The production potential of Kikuyu (*Pennisetum clandestinum*) pastures over-sown with Ryegrass (*Lolium spp.)*

by

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Submitted in partial fulfilment of the requirements for the degree MSc (Agric): Pasture Science
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For my Grandfather, Attie van der Colf, and my father, Riaan van der Colf

*You moulded me into the proud and educated woman I have become,
cultivated in me a love for agriculture and enabled me to follow my dreams of
contributing to the agricultural field.*

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DECLARATION

I hereby certify that this thesis is my own work, except where duly acknowledged. I also certify that no plagiarism was committed in writing this thesis.

Signed______________________
(Janke van der Colf)

List of abbreviations

%	percentage
ADF	acid detergent fibre
AOF	analysis of variance
b	y intercept
BF	Butterfat
°C	degree Celsius
Ca	Calcium
CF	Crude fiber
CP	Crude Protein
Cu	Copper
cv	cultivar
DMD	dry matter digestibility
DOM	digestible organic matter
DCP	Digestible crude protein
DM	Dry matter
DMI	Dry matter intake
FCM	fat corrected milk
g	gram
ha	hectare
IR	Kikuyu over-sown with Italian ryegrass treatment
K	Potassium
KCl	Potassium chloride
kg	kilogram
L	liter
LAN	Limestone-ammonium nitrate
ME	metabolisable energy
Mg	magnesium
mg	milligram
MJ	Millijoule
m	gradient

mm	millimeter
MUN	milk urea nitrogen
MS	milk solids
N	nitrogen
Na	sodium
NaCl	Sodium chloride
NDF	neutral detergent fiber
NPN	non-protein nitrogen
NPON	non-protein organic nitrogen
OMD	organic matter digestibility
P	phosphorous
PR	Kikuyu over-sown with perennial ryegrass treatment
RPM	rising plate meter
t	ton
NSC	non-structural carbohydrates
UDP	undegradeable protein
WR	Kikuyu over-sown with Westerwolds ryegrass treatment
WSC	water-soluble carbohydrates
Zn	Zinc

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Abstract

The production potential of kikuyu (*Pennisetum clandestinum*) pastures over-sown with ryegrass (*Lolium* spp.)

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Kikuyu (*Pennisetum clandestinum*) is highly productive during summer and autumn and capable of supporting high cattle stocking rates., The winter and spring production of kikuyu, however, is low, while forage quality, and consequently milk production per cow, is also low compared to temperate grass species. The aim of this study was to determine the dry matter yield, botanical composition, nutritional value, grazing capacity and milk production potential of irrigated kikuyu over-sown with Italian ryegrass (*Lolium multiflorum* var. *italicum*), Westerwolds ryegrass (*Lolium multiflorum* var. *westerwoldicum*) or perennial ryegrass (*Lolium perenne*) under an intensive grazing system with Jersey cows. Calibrations for the rising plate meter (RPM) were developed for the kikuyu-ryegrass systems. These calibrations were evaluated for seasonal variation, linearity and were also combined over seasons, treatments and years to develop a calibration equation that could be used by dairy farmers in the region.

The three kikuyu based pasture systems reached their peak growth rates during different months and seasons. All treatments experienced lower growth rates during winter, while peak growth rates occurred during spring for the Italian ryegrass treatment; summer for the Westerwolds ryegrass treatment and late spring/early summer for the perennial ryegrass treatment. All three treatments had similar total annual dry matter yields (kg DM ha^{-1}) during the first year of the study. However, during year 2 the PR treatment had a higher annual DM production than IR and WR treatments. The ability of the PR treatment to maintain DM production during periods when the other treatments underwent a dip in production (WR during spring and IR during summer) enabled the PR treatment to maintain a higher annual DM production during year 2 than the systems based on annual ryegrass species. As the kikuyu component increased in kikuyu-ryegrass pastures from winter to summer, the DM and NDF content increased, while the ME content decreased. All three treatments were deficient in Ca throughout the study and deficient in P during summer and autumn for high producing dairy cows. The Ca:P ratio was below the recommended ratio of 1.6:1 for high producing dairy cows throughout the study.

The grazing capacity of all three kikuyu-ryegrass systems was lower during winter and autumn than during spring and summer. The seasonal grazing capacity of the perennial ryegrass treatment, however, was more evenly distributed than that of the Italian and Westerwolds ryegrass treatments. The perennial ryegrass treatment had a lower butterfat and milk production per lactation than the Italian and Westerwolds ryegrass treatments during both years, but had the highest milk production per ha. The latter was a result of the higher annual grazing capacity achieved by the perennial ryegrass treatment. It was thus concluded that, because kikuyu over-sown with perennial ryegrass supported a higher number of animals and had a more evenly distributed fodder-flow, it allowed for higher animal production per ha than kikuyu over-sown with annual ryegrass varieties such as Italian and Westerwolds ryegrass.

The pre-grazing and post-grazing regressions of all three the kikuyu based pastures developed for the RPM differed over seasons and years, primarily due to the change in botanical composition from ryegrass based pastures during winter to kikuyu-based pastures in the summer and the associated change in pasture structure. The post-grazing regressions developed during the study did not have a lower degree of accuracy (R^2 values) than the pre-grazing regressions. The generalised RPM regression equations developed for kikuyu-ryegrass pastures (consisting of large data sets pooled over treatments and years) could be of

use to farmers in the surrounding area, but are not recommended for research purposes due to the large errors and variation associated with such regressions. In the event that farmers employ these calibrations it is important that pasture type and pasture management practices be similar to those utilised during the study.

The decision on which kikuyu-ryegrass system to utilize should be based on the specific conditions prevalent on a particular farm, an economic analysis on and a comparison between the three systems, as well as the particular fodder-flow program requirements within the pasture system.

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CHAPTER 1

INTRODUCTION, LITERATURE REVIEW AND STUDY AIM

1. Introduction

Pasture forms the base for milk production in the Southern Cape region in South Africa (Meeske et al. 2006), with kikuyu (*Pennisetum clandestinum*) comprising the greater part of summer and autumn pasturage (Botha et al. 2008b). Kikuyu is a C_4 pasture specie that is well adapted to the main milk producing areas in the Western Cape Province of South Africa (Botha 2003). Although kikuyu is highly productive during summer and autumn, winter and spring dry matter (DM) production is low. The forage quality of kikuyu is low, and consequently milk production per cow is also low (Marais 2001). Kikuyu fertilised with nitrogen is capable of supporting high stocking rates and milk production per hectare, but production per cow is relatively low (Colman and Kaiser 1974, Reeves 1997). As the pasture growth season progresses, daily milk yield per cow can also drop by as much as 38% from December to May (Henning et al. 1995). This trend is often referred to as the "autumn slump".

The strategic incorporation of temperate grasses like Westerwolds ryegrass (*Lolium multiflorum* var. *westerwoldicum),* Italian ryegrass *(L. multiflorum* var. *italicum)* and perennial ryegrass (*L. perenne)* into kikuyu pasture, can increase the seasonal DM production and quality of the pasture (Botha 2003). Dairy farmers have to make decisions on the species (annual or perennial) and variety (Italian or Westerwolds) of ryegrass as well as the method of over-sowing these ryegrasses into kikuyu. These decisions can have a major impact on the profitability of dairy farming. At present no applicable scientific data comparing different systems with annual or perennial ryegrass and grazed by dairy cows is available to assist farmers to make these decisions. Farmers have requested an in depth evaluation of over-sowing systems, using ryegrass, to identify the most suitable pasture system. Furthermore a need was identified to develop calibration equations for a common pasture yield measurement method in the region, the rising plate meter, for systems based on kikuyu over-sown with ryegrass.

In support of this study the following review of the available information and literature on pasture systems for milk production based on kikuyu, ryegrass and kikuyu reinforced with various temperate species was undertaken. The main aim of the literature review was to describe the production potential (dry matter and milk production), nutritive value and best management practices for each of the above pasture based systems, so as to identify the inherent deficiencies of each and identify possible solutions to these deficiencies. A short study was also made of pasture measurement, the rising plate meter and factors that could affect calibration accuracy of the rising plate meter.

2. Pasture based systems for dairy production

2.1 Optimal choice of forage species for pasture based dairy systems

The optimal choice of forage species to employ within a pasture based dairy system will play an important role in the fodder-flow planning and profitability of such a system (Burger 2007b). There are a number of factors that should be considered when attempting to identify the optimal forage specie for a pasture based dairy system, which include (Lambert and Litherland 2000, Tainton 2000, Dickenson et al. 2004, Neal et al. 2007):

- The mean annual, effective, seasonal distribution and variability of rainfall;
- The climatic characteristics of the region in terms of excessively high temperatures, intensity and duration of frosts, wind and photoperiod;
- Topography of the site in terms of slope and aspect;
- The physical and chemical properties of the soil;
- The inherent nutritional characteristics of pasture species such as legumes vs. grasses or temperate vs. sub-tropical species;
- The dry matter (DM) production potential of forage species;
- Seasonal distribution of DM production;
- Establishment costs;
- Possible costs of harvesting and feeding a particular forage crop;
- Availability, quantity, quality and costs of irrigation;
- Milk production obtainable from different forage species
- Whether pastures will be perennial or annual (re-established every year)
- Resistance to defoliation, trampling and weed infestation of different forage crops

Neal et al. (2007) concluded that a mix of forage species, rather than single forage specie, should be considered within a pasture based dairy system. Inclusion of alternative forage species, manipulation of pasture establishment dates to shift production curves and the preservation of pasture in excess of animal requirements during peak pasture growth periods in the form of silage, hay or foggage can also be included when formulating the optimal species selection for a pasture based dairy system (Burger

2007b). It is important to note that the production of pastures is subject to the laws of diminishing returns, with pasture output (DM production) initially increasing as input increases (for example fertilisation costs) up to a certain point, after which it declines (Archibald 2004). Thus, although the correct choice of forage species can play a large role in determining the profitability of a pasture based dairy system, correct management of the system in terms irrigation scheduling, fertilisation practices, correct timing of grazing and optimal pasture utilisation for each species will also play an important role (Burger 2007a).

2.2 Grazing management

Grazing management is considered the control of pastures, livestock and their movements in a pasture ecosystem, aimed at maximising profits, maintaining a stable biological system and maintaining minimal animal stress (Morley 1966). High rates of pasture utilisation ensure that pasture is maintained in a vegetative state and at highest possible pasture quality, whilst also ensuring that pasture is not lost due to maturation and decay (Van Houtert and Sykes 1999).

Grazing intensity is one of the key determinants of both the extent and efficiency with which pasture is converted into an animal product (Murtagh et al. 1980). At low stocking rates, animals tend to graze more selectively, and although the selected diet may be of higher nutritive value (in terms of digestibility) and the resultant milk production per cow greater, pasture wastage will also increase. In contrast, high stocking rates enhance pasture utilisation efficiency and increase milk production per ha (Van Houtert and Sykes 1999). As stocking rate increases, per animal production decreases, but productivity per unit area increases. There is, however, a critical threshold for stocking rate (where increases in stocking rate will no longer increase production per unit land) that will be dependent on the pastures and animals present within a system (Tozer et al. 2004). In a study conducted by MacDonald et al. (2007) it was found that as stocking rate of dairy cows grazing pasture increased, the pasture grown per ha, pasture consumed per ha and milk production per ha increased, while post-grazing residual declined and the grazing interval increased. In addition, the organic matter digestibility and metabolisable energy content of pastures increased quadratically as the stocking rate increased. However, milk yield per cow was found to decrease as stocking rate increased, primarily because of a lower peak, less persistent milk profile and shorter lactation.

Higher stocking rates and greater animal production per hectare is obtainable by a rotational grazing system than a continuous grazing system (Tainton 2000). Rotational grazing requires extra fencing and infrastructure and is, as such, more expensive to set up than a grazing system based on continuous grazing. The additional cost associated with a rotational grazing system is only justifiable if it leads to increased profitability (Van Houtert and Sykes 1999). Within a rotational grazing system more frequent allocation of fresh herbage (once a day compared to every fourth day) has been found to improve milk production of dairy cows grazing pasture, primarily due to the increase in dry matter intake of pasture when pasture allocation was more frequent (Abrahamse et al. 2008). Accurate allocation of feed to dairy cows on a daily basis, according to available pasture DM and forage quality, was found by Fulkerson et al. (2005) to improve pasture re-growth, reduce wastage and result in higher milk components than when allocating according to a fixed pasture mass on a daily basis. Pasture allowance refers to the units of pasture offered, typically expressed as kg DM cow^{-1} day^{-1} (Tozer et al. 2004). Pasture allowance is affected by both the pre-grazing mass of pasture and the area allocated to the cow for grazing (Lee et al. 2008). The reduction in intake, associated with concentrate supplementation, has been found to be greater at high pasture allowances than at low pasture allowances, indicating that substitution rate is higher at high pasture allowances (Tozer et al. 2004). At high levels of pre-grazing pasture availability, pasture wastage will tend to be higher than at low pasture availabilities, resulting in a lower response to concentrates when pasture allowances are higher (Tozer et al. 2004, Fulkerson et al. 2005).

In herds where animals are not supplemented, high pasture allowances result in lower pasture use efficiencies and a larger area of land will be required to maintain pasture production (kg DM) at a level that can meet requirements (Tozer et al. 2004). However, increasing pasture allowance has been found to be an alternative strategy to energy supplementation when attempting to increase milk production of grazing dairy cows, especially under circumstances where pasture availability and growth rates are high (Wales et al. 2001). To calculate the amount of pasture required to supply sufficient intake to the herd and/or the rotation length the following method can be used (Tozer et al. 2004):

1. Pasture required (kg DM) = pasture consumed per cow (kg DM cow^{-1}) x number of cows

2. Total amount of pasture required (kg DM) = pasture required (kg DM) ÷ efficiency of harvest (%)

3. Residual (kg DM) = total amount of pasture required (kg DM) x efficiency of harvest (%)

4. Rotation length (days) = [total amount of pasture required (kg DM) – residual after grazing (kg DM)] ÷ growth rate of pasture

It has been reported that as post-grazing height of pasture increased, the pasture accumulation in the subsequent grazing cycle increases linearly. However, increased post grazing height (at similar pasture allowances) also resulted in a decline in milk production per animal, while milk protein increased (Lee et al. 2008). This study indicated that lower pasture allowances, rather than grazing to a lower post-grazing height, were the primary reason for lower milk production from heavily grazed pastures. Fulkerson et al. (2005) however found that if post-grazing height was maintained at a constant height of approximately 50 to 60 mm, it resulted in higher milk components and similar milk yields than when post-grazing height was more varied and higher. It should be kept in mind that at high stocking rates pasture consumed per ha will increase, thus pasture utilization rates will increase (MacDonald et al. 2007).

In most climates forage production will vary according to season, and farmers will have to manage feed supply and demand. A reduction in the efficiency with which pasture is converted into animal products is often seen during periods when pasture growth is rapid and animals have to graze pastures where pre-grazing yields are high (Murtagh et al. 1980). During periods of excessive growth pastures should be managed to avoid rapid accumulation of biomass, by either conserving excess pasture or, alternatively, bringing in additional livestock (Van Houtert and Sykes 1999, Tozer et al. 2004). The latter is however not a practical solution, whereas the former will allow excess feed from one season to meet the deficit that often occurs during other seasons (Van Houtert and Sykes 1999). Another strategy recommended by MacDonald et al. (2007) is to maintain constant high stocking rates, while varying the length of the inter-grazing interval during different seasons, with additional pasture conserved and supplements bought in during periods when pasture cannot meet herd requirements.

Correct management of animals within a pasture based dairy system is thus just as important as correct pasture management to obtain maximum benefits from the cheap feed source that pastures can provide.

