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Productivity evaluation of *Medicago sativa* cultivars under irrigation in a semi-arid climate

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Many *Medicago sativa* cultivars are available in South Africa, each with unique characteristics. This study evaluated 26 cultivars under irrigation on two ecotopes in terms of number of cuttings, dry matter (DM) production, seasonal DM production curve, DM production curve over lifespan and plant density, over nine growing seasons. The production per cutting decreased from 3 624 and 3 401 kg DM ha^{-1} to 902 and 864 kg DM ha^{-1} on soil of medium and high clay content, respectively. The production peaked during the second and third growing seasons, with respectively 22 524 and 22 640 kg DM ha^{-1} on the medium-clay-content soil, and 20 442 and 20 352 kg DM ha^{-1} on the high-clay-content soil. Cumulative production over nine growing seasons varied from 131 762 to 169 408 kg DM ha^{-1} on the medium-clay-content soil and from 84 407 to 130 447 kg DM ha^{-1} on the high-clay-content soil. The relationship between production and dormancy class was only significant after four to five growing seasons. Dormancy class six to eight seems to be more productive in this environment. The cultivars KKS 3864 and Eureka can be considered the best DM-producing cultivars under irrigation in this environment.

Keywords: alfalfa, cultivars, DM production, dormancy, lucerne, *Medicago sativa*, plant density, production curve, production cycle

Introduction

Medicago sativa (lucerne/alfalfa) is a truly perennial fodder crop well suited for hay, silage and grazing, and will yield for at least six years or longer (Dickinson et al. 2010). It is often called the 'king of forage crops' because of its high fodder quality and digestibility. It is palatable and produces large quantities of dry matter (DM), particularly under irrigation (Fair 1989). It is one of the best and most commonly used pasture and hay plants in South Africa (Wasserman et al. 2000; Snyman 2014). In the semi-arid areas of South Africa it is cultivated as a rainfed crop if the annual rainfall exceeds 500 mm and is then mainly utilised as grazing (Graven 1962). On the other hand, when it is irrigated, the usage is mainly for hay-making (Snyman 2014).

Selecting a *M. sativa* cultivar is arguably the most important factor determining production potential in a specific environment (Shroyer et al. 1998) and management is the most important factor in bringing that potential to fruition. Cultivar selection will directly affect DM quantity and quality, pest/disease tolerance and stand life (Poole et al. 2003). The DM yield should be the most important cultivar selection criterion. Stand persistence is important, especially when *M. sativa* is to be produced for a number of consecutive growing seasons, as is the case for most producers. Seed and establishment cost becomes less important the longer the stand persists (Poole et al. 2003).

In South Africa, only the *M. sativa* seed from cultivars on the South African Variety List may be sold. This list began during 1963 and only one cultivar was listed until 1977 when two were listed and three cultivars were listed in 1984. From 1988 the number of cultivars increased substantially (Theron 2001). The number of available *M. sativa* cultivars as listed in the South African Variety List (DAFF 2013) varied from 39 to 46 during the trial period (2003 to 2012). Given the large number of available cultivars, it is very difficult for the *M. sativa* producer and livestock farmers to select the correct cultivar that will suit their requirements. Knowing the production potential of the particular cultivar under particular climatic and soil conditions is of the utmost importance. At present, production information in most cases is based on assumptions rather than facts and in most cases only one or two years production results taken as norm. The production curve and longevity of the cultivars are also in question as establishment costs are high.

Winter dormancy, based on the United States system, is numbered from 1 to 11, where 1 means that the plant is strongly dormant during winter, and 11 that the plant is winter active or strongly non-dormant (Langenhoven et al. 1993; Teuber et al. 1998; Dickinson et al. 2010; Lauriault et al. 2011). In South Africa the National Lucerne Evaluation Program trials have shown that the most suitable range for all local climatic conditions is from 5 (semi-dormant) to 9 (non-dormant) (Langenhoven and Langenhoven 1993; Langenhoven et al. 1993; Snyman 2014). According to Dickinson et al. (2010) the more winter dormant a cultivar, the longer its lifespan and the better adapted it is to grazing. Conversely, the less winter dormant a cultivar is, the shorter its lifespan and the more suited it is for hay production.

Cultivar selection is therefore even more complicated by dormancy class. For example, low dormancy class could be selected, which would normally not be recommended for hay production. A general assumption is that *M. sativa* produces approximately 120 000 kg DM in its life cycle (Snyman 2014). The annual DM yield of the non-dormant cultivars is usually higher than the more dormant cultivars and therefore better suited to hay production (Griggs 2004; Lauriault et al. 2011). By contrast, the opposite was also reported that no relationship between DM and dormancy could be found (Serafin et al. 2008; Wang et al. 2009; van Heerden 2012). Dormant cultivars handle stress (environment or utilisation) better than non-dormant cultivars (Dickinson et al. 2010).

There is an urgent need to evaluate all the available cultivars under the same climatic and soil conditions in terms of suitability for hay purposes. The aim of this study was therefore to compare the different *M. sativa* cultivars available under irrigation for hay-making purposes on two different soil forms in a semi-arid climate. A cultivar ranking procedure was also developed for *M. sativa*.

Materials and methods

Study site

The study was conducted at Glen Agricultural Development Institute near Bloemfontein (26°20′ E, 28°57′ S; altitude 1 320 m), which is situated in the semi-arid region of South Africa, also described as a Cold Arid Steppe (BSk) according to the Köppen-Geiger classification (Peel et al. 2007; Conradie 2012), with a summer mean average precipitation of 539 mm. Rain falls almost exclusively during summer (87% occurs from October to April), which is the active growth season of summer crops. Annual precipitation is highly variable (SD = 180 mm; Botha 1964) and is received as scattered thunder showers during summer followed by dry winter months (Eloff 1984).

The mean maximum temperature is 31 °C and 17 °C for January and July, respectively. The mean minimum temperature ranges from 15 °C (January) to −1.6 °C (July). On average, frost occurs on 119 days per year (Schulze 1979).

Two experimental sites were laid out. One site was on a Glen Oakleaf (GOa) ecotope with an Oakleaf soil form (18% clay in top 300 mm layer with a bulk density of 1.78 g cm^{-3}) and one site was on a Glen Valsrivier (GVa) ecotope with a Valsrivier soil form (46% clay in top 300 mm layer with a bulk density of 1.40 g cm^{-3}) (MacVicar et al. 1974; Soil Classification Working Group 1991; Snyman and Theron 2009). The soils were at least 2 m deep.

Experimental procedure

Twenty-six *M. sativa* cultivars were received from the major seed marketing companies in South Africa. The 26 cultivars are listed in Table 1 (numbered from 1 to 26) according to the dormancy class indicated by the relevant company.

Four blocks of each cultivar were planted on both ecotopes (GOa and GVa). The gross plot size on the GOa ecotope was 11 m × 2 m (22 m^2), with a sample area of 10 m × 1 m (10 m^2) and on the GVa ecotope 10 m × 2 m (20 m^2) with a sample area of 9 m × 1 m (9 m^2). A total of 104 plots were laid out on each ecotope in a complete randomised block design. The gross site area was 0.32 ha for the GVa ecotope and 0.35 ha for the GOa ecotope.

