Seasonal dry matter production, botanical composition and forage quality of kikuyu over-sown with annual or perennial ryegrass

Janke van der Colf[1,2]*, Philip R Botha[2], Robin Meeske[2] and Wayne F Truter[1]

[1] *Department of Plant Production and Soil Science, University of Pretoria, Pretoria, South Africa*
[2] *Western Cape Department of Agriculture, Outeniqua Research Farm, George, South Africa*
* *Corresponding author, e-mail: JankeVdC@elsenburg.com*

The seasonal growth and low forage quality of kikuyu restrict milk production. The aim of this study was to determine the yield and nutritional value of irrigated kikuyu over-sown with perennial, Italian or Westerwolds ryegrass grazed by dairy cows. The three pasture systems reached optimum growth during different months and seasons. Lowest growth rates occurred during winter. Peak growth rates occurred during spring for the Italian ryegrass–kikuyu, summer for the Westerwolds ryegrass–kikuyu, and late spring and early summer for perennial ryegrass–kikuyu pasture. All three pasture systems had similar total annual dry matter yields (kilograms dry matter [DM] per hectare) during year 1, but the perennial ryegrass–kikuyu pasture achieved a higher annual DM yield during year 2. As kikuyu density increased in kikuyu–ryegrass pastures from winter to summer, the DM and neutral detergent fibre content increased, whereas the metabolisable energy content decreased. All three treatments were deficient in calcium during all seasons and in phosphorus during summer and autumn as a pasture for high-producing dairy cows.

Keywords: forage quality, Italian ryegrass, over-sow, pasture production, perennial ryegrass, ryegrass, Westerwolds ryegrass

Introduction

The coastal belt of the southern Cape provides 51% of the total milk produced in South Africa (Coetzee 2014), making this region a major contributor to dairy production in the country. The majority of dairy production in this region is based on planted pasture systems (Meeske et al 2006). Since its initial invasion of perennial ryegrass–clover pastures in the early 1990s, kikuyu (*Pennisetum clandestinum*) has become an integral part of planted pasture systems in the southern Cape, providing the greater part of summer and autumn pasturage for dairy (Botha et al. 2008b, 2013). As a pasture species well adapted to the local climatic conditions in this region (Botha 2003), kikuyu provides a productive and persistent pasture base (Bell et al. 2011) that has been shown to improve soil quality when utilised within a no-till system (Swanepoel et al. 2014) and supports high stocking rates due to high growth rates during the summer and autumn (Colman and Kaiser 1974; Reeves 1997). However, kikuyu pastures have a low winter and spring production and support low milk production per cow (Marais 2001). The primary reason for the low milk production from animals grazing kikuyu is an inadequate intake of metabolisable energy (ME; Joyce 1974; Reeves et al. 1996). Kikuyu is also deficient in calcium and sodium, whilst also being prone to calcium:phosphorus and potassium:calcium + magnesium imbalances (Fulkerson et al. 1993; Miles et al. 1995; Fulkerson et al. 1998; Marais 2001; Botha 2003).

The complementary growth patterns of kikuyu and temperate species, such as ryegrass (*Lolium* spp.) and white clover (*Trifolium repens*), were reported as early as the 1970s (Lambert et al. 1977). According to Fulkerson et al. (1993) temperate pasture species provide a low-cost option to fill the winter-feed gap and supplement the lower summer forage quality that is characteristic of tropical species. The choice of species over-sown into kikuyu has been found to influence sward production during spring and summer (Elmore et al. 1997; Harris 1999; Botha 2008, 2009). Therefore, careful consideration should be given to the selection of species and how it will affect fodder flow and availability. The maximum benefit from over-sowing is obtained when the sown species complements, rather than replaces, the existing sward (Bartholomew 2005). In a kikuyu pasture the over-sown species should therefore improve winter and early spring production, but should not lower the production of kikuyu during summer and autumn. The strategic incorporation of temperate grasses, such as annual and perennial ryegrass, has been shown to improve the seasonal dry matter (DM) production and quality of kikuyu pasture (Botha 2003). Some of the advantages of such kikuyu–ryegrass systems include greater seasonal DM production, increased grazing capacity, a more even seasonal fodder-flow and ease of management compared to kikuyu–clover systems (Botha et al. 2008a). Currently, three varieties or species of ryegrass, comprising Italian (*Lolium multiflorum* var. *italicum*), Westerwolds (*L. multiflorum* var. *westerwoldicum*) and perennial ryegrass (*L. perenne*), are over-sown into kikuyu in the southern Cape. Data on the impact of the various ryegrass species and their different growth patterns, as related to seasonal production of a kikuyu-based pasture, is limited. The aim of this study was to compare the pasture growth rate, yield, botanical composition and forage quality of kikuyu-based pasture over-sown with annual or perennial ryegrass.

Materials and methods

Study area

This study was part of a larger system trial conducted over two years on the Outeniqua Research Farm (33°58′38″ S, 22°25′16″ E; elevation 201 m) in the Western Cape province of South Africa. The area is characterised by a temperate coastal climate with a mean annual rainfall of 725 mm, and mean minimum and maximum temperatures ranging between 7–15 °C and 18–25 °C, respectively (ARC 2010). Winter was defined as the months June, July and August; spring as September, October and November; summer as December, January and February; and autumn as March, April and May. This article is based on research conducted from June 2007 to May 2008 (year 1) and from June 2008 to May 2009 (year 2). The minimum and maximum temperatures and rainfall during the study period relative to the long-term (30-year) average is shown in Figure 1. The total annual rainfall during year 1 was 491 mm above the 30-year long-term average, with rainfall higher than the long-term average during May, July and between November and February. During November in year 1, a total of 491 mm fell within one month, but this did not impact the trial measurements. During year 2 the total annual rainfall of 583 mm was 142 mm below the long-term average, with monthly rainfall below the long-term average during all months except June, August, November and February. During the study, mean maximum and minimum temperatures did not deviate considerably from the long-term averages.

Experimental layout and treatments

Nine hectares of existing kikuyu pasture under permanent sprinkler irrigation was divided into eight blocks that served as replicates. Each block was divided into three experimental paddocks, to which one of the three treatments was randomly allocated. This resulted in a total of 24 experimental paddocks with a mean size of 0.375 ha, with eight experimental paddocks allocated to each treatment. The treatments consisted of annual Italian ryegrass ‘Jeanne’, annual Westerwolds ryegrass ‘Jivet’ or perennial ryegrass ‘Bronsyn’ over-sown into kikuyu.

Pastures were established on an annual basis using the methods laid out in Table 1. The Italian and Westerwolds ryegrass was over-sown during March and the perennial ryegrass during April. The perennial ryegrass was re-established annually due to its poor persistence into the second year, as is common to this region (Botha et al. 2008c; van der Colf and Botha 2014).

Pasture management

Irrigation was scheduled by means of irrometer tensiometers (Calafrica SA, Nelspruit, South Africa) placed at strategic locations throughout the experimental area at a depth of 150 mm. Irrigation commenced at a tensiometer reading of −25 kPa and was terminated at −10 kPa (Botha 2002). Drought conditions during December and January in year 2 (Figure 1), accompanied by a low availability of irrigation water, resulted in irrigation below optimum levels during January and February of year 2.