2.3 Supplementation of dairy cows on pasture based dairy systems

Pasture may not be the cheapest feed source for dairy cows under all circumstances, with the appropriateness varying according to region, the cost and quality of alternative feed sources (such as crop residues) and the growth season of pastures in the particular area (Van Houtert and Sykes 1999). For example, a “New Zealand System”, where dairy cows graze only pastures and no concentrates are fed, has not been proved to be economical under South African conditions, primarily because the quality of forages (under South African conditions) is poor much of the year compared to New Zealand pastures (Stewart et al. 1995). The capital investment in a pasture based system will generally be lower than for a confinement system, primarily due to the cost incurred for feeding and housing in a confinement system (Tozer et al. 2004). High quality pasture has many positive nutritional attributes for the lactating cow, but also possesses some inherent nutritional imbalances and deficiencies such as inadequate rumen undegradeable protein (RUP) irrespective of a high crude protein content (CP), low fermentable carbohydrate content, low fiber content (in young temperate pastures) and low levels of various minerals including calcium, phosphorous, magnesium, sulphur and zinc (Muller 2003).

The energy requirements of ruminants are often poorly characterised for grazing animals, since estimates from pen-fed animals will often fall short of predicting expected gain responses associated with energy supplementation (Caton and Dhuyvetter 1997). Kolver and Muller (1998) reported that the milk production of cows grazing pasture, without supplementation, was 33% lower than cows that received a total mixed ration (TMR). In addition, the fat and protein yield for cows grazing pasture was also lower, with the pasture fed cows losing more weight and body condition during lactation. The lower milk production of dairy cows grazing pastures has been attributed to the greater energy expenditure in a grazed pasture system, the lower intake capacity of the cows when fully fed on a bulky feed and the inability of cows to maximise pasture utilisation (Pedernera et al. 2008). Pedernera et al. (2008) investigated the effect of including a partial mixed ration (PMR) in the diet of dairy cows grazing pastures, compared to cows receiving a concentrate during milking only. The results from this study showed that cows receiving a PMR, in addition to pasture, achieved a higher (up to 30%) milk yield per lactation (kg cow^{-1} lactation^{-1}), higher milk protein content (%), lower milk fat content (%) and that these cows reached their peak milk yield earlier than the group not receiving the PMR. Although there were no differences in the loss of weight or body condition score between the groups, it was also found that the energy balance of cows receiving a PMR was less negative early in lactation, indicating that the mobilization of body reserves was lower in the PMR group. Wales et al. (2001) noted the role that body condition score can play in the response obtained from cows grazing pasture, with cows in a poor body condition score responding better to supplementation than cows in better condition.

The milk production of dairy cows has been found to respond positively to concentrate supplementation (Tozer et al. 2004). Dry matter intake of high quality pastures, however, rather than ME content, has been identified as the major factor limiting the energy supply from pastures (Kolver and Muller 1998). For this reason, cows grazing pasture should be supplemented with energy dense concentrates to achieve their genetic milk potential and in order to reduce the need to mobilize excessive amounts of body reserves in early lactation (Kolver and Muller 1998, Bargo et al. 2003, Pedernera et al. 2008). Of interest is that Tozer et al. (2004) did not report an improvement in feed conversion efficiency (in terms of milk production) of supplemented cows compared to cows grazing only pasture. Supplementation of forages with grain or sugar is intended to increase the overall energy intake of the animal (Meissner 1997). Providing additional energy in the form of a supplement has often produced reductions in the intake of grazed forage, whilst it can also affect pasture digestibility (Caton and Dhuyvetter 1997, Tozer et al. 2004). Fulkerson et al. (2006) reported that in dairy cows grazing kikuyu pastures there was an 8% decrease in pasture digestibility for every 9% increase in concentrate intake as a proportion of the diet. The supplementation of grazing animals with high energy feeds results in a depression of cell wall digestibility, which leads to a marginal increase in total energy consumption (Meissner 1997). Although Fulkerson et al. (2006) reported that cows were prepared to utilise more pasture as the proportion of concentrate increased and that the efficiency of use of the roughage component did not decrease as this occurred. When attempting to identify a milk response from supplementation with energy dense concentrates of dairy cows, consideration should however be given to the inherent energy content of pastures (as influenced by botanical composition and maturity). Stockdale (1999b), for example, found that as the metabolisable energy content of pastures increased and the fiber content decreased, the milk response of dairy cows receiving high energy supplements decreased.

Milk fat decline is one of the major economic disadvantages of producing milk from pastures, with the effect particularly pronounced in lush temperate pastures with a low fiber content (Polan et al. 1985). A possible reason for the lower milk protein reported in cows grazing pasture, compared to cows fed a TMR, has been identified as an efficient utilisation of ingested N, most likely because a large proportion of amino acids is partitioned towards gluconeogenesis (Kolver and Muller 1998). As result, animals grazing pastures will show an increase in milk protein levels when supplementation levels increase (Lehmann et al. 2007). The milk fat content (%) of cows grazing pasture has been found to decrease as the amount of energy concentrate fed increases (Polan et al. 1985), while fat yield (kg fat cow^{-1}) has been reported to increase, primarily due to the increase in milk yield when dairy cows grazing pastures are supplemented (Tozer et al. 2004). Stockdale et al. (2001) and Lehmann et al. (2007) were however of the opinion that cows grazing good quality pastures can ingest relatively large quantities of high-energy supplements before milk fat depression occurs. The partial replacement of maize and soybean oilcake with high fiber by products, such as hominy chop, maize gluten and bran, was found to increase the milk fat content (%) of dairy cows grazing annual ryegrass pastures (Meeske et al. 2009). Meeske et al. (2009) thus concluded that that by lowering the starch content of dairy concentrate, the milk fat content and 4% FCM production of supplemented dairy cows grazing pastures could be increased. Reeves (1997) also found that the inclusion of a $NaHCO_3$ (which would reduce the decline in rumen pH associated with high starch cereal concentrates) prevented the reduction in pasture digestibility that results from barley supplementation.

Although energy supplementation can play an important role in improving milk production, the inclusion of a high quality protein supplement (low degreadeabilty and a good amino acid composition), such as fishmeal, has also been found to improve the milk production of Jersey cows grazing high quality annual ryegrass pastures (Malleson et al. 2008). Cows that were fed 240 g fishmeal per day in addition to a maize concentrate and pasture, had higher milk, butterfat and protein yields than cows that did not receive fishmeal. Malleson et al. (2008) concluded that this response was indicative of RUP or some amino acid limiting production of the control animals, rather than metabolisable energy.

Appropriate strategies for supplementation of high producing dairy cows requires an understanding of the effect of different types of supplements on dry matter intake, animal performance and digestion, and of providing nutrients that complement the nutrient content of the available pasture (Bargo et al. 2003). Although supplementation is a useful tool in improving milk production from pastures, maintenance of high forage quality and high forage utilisation by correct pasture management is a must to maintain profitability of concentrate feeding within a pasture based dairy systems (Stewart et al. 1995).

3. Kikuyu (Pennisetum clandestinum)

3.1 Morphology and growth habit of kikuyu

Kikuyu is a robust, vigorous creeping perennial that possesses strongly noded stolons (above ground) and rhizomes (below ground) (Quinlan et al. 1975). Kikuyu regularly propagates vegetatively from these vigorously spreading stolons that can form secondary stolons (Marais 2001). The profusely branched stolons and rhizomes posses the ability to form roots at the nodes (Whyte et al. 1968, Mears 1970). Short leafy branches are formed from stolons, with leaf blades strongly folded into a bud when young (Dickenson et al. 2004), later expanding to 45-115mm long and 6mm wide, tapering to sub-obtuse tips (Mears 1970). The sward tends to grow vertically to a maximum height of approximately 45 cm before lodging (Whitney 1974b). The leaf surface of kikuyu is sparsely and softly hairy, the ligule characterised by a ring of hairs and the collar a prominent pale yellow colour. Under favourable moisture and soil conditions the persistent sod of kikuyu can be highly productive, but a thick, stemmy mat can form under less favourable conditions (Whitney 1974a).

South African kikuyu does not appear to flower under pasture conditions, but the cultivar Whittet does flower regularly (Marais 2001). The seeds are dark brown in colour, flat and ovoid and 1.5mm by

2.5mm in size. The seed is formed almost at ground level and can only be seen by pulling away the sheathing leaves and the remaining flowers (Ross 1999).

The natural distribution of kikuyu is limited to the upland areas of east central Africa, at altitudes of between 2000 and 3050 m above sea level (Whyte et al. 1968) where the annual rainfall is approximately 1000 to 1600 mm (Mears 1970). Kikuyu is an aggressive colonizer and under different circumstances it can be viewed as a weed, soil cover or pasture grass (Whitney 1974a).

3.2 Growth requirements of kikuyu

3.2.1 Temperature

The growth pattern of kikuyu is greatly influenced and dictated by temperature (Marais et al. 1987, Minson et al. 1993). Kikuyu is a subtropical grass for which optimum growth occurs between 6-21ºC (Marais 2001). Growth of kikuyu reaches maximum levels at mean atmospheric temperatures of 25°C (Murtagh et al. 1987) and ceases when mean atmospheric temperatures fall below 10ºC (Minson et al. 1993).

Kikuyu is more sensitive in terms of plant growth to high temperatures than many other tropical species, with growth often restricted when temperatures exceed 40°C (Ivory and Whiteman 1978). Furthermore, kikuyu is also more sensitive to temperature change than other tropical species with the optimum temperature for tillering in kikuyu approximately 10°C lower than blue buffalo grass (*Cenchrus cilliaris*), green panic (*Panicum maximum*) and Makarikari (*Panicum coloratum* var. *makarikariense*) (Ivory and Whiteman 1978). The poor performance of kikuyu in low latitude tropical climates suggests that the species is not well adapted to high temperatures (Mears 1970). Murtagh et al. (1987) reported that although yields of kikuyu were higher at 30°C than at 25°C, the higher growth rates were associated with thickening of stems and an increase in internodal length rather than increased laminae extension. In South Africa the growth of kikuyu increases from November to February as the temperature increases, and will decline markedly as the temperatures decrease later in the season (Marais et al. 1987). Although kikuyu will not survive sustained winter frosting (Mears 1970), moderate frost will tend to only kill the top-growth of kikuyu while stolons will be unaffected (Marais 2001).

The growth rate of kikuyu is sensitive to soil temperature, with growth reduced by as much as 11 kg ha^{-1} day^{-1} for each degree reduction in average minimum soil temperature below 18°C (Whitney 1974b). Increased soil heating markedly increased the top and root growth of kikuyu (Whitney 1974b).

3.2.2 Water

Murtagh (1988) did extensive research to determine the growth requirements of kikuyu in terms of water supply. This author indicated that kikuyu was capable of continued growth at relatively low soil water contents, but that evaporative demand played a large role in its tolerance to water stress. The relatively good drought resistance of kikuyu is attributed to the relatively deep root system it develops in well-drained soils (Marais 2001). The growth of kikuyu is sensitive to water stress, with kikuyu growth reduced by up to 61% when the evaporative demand was 5 mm day^{-1} (Murtagh 1988). As result, the response of kikuyu to irrigation may be lower than expected, because irrigation is incapable of alleviating all the stress induced by high evaporative demand. Irrigation of kikuyu should thus be frequent under circumstances of high evaporative demand (Murtagh 1988).

When the growth rate of kikuyu is high, such as under high nitrogen fertilisation regimes, irrigation can play a significant role in improving growth rate (Mears 1970). Kikuyu grows reasonably well on badly drained soils, but will not tolerate waterlogging for long periods of time (Dickenson et al. 2004).

3.2.3 Soil nutrient status

Decreasing the soil pH below 4.36 was found to negatively affect the root and top growth of kikuyu, but it could tolerate a pH of 4.8 and upwards (Awad et al. 1976). Regardless of this tolerance to soil acidity, kikuyu growth is greatest at a pH (KCl) of 5.0 to 6.0 (Dickenson et al. 2004). Although kikuyu is highly tolerant of soil acidity, with productivity unaffected at soil acid saturations up to 60%, continuous liming is advocated to ensure that calcium levels are maintained at adequate levels in kikuyu herbage for animal production (Miles 1999). Increasing the pH and phosphorous (P) levels in the soil has a positive effect on kikuyu growth by improving P availability and P uptake (Awad et al. 1976).

The optimum soil P test for kikuyu is 10 mg L^{-1} on clay soils and at least 18 mg L^{-1} on loam and sandy soils (Miles 1999) with levels of 15 mg P kg^{-1} recommended under dry land and 30 mg P kg^{-1} under irrigation by Dickenson et al. (2004). The soil test potassium (K) levels that give the best response are 140 mg K kg^{-1}, even though deficiencies generally only occur at levels below 75 mg K kg^{-1} (Miles 1999). Concentrations of at least 80 mg K kg^{-1} are thus recommended on light soils and 120 mg K kg^{-1} for heavy soils (Dickenson et al. 2004). Kikuyu is highly tolerant of low levels of exchangeable Ca and Mg in the soil (Whitney 1974a), although these may affect palatability, nutritive value and result in mineral imbalances.

3.3 Production potential of kikuyu

3.3.1 Pasture production potential

As can be seen from the data in Table 3.1, tropical grasses, if well watered and fertilised, can yield almost twice as much dry matter per year as temperate species and have the potential to support higher grazing capacities (Minson et al. 1993). The higher dry matter production and grazing capacity of tropical grasses can be attributed to the greater efficiency of the photosynthetic pathway (C_4) and the higher light intensity in the tropics (Minson et al. 1993).

Table 3.1: Mean production and light energy conversion by well fertilised and watered temperate and tropical grasses (Minson et al. 1993)

	Temperate	Tropical	Difference (%)
No. of studies	6	17	-
Dry matter yield (t DM ha^{-1} year^{-1})	22	49	125
Potential carrying capacity (cow ha^{-1})	5.5	12	125
Light energy conversion (%)	2.3	3.0	30
Photosynthetic pathway	C_3	C_4	-

Kikuyu has a high annual DM yield potential with values of up to 28.2 t ha^{-1} annum^{-1} recorded in the literature for well-established kikuyu (Gherbin et al. 2007). Under very high nitrogen (N) fertilisation rates of 874 kg N ha^{-1} annum^{-1}, Whitney (1974a) reported yields of 35 t ha^{-1} annum^{-1} for kikuyu, stating that yields could probably be further increased with higher N fertilisation rates. The range in annual DM yields recorded for kikuyu by various authors is given in Table 3.2. The large variation in DM yields reported by various authors in the literature is most likely due to differences in management, local environment and climatic conditions at different sites.

Kikuyu is well known for its seasonality in DM production (Marais 2001). The most active growth period in kikuyu occurs from summer to autumn (Cook and Mulder 1984a, Hacker and Evans 1992, Andrewes and Jagger 1999), whilst growth rates are lowest during winter (Mears and Humphreys 1974, Andrewes and Jagger 1999) and spring (Fulkerson et al. 1993a, Botha et al. 2008a). The growth rate of kikuyu during spring at 33.9 kg DM ha^{-1} day^{-1} can be as low as half of summer growth rates of 67.0 kg DM ha^{-1} day^{-1} (Botha et al. 2008a), with as much as 50% of total annual DM yield occurring in the summer months (Gherbin et al. 2007). The commencement of kikuyu growth during spring is generally dependant on the availability of adequate moisture and nitrogen for the kikuyu during this period (Hartridge 1969).