The phosphorous status of the topsoil (0–200 mm) was 22 mg P kg^{-1} (Olsen) and 28 mg P kg^{-1} (Olsen) for the GOa and GVa ecotopes, respectively. An additional 45 kg P ha^{-1} (429 kg ha^{-1} superphosphate, 10.5% P) was incorporated into the soil for production purposes (FSSA 2003). On 28 April and 29 April 2004, after the seed was inoculated with *Rhizobium* bacteria (Stimuplant CC, *M. sativa* inoculants' powder and Celacol adhesive), the plots were broadcasted at a seeding rate of 25 kg ha^{-1} seed (Stout 1998) and rolled for better contact between seed and soil.

The water requirement for *M. sativa* in the studied area is 1 400–1 800 mm y^{-1} (Snyman and Theron 2010). Irrigation took place on a weekly basis or as soon as 50% of the plant extractable water had been utilised as determined by a neutron hydroprobe (CPN Hydroprobe Model 503DR) and access tubes. A floppy overhead sprinkler irrigation system with a precipitation rate of 5 mm h^{-1} was used. Irrigation commenced as soon as the circumstances were favourable for effective application and utilisation of irrigation water. Irrigation ceased as soon as wind speed exceeded 20km h^{-1}.

The first harvest took place on 25 October 2004 (GOa) and 22 November 2004 (GVa), which is 6–7 months after sowing. All plots at a location were harvested as soon as regrowth was observed at the crowns of the plants in the majority of cultivars, which correlate with the flowering bud stage (Snyman 2014). This may have put the more dormant cultivars at a disadvantage as they start to grow

Table 1: Classification of cultivars into dormancy classes and groups as received from the seed marketing companies

Cultivar no.	Cultivar name	Dormancy class	Dormancy group (DG)
1	Alfagraze	2	DG 2-5
2	AC Grazeland	4	DG 2-5
3	PAN 4546	5	DG 2-5
4	SA Standard	6	DG 6-7
5	Aurora	7	DG 6-7
6	Genesis	7	DG 6-7
7	KKS 3864	7	DG 6-7
8	KKS 9595	7	DG 6-7
9	PAN 4764	7	DG 6-7
10	PEX 1	7	DG 6-7
11	PEX 2	7	DG 6-7
12	UQL 1	7	DG 6-7
13	WL 414	7	DG 6-7
14	Aquarius	8	DG 8
15	Eureka	8	DG 8
16	Hallmark	8	DG 8
17	PAN 4860	8	DG 8
18	WL 525 HQ	8	DG 8
19	PAN 4956	9	DG 9-10
20	PAN 4961	9	DG 9-10
21	Robusta	9	DG 9-10
22	Salado	9	DG 9-10
23	Sequel	9	DG 9-10
24	Topaz	9	DG 9-10
25	WL 625 HQ	9	DG 9-10
26	PEX 3	10	DG 9-10

later in spring and shut down sooner in autumn. Cutting at this stage, rather than 10% flowering, results in increased protein content and digestibility with a small yield decline (Slarke and Mason 1987). Probst (2008) also found a cutting interval of 30–35 d to be best. The plants were cut to 100 mm high with a sickle mower. The wet material of the sample plot was weighed and a sample of 1 kg was dried in a forced draft oven at 50 °C (Hodge 1953). From the dried material the DM production per hectare was calculated for each individual plot and cutting.

Plant density counts were done by averaging the plant count in three 1 m^2 quadrats for each plot at the end of growing seasons six to nine.

Average DM production refers to the average DM production of all cultivars in the trial as calculated for the factor being discussed. Year or growing season indicate the active growing cycle and not the calendar year and range from one to nine, which was the time span of the trial. A growing season includes a number of harvests, referred to as cuttings, and usually ranges from one to six and in some cases to eight. The first cutting of the growing season was not fixed on a date, but was determined by the growth in spring. The subsequent cuttings were determined as indicated above. The date of the first and last cuts of the growing seasons is indicated in Table 2. The term cutting, rather than a calendar month, is therefore used to indicate the time of harvesting during a growing season.

Statistical analysis

Data were analysed by analysis of variance (ANOVA) using the repeated option of Proc GLM of the SAS Enterprise Guide 4.2 software package (SAS Institute, Cary, NC, USA) as well as Statgraphics® 5 Plus (Manugistics, Rockville, MD, USA). The MEAN procedure in the SAS Enterprise Guide software was used to calculate applicable standard deviations (SD) and 95% confidence intervals (CI) for the data. Multifactor ANOVA (factors were cultivar, growing season, block, ecotope, cutting, and dormancy group) as well as simple regression analyses were used on the data. The combination of *P*-value, SD and 95% CI was used to indicate the variability of the observed values, the meaningfulness at 95% and the precision of estimated summaries, respectively (Steiner 1996; Carter 2013).

Results and discussion

Harvesting information

The first cutting of the growing season varied from the beginning of September to mid-October on the GOa ecotope and from the last third of September to the end of October on the GVa ecotope, excluding the first growing season (Table 2). The first cutting during the first growing season was delayed to enable increased root development. On average, one less cutting per growing season was made on the GVa ecotope compared with that of the GOa ecotope (Table 2). This is probably due to the temperature difference between the two ecotopes. The GVa ecotope is colder and lower in the landscape (next to a river) than the GOa ecotope. The mean minimum grass temperature was 5.9 °C and 7.1 °C on the GVa ecotope and GOa ecotope, respectively. The average maximum grass temperature was 28.7 °C and 28.4 °C on the GVa and GOa ecotopes, respectively. According to most researchers, at least six cuttings per growing season over a lifespan of six years can be obtained from a cultivar such as SA Standard (Fair 1989; Dickinson et al. 2010; Snyman 2014).

Dry matter production curve

To calculate the production curve (Figure 1), the cumulative DM production for each cultivar for each growing season was calculated first. The DM production for each cultivar and cutting during each growing season was expressed as a percentage of the total seasonal DM to which the individual cut belongs. Only growing seasons two to five were included. The first growing season had only a few cuttings, which will skew the curve and is not a representation of

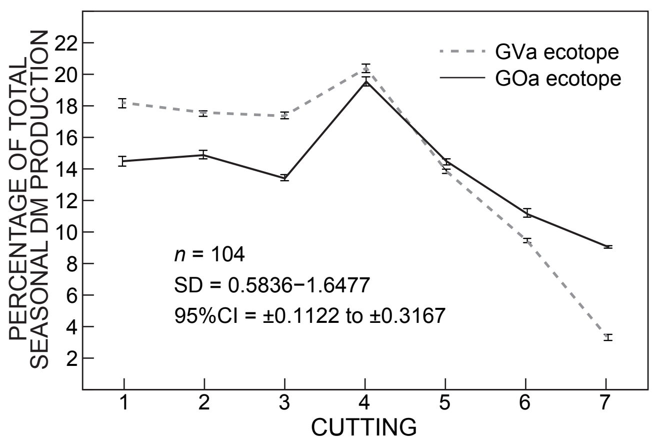

Figure 1: Dry matter (DM) production curve (expressed as a percentage of the total growing season DM production) based on growing seasons two to five for *M. sativa* for the GOa and GVa ecotopes. Error bars, observations (*n*), standard deviation range (SD) and the 95% confidence interval (CI) range are indicated

Table 2: Harvest information for the trial period (2004/05 to 2012/13) on the GOa and GVa ecotopes