Soil samples were taken to a depth of 100 mm on an annual basis during February and analysed for pH (KCl), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), phosphorus (P), copper (Cu), zinc (Zn), manganese (Mn), boron (B), sulphur (S) and carbon (C) concentrations. Fertiliser was applied according to the soil analysis to raise the soil P (citric acid method) concentration to 35 mg kg^{-1},

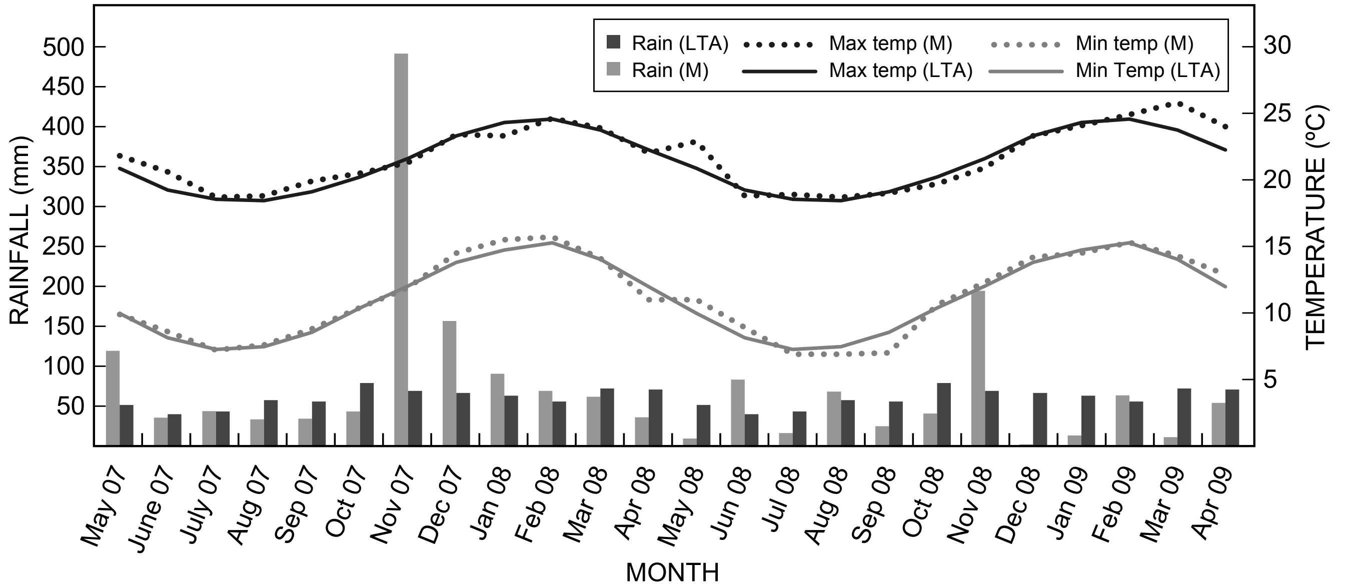

Figure 1: Mean monthly (M) maximum temperature (max temp), minimum temperature (min temp) and total rainfall (mm) on the Outeniqua Research Farm during year 1 (2007/08) and year 2 (2008/09) in comparison with the long-term (30-year) average (LTA)

Table 1: The treatments, seeding rates and over-sowing methods used to over-sow Italian, Westerwolds or perennial ryegrass into kikuyu

Treatment	Cultivar	Seeding rate (kg ha^{-1})[a]	Over-sowing method
Italian ryegrass–kikuyu	Jeanne	25	Graze kikuyu to 50 mm Mulcher Seeder Land roller
Westerwolds ryegrass–kikuyu	Jivet	25	Graze kikuyu to 50 mm Broadcast seed Mulcher Land roller
Perennial ryegrass–kikuyu	Bronsyn	20	Graze kikuyu to 50 mm Mulcher Seeder Land roller

[a] According to recommendations by Dickenson et al. (2010)

the K concentration to 80 mg kg^{-1} and pH (KCl) to 5.5 (Beyers 1973). All the treatments were topdressed on a monthly basis with limestone ammonium nitrate (LAN) at a rate of 55 kg N ha^{-1} (Marais 2001; Botha 2003).

Jersey cows were used to strip-graze pasture treatments in a put-and-take system according to DM yield. A fresh block of grazing was allocated to the cows after each milking and cows were allowed to back-graze for a maximum of 2 d. Cows were on the experimental area for a total of 32 d at a time. Thus, the grazing cycle during the experimental period was 32 d. However, while one block was being grazed, the other seven were rested, resulting in a 28-day period of absence from each block. Animal production parameters, including grazing capacity, milk production per animal and milk production per hectare for this study are discussed in detail in van der Colf et al. (2015).

Pasture dry matter production determination

Dry matter production of the pasture treatments was estimated using a rising plate meter (RPM; Stockdale 1984; Fulkerson 1997) that was calibrated three times per grazing cycle or approximately every 10 d. The RPM was calibrated by developing a linear regression that related the RPM height to aboveground herbage DM per unit area. The height of the pasture was measured with the RPM at a specific point, a ring of the same size as the RPM plate (0.098 m^2) placed over the RPM and all DM within the ring borders ('t Mannetjie 2000) cut above a height of 30 mm (Fulkerson and Slack 1993; Botha 2003). Six samples were cut at a height estimated by the operator as low, medium and high growth in a specific pasture, respectively, per treatment. A total of 18 calibration samples were cut per treatment at each calibration. Pre-grazing calibrations were cut the day before animals entered a paddock. The data collected during calibration cuts was used to construct a linear regression model that related meter height to DM production according to the equation $Y = mH + b$, where m = the gradient, H = the rising plate meter height, and b = the intercept. Data were progressively pooled within a season to develop a cumulative seasonal regression as the season progressed.

Pasture height of each paddock was estimated by taking 200 RPM measurements per paddock in a zigzag pattern before and after grazing. Measured pasture height and the developed calibration equations were used to estimate the average DM per hectare.

Botanical composition

Botanical composition was estimated by placing six 0.25 m^2 quadrants randomly within an experimental paddock and cutting samples to a height of 30 mm. The six samples were pooled and thoroughly mixed; a grab sample of approximately 500 g was taken and then separated into three fractions. The three fractions were kikuyu, ryegrass and 'other'. The 'other' component consisted primarily of grasses such as *Bromus catharticus* and *Paspalum notatum* and the broadleaf weed *Arctotheca calendula*. The samples were dried at 60 ºC for 72 h, weighed and the percentage contribution of each fraction calculated on a DM basis (Fenthum-Vermeulen 2009).

Forage quality

Samples for quality analyses were collected at the same time as the calibration clippings. A total of six samples were cut at a height of 30 mm per treatment at each sampling date. Samples were dried at 60 ºC for 72 h to a constant mass and weighed to determine the DM content (%). The six samples of each treatment were pooled and milled (SWC Hammer mill, 1 mm sieve). Samples were analysed for *in vitro* organic matter digestibility (IVOMD) (Tilley and Terry 1963), crude protein (CP; AOAC 2000a), neutral detergent fibre (NDF; Robertson and van Soest 1981), Ca (Giron 1973), P (AOAC 2000b) and Mg (Giron 1973) content. Metabolisable energy (megajoules per kilogram DM) was calculated from the IVOMD ($ME = 18.4 \times IVOMD\% \times 0.81$) (ARC 1984; MAFF 1984).

Statistical design

The experiment used a complete block design with the three treatments randomly allocated within each of the experimental blocks. The blocks cannot be viewed as independent of each other because they were grazed successively (Wilkens et al. 1995). A factorial analysis of variance was performed with seasons, months or years included as factors. Student's *t*-LSD (least significant difference) was calculated at the 5% significance level to compare treatment means. The STATS module of SAS version 9.12 was used to analyse the data (SAS Institute 1999).

