Cactus pears *Opuntia ficus-indica* and *O. robusta* and their water utilization

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Introduction

In South Africa approximately 65% of the land area is classified as arid and semi-arid with a mean annual rainfall of 500mm or less. *Opuntia* species have developed phenological, physiological and structural adaptations favourable to their development in these arid and semi-arid environments, in which water are the main factor limiting the development of most plant species. Cactus pear (*Opuntia* spp.) is therefore particularly attractive as a feed because of its efficiency in converting water into dry matter and thus to digestible energy (Snyman 2005). Cactus is useful not only because it can withstand drought, but also because its conversion efficiency is greater than C_3 grasses and C_4 broadleaves. Even a rain shower of a few millimetres which is normally of almost no value to the common fodder plants, can be efficiently used by the cactus pear (Snyman 2006a). It is able to do this because of its relatively shallow and horizontally spreading root system and the ability to still withdraw water from the soil at a stage when other crops are not able to (Han and Felker 1997).

Studies on water utilization of CAM plants at plant community level under field conditions over a full growing season have not often been reported in the past (Snyman 2006b). From an agronomical point of view, however, this kind of study is of great significance, both in theory and in practice. The cactus pear is one of the few crops that can be used as both human food and cattle feed (Potgieter 1998). Commercial cultivation on cactus pear in South Africa is a recent undertaking (Oelofse 2002). Therefore, this study aimed at quantifying the water utilization for one, two, three and four-year-old plants of the widely cultivated *Opuntia ficus-indica* (green cladode) and the wild species *O. robusta*.

Procedure

The research was conducted near Bloemfontein, in the semi-arid, summer rainfall (annual average 530mm) region. The soil is a fine sandy, loam soil of the Bloemdal Form (Roodeplaat family – 3 200). Clay content increases down the profile from 10% in the A horizon (0-

300mm) to 24% in the B1 horizon (300-600mm) and 42% in the B2 horizon (600-1 200mm). The pH (KCl) was 4.5 over the first 0 to 300mm layer. Planting took place during August 2002 under dry land conditions and was well cultivated (300mm deep) before planting. The values for K and Mg were above the recommendations, while P was low compared to the record provided by Wessels (1988). Liming to raise the soil pH, as per laboratory analysis used during the study was 4t (dolomite lime) per hectare. Super phosphate was added at 300kg/ha (30kg P/ ha), with 20kg/ha of N-fertilizer applied with establishment. As top dressing at the beginning (August) of the second, third and fourth growing seasons, 60, 90 and 120 kg N/ha was applied respectively. For the second, third and fourth years 10, 15 and 20kg P/ha was added respectively. Weed control was done chemically with the herbicide Roundup™ (active ingredient – glyphosate) with the cactus pear plant covered by plastic cans at the time of spraying.

The planting (one-year-old cladodes) of the species *Opuntia ficus-indica* (cultivar Morado, green cladode) and *O. robusta* (cultivar Monterey, blue cladode) took place on 4 August 2002 in two lines, with 5m spacing between rows and 2m within a row (1 000 plants/ha). This was done in each of three blocks, 15 x 17m each, adjacent to each other. The plants of the two species were randomly placed over the area within a block. The cladodes were planted with one quarter in the soil and were facing north/south. In each block eight plants per block were therefore established. At the end of each growing season, one plant per species per block were randomly selected and studied.

Water utilization (WU) is defined as the amount of plant material (dry matter of cladodes) produced per unit of water used (evapotranspiration). At the end of each season the utilization of water was calculated by only taking the newly formed cladodes into account.

Evapotranspiration (Et) was determined by the soil-water balance equation. Rainfall (P) was measured daily with rain gauges. The change in soil water (ΔW) was calculated following the method of Moore *et al*. (1988), where (+) indicated an increase and (-) a decrease in the quantity of water within the root zone. The soil-water content was determined gravimetrically by means of a Veihmeyer tube at 50 mm depth intervals up to a depth of 1m every month. Five samples were taken at 100mm intervals away from the stem of one plant in each block. In this deep soil and considering the low rainfall of the study area, it is very difficult to obtain drainage (D) and hence it can be discarded as a factor in the water balance. Runoff (R) was determined from three runoff plots, each measuring 2 x 15m, with an average slope of 3.5%. Plot edging

Table 1: Rainfall, run-off, average evapotranspiration (±SE) and water content (±SE) in the cladodes of *O. ficus-indica* and *O. robusta* over the 2002/2003 to 2005/06 growing seasons. Means (*n* = 3) within a season with different superscripts differ significantly (p≤0.01).