Ecotope	Harvest	Growing season and calendar year								
		1 2004/05	2 2005/06	3 2006/07	4 2007/08	5 2008/09	6 2009/10	7 2010/11	8 2011/12	9 2012/13
GOa	First cutting (day/month)	25/10	5/09	12/09	8/10	6/10	21/09	5/10	17/10	16/10
	Last cutting (day/month)	11/04	2/05	8/05	14/04	20/04	14/04	5/04	24/04	16/04
	No. of cuttings	5	7	8	7	7	7	7	7	7
GVa	First cutting (day/month)	22/11	20/09	20/09	16/10	13/10	20/10	12/10	24/10	22/10
	Last cutting (day/month)	7/03	3/04	24/04	7/04	23/03	12/04	23/03	7/05	3/04
	No. of cuttings	3	6	7	6	6	6	5	7	6

the normal growth pattern. The recommended lifespan for *M. sativa* under commercial conditions in this area is five or six growing seasons. The GOa ecotope had one year with eight cuttings. For the purpose of the calculation, the seventh and eighth cuttings were added together as cutting seven. The first cutting usually took place during September or October, as indicated in Table 2, and the other cuts were on average monthly thereafter. The GVa ecotope produced a larger portion during the early growing season (cuttings one to four) and less during the late season (cuttings six and seven) than the GOa ecotope. Ecotope and cutting had a significant ($P < 0.0001$) interaction effect on the DM production distribution. Generalisation of growth curves can lead to large errors in DM production calculations for a fodder flow program. Cutting four was usually during mid-summer (January).

The cumulative percentage DM production for each ecotope is shown in Figure 2. After four of the possible seven cuttings, 73.4% and 62.4% of the seasonal DM production was produced on the GVa and GOa ecotopes, respectively. This indicates the importance of correct management during the early and mid-season of production (cuttings one to four).

Dry matter production per cutting

The average DM production per cutting decreased over the lifespan of *M. sativa (*Figure 3). The lower yield per cut and fewer cuts during the first growing season on the GVa ecotope, compared with the GOa ecotope, may be due to lower temperatures and slower root system establishment (Wasserman et al. 2000; Snyman 2014). The maximum average yield was 3 624 and 3 407 kg DM ha^{-1} cut^{-1} for the GOa (growing season one) and GVa ecotopes (growing season two), respectively. The decrease in yield for the GVa ecotope was almost linear from growing season two to nine and was highly significant ($P < 0.0001$) between seasons. This decline in yield from the maximum of 3 407 kg DM ha^{-1} cut^{-1} (growing season two) to growing season nine (864 kg DM ha^{-1} cut^{-1}) is 2 543 kg DM ha^{-1} cut^{-1}. On the GOa ecotope the decrease in yield from growing season one (3 624 kg DM ha^{-1} cut^{-1}) to seven (2 557 kg DM ha^{-1} cut^{-1}) was 1 067 kg DM ha^{-1} cut^{-1}. After growing season seven, it decreased by 1 655 kg DM ha^{-1} cut^{-1} for a total decrease of 2 722 kg DM ha^{-1} cut^{-1} to the same level as that of the GVa ecotope.

Dry matter production over lifespan

On both ecotopes, the total seasonal DM production increased ($P \leq 0.05$) from season one to two (Figure 4). This was due to fewer first year cuts on both ecotopes and, in the case of the GVa ecotope, also smaller harvest per cutting. Seasons two and three did not differ significantly ($P > 0.05$) from each other on both ecotopes, although the ecotopes differ significantly. After season

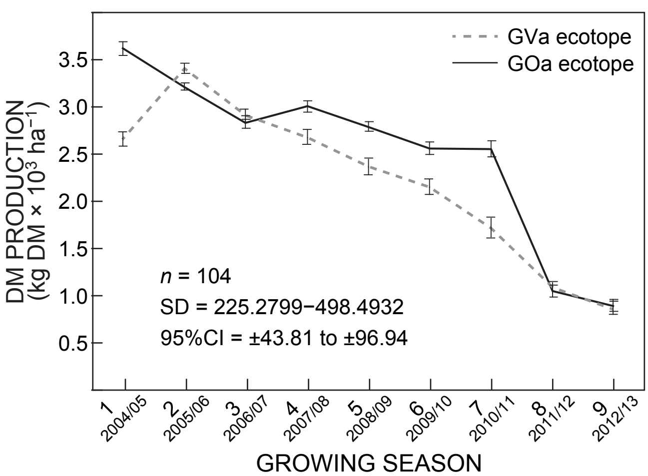

Figure 3: Average dry matter (DM) production per cutting for each growing season (2004/05 to 2012/13) on the GOa and GVa ecotopes. Error bars, observations (*n*), standard deviation range (SD) and the 95% confidence interval (CI) range are indicated

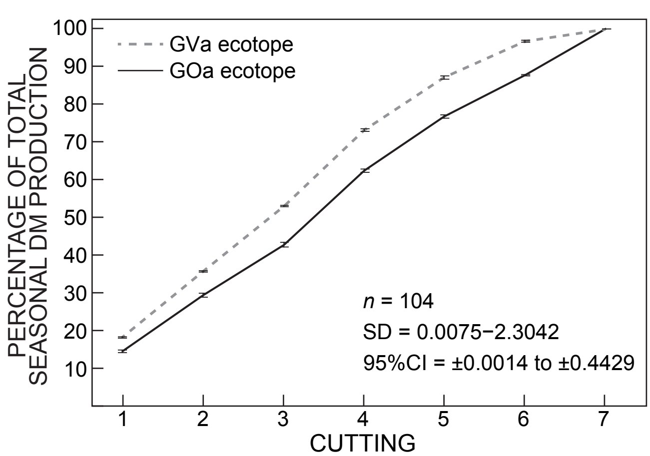

Figure 2: Cumulative dry matter production (% of total seasonal DM production) on the GOa and GVa ecotopes. Error bars, observations (*n*), standard deviation range (SD) and the 95% confidence interval (CI) range are indicated

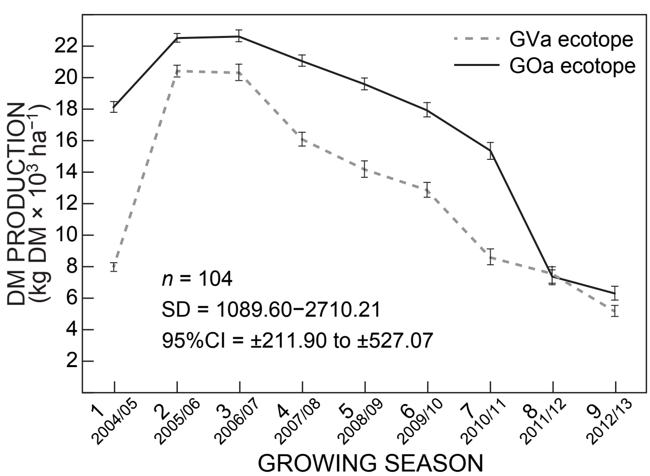

Figure 4: Average total dry matter production (kg DM ha^{-1}) for each growing season (2004/05 to 2012/13) on the GOa and GVa ecotopes. Error bars, observations (*n*), standard deviation range (SD) and the 95% confidence interval (CI) range are indicated

three, DM production decreased ($P \leq 0.05$) in each succesive growing season on both ecotopes. It was clear from the total DM production values that the highest DM production occurred during the second and third growing seasons on both ecotopes. The decrease on the GOa ecotope was slower than that on the GVa ecotope up until growing season seven.