Table 3.2: The range of annual dry matter (DM) yield recorded across literature for kikuyu

Reference	Annual DM yield (t DM ha^{-1} $annum^{-1}$)
Whitney 1974a	35.0
Pearson et al. 1985	15.1
Evans and Hacker 1992	7.10
Hacker and Evans 1992	6.24
Andrewes and Jagger 1999	10-16
Fulkerson et al. 1999	7.8 –12.1
Cruywagen et al. 2007	13.1
Gherbin et al. 2007	28.2
Botha et al. 2008a	13.1

Various other tropical species have been reported to out-yield kikuyu, but kikuyu tended to possess a higher forage density and leaf density (Hacker and Evans 1992), a higher proportion of leaf and a higher leaf yield (Pearson et al. 1985). Pasture yield alone may, however, be a poor indicator of kikuyu productivity because the creeping growth form of kikuyu makes ground level difficult to define. As result, a small variation in cutting height will result in large variation in yield (Andrewes and Jagger 1999). In addition quality, rather than yield, is the primary limitation to animal production from pastures based on C_4 grasses (Fulkerson et al. 1999).

3.3.2 Milk production potential

The daily milk production from cows grazing kikuyu ranges from 10.1 to 22.0 kg cow^{-1} day^{-1} (Table 3.3). The milk production from cows grazing kikuyu is often lower than expected (Quinlan et al. 1975, Bredon 1980), with the discrepancy between production (calculated from *in-vivo* nutritive value) and actual milk production often increasing as the growth season progresses (Bredon 1980). Beef animals grazing kikuyu have also shown poor annual weight gains when compared with other tropical species, with animal performance especially low during summer (Evans and Hacker 1992).

The supplementation of dairy cows grazing kikuyu with cereal based concentrates can be used to enhance milk production to more reasonable levels (Reeves et al. 1996a). Fike et al. (2003) stated that production per land area may be a more appropriate measure of profitability for dairies using grazing systems. This is obtained by multiplying the milk production per cow with cows ha^{-1}. With the high pasture dry matter production obtained from kikuyu (section 3.3.1) this may be particularly relevant. Milk production from kikuyu is primarily limited by the decline in quality as it matures (Minson et al.

1993). If animals are forced to graze the more fibrous component of kikuyu, animal production is often lowered because the pasture being ingested is of low nutritive value (Betteridge 1985).

Table 3.3: Milk Production of cows grazing of kikuyu

Reference	Breed	Description	kg cow^{-1} day	Butterfat	Protein
Henning et al. 1995	Holstein Friesan	30 day grazing cycle	10.1	3.6%	3.2%
Reeves et al. 1996a	Holstein Friesan	3-4 months	17.3		
		5-6 months	14.2		
		7 months	12.5		
		unsupplemented	14.2	3.77%	3.22%
		3 kg concentrate	18.3	3.51%	3.22%
		6 kg concentrate	18.0	3.26%	3.19%
Botha et al. 2008b	Jersey	Spring	15.0	5.05%	3.39%
		Summer	14.4	4.41%	3.38%
		Autumn	12.1	4.95%	3.48%
Meeske et al. 2009		High maize supplement	21.0		
		Low Maize supplement	20.1		

Milk production from kikuyu often declined as the growing season progressed, reaching the lowest levels during the autumn months of March and April (Bredon 1980). The possible reasons for this "autumn-slump" in milk production have been listed as the poor palatability and consequent poor intake of kikuyu during the latter period, a lower intake of energy due to the excessive degradation of crude protein in the rumen and an over-all reduction in the quality of kikuyu during this period (Joyce 1974, Bredon 1980). The reduction in the digestibility of kikuyu and intake from the summer onwards have also been identified as contributing factors involved in the drop seen in milk production as the growth season progresses (Colman and Kaiser 1974, Henning et al. 1995). Henning et al. (1995) reported that dairy cows grazing kikuyu showed a drop of up to 38% in daily milk production from December to May. This drop was accompanied by a 43% drop in kikuyu digestibility and intake (Figure 3.1).

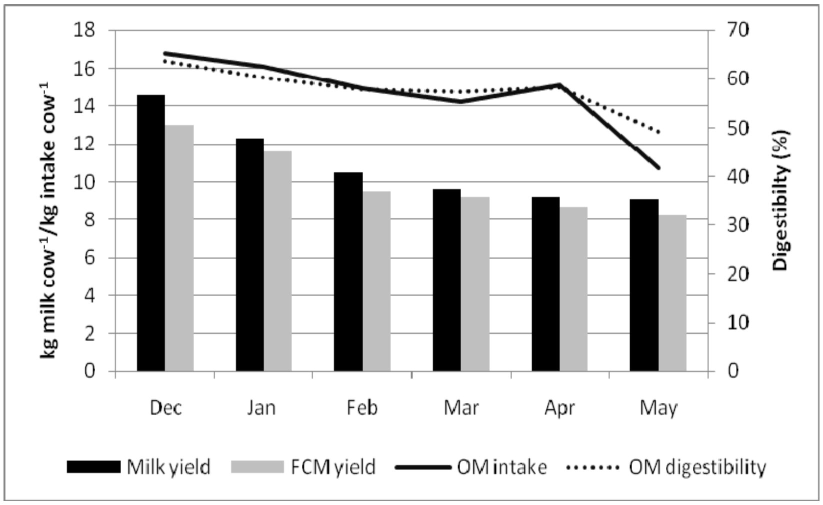

Figure 3.1: The mean daily milk yield per cow, mean fat corrected milk (FCM) yield per cow, daily organic matter (OM) intake per cow and in vitro OM digestibility of kikuyu during the growing season at a grazing interval of 30 days. (Henning et al. 1995)

3.4 Chemical composition and nutritive value of kikuyu for grazing animals

3.4.1 Dry matter percentage

At approximately 20%, the DM percentage of green kikuyu forage is low relative to most tropical species (41%) (Gherbin et al. 2007).

The DM content of kikuyu has been found to be influenced by defoliation interval and decreased from 15.5 to 12.5 % DM as defoliation interval increased from 7 to 35 days, and then increased to 14 % at a 42 day interval (Cruywagen et al. 2007). The most dramatic increase in DM content of kikuyu occurred from week four to week 36 of re-growth, with the DM content increasing from 22.2% to 49.8% during this period. The increased DM content of kikuyu with re-growth stage, at a 0.83% increase per week from four to 36 weeks, was however lower than other tropical species such as that of pongola grass (*Digitaria decumbens* Stent.) which increased by 1.14% per week (Gomide et al. 1969a). Increased N fertilisation rates will result in a lowered DM content in tropical grasses (Gomide et al. 1969a), most probably due to increased growth rate associated with N fertilisation.

3.4.2 Protein

The dietary protein content of feedstuffs generally refers to the crude protein (CP) content, defined as the nitrogen (N) content multiplied by a factor of 6.25. This CP fraction consists of both true protein and non-protein nitrogen (NPN). Grass forages contain larger proportions of NPN than other feedstuffs. These are composed largely of peptides, free amino acids and nitrate (NRC 2001). Tainton

(2000) warned against evaluating the nutritive value of pastures according to crude protein content alone, since crude protein does not distinguish between the protein needs of micro-organisms, the protein available for absorption in the lower digestive tract or the origin and quality of protein.

The CP content of kikuyu reported in the literature varies between 10.7 and 23.7% (Table 3.4). Although the CP concentration of kikuyu is higher than for most other tropical grasses (Gomide et al. 1969, Mears 1970, Jeffrey 1971, Bredon 1980, Evans and Hacker 1992, Fulkerson et al. 2007, Gherbin et al. 2007), it still has a lower CP concentration than temperate grasses such as ryegrass (Joyce 1974, Betteridge 1979, Reeves et al. 1996b, Fulkerson et al. 1998, Andrewes and Jagger 1999). Due to the high dry matter production of kikuyu, it often achieves a higher CP yield per ha than other warm season grasses and legumes (Gherbin et al. 2007).

Table 3.4: The crude protein content (%) of kikuyu. Information not available is indicated by a dash (-)

Reference	Cutting height	Age	Fertiliser (kg N ha^{-1} annum^{-1})	CP %
Gomide et al. 1969a	-	4 – 36 weeks	0-200	15.2
Jeffrey 1971	-	-	0	11.7
Joyce 1974	-	80-130 mm	-	10.7
	-	200-300 mm	-	16.9
Kaiser 1975	-	-	228	15.09
Cook and Mulder 1984b	-	-	300-1200	15.19
Dugmore and Du Toit 1988	50 mm	-	-	18.70
Dugmore et al. 1991	Ground level	28 days	120	11.98
Evans and Hacker 1992	-	28 days	-	19.31
Fulkerson et al. 1993	-	-		14.4-18.8
Reeves et al. 1996a	Grazing height	18-24 days	400 kg urea	20.1-20.8
Reeves et al. 1996b	-	-	-	20.7
Fulkerson et al. 1998	Grazing height	12-35 days	-	20.0
Miles et al. 2000	-	-	200-600	21.06
Fulkerson et al. 2006	Grazing height	-	-	27.6
Gherbin et al. 2007	50 mm	28 days	-	15.2
Botha et al. 2008a	50 mm	28 days	600	23.1-23-7

The poor availability of protein (Reeves et al. 1996) and restricted intake often experienced on kikuyu pastures (Jeffrey 1971) (regardless of a high CP content), has been identified as a possible reason for the poor animal performance often seen on kikuyu pastures. The high nitrogen content of kikuyu has even been linked to the poor intake often experienced on kikuyu pastures (Pienaar et al. 1993b). The poor production response of animals grazing kikuyu to rumen undegradeable protein supplementation (Reeves et al. 1996b) and readily degradable protein supplementation (Brand et al. 1999), however, indicates that this is unlikely.

Fulkerson et al. (1999) reported that the protein content of kikuyu shows seasonal variation, with values during summer and the autumn-winter period significantly higher than during spring, whilst Dugmore and Du Toit (1988) recorded a peak in N concentrations of kikuyu during autumn. Animals have been found to select a diet with a different CP content to the pasture on offer, in this manner maintaining their CP intake at a relatively constant concentration, regardless of seasonal changes in sward CP concentrations of kikuyu (Dugmore et al. 1991, Brand et al. 1999). For example, sheep were capable of selecting kikuyu pasture higher in CP during certain months but lower in CP when kikuyu reaches its highest concentrations (Brand et al. 1999). Dugmore et al. (1991) hypothesized that animals have an optimum CP concentration according to which they select pasture, and that management such as fertilisation and grazing should be aimed at maintaining this level.

The N concentration in kikuyu herbage increases with increased N application rates (Awad et al. 1979), with the increase especially marked at four weeks of re-growth when compared to longer cutting intervals (Gomide et al. 1969a). The reduction in protein accumulation after six weeks of re-growth has been attributed to an exhaustion of soil organic nitrogen, rather than the maturation process of the grass itself (Whitney 1974b). The response of the CP content in kikuyu tends to be seasonally affected by fertilisation practices, with lime application reported to increase the N concentration of kikuyu during autumn and winter, a period when N content was found to be unaffected by N fertilisation (Figure 3.2).

The CP content of N fertilised kikuyu was found to decline with increased age from 21.6 % at four weeks to 13.1% at 32 weeks, with the greatest drop occurring between four and eight weeks of age (Gomide et al. 1969a), after which CP content tended to level off (Whitney 1974b). Fulkerson et al. (1999) also reported a significant decline (approximately 1.4 %) in the nitrogen concentration of kikuyu when grazed at a 6 leaves/tiller rather than at 2 leaves/tiller stage, while Reeves et al. (1996b) found that the CP concentration of kikuyu exhibited a marked decline after the 4½ leaves/tiller stage of re-growth.

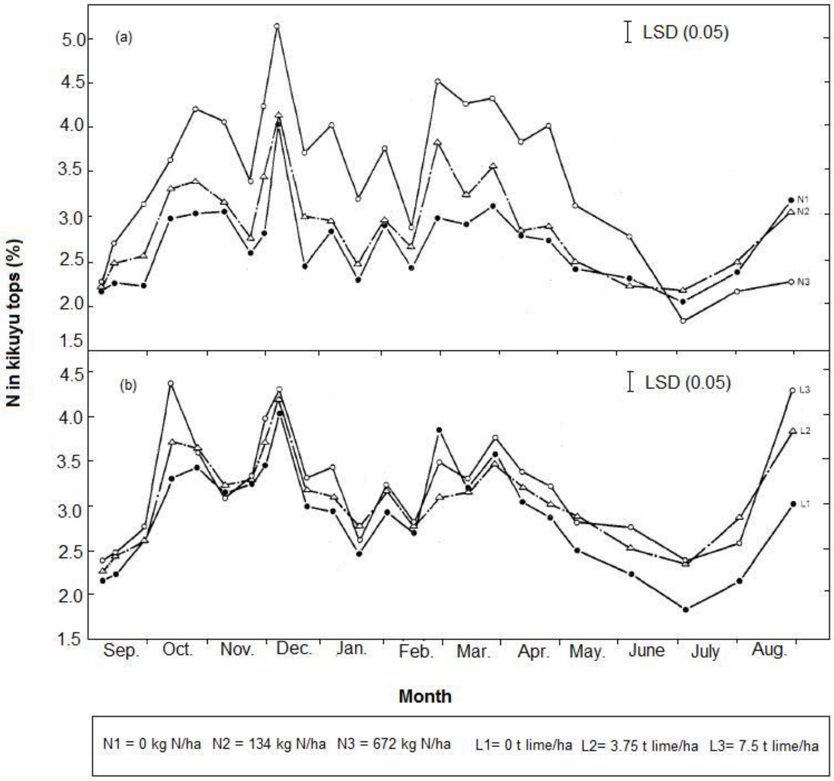

Figure 3.2: Seasonal changes in nitrogen (N) concentration in a kikuyu pasture at different rates of a) different nitrogen application and b) lime application (Awad et al. 1979)

The NPN content of N-fertilised kikuyu has been reported to be lower than for other tropical species such as stargrass (*Cynodon nlemfuensis*) and coastgrass II (*Cynodon dactylon*) (Le Roux et al. 1984), but higher than for temperate species such as ryegrass (Reeves et al. 1996b), with peak levels occurring during late summer and autumn (Van der Merwe 1999). A negative relationship has been reported between the NPN content and the dry matter intake (DMI) of kikuyu, with high NPN concentrations, particularly during summer and autumn, a possible reason for the low DMI and low animal production from kikuyu pastures during this period (Dugmore and Du Toit 1988). Furthermore, high levels of N in young re-growth of kikuyu may result in excessive rumen ammonia, which is lost in the form of urea via urine and milk (Marais 2001). The contribution of different nitrogenous compounds to the CP of kikuyu is shown in Table 3.5. The true protein content is higher in the leaf tissue of kikuyu than in stem tissue, with the stem having higher levels of nitrate nitrogen and non-protein organic nitrogen (Marais 1980, Marais et al. 1987). The contribution of true protein to the organic nitrogen is as high as 77% in the leaf tissue, with true protein only making up 59% of the nitrogen in the stem tissue (Marais 1990). The age of re-growth in kikuyu also affects the contribution of the different nitrogenous components to CP, with the nitrate levels generally decreasing as individual leaves age, whilst non-protein organic nitrogen (NPON) and protein N levels increase (Marias et al. 1987).

Table 3.5: The contribution of different components to crude protein content in the leaves, stem and total sward of kikuyu (Marais 1990)

	Crude protein	Protein N	NPON[1]	Nitrate
Sward	36.0	25.2	10.9	4.02
Stem	30.1	17.7	12.4	6.77
Leaf	41.1	31.5	9.5	1.74

[1] Non protein organic nitrogen

The digestible crude protein (DCP) content of kikuyu shows some seasonal variation, decreasing from spring to summer (Van Ryssen et al. 1976, Bredon 1980), then increasing considerably from summer to autumn (Van Ryssen et al. 1976). The universal protein digestibility co-efficient often used to calculate the DCP content of pasture forages has been found to not be applicable to kikuyu pastures, with Jeffrey (1971) and Bredon (1980) recommending that a unique co-efficient be developed for kikuyu and different kikuyu pasture types.