	Plant age or season			
	One year 2002/03	Two years 2003/04	Three years 2004/05	Four years 2005/06
Rainfall (mm)	529	425	443	690
Runoff (% of rainfall as runoff)	22.14 (±1.14)	2.90 (±0.16)	12.68 (± 3.14)	18.84(±4.15)
Evapotranspiration (mm)				
O. ficus-indica	380^a (±31)	409^a (±42)	372^a (±26)	560^a (±66)
O. robusta	372^a (±26)	386^a (±31)	351^a (±20)	544^a (±40)
Species LSD (0.01)	18.16	31.16	22.14	36.15
Water content in cladodes (%)				
O. ficus-indica	88.16^a (±1.12)	88.02^a (±1.11)	88.19^a (±1.26)	88.21^a (±1.11)
O. robusta	87.41^a (±1.23)	87.51^a(±1.36)	87.23^a (±1.14)	87.52^a(±1.02)
Species LSD (0.01)	3.14	3.36	3.24	3.12

was done by overlapping short lengths of iron sheeting placed in the soil to a depth of 200mm. The water was collected by a gutter fixed at the bottom end of each plot and sampled in 1 000 ℓ water tanks (placed into the soil). The runoff plots, although not planted with cactus pear received the same cultivation than the rest of the area planted with cactus pear. Evapotranspiration was therefore calculated as follows:

$$Et = P \pm \Delta W - R$$

Where P is precipitation, ΔW the change in soil-water content and R the runoff.

The layout was a split plot experimental design, consisting of three replications as blocks, years were main plots and species as sub-plots. Data on cladode mass, evapotranspiration and water utilization were analysed using a two-way ANOVA.

Results and discussion

Evapotranspiration (Et)

For the first growing season, the total rainfall was almost (only 0.2% lower) similar to the long-term mean for the study area (Table 1). Rainfall for the 2003/2004 and 2004/2005 growing seasons were 20% and 16% lower, respectively, than the long-term mean expected for the study area. These two seasons were characterized by a significant low rainfall during the first half of the growing season (October to December), which were on average 44% less than that of the long-term mean. The rainfall for the fourth season was 30% above the long-term mean.

Over the four growing seasons, an average of 85mm of the annual rainfall ran off per year (Table 1). Very high precipitations of 90 and 123mm during August and March, respectively, of the first growing season (long-term average 11 and 51mm respectively) were responsible for the higher runoff loss accompanying this growing season.

The evapotranspiration (Et) of *O. ficus-indica* and *O. robusta* differed non-significantly ($P>0.05$) from each other for all four seasons. The lower ($P>0.05$) Et actually occurring with *O. robusta* versus that of *O. ficus-indica* (Table 1) with a resultant higher soil-water content, can be ascribed to the wider root distribution (Snyman, 2006a) and the finer root system of *O. robusta* which can utilize light rain showers much more effectively (Snyman, 2006b).

Water content in cladodes

The percentage water in the cladodes differed not significantly ($p>0.05$) between the two species for all four seasons and ranged between 88.02% and 88.21% for *O. ficus-indica* and for *O. robusta* between 87.25 and 87.52% for the one, two, three and fourth-year-old cladodes (Table 1). The water content is also strongly influenced by environmental conditions as showed in this study. According to most researchers cactus cladodes aged 1 to 3 years, are high in water content (75-85%) in summer and early fall and in winter and spring (80-85%)

Aboveground biomass production

The fresh mass of *Opuntia ficus-indica* cladodes was significantly ($p\leq0.01$) higher than that of *O. robusta* over all four growing seasons (Figure 1). *Opuntia ficus-indica* not only produced larger cladodes than *O. robusta*, but also more new cladodes per season. On average the one to four-year-old plants produced 26.8 and 24.5 new cladodes for *O. ficus-indica* and *O. robusta* respectively. The average fresh mass of *O. ficus-indica* of 1 299g/cladode over the four seasons is 7% higher than that obtained for the same cultivar by Oelofse (2002) from a full grown plantation. The total fresh mass production for *O. ficus-indica* over the first, second, third and fourth growing season was 5.61, 23.51, 39.33 and 80.54kg/plant or t/ha respectively. For *O. robusta* the total fresh mass production over the first, second, third and fourth growing season was 4.21, 18.54, 32.36 and 64.44 kg/plant or t/ha respectively. These productions are much higher than the 5.26t/ha