Relationship between dry matter production and dormancy class

Based on the spread of cultivars over the dormancy spectrum, the cultivars were divided into four dormancy groups as indicated in Table 1. The cumulative seasonal DM production was used to determine the relationship between DM production and dormancy group.

Growing season and dormancy group had a significant ($P < 0.0001$) effect on cumulative DM production. There was also a significant interaction between these two factors in respect to DM production on both the GOa ($P < 0.0001$) and GVa ($P < 0.0001$) ecotopes (Figures 5 and 6).

At the start of the trial, very little difference existed among dormancy groups. The differences between dormancy groups grew larger as the trial progressed. At the end of the trial, dormancy group 6–7 produced significantly ($P < 0.05$) more than the 9–10 group on the GOa ecotope, although not significantly ($P < 0.05$) more than the other two groups. By contrast, on the GVa ecotope, dormancy group 2–5 lagged significantly ($P < 0.05$) behind dormancy group 6–7, but not significantly ($P < 0.05$) behind groups 8 and 9–10. The same was observed with dormancy group 9–10, although not as much as in the former case. From this it could be concluded that the cultivars with dormancy 6 to 8 will produce the most DM over the long run for this specific environment.

Relationship between dry matter production and plant density

On average, there are 440 000 *M. sativa* seeds kg^{-1}. A 45% establishment rate will result in a stand of 500 plants m^{-2} (Birch and Engelbrecht 1981; MacDonald et al. 2003), which is much more than needed for maximum DM production and good quality (Birch and Engelbrecht 1981; Min et al. 2000).

The average plant density (plants m^{-2}) for growing season six to nine on the two ecotopes is shown in Tables 3 and 4. The cultivars WL 525 HQ and WL 625 HQ had significantly ($P < 0.01$) more plants than all the other cultivars on both ecotopes, whereas Hallmark, Sequel and AC Grazeland had the fewest plants. The cultivars with the higher plant densities at the end of the trial period produced the most DM over the trial period (Tables 5 and 6), and likewise for the cultivars with the lower plant densities. From this it can be concluded that the more persistent the cultivar, the higher the cumulative seasonal DM production.

The relationship between the average DM production per season and plant density (plants m^{-2}) is shown in Figure 7. The maximum seasonal DM production is also indicated for the two ecotopes. Two linear regression equations were calculated to determine DM production per season from plant density (Figure 7). From the equations, it was estimated that the plant density at average maximum DM production was about 54 plants m^{-2} for the GOa ecotope and 48 plants m^{-2} for the GVa ecotope, respectively. These findings support those of McDonald et al. (2003) and Hall et al. (2004) that DM production decreases as plant population decreases below 50 plants m^{-2}. Weed infestation can take place much easier due to an open plant stand.

Total dry matter production over the full production period for the different cultivars

The highest and lowest DM-producing cultivars over the nine growing seasons on the GOa ecotope were WL 525 HQ and AC Grazeland with 169 408 kg DM ha^{-1} and 131 762 kg DM ha^{-1}, respectively (Table 5). These cultivars differed significantly ($P \leq 0.05$) by 37 646 kg DM ha^{-1} over the nine production years, an average of 4 182 kg DM ha^{-1} y^{-1}. The seven highest DM-producing cultivars did not differ significantly ($P \leq 0.05$) from each other. The average total DM production for all cultivars for the nine growing seasons was 150 855 kg DM ha^{-1}, an average of 16 762 kg DM ha^{-1} y^{-1}. SA Standard is a very old, well-known cultivar and is taken in many cases as a benchmark. It produced (155 305 kg DM ha^{-1}) above-average DM for the trial period, although significantly ($P \leq 0.05$) lower than the top-producing cultivar WL 525 HQ.

The highest and lowest DM-producing cultivar over the nine growing seasons on the GVa ecotope was WL 625 HQ and AC Grazeland, with 130 447 kg DM ha^{-1} and 84 407 kg DM ha^{-1}, respectively (Table 6). The difference between these two cultivars (46 040 kg DM ha^{-1}) was significant ($P \leq 0.05$). This was an average difference of 5 116 kg DM ha^{-1} y^{-1}. The 13 highest DM-producing cultivars did not differ significantly ($P \leq 0.05$) from each other. That is half of all cultivars in the trial. The average total DM production for all cultivars over the nine-year period was 113 358 kg DM ha^{-1} with an average DM production of 12 595 kg DM ha^{-1} y^{-1}. The highest-producing cultivar, WL 625 HQ, produced an average of 14 494 kg DM ha^{-1} y^{-1}. More cultivars differed significantly ($P \leq 0.05$) from each other than was observed on the GOa ecotope (Tables 5 and 6). SA Standard produced less than the average DM production on the GVa ecotope. Five cultivars produced significantly more DM than SA Standard.

The highest DM-producing cultivars on the GOa ecotope were also the highest-producing cultivars on the GVa ecotope with only changes in ranking order. The highest DM-producing cultivars on the GVa ecotope (Table 6) produced the same quantity as the lowest DM-producing cultivars on the GOa ecotope (Table 5). The difference between the average DM production on the GOa and GVa ecotopes was 37 497 kg DM ha^{-1}, which was 4 166 kg DM ha^{-1} y^{-1}. No clear-cut cultivar selection can be made from Tables 5 and 6..

Ranking of cultivars

Normally, in cultivar trials, the cultivars are ranked from the highest to the lowest DM-producing cultivar. By applying this technique for each individual growing season, the ranking order of cultivars changes so drastically that no clear conclusion on the best cultivar could be made. Even calculating the total DM production over lifespan, as presented in Tables 5 and 6, does not indicate the best cultivar, because the production over lifespan for each cultivar differed season by season.