Results and discussion

Growth rate, seasonal and annual dry matter production

Mean monthly pasture growth rate (kilograms DM per hectare per day) of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass during year 1 and year 2 is presented in Tables 2 and 3, respectively. Growth rate varied with respect to months and treatments during both years. Irrespective of the ryegrass over-sown, the lowest ($P < 0.05$) growth rate for all systems either occurred during June, July or August. The ryegrass over-sown into kikuyu influenced the month or months during which the highest growth rate was obtained. For the Italian ryegrass–kikuyu system the highest ($P < 0.05$) and similar ($P > 0.05$) to the highest growth rates occurred during October, November, December and February in year 1. During year 2 the highest ($P < 0.05$) growth rate for this treatment was during October. When kikuyu was over-sown with Westerwolds ryegrass the highest ($P < 0.05$) and similar ($P > 0.05$) to the highest growth rates occurred during January and February during year 1 and December, January and March in year 2. The highest ($P < 0.05$) and similar ($P > 0.05$) to the highest growth rates for the perennial ryegrass–kikuyu pasture occurred between December and February during year 1 and between October and December in year 2.

During both years, the growth rate of kikuyu over-sown with Italian ryegrass was higher ($P < 0.05$) during October and November than when over-sown with Westerwolds ryegrass. The growth rate of the Westerwolds ryegrass–kikuyu pasture was, however, higher ($P < 0.05$) than that of Italian ryegrass–kikuyu during January and February. The growth rate of perennial ryegrass–kikuyu was the highest ($P < 0.05$) or similar ($P > 0.05$) to the highest within months from November to February in year 1 and from September to December during year 2. Thus, the perennial ryegrass–kikuyu system achieved similar growth rates to Italian ryegrass–kikuyu during spring and Westerwolds ryegrass–kikuyu during early summer, which coincided with a peak in production for the latter two systems.

The total seasonal DM production for kikuyu over-sown with Italian, Westerwolds or perennial ryegrass is shown in Table 4. The spring and summer DM production for all kikuyu–ryegrass treatments was higher ($P < 0.05$) than winter or autumn production for both years. These results are similar to those of Garcia et al. (2006), with lower yields during winter–autumn than spring summer for kikuyu–annual ryegrass pastures in Australia. Swanepoel et al. (2015) also reported that kikuyu-based pastures exposed to different degrees of cultivation to establish ryegrass showed mutually low growth rates during winter and attributed it to low ambient soil temperatures rather than treatment effects. Although winter production was lower than during other seasons for treatments in this study, growth rates and seasonal production compared favourably with seasonal yields of between 2 and 5 t DM ha^{-1} for pure swards of annual and perennial ryegrass in the region (van der Colf and Botha 2013; van der Colf et al. 2013).

For the Italian ryegrass–kikuyu pasture, the spring and summer production were similar ($P > 0.05$). However, for the Westerwolds ryegrass–kikuyu pasture summer production was higher ($P < 0.05$) than during spring. The perennial ryegrass–kikuyu pasture had higher ($P < 0.05$) summer than spring production during year 1, but seasonal production was similar ($P > 0.05$) during year 2.

As for growth rates, seasonal production showed distinct trends depending on the ryegrass species or variety over-sown. Italian ryegrass–kikuyu out-yielded ($P < 0.05$) Westerwolds ryegrass–kikuyu during spring, whereas Westerwolds ryegrass–kikuyu had higher ($P < 0.05$) summer production. These results indicate that that the spread of seasonal production, particularly during spring and summer,

Table 2: Mean monthly growth rate (kg DM ha^{-1} d^{-1}) of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass during year 1. Means followed by a different superscript letter differ significantly ($P < 0.05$). LSD (0.05) compares over treatments and months

Month	Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu
June	30.8^{pqr}	30.3^{pqr}	0
July	30.8^{pqr}	26.8^{qrs}	17.5^{s}
August	37.6^{opq}	40.0^{op}	45.0^{no}
September	64.5^{jklm}	60.0^{lm}	55.2^{mn}
October	84.9^{cdef}	61.0^{klm}	65.4^{ijklm}
November	77.1^{efgh}	57.1^{m}	71.0^{ghijkl}
December	78.5^{efg}	76.5^{efghi}	91.7^{bcd}
January	70.4^{ghijkl}	95.1^{abc}	86.4^{bcde}
February	81.3^{defg}	106.0^{a}	97.8^{ab}
March	66.4^{hijklm}	72.7^{ghijkl}	74.0^{fghij}
April	Re-establish ryegrass	Re-establish ryegrass	58.3^{m}
May	25.6^{rs}	28.0^{qrs}	Re-establish ryegrass
LSD (0.05)		11.8	

Table 3: Mean monthly growth rate (kg DM ha^{-1} d^{-1}) of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass during year 2. Means followed by a different superscript letter differ significantly ($P < 0.05$). LSD (0.05) compares over treatments and months

Month	Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu
June	28.9^{l}	32.6^{l}	20.4^{m}
July	35.6^{kl}	34.4^{l}	33.0^{l}
August	43.2^{jk}	44.2^{ij}	49.7^{ghij}
September	54.2^{efgh}	47.4^{hij}	60.0^{cdef}
October	74.8^{ab}	53.7^{efgh}	77.4^{a}
November	63.5^{cd}	53.8^{efgh}	72.4^{ab}
December	57.1^{defg}	71.9^{ab}	71.7^{ab}
January	50.7^{ghij}	71.8^{ab}	62.8^{cd}
February	48.1^{hij}	60.9^{cde}	52.2^{fghi}
March	59.5^{cdef}	67.6^{bc}	58.9^{def}
April	Re-establish ryegrass	Re-establish ryegrass	34.0^{l}
LSD (0.05)		8.09	

Table 4: Total seasonal dry matter (DM) production (kg DM ha^{-1}) of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass during year 1 and year 2. Means followed by a different superscript letter differ significantly ($P < 0.05$). LSD (0.05) compares over seasons within a year

Year	Season	Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu
Year 1	Winter	$3\,512^{d}$	$3\,422^{d}$	$2\,084^{e}$
	Spring	$6\,073^{b}$	$4\,774^{c}$	$5\,117^{c}$
	Summer	$6\,161^{b}$	$7\,412^{a}$	$7\,380^{a}$
	Autumn	$3\,022^{d}$	$3\,272^{d}$	$3\,502^{d}$
LSD (0.05)			780	
Year 2	Winter	$2\,864^{de}$	$2\,958^{de}$	$3\,273^{d}$
	Spring	$4\,980^{ab}$	$4\,149^{c}$	$5\,610^{a}$
	Summer	$4\,385^{bc}$	$5\,516^{a}$	$5\,044^{ab}$
	Autumn	$1\,428^{g}$	$1\,621^{fg}$	$2\,275^{ef}$
LSD (0.05)			687	

will differ depending on the ryegrass over-sown into kikuyu. These characteristics are due to differences in the inherent production patterns between the over-sown species and the effect the growth of these species has on the recovery of kikuyu from winter dormancy.

Zulu et al. (2014) found that pure swards of Italian and Westerwolds ryegrass differ in growth rate during spring, with Italian ryegrass out-yielding Westerwolds ryegrass from October onwards when sown during autumn. A similar pattern was seen in this study, with the Italian ryegrass–kikuyu pastures having higher growth rates during spring than the Westerwolds ryegrass–kikuyu pastures. This coincides with the period when newly emerging kikuyu will have to compete with ryegrass to start its growth season (Willis 1995; Fulkerson and Reeves 1996). The relatively low growth rate of Westerwolds ryegrass during spring would allow a more rapid recovery of the kikuyu compared to Italian ryegrass, and this is reflected in the higher growth rates and seasonal DM production obtained from the Westerwolds ryegrass–kikuyu pasture during summer. Harris and Bartholomew (1991) found similar results under cutting trials where kikuyu was over-sown with Italian or Westerwolds ryegrass.