3.4.3 Non-structural carbohydrates and water soluble carbohydrates

Carbohydrates are the major source of energy in diets fed to dairy cattle, and usually comprise 60 to 70 percent of the total diet. The main function of the carbohydrates is to provide energy for rumen microbes and the host animal. A secondary, but essential, function of certain carbohydrates is to maintain the health of the gastrointestinal tract. The carbohydrate fraction of feed is a complex mixture of various monomers and polymers that are usually defined according to analytical procedures and availability to the animal. Carbohydrates are broadly classified as either structural or non-structural. Non structural carbohydrates (NSC) are found inside cells of plants and are usually more digestible than structural carbohydrates that are found inside cell walls (NRC 2001).

Sugars, starches, organic acids, and other reserve carbohydrates make up the NSC fraction and are major sources of energy for high producing dairy cattle. Non-structural carbohydrates are highly digestible and generally increase in the diet at the expense of neutral detergent fibre (NRC 2001). Non structural carbohydrates can be divided into water soluble carbohydrates (WSC) and starch. Sub-tropical species, such as kikuyu, generally accumulate starch in their vegetative tissue, rather than fructans as is the case with temperate species (McDonald et al. 2002).

The NSC content in kikuyu is generally lower than for ryegrass (Betteridge 1979, Andrewes and Jagger 1999, Fulkerson et al. 2007), with higher concentrations occurring during spring than autumn/winter (Betteridge 1979). In addition, the concentration of WSC is lower in kikuyu than temperate pasture grasses (Reeves *et* al. 1996b, Fulkerson et al. 1998, Dugmore 1999, Fulkerson et al. 2007), due to the main storage polysaccharide in kikuyu being starch (Reeves et al. 1996b, Fulkerson et al. 1998). Results reported by Fulkerson et al. (1998) indicated that the WSC content of kikuyu declined during winter, increased from spring until it peaked in summer during January/February, before decreasing slightly in early autumn (Figure 2.3). The NSC content of kikuyu is highest in spring and lowest in autumn/winter (Fulkerson et al. 1999). The average WSC content reported for kikuyu by Fulkerson et al. (1999) was 5.9 %, which is comparable to levels of 5% reported by Dugmore (1999). Fulkerson et al. (2007) reported slightly lower values for the WSC content in kikuyu with peak levels reached during summer at 3.7% and minimum levels of 2.0 % occurring during autumn.

The NSC content in kikuyu is reported to be high up to 10 days of re-growth (1 ½ leaves/tiller), after which it gradually drops until it stabilizes at 3½ leaves/tiller. This contrasts with the pattern seen in perennial ryegrass, where the WSC content increased in the plant until approximately 3 leaves/tiller had emerged (Fulkerson et al. 1998). Cutting height affected the WSC content in kikuyu, with an increase from 3.9 to 5.1% occurring as defoliation height increased from 30 to 60 mm. The same effect was found for starch content, which increased from 4.5 to 5.5% at the same heights (Fulkerson et al. 1999). Reeves et al. (1996b) recommended that correct timing of grazing during the day may increase the WSC intake of animals grazing kikuyu, since WSC levels in kikuyu increased during the day and then decreased at night.

Fulkerson et al. (1998) did extensive research on how the WSC, CP and the CP: WSC ratio changed in perennial ryegrass and kikuyu as plants aged. The results (Figure 3.3) indicated that although WSC levels increased for a longer period of re-growth in perennial ryegrass, CP levels decreased during the same period. In contrast the NSC concentration in kikuyu dropped as the plant aged, while the CP level remained relatively constant throughout the period. As result the CP: WSC ratio decreased from the 1 to 3 leaves/tiller stage in perennial ryegrass, while the CP: NSC ratio remained relatively constant at 2.8:1 in kikuyu between the one and 4½ leaves/tiller stage. The CP:WSC of kikuyu also tended to vary according to season, with highest values occurring during the winter months. The CP:WSC ratio in ryegrass is on average higher than for kikuyu (Reeves et al. 1996b, Fulkerson et al.

1998), with the CP:WSC ratio of ryegrass at 0.36 up to four times higher than that of kikuyu at only 0.09 (Reeves et al. 1996b).

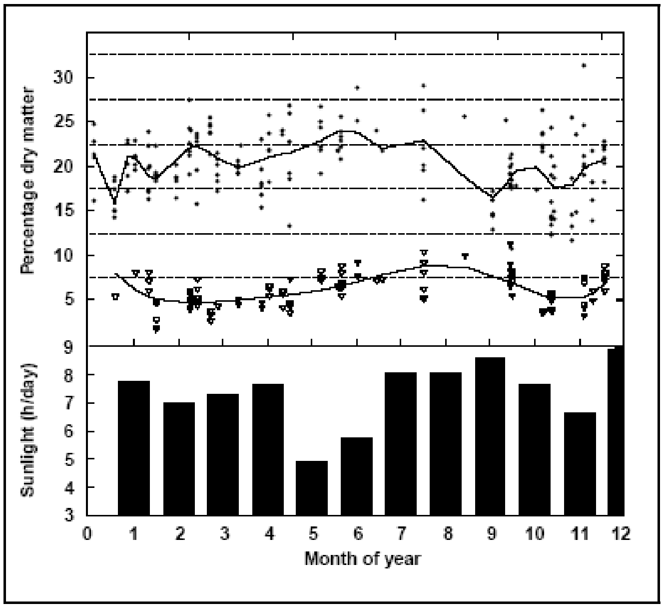

Figure 3.3: Percentage water-soluble carbohydrate (▼) and crude protein (●), and sunshine hours (closed bar) for kikuyu pastures throughout the year. Adjusted r^2 values are: 0.33, WSC; 0.20, crude protein. Month 1: July; Month 12: June (Fulkerson et al. 1998)

3.4.4 Crude fibre, Neutral detergent fibre and acid detergent fibre

Crude fibre (CF), neutral detergent fibre (NDF) and acid detergent fibre (ADF) are the most common measures of fibre used for routine feed analysis, but none of these fractions are chemically uniform. Neutral detergent fibre measures most of the structural components in plant cells (i.e., cellulose, hemicellulose and lignin). Acid detergent fibre does not include hemicellulose, and CF does not quantitatively recover hemicellulose and lignin. Neutral detergent fibre is the method that best separates structural from non-structural carbohydrates in plants, and also measures most of the chemical compounds considered to comprise fibre. (NRC 2001)

In accordance with NRC (2001) neutral detergent fibre will be discussed more extensively than ADF because it is regarded as the best expression of fibre availability, but some mention of ADF will also be made due to its wide spread use, while CF will only be mentioned very briefly. The ADF, NDF and CF content of kikuyu is shown in Table 3.6.

Kikuyu tends to have a lower CF content than other tropical species (Gherbin et al. 2007) with values ranging between 22.9 % (Gherbin et al. 2007) and 29.4% (Gomide et al. 1969). Animals have been found to select a diet higher in CF than the pasture on offer, at least for CF levels below 30%, indicating the selection of older, more mature leaf material. The difference in CF content between selected material and available herbage is predicted to decrease as the CF content of the herbage increases (Dugmore et al. 1991).

Table 3.6: The acid detergent fibre (ADF), neutral detergent fibre (NDF) and crude fibre (CF) content (%) of kikuyu

Reference	ADF	NDF	CF
Joyce 1974	32.9-33.0	-	-
Dugmore and Du Toit 1988	-	-	24.4
Dugmore et al. 1991	-	-	28.5
Reeves et al. 1996b	23.1	60.3	-
Brand et al. 1999	39-50	60-90	-
Dugmore 1999	35	65	-
Fulkerson et al. 1999	-	43-56	-
Miles et al. 2000	29.7	63.1	-
Fulkerson et al. 2006	22.7	56.7	-
Fulkerson et al. 2007	23.1-26.1	50.3-63.9	-
Botha et al. 2008a	_	62.6-64.7	-

The NDF content of kikuyu varies between 60 to 90% (Table 3.6) and differs on a seasonal and monthly basis. The structural carbohydrate content of kikuyu increases from 42.6 to 51.2 % from spring to autumn (Betteridge 1979), indicating the accumulation of structural carbohydrates as the growth season progresses. As the growth season progresses the proportion of stem and senescent material present in kikuyu swards increases, while the proportion of leaf material decreases, resulting in animals having to ingest material of a higher NDF content later in the season (Pienaar et al. 1993a). The lowest NDF concentrations for kikuyu occur during mid-winter and spring (45%), attributed to the low growth rate of kikuyu during this period, whilst the NDF content during active growth is higher at 60% (Fulkerson et al. 1998). Fulkerson et al. (1999) reported that NDF concentrations in kikuyu were highest in summer and lowest in spring, while autumn-winter concentrations were intermediate. In contrast, data from Fulkerson et al. (2007) showed that the NDF content of kikuyu was lowest in summer (50.3%), with highest concentrations occurring during spring (63.9%) and intermediate concentrations during autumn (53.5%).

It has been reported that the digestibility of the NDF fraction in kikuyu seems to improve from spring to autumn, which indicates that although NDF levels are high, the animal might still be able to easily digest kikuyu pasture during autumn (Betteridge 1979). In addition Fulkerson et al. (2007) found that although the NDF levels of kikuyu are high (63.9%) during spring compared to temperate species (55.7%), a large contribution of hemicellulose to this fraction may result in a higher than expected ME value regardless of the high NDF content. Due to the fact that animals grazing kikuyu tend to select a diet lower in both ADF and NDF than the pasture on offer, animals can select pasture of a higher quality than that on offer, regardless of seasonal changes (Brand et al. 1999). Fulkerson et al. (2007) reported that at 50.3% kikuyu had one of the lowest NDF levels during summer compared to various grass species, including perennial ryegrass (51.5%).

The defoliation interval also influences the NDF content of kikuyu, with longer defoliation intervals resulting in higher NDF values (Fulkerson et al. 1999). The NDF content in kikuyu was found to increase from 49 to 52 % when grazed at 2 and 4 leaves/tiller intervals respectively, and then decreased slightly to 50 % at the 6 leaves/tiller interval (Fulkerson et al. 1999). A decline in the rate of NDF disappearance when kikuyu re-growth was older than 28 days indicates that the fibre in kikuyu becomes less digestible if plant material is removed less than once a month (Cruywagen et al. 2007).

The acid detergent fibre (ADF) content of kikuyu varies between 23 and 50% (Table 3.6). The ADF levels of kikuyu rarely falls below 21%, whereas the ADF content of ryegrass is often below this level during winter (Fulkerson et al. 1998, Andrewes and Jagger 1999). The highest ADF content for kikuyu occurs during spring, coinciding with the lowest NDF content, while the lowest ADF concentrations occur during autumn (Fulkerson et al. 2007). Fulkerson et al. (2007) also drew attention to the fact that kikuyu is capable of maintaining a level of 502 g ADF kg^{-1} NDF during summer (similar levels to perennial ryegrass) under sub-tropical conditions. The ADF content of kikuyu was affected by N fertilisation, with ADF levels increasing as N fertilisation rates increased (Whitney 1974a).

3.4.5 Metabolisable energy

The metabolisable energy (ME) content of kikuyu, as reported in the literature, is given in Table 3.7, with content ranging from 8.13 to 9.9 MJ kg^{-1} DM. Very low levels of ME (8.92 MJ kg^{-1} DM in summer and 8.13 MJ kg^{-1} DM in autumn) have been recorded in kikuyu (Botha et al. 2008a), with similar values obtained by Fulkerson et al. (1998). Kikuyu generally has a lower ME content than ryegrass (Fulkerson et al. 1998, Andrewes and Jagger 1999), but has been reported to have a similar ME content (9.9 MJ kg^{-1}) to perennial ryegrass in summer (Fulkerson et al. 2007).

Table 3.7: The metabolisable energy (ME) content (MJ kg^{-1} DM) of kikuyu

Reference	Season	ME
Joyce 1974	Summer/Autumn	8.4
Fulkerson et al. 1998	Spring/Summer	8.5
	Winter	9.5
Dugmore 1999	Spring	9.3
	Summer	9.0
	Autumn	8.8
Fulkerson et al. 1999	Not given	8.15-9.30
Fulkerson et al. 2006	Not given	10.3
Fulkerson et al. 2007	Spring	9.5
	Summer	9.9
	Autumn	9.0
Botha et al. 2008a	Summer	8.92
	Autumn	8.13

The ME content of kikuyu exhibits a definite seasonal pattern. Fulkerson et al. (1998) reported mean ME values for kikuyu of 8.5 MJ kg^{-1} DM during the summer and values of 9.0 MJ kg^{-1} DM during the winter, although he indicated that the latter value was represented by few data points. Fulkerson et al. (1999) also reported a seasonal variation in the ME content of kikuyu, with summer values significantly lower than during both autumn-winter and spring. The data reported by Fulkerson et al. (2007) illustrated a slightly different trend, with the highest ME values reported for kikuyu in summer, followed by spring and the lowest values in autumn. Dugmore (1999) reported ME values for kikuyu of 9.3 MJ kg^{-1} DM during summer, 9.0 MJ kg^{-1} DM during spring and 8.8 MJ kg^{-1} DM during autumn. The ME content of kikuyu is not sensitive to changes in defoliation height, but variation in ME content has been found at different defoliation intervals, with higher ME contents obtained at shorter intervals. Metabolisable energy concentration decreased from 9.1 MJ kg^{-1} at 2 leaves/tiller to 8.6 MJ kg^{-1} DM at 6 leaves/tiller (Fulkerson et al. 1999). The ME content of the leaf component (11.0 MJ kg^{-1}) is considerably higher than in the stem (8.8 MJ kg^{-1} DM) (Moir et al. 1979), highlighting the need to maintain a leafy sward in kikuyu pastures.

The poor performance of animals grazing kikuyu has been attributed primarily to an inadequate intake of ME. The consequence is that animals have to utilize protein as an alternative energy resource, further compounding the nutrient deficiencies in animals grazing kikuyu (Joyce 1974). A low level of digestible energy in kikuyu has been implicated in the poor retention of nitrogen by animals grazing this pasture, as digestible energy levels are not adequate to sustain an efficient conversion of plant nitrogen to microbial nitrogen in the rumen (Marais et al. 1990). Research by Reeves et al. (1996a) confirmed that milk production levels of cows grazing kikuyu were influenced by ME levels in the diet rather than protein, since the feeding of a supplement high in rumen undegradeable protein (UDP) did not improve milk yield. Moir et al. (1979) concluded that whether ME was the first factor limiting milk production was dependant on management, its effect on the ME content and the production potential of the animals grazing the kikuyu. These findings were based on the fact that some trial animals were capable of maintaining high levels of milk production at the expense of body weight. The milk production of other animals was however lower due to limited intake and lower genetic capacity.

3.4.6 Digestibility

The digestibility of kikuyu ranges from 60-70% (Quinlan et al. 1975, Dugmore and Du Toit. 1988, Pienaar et al. 1993a). Kikuyu tends to have higher digestibility values than most tropical species (Quinlan et al. 1975, Pearson et al. 1985, Evans and Hacker 1992) but the organic matter digestibility (OMD) is still lower than that of ryegrass (Betteridge 1979, Fulkerson et al. 1998).

The digestibility of kikuyu stems is reported to be higher than for other tropical grass species such as Bermuda grass and Paspalum (*Paspalum dilitatum*), with similar leaf digestibility to Paspalum. Compared to these species, kikuyu also displayed the smallest variation in digestibility over seasons (Pearson et al. 1985). Kikuyu tends to maintain a higher dry matter digestibility (DMD) over the years after establishment than other tropical grasses (Evans and Hacker 1992).