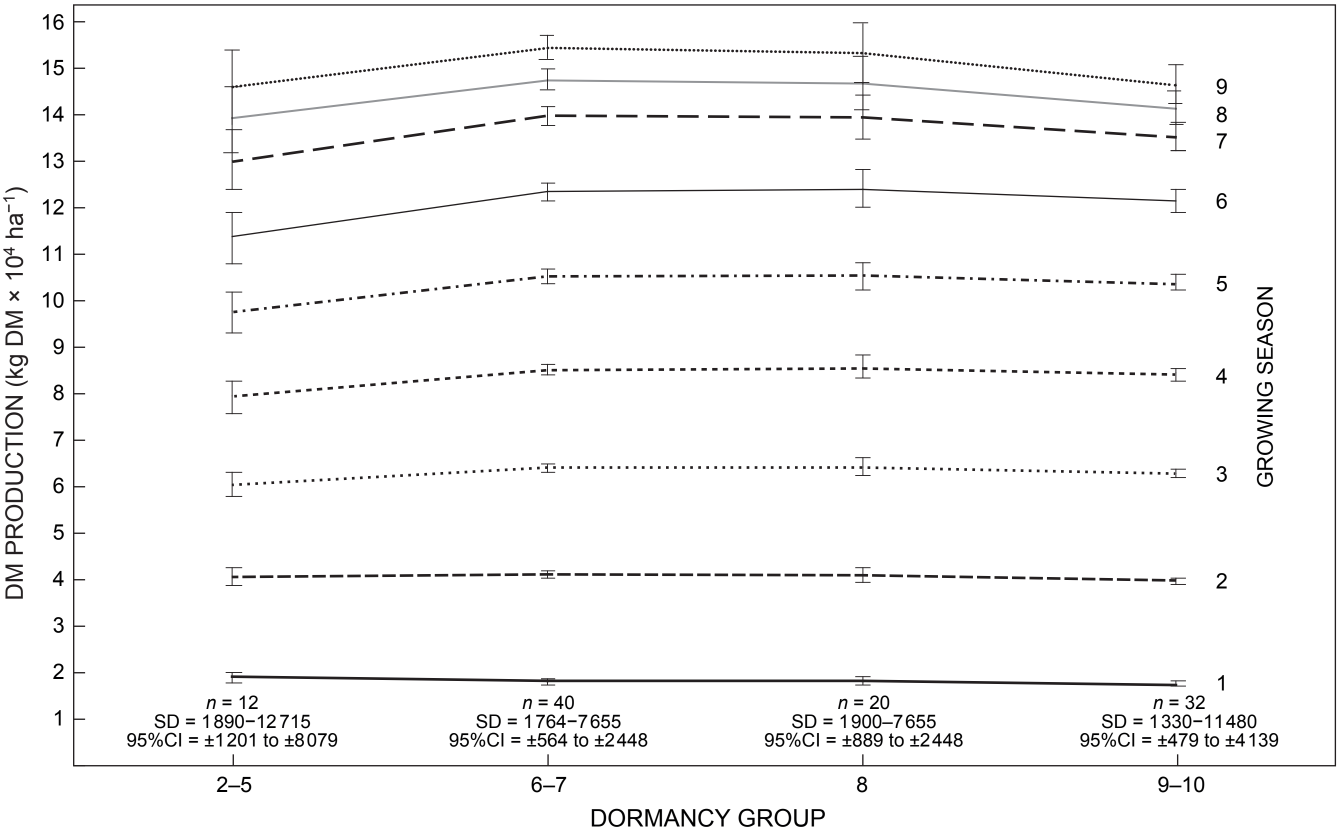

Figure 5: Cumulative dry matter (DM) production (kg DM ha⁻¹) for nine growing seasons according to dormancy groups on the GOa ecotope. Error bars, observations (*n*), standard deviation range (SD) and the 95% confidence interval range (CI) are indicated for each dormancy group

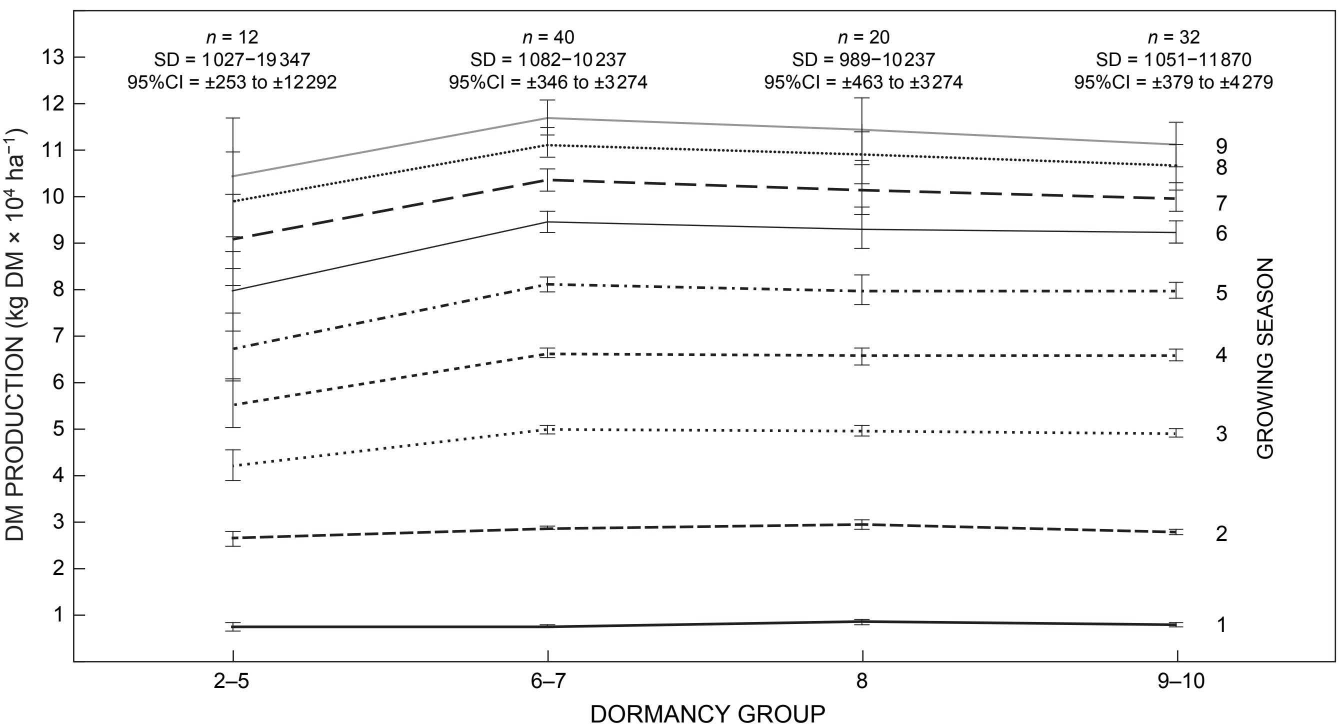

Figure 6: Cumulative dry matter (DM) production (kg DM ha⁻¹) for nine growing seasons according to dormancy groups on the GVa ecotope. Error bars, observations (*n*), standard deviation range (SD) and the 95% confidence interval (CI) range are indicated for each dormancy group

Table 3: Average plant density over four growing seasons (six to nine) for the cultivars on the GOa ecotope. Cultivars with no common letter differed significantly ($P < 0.05$)

Cultivar	Mean density (plants m^{-2})	CI lower limit	CI upper limit	CI significance
WL 625 HQ	12.69	11.037	14.338	a
WL 525 HQ	12.65	10.995	14.297	a-b
WL 414	10.75	9.099	12.401	a-c
KKS 3864	10.73	9.078	12.380	a-c
PEX 1	10.71	9.058	12.359	a-c
PAN 4764	10.65	8.995	12.297	a-d
UQL 1	10.52	8.870	12.172	a-d
PAN 4546	10.38	8.724	12.026	a-d
KKS 9595	10.08	8.433	11.734	b-e
Aurora	9.79	8.141	11.442	c-f
Eureka	9.67	8.016	11.317	c-g
PEX 3	9.63	7.974	11.276	c-g
Genesis	9.19	7.537	10.838	c-g
Alfagraze	9.15	7.495	10.797	c-g
Robusta	8.94	7.287	10.588	c-h
Salado	8.94	7.287	10.588	c-h
Aquarius	8.90	7.245	10.547	c-h
PAN 4860	8.75	7.099	10.401	c-h
PAN 4956	8.29	6.641	9.942	c-h
PAN 4961	8.10	6.453	9.755	d-h
SA Standard	8.10	6.453	9.755	d-h
PEX 2	7.67	6.016	9.317	e-h
Topaz	7.63	5.974	9.276	e-h
Hallmark	7.29	5.641	8.942	f-h
AC Grazeland	7.13	5.474	8.776	g-h
Sequel	6.44	4.787	8.088	h

Average density (plants m^{-2}) = 9.34, $N = 4$, SD = 1.658, SE = 0.829, 95% confidence interval = 1.651