Although the perennial ryegrass–kikuyu system was similar to the Westerwolds ryegrass–kikuyu system in terms of seasonal production during year 1, it was also the only ryegrass–kikuyu system that maintained the highest ($P < 0.05$) or similar ($P > 0.05$) to the highest seasonal production within all seasons in year 2. Limited information is available on the effect of over-sowing a perennial grass into kikuyu. Seasonal production during this study, however, indicates that when kikuyu is over-sown with perennial ryegrass, the seasonal growth pattern and production will be intermediate between that of Italian and Westerwolds ryegrass–kikuyu systems.

The total annual DM production (kilograms DM per hectare) of the kikuyu over-sown with Italian, Westerwolds or perennial ryegrass is shown in Table 5. All treatments had similar ($P > 0.05$) total annual DM yields during year 1, varying between 18 083 and 18 880 kg DM ha^{-1} y$^{-1.}$ During year 2, however, the perennial ryegrass–kikuyu had a higher ($P < 0.05$) annual DM production than the Italian and Westerwolds ryegrass–kikuyu during year 2. During year 2 the ability of the perennial ryegrass–kikuyu system to have the highest or similar to the highest growth rate during all seasons resulted in it having a higher total annual DM production. Whether this trend was due to a lower degree of competition between kikuyu and perennial ryegrass during spring or a contribution from ryegrass to summer production is not clear. The total annual DM production recorded during this study was similar to results previously reported for kikuyu–annual ryegrass of between 15.7 and 20.3 t DM ha^{-1} (Garcia et al. 2006; Botha et al. 2008a; Callow et al. 2012; Swanepoel et al. 2015).

Table 5: Total annual dry matter production (kg DM ha^{-1}) of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass for year 1 and year 2. Means followed by a different superscript letter differ significantly ($P < 0.05$). LSD (0.05) compares over treatments within year

Year	Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu	LSD (0.05)
Year 1	18 768^{a}	18 880^{a}	18 083^{a}	819
Year 2	13 479^{b}	14 040^{b}	16 202^{a}	713

Botanical composition

The seasonal changes that occurred in the botanical composition of treatments, in terms of the percentage kikuyu, ryegrass and other species during year 1 and year 2, are presented in Table 6. The contribution of kikuyu and ryegrass to the botanical composition of the pasture differed between seasons and treatments. The kikuyu component increased in all treatments (except Italian ryegrass–kikuyu in year 1) from spring to autumn, whereas the ryegrass component decreased.

The kikuyu component was similar ($P > 0.05$) for all pastures during winter and spring for both years. During year 1 the Italian ryegrass–kikuyu pasture had a lower ($P < 0.05$) kikuyu component than the Westerwolds ryegrass–kikuyu in summer and a higher ($P < 0.05$) ryegrass component than perennial and Westerwolds ryegrass–kikuyu during autumn. During summer of year 2, perennial ryegrass–kikuyu had a lower ($P < 0.05$) kikuyu and higher ($P < 0.05$) ryegrass component than Westerwolds ryegrass–kikuyu, but both kikuyu and ryegrass were similar ($P > 0.05$) to that of Italian ryegrass–kikuyu. The ryegrass percentage of the perennial ryegrass–kikuyu was higher ($P < 0.05$) during autumn than both the Westerwolds and Italian ryegrass–kikuyu treatment during year 2. The contribution of other species did not differ ($P > 0.05$) between treatments within seasons during year 1.

Nutritive value

The DM content (%) of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass during year 1 and year 2 is given in Table 7. The DM content of all pasture treatments was higher ($P < 0.05$) during summer than winter. Compared within seasons, the DM content of all three kikuyu–ryegrass pastures were similar ($P > 0.05$) during winter and spring, whereas the DM content of perennial ryegrass–kikuyu was highest ($P < 0.05$) or similar ($P < 0.05$) to the highest for summer and autumn. These results are in agreement with the results from Botha (2003), who found that the DM content of kikuyu–annual ryegrass pastures was higher during summer–autumn than spring. The high DM content of the three pastures treatments during summer coincided with an increase in the kikuyu component and high growth rates during this period.

Mean seasonal ME content (MJ kg^{-1} DM), CP content (%) and NDF content (%) of the three kikuyu-based systems during year 1 and year 2 is shown in Table 8. The ME content of kikuyu over-sown with annual or perennial ryegrass species varied between 7.94 and 12.4 MJ kg^{-1} DM. According to Meeske (2002), a 400 kg dairy cow producing 13 kg milk d^{-1} requires a ration with a ME content of at least 10.5 MJ kg^{-1} DM, therefore ME will at times be under-supplied within kikuyu–ryegrass pasture systems. The ME content of all treatments was sufficient during winter, whereas with the exception of perennial ryegrass–kikuyu during summer in year 2, the ME content of all treatments

Table 6: Mean seasonal proportions (%) of kikuyu, ryegrass and other species (all remaining species) of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass during year 1 and year 2. Means followed by a different superscript letter differ significantly ($P < 0.05$). LSD (0.05) compares over seasons and treatments within component. NA = not available

Treatment	Season	Year 1			Year 2		
		Kikuyu	Ryegrass	Other	Kikuyu	Ryegrass	Other
Italian–kikuyu	Winter	NA	NA	NA	10.7^{de}	80.3^{ab}	9.0^{cd}
	Spring	1.3^{e}	93.5^{a}	5.2^{a}	3.5^{e}	93.2^{a}	3.3^{d}
	Summer	43.3^{c}	42.9^{bcd}	13.8^{a}	44.8^{bc}	39.8^{cd}	15.4^{abcd}
	Autumn	26.7^{cd}	43.8^{bc}	29.5^{a}	95.1^{a}	1.9^{f}	3.1^{d}
Westerwolds–kikuyu	Winter	NA	NA	NA	17.5^{de}	73.3^{ab}	9.2^{bcd}
	Spring	16.1^{de}	67.9^{abc}	16.0^{a}	11.6^{de}	66.2^{b}	22.2^{ab}
	Summer	75.0^{ab}	6.1^{de}	18.9^{a}	63.6^{b}	11.8^{ef}	24.6^{a}
	Autumn	88.3^{a}	1.7^{e}	10.0^{a}	86.8^{a}	1.3^{f}	11.9^{abcd}
Perennial–kikuyu	Winter	NA	NA	NA	3.6^{e}	76.1^{ab}	20.3^{abc}
	Spring	14.7^{de}	73.9^{ab}	11.4^{a}	1.7^{e}	78.7^{ab}	19.6^{abc}
	Summer	50.7^{bc}	30.7^{cde}	18.6^{a}	26.3^{cd}	58.7^{bc}	15.0^{abcd}
	Autumn	78.3^{a}	1.8^{e}	19.9^{a}	50.9^{b}	33.1^{de}	16.0^{abcd}
LSD (0.05)		25.10	37.53	25.08	21.63	23.0	13.26

Table 7: Mean seasonal dry matter content (%) of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass during year 1 and year 2. Means followed by a different superscript letter differ significantly ($P < 0.05$). LSD (0.05) compares over treatments and seasons within year

Year	Season	Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu
1	Winter	13.1^{cde}	12.9^{cde}	14.6^{bc}
	Spring	12.8^{cde}	14.1^{bcd}	13.4^{bcde}
	Summer	15.5^{b}	15.4^{b}	17.6^{a}
	Autumn	12.2^{de}	12.0^{e}	13.3^{cde}
LSD (0.05)		2.09		
2	Winter	13.2^{cd}	12.3^{d}	13.3^{cd}
	Spring	12.1^{d}	12.8^{d}	13.1^{d}
	Summer	16.2^{b}	16.9^{ab}	17.4^{ab}
	Autumn	16.8^{ab}	15.8^{bc}	19.5^{a}
LSD (0.05)		2.66		

was below the required concentration of 10.5 MJ kg^{-1} DM during summer and autumn. The ME content of all kikuyu–ryegrass pastures decreased ($P < 0.05$) from winter to spring and from spring to summer during year 1. Botha (2003) reported that although annual ryegrass over-sown into kikuyu can improve the ME content of pastures during spring relative to pure kikuyu pastures, the ME showed a dramatic decrease during summer as the kikuyu content increased. During year 2 the ME content of all three treatments decreased ($P < 0.05$) from winter to summer and from summer to autumn.