The OMD of leaf material is higher than for stem material (Moir et al. 1979), with OMD declining after 4½ leaves/tiller as the proportion of leaf material declines and stem and dead material increases (Reeves et al. 1996a). The digestible organic matter (DOM) content of kikuyu shows two distinct peaks, one in autumn and one in spring (Betteridge 1979, Dugmore and Du Toit 1988), both periods associated with increased leafiness in kikuyu swards. The *in vitro* digestibility of kikuyu can drop from 73.2% in good quality well managed kikuyu to 64.2% in old rank kikuyu (Andrewes and Jagger 1999). Animals grazing kikuyu are capable of selecting a diet higher in OMD than the pasture on offer (Dugmore et al. 1991, Brand et al. 1999). This effect may, however, be reduced at restricted levels of intake, as animals are forced to graze a more fibrous kikuyu component at the base of the standing pasture (Betteridge 1979). Regardless of the above mentioned the intake of OMD by ewes grazing kikuyu during lactation was still inefficient (Brand et al. 1999).

The OMD of kikuyu varies over seasons, with OMD values declining from 59.2% in February to 34% in July, then increasing again towards November (Brand et al. 1999). Digestibility of kikuyu can remain relatively constant at approximately 70% throughout summer and autumn, provided that the kikuyu is grazed at the same stage of growth during this period (van Ryssen et al. 1976).

There appears to be an optimal level for CP in the diet of 14% and when levels fall below this animals tend to select for a diet higher in CP (Dugmore et al. 1991). Results from reported by Joyce (1974) demonstrated that sheep grazing kikuyu excreted high levels of N in their urine, indicating that animals possibly utilize protein as an alternative energy source. This was confirmed by Marais et al. (1990) who found that the DM digestibility of kikuyu increased from 50.6 % to 61.1% when sheep were supplemented with maize.

Nitrate levels in kikuyu affect *in vitro* digestibility (Marais 1980), with digestibility stimulated at low nitrate levels (0.1 mg g^{-1}), but with a reduction in *in vitro* digestibility of up to 26% as nitrate levels increase to 8.0 mg g^{-1}. Marais (1980) reported that this reduction was one of the highest recorded in various temperate and tropical pastures and that the high nitrate levels found in kikuyu is one of the most likely factors contributing to the low animal production observed from these pastures.

3.5 Mineral composition of kikuyu

3.5.1 Calcium

The calcium (Ca) content of kikuyu, as reported in the literature, varied between 0.25% and 0.52% (Table 3.8). The Ca concentration of kikuyu is marginal (Fulkerson *et al*., 1993) and tends to be lower than levels found in temperate species (Kaiser 1975), but similar to most tropical species.

The Ca concentration in kikuyu exhibits a distinct seasonal trend, with minimum concentrations occurring during mid-summer and higher concentrations occurring during spring and autumn (Miles et al. 1995). The highest Ca concentration in kikuyu occurs during the autumn-winter period (Fulkerson et al. 1999). Cows grazing kikuyu were found to have low blood calcium levels at the end of summer, with these levels coinciding with low conception rates (Dugmore 1999). Although the absolute concentrations of Ca in kikuyu may be adequate for grazing animals, the effective level could still be marginal due to a large proportion of Ca binding to insoluble oxalate (Fulkerson et al. 1998). This effect is further aggravated by the fact that the bulk of kikuyu dry matter is produced in summer when Ca concentrations in the pasture are at their lowest (Miles et al. 1995).

The Ca concentration in kikuyu is affected by its growth rate (Awad et al. 1976). During the rapid initial growth of kikuyu Ca content can be as low as 0.11%, but rapidly increases once growth rate decreases. Defoliation interval will thus also play a role in the Ca concentration of kikuyu, with the Ca concentration increasing from 0.22% at 4 leaves/tiller to 0.26% at 6 leaves/tiller (Fulkerson et al. 1999). The Ca content of individual leaves will also increase as leaf age increases (Reeves et al. 1996a). However, once plant age exceeds 4 weeks a drop in Ca content of kikuyu has been recorded (Gomide et al. 1969b). This could be attributed to an increase in the proportion of stem material as the kikuyu matures, which has been found to have a lower Ca concentration than leaf material (Marais 1990).

3.5.2 Phosphorous

The phosphorous (P) concentrations in kikuyu are higher than in most tropical species (Gomide et al. 1969b, Awad et al. 1979), ranging from 0.18% to 0.50% (Table 3.8).

The P content of kikuyu is marginal (Fulkerson et al. 1993a), with the deficiency often aggravated by the fact that phosphorus deficiency is one of the most widespread deficiencies in South Africa. The P content of kikuyu was found to be highest during the period of most active growth (in the summer-autumn period) and lowest during spring when growth rates were minimal (Fulkerson et al. 1998, Fulkerson et al. 1999). Awad et al. (1979) recorded a similar pattern, with the P content minimal in spring, but in this case P reached peak concentrations during mid-autumn and decreased afterwards. The summer concentration of P in kikuyu is generally adequate for animal production, but concentrations during the spring and autumn periods may be marginal (Miles et al. 1995). The P content of tropical grasses, including kikuyu, decreases with plant age (Gomide et al. 1969b).

2.5.3 Magnesium

The magnesium (Mg) content of kikuyu shows seasonal variation, but cited literature differs in opinion as to when maximum and minimum concentrations are reached. Miles et al. (1995) reported that the Mg concentration in kikuyu is highest during spring and autumn and lowest during summer when the growth rate of kikuyu is at its greatest, with seasonal trends in Mg concentrations similar to that of Ca and the inverse to that of P concentrations. Awad et al. (1979) reported a different pattern, with the concentration of Mg in kikuyu lowest during winter-spring and highest during summer when temperatures were higher and growth more prolific. However, it should be noted that there was a clover component in the pastures analyzed by Awad et al. (1979).

Although the Mg concentrations found in kikuyu are higher than various other tropical species (Evans and Hacker 1992), dairy cows at Cedara in South Africa have responded to magnesium supplementation on kikuyu through improved fertility (Dugmore 1999). The Mg in fresh herbage is relatively unavailable to grazing animals, with the effect confounded when potassium and nitrogen levels are high due to their antagonistic effect on magnesium uptake by the plant (Dugmore 1999). The high K levels often found in kikuyu can thus aggravate the Mg deficiency in kikuyu by reducing the availability of Mg to grazing animals (Miles et al. 1995). The Mg content of kikuyu has been found to increase as the pasture increased in age (Reeves et al. 1996b), resulting in recommendations on the correct timing of grazing advocating longer defoliation intervals for kikuyu.

3.5.4 Potassium

The potassium (K) content of kikuyu has been reported to exceed the requirements of most grazing animals (Marais 1990). The dietary concentration at which potassium toxicity occurs is not well defined, but very high levels of potassium can present metabolic and physiological challenges for grazing animals and result in the excretion of large amounts of potassium into the environment (NRC 2001).

The K concentrations in kikuyu tend to decline progressively from summer, through autumn-winter, to the lowest concentrations during spring (Fulkerson et al. 1999). Miles et al. (1995), however, did not report any significant seasonal trends for the K concentrations in kikuyu. Kikuyu maintains a higher K content than other tropical species, as well as showing a less pronounced decrease than the other species with age (Gomide et al. 1969b). Regardless of this, the concentration of K in kikuyu does decrease as the plant ages (Reeves et al. 1996b). A relationship between N and K was noted by Miles et al. (1995), with high N fertilisation rates promoting the luxury uptake of K in kikuyu.

3.5.5 Sodium

Kikuyu is a natrophobic plant, which means it accumulates its sodium (Na) in its roots and not leaves (Dugmore 1999). For this reason kikuyu tends to have marginal sodium levels (Evans and Hacker 1992, Miles et al. 1995) that are below those reported in temperate species such as ryegrass (Reeves et al. 1996b). Sodium concentrations in kikuyu were lower during spring than in autumn (Betteridge 1979) and tend to be at their lowest during summer months (Reeves et al. 1996b).

3.5.6 Zinc and Copper

Zinc (Zn) and Copper (Cu) concentrations, at 29 mg kg^{-1} and 14 mg kg^{-1} respectively, tend to be marginal for high producing dairy cows grazing kikuyu (Fulkerson et al. 1998). Miles et al. (2000) also noted the deficiency in Cu of kikuyu, although levels were considerably lower at 6mg kg^{-1}. The low concentrations of Zn and Cu in kikuyu may reduce milk yields, reproductive performance and disease resistance (NRC 2001).

Table 3.8: The mineral (phosphorous (P), calcium (Ca), magnesium (Mg), potassium (K) and Sodium (Na)) content (%) of kikuyu

Reference	Description	P	Ca	Mg	K	Na
Gomide et al. 1969b	-	0.18	0.42	0.32	0.86	-
Kaiser 1975	-	0.31	0.35	0.40	3.66	0.03
Betteridge 1979	Spring	0.38	0.60	0.18	2.78	0.04
	Autumn	0.40	0.84	0.21	2.72	0.09
Marais 1990	-	-	0.20	-	-	-
Evans and Hacker 1992	-	0.29	0.38	0.20	2.41	0.08
Miles et al. 1995	Site 1	0.35	0.26	0.28	4.10	0.04
	Site 2	0.33	0.28	0.32	3.42	0.04
	Site 3	0.35	0.31	0.32	3.45	0.04
Reeves et al. 1996a	Mar/Apr	0.27	0.31	0.27	3.82	0.04
	May	0.24	0.50	0.34	3.11	0.04
	Feb	0.31	0.31	0.22	3.07	0.02
Reeves et al. 1996b	Early season	0.39	-	0.31	2.05	0.03
	Midseason	0.39	-	0.31	1.58	0.05
	Late season	0.34	-	0.58	1.18	0.03
	Mean	0.31	0.31	0.22	3.07	0.02
Fulkerson et al. 1998	-	0.28	0.42	0.29	2.91	0.10
Fulkerson et al. 1999	Summer	0.33	0.25	-	2.92	-
	Autumn-Winter	0.27	0.34	-	2.63	-
	Spring	0.26	0.26	-	1.69	-
Miles et al. 2000	-	0.40	0.52	0.36	3.40	0.36
Meeske et al. 2006	-	0.33	0.43	0.36	3.0	0.03
Botha et al. 2008a	Summer	0.51	0.32	-	-	-
	Autumn	0.58	0.36	-	-	-

3.6 Anti-quality factors of kikuyu

3.6.1 Mineral imbalances

Kikuyu is well known for its inverse Ca:P ratio, since it often contains more P than Ca (Miles et al. 1995), which necessitates the supplementation of grazing cows with feedlime (Dugmore 1999).

The Ca:P ratio is lowest during active growth (summer) at 1.2:1 and highest during spring at about 2.3:1 when pastures are relatively dormant (Fulkerson et al. 1998). The Ca:P ratio of 0.62-0.63:1 reported by Botha et al. (2008a) for the summer/autumn period is well below the recommended Ca:P ratio of 1:1 for grazing animals (NRC 1989). The Ca and P content of kikuyu tend to follow a mirror image in their levels (Fulkerson et al. 1998) reaching their minimum and maximum levels in inverse patterns. The Ca:P ratio of kikuyu can fall as low as 0.5:1 during summer (Miles et al. 1995). Under these circumstances it becomes nearly impossible to supplement animals with enough lime (23 Ca m m^{-1}) (without upsetting the rumen environment) to correct the Ca deficiency (Bredon 1980).

The unfavourably high K:Na ratio found in kikuyu may have a negative impact on the reproductive performance of animals (Fulkerson et al. 1998). For this reason Fulkerson et al. (1998) recommended that cows be supplemented with NaCl. Supplementation of animals with minerals has been indicated to improve animal production (Kaiser 1975).

The high K/Mg+Ca ratio found at times in kikuyu has been linked to periodical illness experienced in dairy cattle grazing kikuyu pastures. Miles et al. (1995) attributed the low incidence of grass tetany in cows grazing kikuyu to the supplementation of animals with Mg in concentrate feeds. Colman and Kaiser (1974) however reported that animals showing symptoms under these conditions did not respond to supplementation with intravenous Ca, Mg and K, and as such were of the opinion that the mineral imbalance was not related to the sick animals. Liming can reduce the severity of the high K/Mg + Ca ratio in kikuyu to levels that are more acceptable, especially under acidic soil conditions and when N fertilisation rates are very high (Awad et al. 1979). High levels of K in the soil could also lead to luxury uptake of K by kikuyu, which can result in a marked decline in the concentrations of Ca, Mg and Na in plants (Miles 1991), thus resulting in mineral imbalances. In addition, Ca and Mg levels in kikuyu are both at their lowest during the summer months, thus the K/ Ca + Mg ratio of kikuyu will also be at its lowest during this period (Miles et al. 1995).

3.6.2 Oxalate

Kikuyu contains higher concentrations of insoluble oxalate than various other tropical (Marais 1990) and temperate grasses (Reeves et al. 1996b). The above, combined with the low concentrations of Ca found in kikuyu, could affect the performance of grazing animals by altering the digestibility of kikuyu and inducing Ca deficiencies (Marais 1990). Figure 3.4 indicates how oxalate impacts on the health of a grazing animal (Marais 2001).

Soluble oxalate in kikuyu should, however, not present any real health hazard to ruminants which are adapted to oxalate, since they are capable of breaking it down to less harmful substances in the rumen (Marais 1990). In addition, sheep grazing kikuyu have been found to posses the ability to select pasture lower in oxalate than the pasture on offer, thereby also reducing the risk of toxicity (Pienaar et al. 1993a).

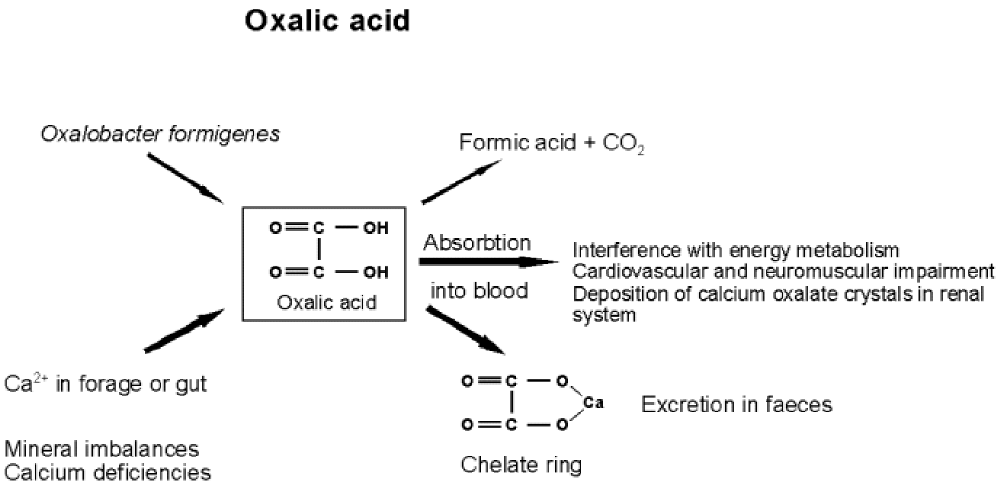

Figure 3.4: The impact of oxalate on the grazing animal (Marais 2001)

Marais (1990) reported the oxalate content of kikuyu to be approximately 9g kg^{-1} DM, consisting of almost equal amounts of soluble and insoluble oxalate, with stem tissue containing appreciably higher concentrations of insoluble oxalate than the leaves tissue.

Fertilising with KCl and NaCl did not have an effect on the oxalate concentrations in kikuyu, indicating that this specie does not use K or Na to form unusually high oxalate concentrations (Williams et al. 1991). Nitrogen fertilisation has, however, been found by Marais (1990) to increase the oxalate concentration in kikuyu.

3.6.3 Nitrate

In most instances nitrate absorbed by a plant is rapidly reduced to ammonia, after which it is incorporated into mainly proteins and nucleic acids. However, there are certain instances when nitrate uptake may exceed assimilation rates in the plant, resulting in excessive nitrate concentrations in the plant (Marais 1980). Nitrate in itself is relatively non-toxic to animals, but is readily reduced to ammonia in the rumen, with nitrite as an intermediate product (Marais 2001). If nitrite is absorbed into the bloodstream it can form methaemoglobin which is unable to bind oxygen, resulting in oxygen starvation of tissues and eventually death (Marais 2001). This process whereby nitrate is converted to nitrite in the rumen is illustrated in Figure 3.5.