Table 4: Average plant density over four growing seasons (six to nine) for the cultivars on the GVa ecotope. Cultivars with no common letter differed significantly ($P < 0.05$)

Cultivar	Mean density (plants m^{-2})	CI lower limit	CI upper limit	CI significance
WL 525 HQ	12.67	11.582	13.751	a
WL 625 HQ	12.35	11.270	13.438	a-b
PEX 1	10.38	9.291	11.459	b-c
KKS 3864	10.04	8.957	11.126	c
KKS 9595	9.96	8.874	11.043	c-d
WL 414	9.65	8.562	10.730	c-e
Robusta	9.50	8.416	10.584	c-f
Eureka	9.40	8.312	10.480	c-f
UQL 1	9.25	8.166	10.334	c-f
PAN 4764	8.98	7.895	10.063	c-f
Aquarius	8.92	7.832	10.001	c-f
Salado	8.90	7.812	9.980	c-f
PAN 4546	8.73	7.645	9.813	c-f
Genesis	8.67	7.582	9.751	c-f
PEX 3	8.21	7.124	9.293	c-g
PAN 4860	7.83	6.749	8.918	d-h
Topaz	7.73	6.645	8.813	e-i
PAN 4961	7.69	6.603	8.772	e-i
PAN 4956	7.54	6.457	8.626	e-i
SA Standard	7.48	6.395	8.563	e-i
Alfagraze	7.44	6.353	8.522	f-i
Aurora	7.35	6.270	8.438	f-i
PEX 2	6.48	5.395	7.563	g-i
Hallmark	6.13	5.041	7.209	g-i
AC Grazeland	5.96	4.874	7.043	h-i
Sequel	5.60	4.520	6.688	i

Average density (plants m^{-2}) = 8.57, $N = 4$, SD = 1.089, SE = 0.545, 95% confidence interval = 1.084

Table 5: Total dry matter (DM) production over nine growing seasons (2004/05 to 2012/13) for the cultivars on the GOa ecotope. Cultivars with no common letter differed significantly ($P < 0.05$)

Cultivar	Mean yield (kg DM ha^{-1})	CI lower limit	CI upper limit	CI significance
WL 525 HQ	169 408	163 534	175 282	a
WL 625 HQ	164 237	158 363	170 111	a-b
KKS 3864	163 909	158 036	169 783	a-b
Eureka	159 546	153 672	165 419	a-c
PEX 1	159 358	153 484	165 231	a-c
PAN 4546	158 930	153 056	164 804	a-c
KKS 9595	158 571	152 697	164 444	a-d
PAN 4764	157 112	151 238	162 985	b-e
PEX 3	156 832	150 958	162 706	b-e
WL 414	156 333	150 459	162 207	b-e
SA Standard	155 305	149 432	161 179	b-e
PAN 4860	153 213	147 340	159 087	b-e
UQL 1	153 048	147 174	158 921	b-f
Salado	150 782	144 909	156 656	c-g
Genesis	149 623	143 750	155 497	c-g
Aquarius	149 620	143 746	155 494	c-g
Aurora	149 616	143 742	155 489	c-g
Robusta	147 820	141 946	153 693	c-g
Alfagraze	147 172	141 298	153 046	d-g
PAN 4956	146 288	140 414	152 162	e-h
PEX 2	141 353	135 479	147 226	f-i
Topaz	139 455	133 581	145 328	g-i
PAN 4961	134 841	128 967	140 714	h-i
Hallmark	134 449	128 576	140 323	i
Sequel	133 642	127 768	139 516	i
AC Grazeland	131 762	125 888	137 636	i

Average yield (kg DM ha^{-1}) = 150 855, $N = 4$, SD = 5 897.02, SE = 2 948.51, 95% confidence interval = 5 873.692

Table 6: Total DM production (kg DM ha-1) over nine growing seasons (2004/05 to 2012/13) for the cultivars on the GVa ecotope. Cultivars with no common letter differed significantly ($P < 0.05$)

Cultivar	Mean yield (kg DM ha^{-1})	CI lower limit	CI upper limit	CI significance
WL 625 HQ	130 447	123 771	137 123	a
KKS 3864	128 873	122 197	135 549	a
WL 525 HQ	127 564	120 888	134 239	a-b
Eureka	127 331	120 655	134 007	a-b
PEX 1	125 656	118 981	132 332	a-c
KKS 9595	124 587	117 911	131 263	a-d
PAN 4546	124 003	117 327	130 679	a-d
WL 414	121 446	114 770	128 122	a-e
PAN 4764	118 081	111 405	124 757	a-f
PAN 4956	117 978	111 302	124 654	a-f
Aquarius	117 864	111 188	124 540	a-f
UQL 1	117 219	110 544	123 895	a-g
PEX 3	117 182	110 506	123 858	a-g
Robusta	114 649	107 973	121 325	b-h
Genesis	112 526	105 850	119 201	b-i
SA Standard	111 940	105 264	118 615	d-i
Salado	111 538	104 862	118 214	d-j
Aurora	110 458	103 782	117 134	e-k
Alfagraze	105 384	98 708	112 060	f-l
PAN 4860	104 236	97 560	110 912	g-l
Topaz	103 452	96 776	110 128	h-l
PEX 2	99 979	93 303	106 656	i-l
Sequel	98 555	91 880	105 232	j-l
PAN 4961	97 892	91 217	104 569	k-l
Hallmark	94 053	87 377	100 730	l-m
AC Grazeland	84 406	77 730	91 082	m

Average yield (kg DM ha^{-1}) = 113 358, $N = 4$, SD = 6 702.32, SE = 3 351.16, 95% confidence interval = 6 675.887

With this study, another approach is suggested, where cultivars are ranked on cumulative seasonal DM production over lifespan. For growing season one, ranking is done on the total first-year DM production. Ranking for the second growing season is done on the cumulative DM production for seasons one and two. The same is done for the rest of the growing seasons. The results from this technique are given in Figures 8 and 9 for the GOa ecotope and GVa ecotope, respectively. The cultivar number under each growing season is linked from season to season to indicate the change in ranking position. The rectangle indicates the 95% CI of the highest DM-producing cultivar

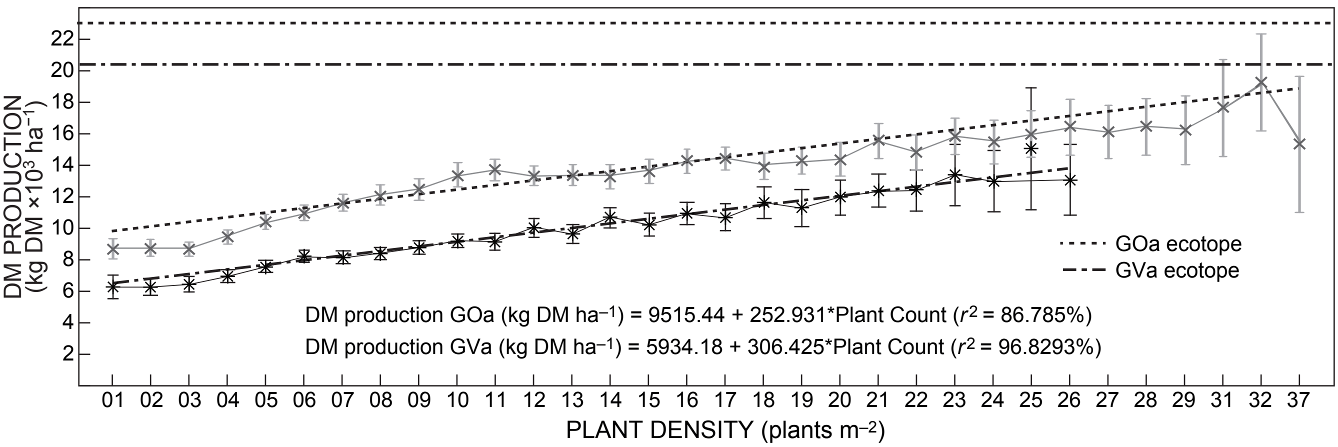

Figure 7: Relationship between total growing season dry matter production (kg DM ha^{-1}) and plant density (plants m^{-2}) for growing seasons six to nine (2009/10 to 2012/13) on the GOa and GVa ecotopes. The maximum growing season DM production and regression equations for both ecotopes are indicated. Error bars indicate the 95% confidence intervals