When compared within seasons and years (same rows), the ME content of all three treatments were similar ($P > 0.05$) during winter and spring of year 1 and year 2. During year 1 the Italian ryegrass–kikuyu treatment had a higher ($P < 0.05$) ME content than the Westerwolds and perennial ryegrass–kikuyu during autumn. The ME content of perennial ryegrass–kikuyu was similar to ($P > 0.05$) or higher ($P < 0.05$) than the other treatments during all seasons in year 2. The ME content of all the ryegrass–kikuyu pastures were higher than the concentrations of 8.92 and 8.13 MJ kg^{-1} DM reported for pure kikuyu during summer and autumn by Botha et al. (2008a), except during autumn in year 2 when Italian ryegrass–kikuyu and Westerwolds ryegrass–kikuyu had very low ME contents of 7.94 and 8.19 MJ kg^{-1} DM, respectively. In the same study conducted by Botha et al. (2008a), the mean annual ME content of kikuyu over-sown with annual ryegrass was found to be 9.28 MJ kg^{-1} DM, and also decreased from 11.5 MJ kg^{-1} DM during spring to as low as 7.87 MJ kg^{-1} DM during autumn. Although the drop in ME value could be partially attributed to the increase in the kikuyu component in the pastures investigated here, it has been found that the ME content of both annual and perennial ryegrass dropped below 9.0 MJ kg^{-1} DM during summer when grown in pure ryegrass swards in the subtropics (Lowe et al. 1999).

The seasonal CP content across all treatments varied between 17.9% and 32.4% over two years. These CP contents were all above the recommended rate of 15% CP for high-producing dairy cows (NRC 2001). The CP content of perennial ryegrass–kikuyu was the lowest ($P < 0.05$) during the winter of year 1 compared to the other treatments and lower ($P < 0.05$) than Italian ryegrass–kikuyu during autumn. These results are similar to those of Lowe et al. (1999) that showed a higher CP content for Italian ryegrass than perennial ryegrass in winter, with non-significant differences during the other seasons ($P > 0.05$). During year 2 all three treatments had similar ($P > 0.05$) seasonal CP contents when compared within season. This agrees with the findings by Fulkerson et al. (1993) and Tharmaraj et al. (2008) that annual and perennial ryegrasses have similar CP contents, and that during summer and autumn CP values are largely based on kikuyu. The CP contents of all treatments were higher ($P < 0.05$) in winter than in summer and autumn. Like ME, the CP content of all pasture treatments tended to decrease from winter to summer as the kikuyu component increased and pastures reached their peak growth rates. Botha et al. (2008a) also reported that the CP content of kikuyu–ryegrass pastures was higher in spring than in summer and autumn.

Table 8: Mean seasonal dry metabolisable energy (ME), crude protein (CP) and neutral detergent fibre (NDF) content of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass. Means followed by a different superscript letter differ significantly ($P < 0.05$). LSD (0.05) compares over treatments and seasons within year for each nutrient

Year	Season	ME (MJ kg^{-1})			CP (%)			NDF (%)		
		Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu	Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu	Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu
1	Winter	12.0^{a}	12.0^{a}	11.9^{a}	30.4^{a}	32.4^{a}	25.1^{bc}	37.9^{e}	37.4^{e}	41.5^{e}
	Spring	11.0^{b}	10.6^{bc}	10.9^{b}	22.7^{cde}	22.5^{cde}	22.0^{def}	45.9^{d}	48.9^{d}	48.7^{d}
	Summer	10.0^{cd}	9.4^{de}	9.2^{e}	19.8^{efg}	19.3^{fg}	17.9^{g}	56.8^{bc}	61.9^{a}	59.1^{ab}
	Autumn	10.3^{bc}	9.2^{e}	9.4^{de}	26.7^{b}	24.9^{bcd}	23.7^{cd}	54.5^{c}	58.0^{abc}	56.9^{bc}
LSD (0.05)			0.74			3.06			4.34	
2	Winter	12.4^{a}	12.2^{a}	11.8^{a}	26.6^{ab}	29.6^{a}	27.2^{abc}	41.3^{e}	44.5^{e}	46.3^{de}
	Spring	12.4^{a}	11.9^{a}	12.2^{a}	25.4^{cd}	25.8^{bcd}	25.7^{bcd}	44.9^{de}	51.9^{bc}	50.3^{cd}
	Summer	9.8^{bc}	9.3^{c}	10.5^{b}	22.6^{d}	23.1^{d}	23.2^{d}	55.8^{ab}	59.2^{a}	57.0^{ab}
	Autumn	7.9^{d}	8.2^{d}	9.6^{c}	22.7^{d}	22.6^{d}	23.6^{d}	57.8^{a}	61.0^{a}	57.8^{a}
LSD (0.05)			0.473			3.26			5.42	

The NDF of all treatments was lower ($P < 0.05$) during winter and spring than during summer and autumn. These results compare favourably with those of Botha et al. (2008a) who reported an increase in the NDF content of annual ryegrass–kikuyu pastures from spring to summer. During year 1 the NDF content of all treatments was similar ($P > 0.05$) during winter, spring and autumn when compared within season. The higher ($P < 0.05$) NDF content observed within all treatments during summer and autumn, compared with spring and winter, was associated with an increase ($P < 0.05$) in the kikuyu component from spring to autumn for all treatments. This is in agreement with Botha (2003) who identified botanical composition as the main determinant of NDF content in kikuyu-based systems.

During year 2 the NDF content was similar for all pastures during winter, summer and autumn when compared within season. The NDF content of Westerwolds ryegrass–kikuyu was higher ($P < 0.05$) during the summer of year 1 than for Italian ryegrass–kikuyu. During year 2 a similar trend was seen during spring, with the NDF content of Italian ryegrass–kikuyu lower ($P < 0.05$) than that of Westerwolds ryegrass–kikuyu. The NDF content of temperate species, such as perennial ryegrass, have been found to be lower than for kikuyu (Reeves et al. 1996). The NDF content of all pastures remained below values of 62.6–64.7% reported by Botha et al. (2008a) for pure kikuyu pastures during summer and autumn. Thus it can be concluded that if ryegrass is maintained in kikuyu pastures for longer during summer and autumn, it will reduce the NDF content of these mixed pastures. The NDF content of Italian and Westerwolds ryegrass–kikuyu was similar to those reported by Fulkerson et al. (2007) for annual ryegrass during winter (42.4–45.9%) and spring (49.5–53.1%). The NDF content of perennial ryegrass–kikuyu during winter and spring was similar to concentrations of between 39.1% and 44.7% for perennial ryegrass during this period reported in the literature (Lowe et al. 1999).