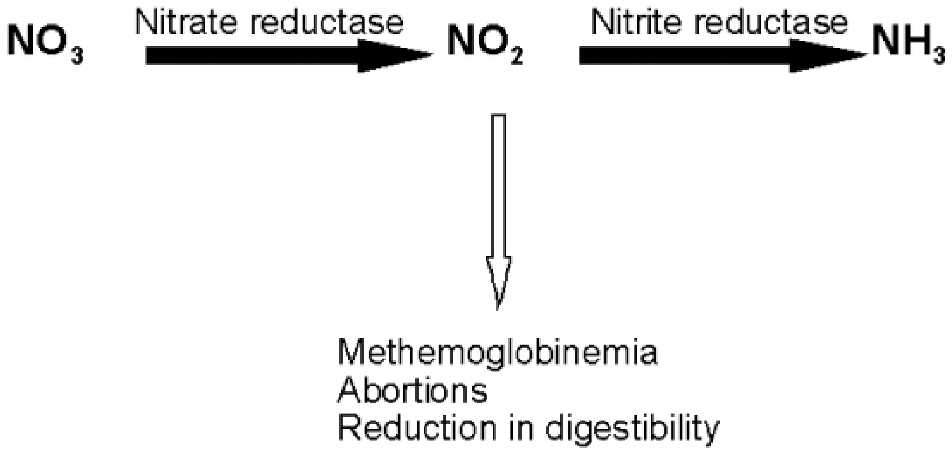

Figure 3.5: Reduction of nitrate to nitrate in the rumen (Marais 1999)

Aside from the direct negative impact on the health of grazing animals, high levels of nitrate in kikuyu may negatively affect the rumen organisms and digestion, resulting in lowered production without any visible systems of toxicity (Marais 1980). The high nitrate concentrations of kikuyu have also been identified as the most likely cause for the low animal production often seen on these pastures (Marais 1980). The nitrate concentration tends to increase as kikuyu ages and accumulate at a higher level in stem than leaf tissue (Marais et al. 1987).

Reeves et al. (1996b) found that once the CP content of kikuyu exceeded 23%, the nitrate level also rose dramatically, indicating a relationship between the CP content of kikuyu and nitrate concentrations in the kikuyu. An inverse relationship exists between the nitrate concentrations in kikuyu and other nitrogenous compounds, with non-protein organic nitrogen (NPON) and protein N concentrations generally high when nitrate concentrations are low and *vice versa* (Marais et al. 1987).

The rate at which nitrogen fertilisation occurs will affect the levels of nitrate in kikuyu, with the effect often compounded by season. As the rate of nitrogen fertilisation increases, nitrate levels tend to increase in kikuyu (Reeves et al. 1996b). Marias (1980) illustrated that fertilising kikuyu at a rate of 120 kg LAN ha^{-1} during spring was insufficient for both dry matter production and high nitrate accumulation in kikuyu. However, by the end of the growing season the same fertiliser regime resulted in higher concentrations of nitrate. This pattern is related to the growth pattern of kikuyu, with nitrate concentrations in kikuyu lower during the period when growth rate is at its highest (summer) while concentrations increase rapidly, when growth rate declines, such as during autumn (Marais et al. 1987).

The form in which nitrogen fertilisation is applied will also affect nitrate accumulation, with urea rapidly increasing nitrate to toxic levels if soil already contains high nitrate levels or environmental conditions are such that ammonia is rapidly converted to nitrate. Manure applied at high concentrations can also result in increased nitrate concentrations in kikuyu (Williams et al. 1991). Another contributing factor to the rate at which nitrate accumulates in kikuyu is the soil organic nitrogen status, with fertilised kikuyu growing in soil with a high soil organic nitrogen status accumulating nitrate more rapidly (Marais 1980, Marais et al. 1987). Kikuyu should be allowed a period of two weeks recovery following N fertilisation to reduce the risk of high nitrate in pastures offered to grazing animals (Pienaar et al. 1993a).

3.7 Management of kikuyu

3.7.1 Establishment of kikuyu

The only commercial cultivar of kikuyu for which seed is currently available in South Africa is “Whittet”. In a weed free, well prepared seedbed, kikuyu can be established satisfactorily with seed using mechanical methods of planting. Establishment of kikuyu with seed is more tedious and slower than with vegetative material, primarily because the kikuyu seedlings are slow to establish/develop and very sensitive to both weed competition and frost. For this reason a good, weed free seed bed should be prepared and it must be ensured that the seed is planted long before frost normally occurs, at a rate of at least 2-3 kg ha^{-1}(Dickenson et al. 2004).

Kikuyu can be established very successfully with vegetative material (removed effectively with a rotavator), with various methods available (Dickenson et al. 2004):

- kikuyu slips planted by hand 450 mm x 450 mm apart;
- stolons and rhizomes buried at 100 mm in furrows and then tramped down;
- specialized sprig planters can be used to plant the rhizomes and stolons;

- stolons and rhizomes are cut into lengths and spread evenly onto the ground after which it is disced in and rolled to ensure good contact with the soil.

3.7.2 Nitrogen fertilisation

Many authors have reported on the responsiveness of kikuyu to nitrogen fertiliser (Mears and Humphreys 1974, Whitney 1974a, Awad & Edwards 1977, Le Roux et al. 1984, Miles 1997). Kikuyu production responds well to higher rates of nitrogen, at times better than other sub-tropical grasses (Le Roux et al. 1984). The fertiliser requirement of kikuyu is dependent on factors such as available moisture, length of growing season and the level of production required (Miles 1999). In addition, N fertilisation has been found to increase the proportion of kikuyu in pastures consisting of multiple species (Pearson et al. 1985).

The reaction of kikuyu to N fertilisation was reported by Pearson et al. (1985) to be affected by season, with the response nil during the winter and highest during summer months when growth rates were also at their highest (due to higher temperatures). Responses to nitrogen in summer are mainly in the form of increased kikuyu growth, and dependant on soil moisture levels, with values ranging from 3.5 kg DM kg^{-1} N when soil moisture levels are low and 20kg DM kg^{-1} N when rain and soil moisture levels are high (Andrewes and Jagger 1999).

High N fertilisation rates have been associated with increased soil acidity and high levels of soluble aluminium in the soil, which could be potentially toxic to plants and reduce yield (Awad and Edwards 1977). High N application rates of kikuyu pastures have also been connected to the depletion of soil K (Whitney 1974a). Moderate N fertilisation rates led to a higher yield (kg DM) per kg N applied than very high rates. Thus, the efficiency of N utilization is higher at more moderate N rates than at high rates (Awad and Edwards 1977) and the efficiency of N utilization by kikuyu decreases as the application rate increases (Miles 1999).

The excellent response of kikuyu to N fertilisation at rates between 450 and 650 kg N ha^{-1}, make it suitable for use in high input pasture systems that are heavily fertilised (Le Roux et al. 1984). Higher rates of N application at approximately 336 kg N ha^{-1} annum^{-1} have been reported to significantly increase the rate of N uptake by kikuyu compared to lower or no N applications (Mears and Humphreys 1974). Miles (1997) reported that if N was applied over six dressings, rather than three dressings, over the growth season of kikuyu, it improved the yield and in turn the efficiency of N utilization. Marais (2001) recommended a fertilisation rate of 300 to 500 kg N ha^{-1} administered in split dressings throughout the growing season to obtain optimum dry matter production from kikuyu.

Mears and Humphreys (1974) attempted to investigate and explain the complex interaction of stocking rate and nitrogen fertilisation. They found that the rate of N application had a greater effect on N concentrations in kikuyu than did stocking rate. The only effect of stocking rate on the N status of the sward was that at high stocking rates the proportion of N cycled through the animal increased at the expense N returning to the plant via decomposing litter. This was mainly because the grazing animals tended to remove more litter at high stocking rates. Although kikuyu may initially be capable of achieving high yields under nil N fertiliser rates, due to the large N soil reserves found on heavily fertilised and grazed pastures, reserves are rapidly depleted and the yield declines (Miles 1997). When kikuyu is poorly grazed the large thick mat of dead leaves and stolons that is formed results in a large pool of accumulated organic N. This organic N can be rapidly broken down and taken up by the kikuyu, acting as an additional source of N (Marais et al. 1987).

Under high N fertilisation regimes kikuyu undergoes a rapid period of vegetative growth after fertilisation, followed by the production of mature stem tissue (Whitney 1974a). This is a possible reason why, as the rate of nitrogen fertilisation increases, the stem:leaf ratio of the sward often increases (Whitney 1974a), in turn decreasing the leafiness of the sward and having a negative effect on the nutrient quality. Mears and Humphreys (1974) reported that as N fertilisation increased from 0 to 672 kg N ha^{-1} annum^{-1} the percentage stem increased from 49 to 54%.

High N fertiliser applications can also adversely affect nutrient quality of kikuyu by decreasing Ca, P and Mg concentrations in kikuyu swards (Whitney 1974a; Awad and Edwards 1977). Furthermore it has been suggested that as the nitrogen content of kikuyu increases, as is the case with high nitrogen fertilisation, the bio-availability of Ca in kikuyu decreases (Marais 1990). The dry matter percentages of tropical grasses, such as kikuyu, decreased as the nitrogen fertilisation rate increased (Gomide et al. 1969a), possibly due to the higher growth rates experienced under these regimes. A further negative impact of high rates of N fertilisation is the increases in the proportion of NPN of CP, which could be dangerous for grazing animals. At rates of less than 650 kg N ha^{-1} year^{-1} the NPN content has been found to remain below hazardous levels (Le Roux et al. 1984).

3.7.3 Lime application

Awad and Edwards (1977) found substantial yield increases from kikuyu in response to lime applications at rates of both 3.75 and 7.5 tons ha^{-1} annum^{-1}, whether it was fertilised with nitrogen or not. Although responses were recorded at low N rates, higher responses to lime were recorded when lime was used in conjunction with high N fertilisation rates. Liming, by raising soil pH levels, increased the concentration of exchangeable Ca in the soil, concurrently lowering the concentrations of toxic soluble Al, which resulted in increased Ca concentrations in plant leaves (Awad et al. 1976). Low soil pH, which is alleviated by liming, can also increase exchangeable K in the soil (Awad et al. 1976).

Lime application can improve the nutritional composition of kikuyu by substantially increasing the Ca, P, N and Mo concentration in kikuyu swards (Awad and Edwards 1977). Liming can be a more cost effective and successful way of increasing the low P levels often experienced in kikuyu swards during spring than applying high rates of P fertiliser, especially when soil acidity is problematic (Awad et al. 1979).

Of importance in regard to lime application on heavily fertilised pastures is the short-lived improvement from liming, greatly attributable to the acidifying effect of N fertiliser, necessitating the frequent liming of pastures (Miles 1991).

3.7.4 Phosphorous application

Phosphorous (P) fertilisation will not generally affect the yield potential of kikuyu, except on unlimed soil at high N fertiliser rates (Awad and Edwards 1977) or when soil P test levels are below 10 mg L^{-1} (Miles 1997). Under South African conditions, where soils are generally deficient in P, kikuyu has been found to respond in terms of yield when fertilised with P, especially at high rates of N fertilisation (Miles 1991). Kikuyu is also highly responsive to P application during the establishment phase of growth (Miles 1999), since P requirements of pastures are greater during the early establishment phase than once the plant is mature (Hardy 2006).

The main positive effect of P fertilisation is that of increasing P levels in kikuyu by up to 0.20% (Awad and Edwards 1977, Awad et al. 1979). Increasing the pH and the P applications was found by Awad et al. (1976) to increase available P and P uptake from the soil. At low P applications (22 kg P ha^{-1}) and a high pH, P in kikuyu (at 0.15 to 0.18%) was below the critical level of 0.22% for animal production. As result, P could be limiting under these conditions. The primary effect of higher levels of P application at a low soil pH is to decrease the levels of soluble Al caused by high fertilisation levels with ammonium sulphate, rather than improving P nutrition of the plant, while at the same time improving the availability and uptake of calcium (Awad et al. 1976).

Kikuyu has a greater P requirement in spring and early summer than in midsummer (Hardy 2006). Late winter/early spring is the best time to apply P to kikuyu, since this is the period when P levels in the plant are at their lowest, primarily due to the lower temperatures and resultant lower uptake of P by kikuyu's roots (Miles 1999).

3.7.5 Grazing management

Optimum pasture utilisation requires stocking rates at which forage consumption is maximized, but where animal production and pasture productivity is not compromised (Fike et al. 2003). The grazing system for kikuyu, in particular, should be aimed at reaching an effective compromise between quantity and quality, with maximum utilization through grazing and conservation (Minson et al. 1993). The optimum stocking rates on kikuyu tend to be much higher than for temperate pastures (Colman and Kaiser 1974). Kikuyu has also been found to produce higher yields under grazing than cutting (Miles 1991).

With most forage based animal production systems, production per animal unit tends to decrease as stocking rate increases, but production per unit land area decreases (Fike et al. 2003). Similarly, when the stocking rate of dairy cows on kikuyu was increased, it resulted in a decrease in production per cow, but allowed for greater production per hectare (Colman and Kaiser 1974). The butterfat production per cow was reported by Colman and Kaiser (1974) to decrease by 6.1 kg per cow and increase by 72.6 kg per hectare as the stocking rate of kikuyu increased by a unit, whilst liveweight gain per animal unit was generally higher at lower stocking rates. The forced intake of the more fibrous component of kikuyu at the base of the sward that occurs when kikuyu is stocked at high rates, results in a poorer nutritive value of ingested herbage (Betteridge 1979). In addition, animals will be forced to ingest more stem and less palatable patches around dung if kikuyu is grazed at high stocking rates (Mears and Humphreys 1974).

The recommended grazing interval for kikuyu, as reported by various authors, is shown in Table 3.9, with values based on both days and re-growth stage according to leaf appearance. Fulkerson et al. (1999) and Reeves et al. (1996b) recommended that kikuyu be grazed when approximately four leaves had appeared per tiller (12 days in spring and summer) when it is actively growing. The data from Cruywagen et al. (2006) showed that a more lax defoliation interval (based on yield potential and nutritive value) of 28 to 35 days would be best suited. A longer grazing interval is recommended during autumn and winter when kikuyu is relatively dormant (Fulkerson et al. 1999).

As the defoliation interval of kikuyu increases, the proportion of stem and dead material increases while the proportion of leaf material decreases (Reeves et al. 1996b, Fulkerson et al. 1999), with the effect most pronounced during summer when kikuyu is undergoing rapid growth (Fulkerson et al. 1999). Once the re-growth period of kikuyu exceeds four weeks, it tends to accumulate a large amount of lignified stem tissue at the expense of sward leafiness (Whitney 1974b). Frequent defoliation can be employed as a possible management technique to reduce the proportion of fibrous stem and increase the leafiness of grazed swards (Minson et al. 1993). The effect of defoliation interval and height on the total live leaf and stem and dead material can be seen in Table 3.10 (Fulkerson et al. 1999). In this study the most severe defoliation practice (at 2 leaves/tiller to a height of 30 mm) resulted in the highest annual leaf and live material yield (kg ha^{-1}), but it was not significantly higher than yields when defoliating at longer intervals at the same height (4 and 6 leaves/tiller at 30 mm). Although Fulkerson et al. (1999) found that severe defoliation practices did not negatively impact on the productivity of kikuyu during summer, he warned against attempting to graze at too short intervals, since it may present a problem in terms of animal pre-hension.