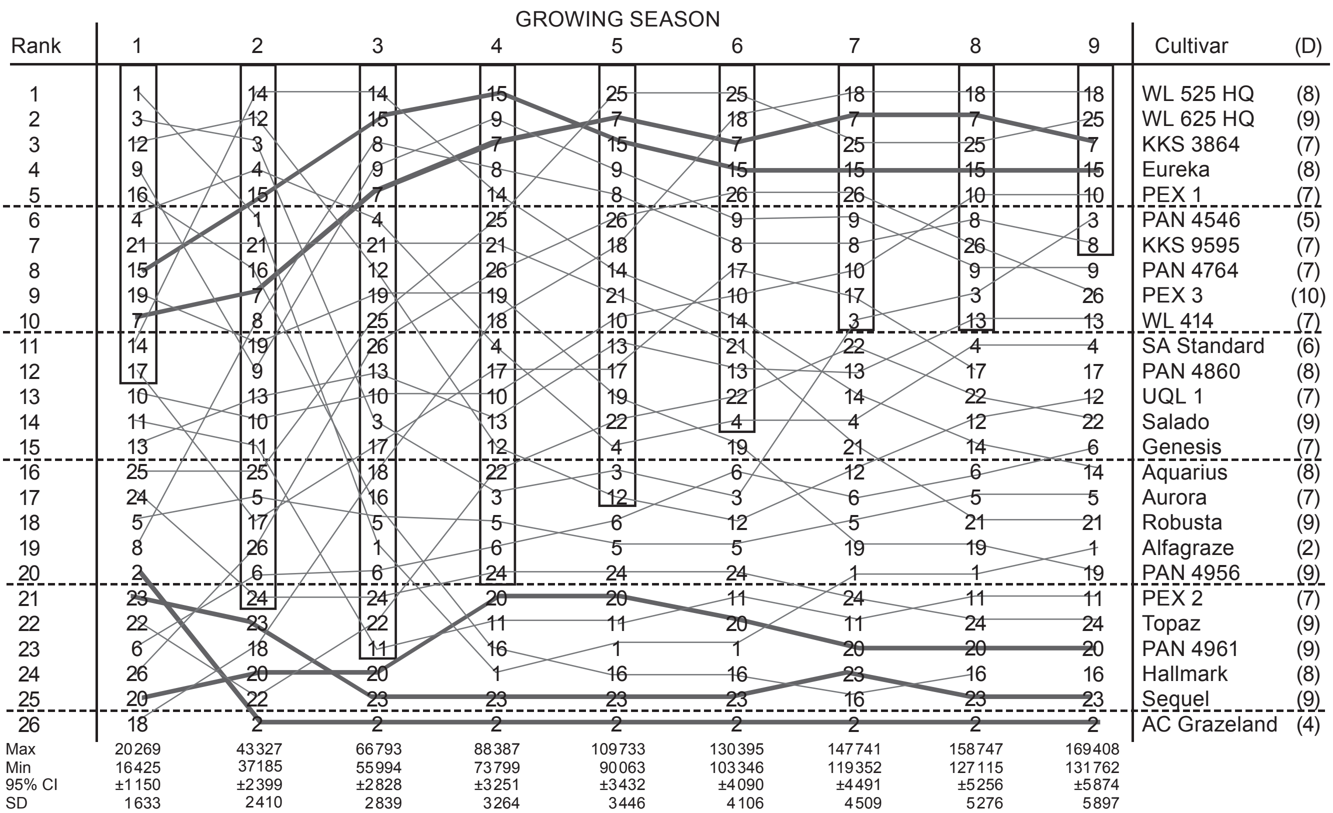

Figure 8: Ranking of the cumulative dry matter (DM) production (kg DM ha^{-1}) over nine growing seasons (2004/05 to 2012/13) for the GOa ecotope. The rectangles indicate the non-significant cultivars compared to the highest producing for the specific growing season. The numbers in the Growing Season columns represent the cultivar number allocated. The cultivar names and dormancy class are in the rightmost column. The lines connect the cultivar from growing season to growing season. (D) = Dormancy; Max = DM production of 1st ranked cultivar; Min = DM production of 26th ranked cultivar; 95% CI = 95% confidence interval; SD = standard deviation

for each growth season. Therefore, the cultivar numbers inside the rectangle do not differ significantly ($P > 0.05$) from the highest-ranking (cumulative highest producing) cultivar. Beneath each growing season's column, the cumulative DM production for the highest (Max) and lowest (Min) DM-producing cultivar, 95% CI and SD is given. For example, in Figure 8, in growing season four, the highest cumulative producing cultivar namely, Eureka (no. 15), produced 88 387 kg DM ha^{-1} and the 95% CI was ±3 251 kg DM ha^{-1}. The lowest DM-producing cultivar was AC Grazeland (no. 2) with 73 799 kg DM ha^{-1}.

From Figure 8 it can be concluded that during the first growing season, half of the cultivars did not differ significantly ($P > 0.05$) from the highest DM-producing cultivar (Alfagraze, no. 1). During the third growing season only three cultivars differed significantly ($P \leq 0.05$) from the highest DM-producing cultivar (Aquarius, no. 14). As time progressed, the ranking of cultivars changed and the difference between cultivars grew larger and more cultivars differed significantly ($P \leq 0.05$) from the highest DM-producing cultivar.

The ranking of some cultivars was initially high but rapidly declined (e.g. Alfagraze, no. 1 and Hallmark, no. 16). Other cultivars started out lowly ranked and rapidly increased in ranking (e.g. WL 525 HQ, no. 18 and WL 625 HQ, no. 25). These changes do not seem to be correlated to dormancy as Alfagraze (dormancy 2) and Hallmark (dormancy 8) decreased in ranking, where as WL 525 HQ (dormancy 8) and WL 625 HQ (dormancy 9) increased in ranking. Some cultivars were more stable in ranking. PAN 4961 (no. 20), Sequel (no. 23) and AC Grazeland (no. 2) produced significantly ($P \leq 0.05$) less DM during all growing seasons than the highest DM-producing cultivar. Cultivars such as KKS 3864 (no. 7) and Eureka (no. 15) always ranked in the non-significant band, therefore did not differ significantly ($P > 0.05$) from the highest DM-producing cultivar during any of the growing seasons. The same could be said for PAN 4764 (no. 9), as it only differed significantly during the ninth growing season from the highest DM-producing cultivars. SA Standard (no. 4) was within the non-significant band for the first six growing seasons. Cultivars that initially produce DM slowly but subsequently show increased DM production will result in slower recovery of input costs. On the other hand, cultivars in which DM production is initially high but then rapidly declines will limit the economic lifespan of the cultivar. Thus a cultivar showing high stability of DM production is preferable.