Seasonal changes in forage quality within the different ryegrass–kikuyu pastures investigated were closely related to changes in seasonal botanical composition, with all systems changing from primarily ryegrass during winter to kikuyu during summer. The tendency for ME to decrease and NDF to increase in kikuyu–annual ryegrass pastures from winter to summer was found to negatively affect potential milk production and intake (Farina 2009), with the primary limitation not ME content alone, but the ability of dairy cows to achieve sufficient ME intake (Garcia et al. 2014). Crude protein tended to be highest for all the ryegrass–kikuyu systems during winter and lowest during summer or autumn. The variable ME and CP contents of pasture were found by Erasmus (2009) to result in CP and ME being over-supplied during winter on kikuyu–ryegrass pastures when animals receive concentrate supplementation in addition to pasture. Concentrate supplementation thus remains a challenge within a kikuyu-based pasture system due to the complex seasonal changes in botanical composition and forage quality. The impact of the ryegrass species over-sown into kikuyu on the CP and NDF of the pasture was less pronounced than that of seasonal effects. However, the ME content was higher in instances where a ryegrass component was maintained into summer and autumn, specifically for Italian ryegrass–kikuyu during autumn in year 1 and perennial ryegrass–kikuyu during summer and autumn in year 2.

The mean seasonal Ca, P and Mg contents of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass is shown in Table 9. The Ca content of all treatments was similar ($P > 0.05$) within spring and summer of year 1. During autumn of year 1, however, perennial ryegrass–kikuyu had a higher ($P < 0.05$) Ca content than Westerwolds ryegrass–kikuyu, but did not differ ($P > 0.05$) from Italian ryegrass–kikuyu. There were no differences ($P > 0.05$) between the three treatments in seasonal Ca content in year 2. Although Botha et al. (2008a) did not report an improvement in the Ca content of kikuyu pastures by over-sowing it with ryegrass, the winter Ca contents during the study compared favourably with values of 0.41% reported for annual ryegrass (Thom and Prestridge 1996), and were higher than the range of 0.21–0.39% reported for perennial ryegrass by Fulkerson et al. (1993). The Ca contents obtained during the study were, however, similar to a concentration of 0.36% reported by Meeske et al. (2006) for kikuyu pastures during summer and autumn in the same region. All pastures were deficient in Ca during the entire study period, and

Table 9: Mean seasonal calcium, phosporous and magnesium content of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass. Means followed by a different superscript letter differ significantly (*P* < 0.05). LSD (0.05) compares over treatments and seasons within year for each nutrient

Year	Season	Calcium (%)			Phosphorus (%)			Magnesium (%)		
		Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu	Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu	Italian–kikuyu	Westerwolds–kikuyu	Perennial–kikuyu
1	Winter	0.36^{cde}	0.39^{abc}	0.41^{ab}	0.42^{ab}	0.45^{a}	0.42^{ab}	0.57^{a}	0.59^{a}	0.51^{b}
	Spring	0.41^{ab}	0.42^{a}	0.41^{ab}	0.39^{ab}	0.38^{ab}	0.40^{ab}	0.30^{d}	0.30^{d}	0.30^{d}
	Summer	0.34^{de}	0.33^{e}	0.37^{bcde}	0.38^{ab}	0.35^{b}	0.37^{b}	0.31^{d}	0.32^{d}	0.31^{d}
	Autumn	0.38^{abcd}	0.36^{cde}	0.41^{ab}	0.36^{b}	0.40^{ab}	0.39^{ab}	0.38^{c}	0.41^{c}	0.38^{c}
LSD (0.05)			0.044			0.074			0.053	
2	Winter	0.43^{a}	0.38^{a}	0.41^{a}	0.39^{ab}	0.42^{a}	0.39^{ab}	0.39^{bcde}	0.37^{cde}	0.35^{de}
	Spring	0.39^{a}	0.40^{a}	0.40^{a}	0.38^{ab}	0.39^{ab}	0.38^{ab}	0.35^{de}	0.34^{de}	0.33^{e}
	Summer	0.38^{a}	0.37^{a}	0.40^{a}	0.33^{bc}	0.34^{bc}	0.33^{bc}	0.39^{bcd}	0.40^{bcd}	0.37^{cde}
	Autumn	0.41^{a}	0.39^{a}	0.37^{a}	0.30^{c}	0.35^{bc}	0.30^{c}	0.49^{a}	0.45^{ab}	0.42^{abc}
LSD (0.05)			0.061			0.070			0.065	

kikuyu–ryegrass pastures alone did not meet the requirements of high-producing dairy cows of 0.67% Ca (NRC 2001). As a result, Ca should be adequately supplemented to high-producing dairy cows grazing kikuyu–ryegrass pasture. Botha et al. (2008a) noted that the inclusion of clover in a kikuyu based pasture is another potential management practice to reduce the risk of Ca deficiencies that are common for kikuyu–ryegrass pastures.

The type of ryegrass over-sown into kikuyu did not result in different P content's when compared within season. During year 1 the P content of the Italian and perennial ryegrass–kikuyu pastures was similar (*P* > 0.05) during all seasons, but decreased (*P* < 0.05) from winter to autumn during year 2. The P content of all pasture treatments were sufficient or above 0.38% (NRC 1989) for high-producing dairy cows during winter and spring, but below requirements for summer and autumn. The P content of pastures during this study was higher than reported for kikuyu-based systems by Fulkerson et al. (1999), lower than those reported by Botha et al. (2008a) and similar to those reported by Garcia et al. (2006). The P content of kikuyu–ryegrass pastures thus seems to be highly variable across studies, which could make supplementation of this nutrient for dairy cows grazing kikuyu-based pastures particularly challenging.

At between 0.30% and 0.59%, the Mg concentration remained at or above the requirements for high-producing dairy cows of 0.30% (NRC 1989) for all treatments. During year 1, the Mg content of all treatments was the highest (*P* < 0.05) during winter and lowest (*P* < 0.05) during spring and summer. The Mg content of all three treatments was similar (*P* > 0.05) within all seasons during year 1 and year 2, except during winter of year 1 when perennial ryegrass–kikuyu had a lower (*P* < 0.05) Mg content than Westerwolds and Italian ryegrass–kikuyu.

Conclusions

The growth rate of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass varied monthly, with the treatments reaching their peak growth rates during different months and seasons. Winter growth rates were low compared to other seasons. Italian ryegrass experienced its highest growth rates during spring, the Westerwolds ryegrass–kikuyu treatment during summer and the perennial ryegrass–kikuyu treatment during late spring and early summer.

The lower growth rate of the Westerwolds ryegrass treatment during spring, compared with the Italian ryegrass, resulted in a higher kikuyu component during spring, summer and autumn. The high growth rate of the Italian ryegrass during spring impacted negatively on the summer DM production of the Italian ryegrass–kikuyu pasture due to the delayed commencement of kikuyu growth during spring and resultant lower kikuyu density in summer. During year 2 the perennial ryegrass–kikuyu treatment had a higher seasonal DM production than Westerwolds ryegrass–kikuyu during spring and Italian ryegrass–kikuyu during summer and autumn. The ability of the perennial ryegrass–kikuyu treatment to maintain DM production during periods when the other treatments underwent a decrease in production enabled it to achieve a higher annual DM production during year 2.

