48.7									
Average evaporation	2.5	2.9	3.8									
Total cold units	93.5	106.5	40.5									
Total heat units	5.4	19.9	141.4									
Average rainfall Tweespruit	13.2	22	28	84	87.9	71.8	77.4	96.4	87.9	59.6	25.4	14.1
Average rainfall Glen	8.7	11.5	18.9	48.6	68.1	66.1	83.6	80.7	83.5	50.5	18.6	8.7
Cumulative average rainfall Glen	8.7	20.2	39.1	87.7	155.8	221.9	305.5	386.2	469.7	520.2	538.8	547.5
Cumulative rainfall Welgegund	0.0	0.0	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7