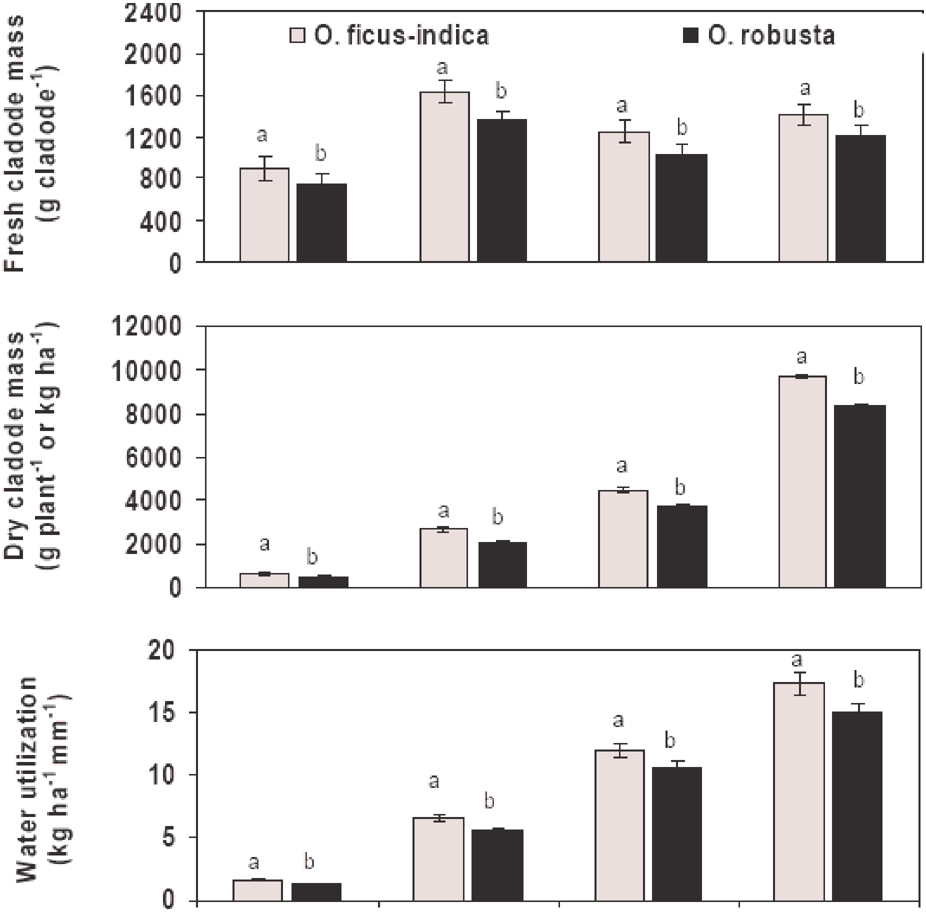

Figure 1: Mean (±SE) cladode fresh and dry mass, as well as the water utilization for *O. ficus-indica* and *O. robusta* over the 2002/03 to 2005/06 growing seasons. Means (*n* =3) within a season with different superscripts differ significantly ($p \leq 0.01$). Vertical bars are standard error of mean.

obtained from *O. robusta* (cultivar Monterey) in the Karoo, from two-year-old plants (De Kock, 2001). From five-year-old plants, Oelofse (2002) reported a fresh mass of 78.84kg/plant for *O. ficus-indica* (cultivar Morado).