As the kikuyu component increased for all treatments from winter to summer, it resulted in an increase in DM and NDF content, while the ME content decreased. It was found that if ryegrass was maintained at higher levels during summer and autumn (as for the Italian ryegrass–kikuyu treatment during year 1 and the perennial ryegrass–kikuyu treatment during year 2) it resulted in higher ME values of pastures during these seasons. Thus, if ryegrass can be maintained in kikuyu pastures during summer and autumn, it could potentially improve the nutritive value of these pastures. All pastures were deficient in Ca and did not meet the requirements for dairy cows throughout the experimental period. Therefore, dairy cows grazing kikuyu over-sown with ryegrass should be supplemented with Ca. The P contents of the kikuyu-based systems were also deficient, especially for high-producing dairy cows during summer and autumn.

In conclusion, the ryegrass species and varieties over-sown into kikuyu during autumn will influence the production potential of kikuyu during summer and autumn. Kikuyu over-sown with perennial ryegrass on an annual basis achieved a higher annual DM production than kikuyu over-sown with annual ryegrass varieties. The presence of a ryegrass component in kikuyu pastures during summer and autumn improved forage quality.

References

AOAC (Association of Official Analytical Chemists). 2000a. Method 988.05: Protein (crude) in animal feed and pet food. In: Horwitz W (ed.), *Official methods of analysis*, vol. 1 (17th edn). Gaithersburg, MD: AOAC International.

AOAC. 2000b. Method 965.17: Phosphorus in animal feed and pet food. In: Horwitz W (ed.), *Official methods of analysis*, vol. 1 (17th edn). Gaithersburg, MD: AOAC International.

ARC (Agriculture Research Council). 1984. *The nutrient requirements of ruminant livestock*. Lavenham: Lavenham Press.

ARC-ISCW (Agricultural Research Council–Institute for Soil Climate and Water). 2010. Agro-climatology database. Pretoria: ARC-ISCW.

Bartholomew PW. 2005. Comparison of conventional and minimal tillage for low-input pasture improvement. *Forage and Grazinglands* 3: DOI:10.1094/FG-2005-0913-01-RV.

Beyers CP. 1973. Bemesting van aangeplante weidings. *Winterreën Spesiale Uitgawe* 5: 54–59.

Bell MJ, Cullen BR, Eckard RJ. 2011. The production of perennial ryegrass and kikuyu pastures in south eastern Australia under warmer and drier future climate scenarios. In: Chan F, Marinova D, Anderssen RS (eds), *MODSIM2011: 19th International Congress on Modelling and Simulation, Perth, Australia, 12–16 December 2011*. Perth: Modelling and Simulation Society of Australia and New Zealand. pp 753–759.

Botha PR. 2002. Die gebruik van vogspanningmeters vir besproeiingskedulering by weidings. In: Weidingskursus 2002 Inligtingsbundel. George: Suid-Kaap Landbouontwikkelinsentrum, Departement Landbou Wes-Kaap. pp 141–149.

Botha PR. 2003. Die produksiepotensiaal van oorgesaaide kikoejoeweiding in die gematigde kusgebied van die Suid-Kaap. PhD thesis, University of the Free State, South Africa.

Botha PR. 2008. Factors influencing the persistence and production potential of kikuyu (*Pennisetum clandestinum*) over-sown with different ryegrass and clover species in the Southern Cape. In: Proceedings of the Outeniqua Research Farm Information Day 2008. George: Department of Agriculture Western Cape. pp 30–40.

Botha PR. 2009. Kikuyu over-sown with different ryegrass species or clover: Recent research. In: Proceedings of the Outeniqua Research Farm Information Day 2009. George: Department of Agriculture Western Cape. pp 56–68.

Botha PR, Gerber HS, Zulu B. 2008c. Die seisoenale droëmateriaalproduksie van Kropaargras, Swenkgras en verskillende meer- en eenjarige raaigrasspesies. In: Proceedings of Outeniqua Research Farm Information Day 2008. George: Western Cape Department of Agriculture. pp 12–21.

Botha PR, Meeske R, Muller CJC, Cloete SWP, Brand TS, de Lange DH, Grwambi B, Monaren N, Burger W, Muller H, Jelander S. 2013. *Outeniqua Research Farm: 60 years of excellence: a snapshot of research (1953–2013)*. Pretoria: AgriConnect Publishers.

Botha PR, Meeske R, Snyman HA. 2008a. Kikuyu over-sown with ryegrass and clover: dry matter production, botanical composition and nutritional value. *African Journal of Range and Forage Science* 25: 93–101.

Botha PR, Meeske R, Snyman HA. 2008b. Kikuyu over-sown with ryegrass and clover: grazing capacity, milk production and milk composition. *African Journal of Range and Forage Science* 25: 103–110.

Callow M, Barber DG, Anstis AR, Chataway RG. 2012. Irrigated mixed sward of annual ryegrass (*Lolium multiflorum*) and kikuyu (*Pennisetum clandestinum*) exceeds 20 t DM/ha/yr utilisation for dairy production. In: Jacobs J (ed.), *Proceedings of the 5th Australasian Dairy Science Symposium, 13–15 November 2012, Melbourne, Australia*. Melbourne: Australasian Dairy Science Symposium Committee. pp 403–406.

Coetzee K (compiler). 2014. *Lacto Data* vol. 17 no. 1. Pretoria: Milk Producers' Organisation.

Colman RL, Kaiser AG. 1974. The effect of stocking rate on milk production from kikuyu grass pastures fertilised with nitrogen. *Australian Journal of Experimental Agriculture and Animal Husbandry* 14: 155–160.

Dickenson EB, Hyam GFS, Breytenbach WAS, Metcalf HD, Basson WD, Williams FR, Scheepers LJ, Plint AP, Smith HRH, Smith PJ et al. 2010. *Lolium multiflorum* and *Lolium perenne*. In: *Kynoch pasture handbook* (2nd English edn). Noordheuwel: Kejafa Knowledge Works. pp 58–70.

Elmore CL, Gibeault VA, Cudney DW. 1997. Invasion resistance of tall fescue (*Festuca arundinaceae*) and perennial ryegrass (*Lolium perenne*) to kikuyu grass (*Pennisetum clandestinum*). *Weed Technology* 11: 24–29.

Erasmus L. 2009. Milk production from cows grazing kikuyu-ryegrass pasture systems. MSc thesis, University of Pretoria, South Africa.

Farina S. 2009. Strategies to maximise intake per ha in a pasture based system. *University of Sydney Dairy Research Foundation: Current Topics in Dairy Production* 14: 33–42.

Fenthum-Vermeulen S. 2009. Evaluation of techniques to determine the production potential of cultivated pastures. MSc thesis, University of the Free State, South Africa.

Fulkerson WJ. 1997. Use of the rising plate meter to allocate pasture. Research to Farm. Wollongbar: Wollongbar Agricultural Institute, New South Wales Department of Agriculture.

Fulkerson WJ, Lowe KJ, Ayres JF, Launders T. 1993. Northern dairy feedbase 2001. 3. Winter pastures and crops. *Tropical Grasslands* 27: 162–179.

Fulkerson WJ, Neal JS, Clark CF, Horadagoda A, Nandra KS, Barchia I. 2007. Nutritive value of forage species grown in the warm temperate climate of Australia for dairy cows: grasses and legumes. *Livestock Science* 107: 253–264.

Fulkerson WJ, Reeves M. 1996. Management and productivity of white clover in a kikuyu grass sward in subtropical Australia. *Proceedings of the New Zealand Grassland Association* 57: 199–201.

Fulkerson WJ, Slack K. 1993. Estimating mass of temperate and tropical pastures in the subtropics. *Australian Journal of Experimental Agriculture* 33: 865–869.