Table 3.9: Recommended defoliation practices for kikuyu pastures

Reference	Season	Growth stage	Days	Defoliation Height
Reeves et al. 1996b	-	4½ leaves/tiller	-	50 mm
Fulkerson et al. 1999	Spring-summer	4 leaves/tiller	12 days	50- 60 mm
	Autumn-winter	6 leaves/tiller	30-40 days	120 mm
Cruywagen et al. 2007	-		28-35 days	50 mm

Table 3.10: Annual yield of total live leaf, stem and dead material for kikuyu under different defoliation practices (Fulkerson et al. 1999).

Defoliation practice		Dry matter yield (kg ha^{-1})			
Interval (leaves/tiller)	Height (cm)	Leaf	Stem	Total live material	Total dead material
2	3	11284	850	12134	372
	6	8707	831	9538	350
	12	6623	1016	7639	292
4	3	11080	1324	12404	1620
	6	10399	1521	11920	1659
	12	7001	1459	8460	1175
6	3	9977	2122	12099	1822
	6	9336	2502	11838	2708
	12	6258	1580	7838	1940

The nutritive value of kikuyu is also sensitive to defoliation interval. The trends in the change in mineral composition and CP content of kikuyu as found by Reeves et al. (1996b) can be seen in Figure 3.6 and 3.7 respectively. Mean CP, K and P content of the whole kikuyu plant decreased after the 4½ leaf stage, while Ca and Mg increased. The organic matter digestibility (OMD) of kikuyu decreased as the defoliation interval increased, primarily due to the accumulation of dead material (Reeves et al. 1996b, Fulkerson et al. 1999) and the associated increase in fibre fractions such as CF and NDF (Cruywagen et al. 2007). Delaying defoliation to four leaves per tiller has a positive impact on the forage quality of kikuyu by resulting in lower CP, K and P levels, as well as increased levels of Ca and Mg (Fulkerson et al. 1999, Reeves et al. 1996b).

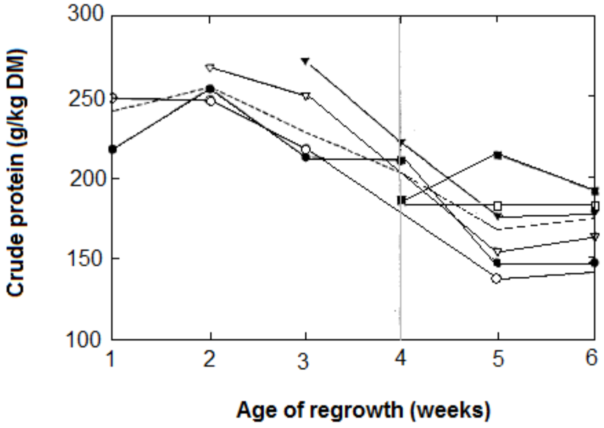

Figure 3.6: Changes in the mean crude protein content of each new leaf (leaf 1 ○, leaf 2 ●, leaf 3▽ , leaf 4▼ , leaf 5☐, leaf 6■) and the mean (-----) for all leaves of kikuyu. The vertical line indicates the 4½ leaf stage (Reeves et al. 1996b)

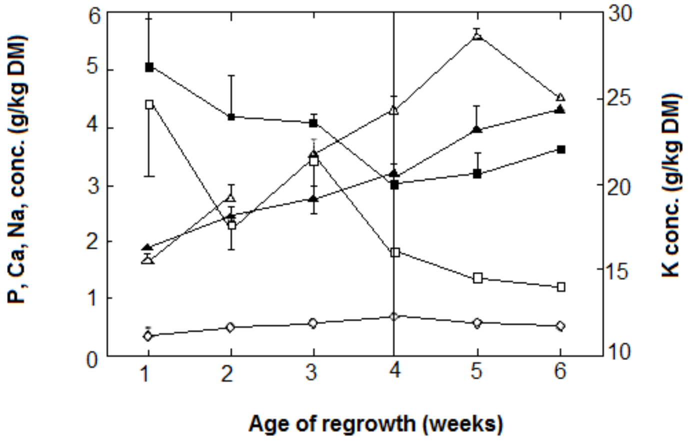

Figure 3.7: Levels of potassium (☐), phosphorous (■), calcium (△), magnesium (▲) and sodium (◊) (g kg^{-1} DM) in the first new leaves to emerge during re-growth. Vertical line indicates 4.5 leaves/tiller stage (Reeves et al. 1996b)

Continuous grazing with animals on kikuyu, even by beef animals, has been found to result in lower animal production per animal unit than a rotational grazing system, especially at relatively high stocking rates (Bransby 1990). High stocking rates also have the additional benefit of increasing the average leaf percentage of a kikuyu sward as well as increasing kikuyu density (Mears and Humphreys 1974). Dugmore and Du Toit (1988) recommended the use of electric fencing to restrict the grazing area and the use of follower animals as methods to restrict the accumulation of old rank kikuyu as the growth season progresses. Kikuyu is capable of delivering enough N from roots to plant shoots even at high grazing pressures to allow for adequate growth (Mears and Humphreys 1974).

The effect of different grazing intervals on the milk production of animals grazing kikuyu is shown in Table 3.11 (Henning et al. 1995). The milk production and fat corrected milk production (FCM) per animal unit of cows grazing kikuyu at an interval of 30 days was higher than at 15 and 60 day intervals. In addition, a grazing interval of 30 days resulted in higher live-weights and a higher solids non fat content of milk.

Table 3.11: The effect of different grazing cycles on milk yield, milk composition and body weight of animals grazing kikuyu pasture (Henning et al. 1995)

Rotation cycle	Milk (kg day^{-1})	FCM (kg day^{-1})	Butterfat (%)	Protein %	Solids non fat (%)	Live weight (kg)
15 days	9.5	8.7	3.7	3.2	8.2	541
30 days	10.9	10.1	3.6	3.2	8.3	558
60 days	8.9	8.3	3.4	3.2	8.1	554

3.7.6 Supplementation of animals grazing kikuyu

The response in milk production of dairy cows to different forms and levels of supplementation can be seen in Table 3.12. Reeves et al. (1996b) found that as the level of concentrate increased, the milk production per cow increased, while Fulkerson et al. (2006) did not report any significant improvement. The latter study did, however, not include an unsupplemented group of animals. Other authors such as Marais (2001) have also reported that animal production from kikuyu can be improved using energy supplementation. Increasing the proportion of concentrate has, however, resulted in a decreased utilisation efficiency of the roughage component in the diet (Fulkerson et al. 2006). As the level of concentrate fed to dairy cows grazing kikuyu increased, intake and pasture digestibility decreased and substitution rate increased (Fulkerson et al. 2006). Figure 3.8 illustrates how the daily milk yield and milk protein content (%) of cows grazing kikuyu increased as the energy content (ME) in the concentrate increased (Reeves et al. 1996b). Butterfat content (%) of milk was however found to decrease as the ME content of the concentrate increased.

Kaiser et al. (1975) found a marginal response when supplementing calves grazing kikuyu with grain, stating that supplementation with grain could only elicit large responses in grazing animals (in terms of animal production) at high grazing pressures and stocking rates. The author in this case was of the opinion that at low stocking rates the grain supplement acted as a replacement for pasture rather than a supplement. Reeves et al. (1996a) however reported that dairy cows supplemented with barley while grazing kikuyu showed a positive production response of 1.4 kg milk increases per 1kg of barley fed, and identified the ME content in the diet as the primary nutrient determining milk production in these animals. The same research showed no positive production response in terms of yield or milk components when animals were supplemented with formaldehyde treated canola meal (a high protein and rumen undegradeable protein source), but rather indicated that such supplementation simply resulted in increased protein wastage and excretion. Including high fibre feeds like hominy chop, wheat bran and gluten 20 has also been reported to improve the milk production and milk fat content (%) of animals grazing kikuyu based pastures (Meeske et al. 2009).

Table 3.12: The milk production (kg cow^{-1} day^{-1}) and composition (%) obtained from animals grazing kikuyu when supplemented with various types and amounts (kg day^{-1}) of concentrate

		Concentrate			Composition	
Reference	Breed	Type	Amount	Milk production	Butterfat content	Protein content
Reeves et al. 1996	Holstein	unsupplemented	0	14.2	3.77	3.06
		barley based	3.0	18.3	3.51	3.22
		barley based	6.0	18.0	3.26	3,19
Fulkerson et al. 2006	Holstein	dairy pellets	2.0	26.75	3.66	3.16
		dairy pellets	3.8	24.75	3.83	3.20
		dairy pellets	5.9	24.50	3.67	3.26
Meeske et al. 2009	Jersey	high maize (80.4%)	6.0	21.0	3.66	3.45
		medium maize (41%)	6.0	20.8	4.03	3.55
		low maize (20.7%)	6.0	20.1	4.41	3.42

Bredon (1980) reported limited response in dairy cows grazing kikuyu when supplemented with dairy meal during spring and early summer, but that supplementation did result in improved milk production during summer and autumn. As mentioned earlier, summer is the period when kikuyu is undergoing active growth and quality is generally at its lowest. Marais et al. (1990) reported that supplemented sheep grazing kikuyu showed total higher daily intakes than animals grazing kikuyu alone, but that the two groups did not differ in terms of kikuyu intake itself. The same author reported that the kikuyu grass supplemented with maize meal had a significantly higher dry matter digestibility and nitrogen retention level than the un-supplemented kikuyu, especially when the nitrogen content of kikuyu was high. Sheep supplemented with molasses or maize meal while grazing kikuyu were however reported by Van Ryssen et al. (1976) to have a lower pasture intake, indicating that concentrates will substitute pasture to some extent. Henning et al. (1995) recommended that dairy cows grazing kikuyu should receive concentrate supplementation from December to April to avoid the "autumn slump" in production.

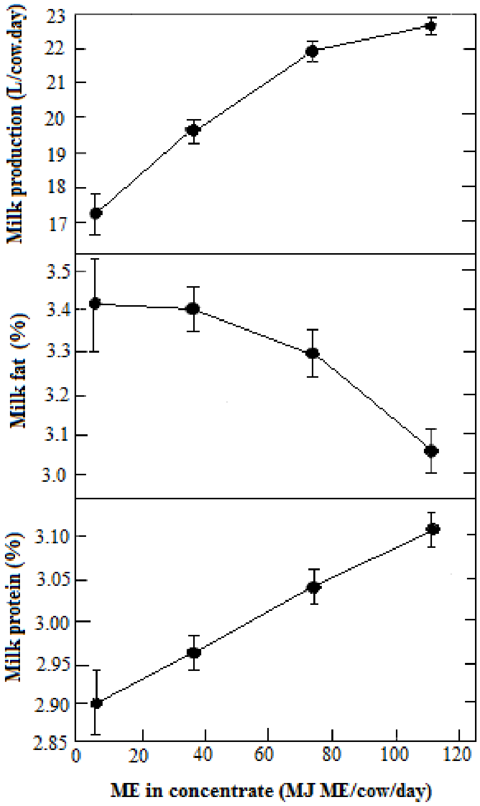

Figure 3.8: Mean (a) milk production (L cow^{-1} day^{-1}), (b) milk fat (%) and (c) milk protein (%) in response to increasing concentrations of metabolisable energy (ME) (MJ cow^{-1} day^{-1}) fed in concentrates to cows (Reeves et al. 1996b).

Supplementing animals grazing kikuyu with feedlime has been reported to improve conception rates, possibly due to improved calcium status (Dugmore 1999). This is expected since the Ca content of kikuyu is marginal for high producing dairy cows (section 3.5.1). Due to the highly deficient levels of Na in kikuyu, all animals grazing kikuyu, especially dairy cows, must continuously be supplemented with salt (Miles et al. 1995), especially during the summer months (Reeves et al. 1996b).

4. Ryegrass (*Lolium spp.)*

4.1 Classification and description of different ryegrass species and varieties

Two common species of ryegrass are widely used in South Africa. The first is *Lolium multiflorum*, commonly known as "annual ryegrass" and the second is *Lolium perenne* or "perennial ryegrass". Annual ryegrass tends to be hardier and grow more quickly than perennial ryegrass (Dickenson et al. 2004). Both the ryegrass species are similar in appearance, but some differences in morphological characteristics do exist and are shown in Table 4.1.

Table 4.1: Morphological differences between annual and perennial ryegrass (Adapted from Cooper and Saeed 1949, Rhind and Goodenough 1973, Dickenson et al. 2004)

Characteristic	Annual ryegrass	Perennial ryegrass
Young leaves	Young leaves are rolled	Young leaves are folded
Leaf appearance	Broad leaves	Narrower leaves
Shoot appearance	Rounded	Flat
Auricles	Large, long and clasping around the leaf sheath	Small, often reduced to wedge-like projections
Threshed seed	Awn	No awn
Florets per spikelet	16-18	6-12
Lemma	Terminates in an awn	End in a blunt point with no awn
Growth habit	Erect with nodes and new tillers often above the level of cutting	More prostrate habit with nodes and vegetative tillers forming at ground level

4.1.1 Annual ryegrass (Lolium multiflorum Lam.)

In Europe *Lolium multiflorum* is considered a biennial, but under South African conditions it is a variable annual species, rarely persisting into a second year (Rhind and Goodenough 1973). There are two varieties of annual ryegrass known by their common names as Italian ryegrass (*Lolium multiflorum* var. *italicum*) and Westerwolds ryegrass (*Lolium multiflorum* var. *westerwoldicum*).

Italian ryegrass varieties are more persistent than Westerwolds ryegrass varieties due to their tillering behaviour (Nash and Ammann 2006) and are at times referred to as a biennial ryegrass (Fulkerson et al. 1998, Kunelius et al. 2004). Westerwolds ryegrass is a very rapid growing, leafy, extreme annual, selected from Italian ryegrass by farmers in the Westerwolds region of Holland in the late nineteenth century (Rhind and Goodenough 1973), and developed as a consequence of repeated harvesting of seed from annually sown fields (Beddows 1973). Westerwolds and Italian ryegrasses are not readily distinguishable from each on the basis of morphological characteristics (Rhind and Goodenough 1973).

Italian ryegrass varieties have a vernalisation gene that delays flowering, thus Italian ryegrasses have a vernalisation requirement for flowering. The vernalisation gene is switched off by a combination of low winter temperatures and/or short winter days followed by long spring days, resulting in flowering (Salisbury and Ross 1992). Italian ryegrass varieties have the ability to produce new daughter tillers after flowering. The degree to which a variety is able to produce new daughter tillers will influence the persistence of the variety into spring and summer. The Westerwolds ryegrass variety does not possess a vernalisation gene, and flowering is not dependant on climatic conditions such as cold or short days (Beddows 1973, Nash and Ammann 2006). As result, Westerwolds ryegrass varieties tend to flower earlier than Italian ryegrass varieties following an autumn planting, while others flower at a time similar to earlier flowering Italian ryegrass varieties. Unlike the Italian ryegrass varieties, Westerwolds ryegrass does not produce daughter tillers after flowering and hence the plants die and the pasture will not persist after flowering (Nash and Ammann 2006). Westerwolds ryegrass is generally not sown in spring, since they will grow for a maximum of 4 to 5 months, whereas Italian ryegrass can remain productive for up to 14 months after spring establishment (Dickenson et al. 2004).

Italian ryegrass will not survive through the summer after autumn establishment in the subtropics and tropics. Dry matter production and yield in Italian ryegrass pastures during year two, without re-establishment, is thus dependent on seedling recruitment from seed set the previous year, rather than survival of autumn established plants (Donaghy et al. 1997).

4.1.2 Perennial ryegrass (Lolium perenne)

Perennial ryegrass (*Lolium perenne*) plants have been described as showing a large variation in growth form, ranging from erect individuals with relatively few tillers, to prostrate compact cushions with numerous vegetative shoots or tillers, with the latter tending to be more persistent than the former (Beddows 1967). The canopy that results when perennial ryegrass undergoes rapid growth can cause the crown of the plant to become elevated, restricting the ability of the plant to survive cold conditions.