Opuntia ficus-indica produced significantly ($p \leq 0.01$) more than *O. robusta* in terms of dry mass over all growing seasons (Figure 1). Both species showed a drastic increase in production, on reaching maturity, to the extent that *O. ficus-indica* and *O. robusta* respectively increased 7.0 and 7.7 times in production from the first to the third season respectively, and with 15.2 and 17.4-fold from the first to fourth season respectively. Although extremely high (50t dry mass/ha/ yr) production is possible for *O. ficus-indica*, a predicted production of 5 to 6t/ha/yr under water-limited conditions, can still surpass productivity of C_3 and C_4 species used for forage (Nobel 2001). The production obtained in this study of 4 460 and 3 710 g/plant or kg/ha for *O. ficus-indica* and *O. robusta* respectively for three-year-old plants, compared well with fodder production results of Potgieter (1998) and Oelofse (2002). Unfortunately there is a lack of one, two and three-year-old plant fodder production results. Most researchers argued that the fodder production of cactus pear is variable over the first three years before obtaining a more constant production. Cactus pear is able to produce up to 5 to 10 aboveground DM/ha/ yr in arid zones, 10 to 20t in semi-arid areas and 20 to 30t in sub-humid zones, under appropriate and close to optimum intensive management. Under such conditions productivity is about 10 times higher than standard rangelands under optimal management conditions. In less than optimal soil and management conditions (no cultivation, no fertilization) yield is still 3 to 5 times higher than standard rangeland .

Water utilization (WU)

Opuntia ficus-indica converted water more efficiently ($p \leq 0.01$) into plant production than *O. robusta* over all four growing seasons (Figure 1). The 20% higher cladode mass, as well as the more new cladodes formed per plant of *O. ficus-indica*, could be attributed to the better WU of this species compared to that of *O. robusta*. As the case with plant production, there is a lack of data on the WU of different cactus pear species and cultivars to compare these findings with. As expected the utilization of water, also showed a drastic increase in efficiency of water-use, as found with plant production, from establishment up to four-year-old plants. The low WU obtained for both species in this study of one-year-old plants, can be attributed to the well-known variable and poor fodder production of cactus pear over the first year of establishment.

Rain-use efficiency is in the order of 2 to 5kg DM/ha/ mm in unspoilt (good ecological condition) world arid rangelands (Le Houérou, 1996). As fodder crop, the WU of 1.67 and 1.30kg/ha/ mm obtained in this study for *O. ficus-indica* and *O. robusta* respectively, is therefore relatively low for one-year-old plants. From the second year after establishment the Wu of cactus pear is comparable with that of rangeland in good condition. Guevera and Estevez (2001) reported a WU of 7.4 kg DM/ha/ mm from cactus pear in a 300mm rainfall area in Argentina. According to them, this low yield was probably due to its unweeded condition. Water utilizations as low as 3.5kg DM/ha/mm were reported on a silty sand soil with a rainfall slightly higher than 200mm (Guevera and Estevez, 2001). Unfortunately most researchers do not mention the age of the plantations. Han and Felker (1997) who studied three- and four-year old plantations argued that the water utilization of cactus pear is among the highest of any plant species (including C_3 and C_4) that has been measured under long-term field conditions. The high WU (62kg DM/ha/mm) from a four-year-old plantation recorded by Han and Felker (1997) was a result of the high biomass productivity in the fourth year after achieving a leaf area index (LAI) > 2. Maximum WUs of 40 to 60kg DM/ha/mm have been attained with cactus pear in semi-arid and sub-humid climates under irrigation and cultivation with fairly high levels of fertilizing and/or manuring, which is close to the biological limit for CAM species According to Felker and Russell (1988) cactus pear is about 3 to 5 times more efficient in water use than C_3 and C_4 plants, such as maize, due to its Crassulacean Acid Metabolism (CAM) pathway (Nobel, 2001) and can therefore be cultivated with great success in drier areas. The combination of a very high rain or water utilization with a high drought-tolerance in cactus pear, is shared by a small number of plants of economic value: cacti and agave are CAM species, while most saltbushes are C_4 plants (Le Houérou, 1996).

Conclusions

Due to the presence of CAM metabolism in *Opuntia*, which results in a high water into dry matter conversion efficiency, cactus can attain very high total biomass productions. This study clearly shows that both *Opuntia ficus-indica* and *O. robusta* not only had high biomass productions and water utilization, but also had high variability in both. The utilization of water increased enormously from establishment up to four-year-old plants. Remarkably, the water utilization even increased from two- to three-year-old plants. After only four years of establishment, it already produced 17.26 and 14.96kg/ha for each millimetre of water used by *O. ficus-indica* and *O. robusta* respectively. It can be expected that mature plants show a still better WU. These are among the little information available on the monitoring of the production and water-use of *Opuntia* over the first few years of establishment. Most of the information on production pertains to mature plantations. These water-balance studies should be extended to other soil forms, various climatic conditions as well as other *Opuntia* species and cultivars. The full potential of this crop will be better determined by an in-depth study of the WU of the mature plants.

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