On the GVa ecotope (Figure 9), the number of cultivars differing significantly ($P \leq 0.05$) from the highest DM-producing cultivar stayed about the same. As in the case on the GOa ecotope (Figure 8), the cultivars Genesis (no. 6), Topaz (no. 24) and AC Grazeland (no. 2) always

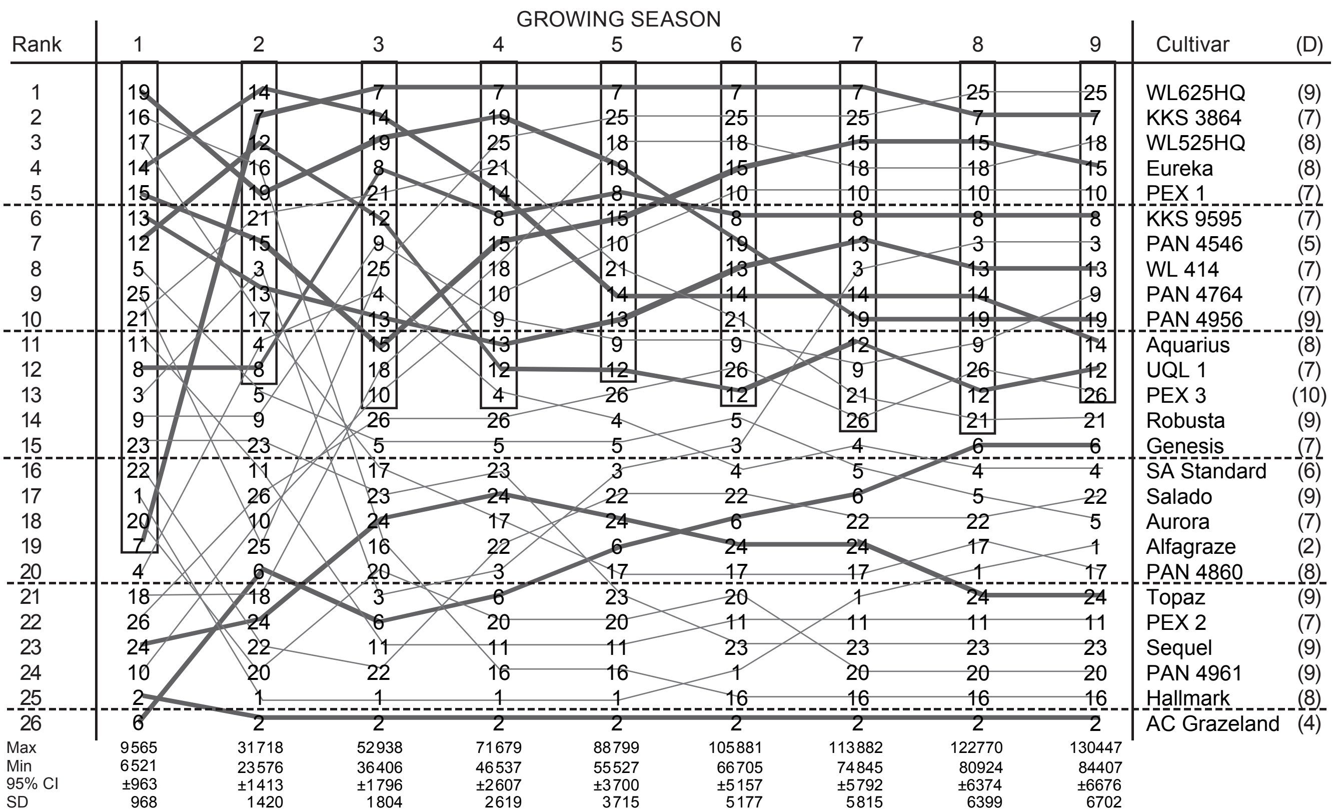

Figure 9: Ranking of the cumulative dry matter production (kg DM ha^{-1}) over nine growing seasons (2004/05 to 2012/13) for the GVa ecotope. The rectangles indicate the non-significant cultivars compared to the highest producing for the specific growing season. The numbers in the Growing Season columns represent the cultivar number allocated. The cultivar names and dormancy class are in the rightmost column. The lines connect the cultivar from growing season to growing season. (D) = Dormancy; Max = DM production of 1st ranked cultivar; Min = DM production of 26th ranked cultivar; 95% CI = 95% confidence interval; SD = standard deviation

produced significantly ($P > 0.05$) less DM than the highest producing cultivar throughout the nine growing seasons. By contrast, the DM production of seven cultivars did not differ significantly ($P \leq 0.05$) over the nine growing seasons from the highest DM-producing cultivar, five more than on the GOa ecotope. This may be an indication of the effect of environmental limitations putting a ceiling on DM production, rather than genetic limitations as may be the case on the GOa ecotope.

SA Standard (no. 4) declined in ranking from ninth after three growing seasons to sixteenth after nine seasons. The DM production of SA Standard (no. 4) differed significantly ($P \leq 0.05$) from the highest DM-producing cultivar after five growing seasons.

Crop rotation must also be considered as it will put a limit on the lifespan of *M. sativa*. If a four-season cycle is taken for example, the possible cultivar selection options are eight cultivars inside the 95% non-significant limit on the GVa ecotope and 10 cultivars on the GOa ecotope. Both KKS 3864 (no. 7, dormancy 7) and Eureka (no. 8, dormancy 8) remained within the non-significant range (95% CI) for all growing seasons on both ecotopes. KKS 3864 showed good DM production when grazed under dryland conditions in the Western Cape (van Heerden 2012).

Conclusion

In a semi-arid climate, *M. sativa* can produce seven or eight cuttings during the growing season. Under commercial conditions it may be less due to weather conditions not being favourable for hay-making. From the data it is evident that more than half (73% and 62%) of the seasonal DM is produced up to the fourth cutting. This corresponds to mid-December to the end of January. Average DM production per cutting decreases as the plants grow older. The highest DM production is attained during the second and third growing seasons. If *M. sativa* is not optimally managed, the production loss cannot be recouped by better management, because the potential DM production decreases over the lifespan.

A relationship between dormancy group and DM production was not observed during the first few growing seasons for the cultivars in this trial under these specific conditions. Only after four and five growing seasons on the GVa and GAo ecotopes, respectively, were statistical differences apparent. Dormancy class six to eight seems to be better adapted and more productive in this environment when aiming for a long lifespan. The DM production per area decreased as the plant density (plants m^{-2}) decreased below 48 and 54 plants m^{-2} for the GVa and GOa ecotopes, respectively.

No single cultivar from the 26 tested could be singled out as the best. Wide variability in DM production was observed with ranking of cultivars changing season on season. One must also take the crop rotation cycle into account. If one is to make a cultivar choice it would be KKS 3864 and Eureka. Both KKS 3864 and Eureka remained within the non-significant range (95% CI) for all growing seasons on both ecotopes and can therefore be considered the best all-round cultivars under irrigation on medium- to high-clay-content soils in a semi-arid climate.

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