Fulkerson WJ, Slack K, Havilah E. 1999. The effect of defoliation interval and height on growth and herbage quality of kikuyu grass (*Pennisetum clandestinum*). *Tropical Grasslands* 33: 138–145.

Fulkerson WJ, Slack K, Hennesy DW, Hough GM. 1998. Nutrients in ryegrass (*Lolium* spp.), white clover (*Trifolium repens*) and kikuyu (*Pennisetum clandestinum*) pastures in relation to season and stage of regrowth in a subtropical environment. *Australian Journal of Experimental Agriculture* 38: 227–240.

Garcia SC, Fulkerson WJ, Kenny S, Nettle R. 2006. Producing 40 t dry matter/ha per year through a complementary forage rotation system. *Proceedings of the New Zealand Grassland Association* 68: 69–73.

Garcia SC, Islam MR, Clark CEF, Martin PM. 2014. Kikuyu-based pasture for dairy production: a review. *Crop and Pasture Science* 65: 787–797.

Giron HC. 1973. Comparison between dry ashing and wet digestion in the preparation of plant material for atomic adsorption analysis. *Atomic Absorption Newsletter* 12: 28–29.

Harris DI. 1999. Oversowing kikuyu with annual ryegrass. In: Bartholomew PE (ed.), *Proceedings of a kikuyu technology day held at Cedara on 25 November 1998*. Pietermaritzburg:

KwaZulu-Natal Department of Agriculture. pp 59–60.

Harris DI, Bartholomew PE. 1991. The production of four ryegrass cultivars over-sown at various seeding rates into irrigated kikuyu. *Journal of the Grassland Society of South Africa* 8: 82–85.

Joyce JP. 1974. Nutritive value of kikuyu grass. *New Zealand Journal of Agricultural Research* 17: 197–202.

Lambert JP, Rumball PJ, Christie JR. 1977. Comparison of ryegrass and kikuyu grass pastures under mowing. *New Zealand Journal of Experimental Agriculture* 5: 71–77.

Lowe KF, Bowdler TM, Casey ND, Moss RJ. 1999. Performance of temperate perennial pastures in the Australian tropics 1. Yield, persistence, and pasture quality. *Australian Journal of Experimental Agriculture* 39: 663–676.

MAFF (Ministry of Agriculture, Fisheries and Food). 1984. *Energy allowances and feeding systems for ruminants* (2nd edn). London: HMSO.

Marais JP. 2001. Factors affecting the nutritive value of kikuyu grass (*Pennisetum clandestinum*) — a review. *Tropical Grasslands* 35: 65–84.

Meeske R. 2002. Weidingskwaliteit en melkproduksie. Weidingskursus 2002 Inligtingsbundel. George: Suid-Kaap Landbouontwikkelingssetrum, Departement Landbou Wes-Kaap. pp 106–109.

Meeske R, Rothauge A, van der Merwe GD, Greyling JF. 2006. The effect of concentrate supplementation on the productivity of grazing Jersey cows on a pasture based system. *South African Journal Animal Science* 36: 105–110.

Miles N, de Villiers JF, Dugmore TJ. 1995. Macro mineral composition of kikuyu herbage relative to the requirements of ruminants. *Journal of the South African Veterinary Association* 66: 206–212.

NRC (National Research Council). 1989. *Nutrient requirements of dairy cattle* (6th revised edn). Washington, DC: National Academy Press.

NRC (National Research Council). 2001. *Nutrient requirements of dairy cattle* (7th revised edn). Washington, DC: National Academy Press.

Robertson JB, van Soest PJ. 1981. The detergent system of analysis. In: James WPT, Theander O (eds), *The analysis of dietary fibre in food*. New York: Marcel Dekker. pp 123–158.

Reeves M. 1997. Milk production from kikuyu (*Pennisetum clandestinum*) grass pastures. PhD thesis, University of Sydney, Australia.

Reeves M, Fulkerson WJ, Kellaway RC. 1996. Production responses of dairy cows grazing well managed kikuyu (*Pennisetum clandestinum*) pastures to energy and protein supplementation. *Australian Journal of Experimental Agriculture* 36: 763–770.

SAS Institute. 1999. *SAS/STAT user's guide, version 8*, vol. 2. Cary: SAS Institute.

Stockdale CR. 1984. Evaluation of techniques for estimating the yield of irrigated pastures intensively grazed by dairy cows. II. The rising plate meter. *Australian Journal of Experimental Agriculture and Animal Husbandry* 24: 305–311.

Swanepoel PA, Botha PR, Snyman H, du Preez CC. 2015. Impact of cultivation method on the productivity and botanical composition of kikuyu–ryegrass pasture. *African Journal of Range and Forage Science*.

Swanepoel PA, Habig J, du Preez CC, Botha PR, Snyman HA. 2014. Biological quality of a podzolic soil after 19 years of irrigated minimum-till kikuyu–ryegrass pasture. *Soil Research* 52: 64–75.

Tharmaraj J, Chapman DF, Nie ZN, Lane AP. 2008. Herbage accumulation, botanical composition and nutritive value of five pasture types for dairy production in southern Australia. *Australian Journal of Agricultural Research* 59: 127–138.

Thom ER, Prestidge RA. 1996. Use of Italian ryegrass on seasonal dairy farms in northern New Zealand 1. Feed production and persistence. *New Zealand of Agricultural Research* 39: 223–236.

Tilley JMA, Terry RA. 1963. A two-stage technique for the *in vitro* digestion of forage crops. *Grass and Forage Science* 18: 104–111.

't Mannetjie L. 2000. Measuring biomass of grassland vegetation. In: 't Mannetjie L, Jones RM (eds), *Field and laboratory methods for grassland and animal production research*. Wallingford: CABI Publishing. pp 151–177.

van der Colf J, Botha PR. 2014. The production potential of perennial ryegrass and perennial ryegrass hybrids in the southern Cape of South Africa. In: Proceedings of the 49th Annual Congress of the Grassland Society of Southern Africa, 20–25 July 2014, Bloemfontein, South Africa. pp 93–94.

van der Colf J, Botha PR. 2013. The evaluation of annual ryegrass cultivars in the southern Cape: 2010 to 2011. In: *Research Article Compilation, Outeniqua Research Farm 2008–2013*. Elsenburg: Western Cape Department of Agriculture. pp 101–107.

van der Colf J, Botha PR, Lombard MM. 2013. The production potential of perennial ryegrass and ryegrass hybrid cultivars over a three year evaluation period. In: *Research Article Compilation, Outeniqua Research Farm 2008–2013*. Elsenburg: Western Cape Department of Agriculture. pp 19–28.

van der Colf J, Botha PR, Meeske R, Truter WF. 2015. Grazing capacity, milk production and milk composition of kikuyu over-sown with annual or perennial ryegrass. *African Journal of Range and Forage Science*.

Wilkens RJ, Gibb MJ, Huckle CA. 1995. Lactation performance of spring-calving dairy cows grazing mixed perennial ryegrass/white clover swards of differing composition and height. *Grass and Forage Science* 50: 199–208.

Willis MJ. 1995. Over- and undersowing kikuyu with ryegrass. Booklet. East London: Kynoch Fertilizer (Pty) Ltd.

Zulu LB, van der Colf J, Botha PR. 2014. The production potential of annual ryegrass cultivars in the souther Cape. In: Proceedings of the 49th Annual Congress of the Grassland Society of Southern Africa, 20–25 July 2014, Bloemfontein, South Africa. p 97.