This is probably of little importance under sub-tropical conditions, but an elevated crown can raise the growth nodes above ground level, making the plant sensitive to severe defoliation to ground level.

Perennial ryegrass can persist for as little as two years, or if conditions are suitable, up-to ten years or longer. The degree of persistence in perennial ryegrass is dependent on environmental and management factors (Nash and Ammann 2006). In addition, the vernilisation or cold requirement response is retarded or even prevented by high temperatures (Aitken 1966, Beddows 1967). The specific temperature and day length requirements that induce flowering in perennial ryegrass are often not met under South African growing conditions. The marginal climatic conditions in South Africa in terms of flowering requirements often results in variable flowering dates and variable percentages of plants that flower from year to year within perennial ryegrass swards (Nash and Ammann 2006). Donaghy et al. (1977) reported a similar situation of low seed set and seedling recruitment in these pastures in the sub-tropical regions of Australia (where the vernalisation requirement of perennial ryegrass is often not met). Consideration should also be given to the role that the ingression of “summer grasses” such as *Pennisetum clandestinum* and *Paspalum dilitatum* will play in the survival of individual perennial ryegrass plants through the summer following an autumn sowing (Fulkerson et al. 1993b).

In contrast to annual ryegrass pastures, which depend on seed recruitment from previous years for continued production for more than one year, the production of perennial ryegrass pastures into a second year is reliant on the survival of individual plants through summer (Donaghy et al. 1997). The persistence or perenniality of perennial ryegrass will thus be dependent on the ability of individual tillers of the plant to form axillary buds on existing tillers from which new shoots can be formed (Beddows 1967). Perennial ryegrass varieties used in the subtropics have very few reproductive tillers and swards are quite easily kept in the vegetative state (Fulkerson et al. 1993a). Under sub-tropical environmental conditions a 100% of Italian ryegrass tillers were reported to become reproductive whilst only between 5-10% of perennial ryegrass tillers entered the reproductive stage (Donaghy et al. 1997, Fulkerson et al. 1998). In addition, Italian ryegrass tended to reach the reproductive stage earlier (September) than perennial ryegrass (late October) (Donaghy et al. 1997). The reduced stem yield obtained from perennial ryegrass, compared to Italian ryegrass, has been attributed to the lower emphasis of the former species on seed set (Lowe et al. 1999a).

4.2 Growth requirements of ryegrass

Although annual and perennial ryegrasses are generally only cultivated under irrigation or when rainfall exceeds 900 mm, it can be grown as a dryland crop. Fulkerson and Slack (1994) found that in subtropical areas, irrigation of perennial ryegrass, even at sub-optimal levels, could greatly increase yield and survival of the plants over summer.

Both annual and perennial ryegrasses prefer to grow in a deep fertile soil with a high soil moisture holding capacity (Dickenson et al. 2004). The recommended soil nutrient status for ryegrass is given in Table 4.2. Ryegrass requires a pH (KCl) of 5.0 or more (Dickenson et al. 2004) and it must be ensured that phosphorous and potassium levels are maintained at the appropriate levels (Fulkerson et al. 1996). The DM production of perennial ryegrass was found to increase when soil pH ($CaCl_2$) increased from 4.6 to 5.8, most likely due to the improved availability of soil organic N (Fulkerson et al. 1993b). Soil fertility is generally not a problem for temperate pastures under irrigation since the high returns from such pastures justify the application of fertiliser inputs (Fulkerson et al. 1993a).

Table 4.2: The soil nutrient requirements of ryegrass of annual and perennial ryegrass (Dickenson et al. 2004)

	pH (KCl)	Phosphorous (mg P kg^{-1})	Potassium(mg K kg^{-1})
Annual ryegrass	>5.0	Heavy soils: 20 Sandy soils: 30	140
Perennial ryegrass	>5.0	>30	150

The optimum temperature for growth of temperate species lies between 20-25ºC (McWilliam 1978). Temperatures in the sub-tropics lie within this optimum range during the cool season and as result the growth of temperate species is likely to be optimised during the winter-spring period in these areas (Fulkerson et al. 1993a).

4.3 Production potential of ryegrass

4.3.1 Pasture production potential

The specific variety or species of ryegrass, seasonal variation in temperature and length of the growing season will all affect the potential dry matter (DM) production of ryegrass pastures (Fulkerson et al. 1993a). Cultivar choice plays a major role in the DM production potential of ryegrass pastures, with recent, adapted, rust tolerant and more summer active cultivars achieving higher yields (by up to 10 t ha^{-1} year^{-1}) than older, rust-susceptible and winter active cultivars (Fulkerson et al. 1993a). The dry matter production potential (kg DM ha^{-1}) of annual and perennial ryegrass based pastures is shown in Table 4.3.

Table 4.3: Dry matter production of annual and perennial ryegrass based systems

Reference	Species	Period	Dry matter production
Donaghy et al. 1997	Annual ryegrass-white clover	March-December	7106 kg ha^{-1}
	Perennial ryegrass-white clover	March-December	5210 kg ha^{-1}
Fulkerson et al. 1998	Italian ryegrass	May-October	1514 kg ha^{-1} grazing^{-1}
		November	1943 kg ha^{-1} grazing^{-1}
	Perennial ryegrass-white clover	December-February	1281 kg ha^{-1} grazing^{-1}
		March-May	1129 kg ha^{-1} grazing^{-1}
		June-August	1522 kg ha^{-1} grazing^{-1}
		September-November	1765 kg ha^{-1} grazing^{-1}
Lowe et al. 1999a	Italian ryegrass	Year 1	1289 kg ha^{-1} week^{-1}
		Year 2	1772 kg ha^{-1} week^{-1}
		Year 3	2043 kg ha^{-1} week^{-1}
	Perennial ryegrass	Year 1	1343 kg ha^{-1} week^{-1}
		Year 2	1665 kg ha^{-1} week^{-1}
		Year 3	1808 kg ha^{-1} week^{-1}
Tharmaraj et al. 2008	Italian ryegrass-clover	Annual	12450 kg ha^{-1} year^{-1}
	High N- Perennial ryegrass-clover	Annual	14400 kg ha^{-1} year^{-1}

Although perennial ryegrass performs better in terms of DM production over long periods (more than one year), annual ryegrass is the most useful ryegrass for annual sowings in the subtropics (Lowe et al. 1999a). Perennial ryegrass pastures tend to be lower yielding in the first six months after establishment, but are capable of yields equivalent to that of annual ryegrass over a 12 month period (Fulkerson et al. 1993a). Following autumn establishment in March, the DM yield of Italian and perennial ryegrass will be similar from July to September, after which perennial ryegrass will out-yield Italian ryegrass during summer/early autumn (Thom and Bryant 1996). Other authors have reported that annual ryegrass can be up to 38% more productive than perennial ryegrass from an autumn sowing until December, identifying the reproductive development and associated increased in the proportion of stem material as the most probable cause (Donaghy et al. 1997). The greater stem yield obtained from Italian ryegrass pastures than perennial ryegrass pastures (278 kg DM ha^{-1} and 106 kg DM ha^{-1} respectively) by Lowe et al. (1999a) supports this hypothesis. This is in agreement with the observation that perennial ryegrass varieties tend to remain vegetative, while Italian ryegrass varieties readily form reproductive tillers once the vernalisation requirement for this specie has been met (see section 4.1). Ryegrass based systems show a seasonal pattern of production with highest DM production occurring during spring, followed by winter and lowest production rates occurring during summer and autumn (Lowe et al. 1999a, Tharmaraj et al. 2008).

Although the total annual herbage yield of Italian and perennial ryegrass based systems are similar in the first year of establishment, Italian ryegrass will not maintain similar yields to perennial ryegrass in the second year (Tharmaraj et al. 2008). In cases where Italian ryegrass has been reported to maintain yields similar to perennial ryegrass in the second year after establishment, it was found that the high yields achieved in such pastures was mainly attributable to the high ingress of summer grasses and weeds (Lowe et al. 1999a). This occurs because the bare soil left by dying ryegrass plants is often colonised by tropical species in response to more light penetrating the sward (Donaghy et al. 1997). A possible way to maintain high yields in Italian ryegrass pastures during successive years is to re-sow the Italian ryegrass each year during autumn (Tharmaraj et al. 2008). Perennial ryegrass pastures will accumulate a large proportion of dead material, particularly in the summer-autumn period (Stockdale 1999a), which could affect the accuracy of yield determination in these pastures.

After establishment of perennial ryegrass pasture, plant numbers decline during the establishment year to a stable population in spring, but then fall again over summer as summer growing grasses invade pastures (Fulkerson et al. 1993a). Poor summer growth in perennial ryegrass in the sub-tropical regions of Australia have been attributed to low tiller appearance and high tiller death rates as result of the high summer temperatures experienced in these areas (McKenzie 1997). As result, the vigour of perennial ryegrass often declines from spring to summer in subtropical regions, especially when temperatures exceed 25°C (McKenzie 1996). The annual DM production of various perennial ryegrass cultivars have similarly been found to decrease during successive years (after establishment) under South African conditions (Botha et al. 2008c). The density and number of ryegrass plants for Italian ryegrass established in perennial ryegrass pastures will also decrease as the season progresses, with the greatest losses occurring between November and February with only approximately 2% of the Italian ryegrass plants surviving through the summer (Thom and Prestidge 1996). In pure Italian ryegrass swards a similar pattern will occur, with plant density decreasing to a greater degree from spring to autumn than for perennial ryegrass pastures (Lowe et al. 1999a).

An extensive trial was conducted on the DM production potential of various cultivars of Italian and Westerwolds ryegrasses on the Outeniqua Research Farm in South Africa (Botha et al. 2008c). This study showed that various Italian ryegrass cultivars could achieve a DM production rate similar to that of Westerwolds ryegrass during winter. The highest DM production during spring was achieved by Italian ryegrass cultivars, with the total annual DM production of Italian ryegrass cultivars found to be higher than Westerwolds ryegrass in the same study.

4.3.2 Milk production potential

The milk production per cow (kg cow^{-1} day^{-1}), 300 day milk yield (kg cow^{-1}) and milk composition of cows grazing either a pure stand of perennial ryegrass or Italian ryegrass is given in Table 4.4 (Lowe et al. 1999b). There were no significant differences with regards to milk production between Italian and perennial ryegrass, but the milk production from Italian ryegrass was almost 2 L cow^{-1} day^{-1} lower than from perennial ryegrass. This is in contrast to results from Lowe et al. (1999a), where it was reported that Italian ryegrass pastures had a higher nutrient quality than perennial ryegrass. The lower DM content (%) of Italian ryegrass compared to perennial ryegrass has been identified as a contributing factor to the lower milk production observed in dairy cows grazing Italian ryegrass (Thom and Bryant 1996). In terms of economics, Italian ryegrass was found by Lowe et al. (1999b) to have higher purchased feed costs and total production costs, while perennial ryegrass had a higher income from milk and gross margin. In addition, dairy cows grazing Italian ryegrass have been reported to gain less weight post-calving than cows grazing perennial ryegrass pastures (Thom and Bryant 1996, Lowe et al. 1999b).

Table 4.4: Milk production and composition for cows grazing perennial ryegrass (PR) cv. Yatsyn and Italian ryegrass (IR) cv. Concord. Means within columns with no common superscript are significantly different ($P<0.05$) (Adapted from Lowe et al. 1999b)

Year	Pasture	Ave milk yield (kg cow^{-1}day^{-1})	300-day milk yield (kg cow^{-1})	Butter fat (%)	Protein (%)	Lactose (%)
1	IR	15.9^{ab}	3767^{a}	3.82	3.15	4.92
	PR	16.9^{a}	3817^{a}	3.85	3.14	4.83
2	IR	20.7^{a}	5900^{a}	3.70	3.15	4.73
	PR	23.7^{a}	6879^{a}	3.76	3.33	4.73
3	IR	21.0^{b}	4692^{b}	4.14	2.95	4.76
	PR	22.4^{ab}	5001^{ab}	3.77	2.87	4.63

The effect of ryegrass specie on the milk production and composition of dairy cows grazing these pastures appears to be seasonal. The milk fat, protein and lactose yield of Italian and perennial ryegrass were found by Thom and Bryant (1996) to be similar during the winter/spring period, but lower for

Italian ryegrass during the summer/autumn period. Perennial ryegrass also had higher milk yields than Italian ryegrass during the summer, while winter and spring milk production was similar for the two species (Thom and Bryant 1996, Lowe et al. 1999b). The seasonal milk production and milk composition of cows grazing Italian and perennial ryegrass based pastures can be seen in Table 4.5 (Thom and Bryant 1996). Apart from the minimal differences between species, the data presented in Table 4.5 shows that milk production of dairy cows grazing ryegrass tended to be lower during the summer/autumn period than during the winter/spring period.

Table 4.5: The seasonal milk production and milk composition (kg cow^{-1}) of cows grazing Italian and perennial ryegrass based systems (Adapted from Thom and Bryant 1996)

Season	Component	Italian ryegrass	Perennial ryegrass
Winter/Spring	Milk	2870	2897
	Fat	128	135
	Protein	99	101
	Lactose	136	138
Summer/Autumn	Milk	782	949
	Fat	37	49
	Protein	27	34
	Lactose	37	44

4.4 Chemical composition and nutritional value of ryegrass for grazing animals

4.4.1 Protein

The crude protein (CP) content of annual and perennial ryegrass, as cited in the literature, varies between 19% and 28% (Table 4.6). Fulkerson et al. (1993a) and Tharmaraj et al. (2008) both found that the protein concentration of Italian ryegrass was similar to that of perennial ryegrass. The data from Fulkerson et al. (2007), however, showed that annual ryegrass had a higher CP content than perennial ryegrass during autumn, winter and spring. These results were similar to those of Lowe et al. (1999a) who reported that the CP content of Italian ryegrass was higher than that of perennial ryegrass throughout all the seasons during the year, with the difference significant during winter.

Season has a marked effect on the CP content of pastures based on Italian and perennial ryegrass, with CP content in both species peaking during winter, after which it gradually declines until it reaches lowest concentrations during summer (Fulkerson et al. 1998; Lowe et al. 1999a; Chapman et al. 2008; Tharmaraj et al. 2008). Figure 4.1 shows the decline in the nitrogen content (and consequently CP content) of Italian ryegrass to very low concentrations during summer after reaching peak concentrations during the winter month of July (Thom and Prestidge 1996). The presence of plants setting seed has been identified as a factor that contributes to the decline in CP content of temperate grass species during the spring and summer periods (Fulkerson et al. 2007).

Table 4.6: The crude protein content (%) different ryegrass species as reported in the literature

Reference	Species	Variety	Cultivar	Season	CP
Reeves et al. 1996b	Perennial			June-October	25.2
Fulkerson et al. 1998	Annual	Italian	Concord		25.1
Lowe et al. 1999a	Annual	Italian	Concord	Summer 1	22.5
				Autumn 1	23.1
				Winter 1	26.8
				Spring 1	25.5
				Summer 2	19.3
				Winter 2	26.1
	Perennial	-	Yatsyn	Summer 1	19.4
				Autumn 1	21.4
				Winter 1	24.3
				Spring 1	24.1
				Summer 2	18.6
				Winter 2	23.9
Fulkerson et al. 2006	Annual	Italian	Concord	August-October	22.3
Meeske et al. 2006	Annual	-	-	Autumn	25.6
				Winter	25.1
				Spring	18.0
Fulkerson et al. 2007	Annual	Italian	Concord	Autumn	26.5
				Winter	26.4
				Spring	24.7
	Annual	Westerwolds	Tetila	Autumn	28.5
				Winter	27.1
				Spring	25.6
	Perennial	-		Autumn	24.0
				Winter	24.3
				Spring	26.3
				Summer	22.1
Lehmann et al. 2007	Annual	Westerwolds	Energa	August/September	25.0

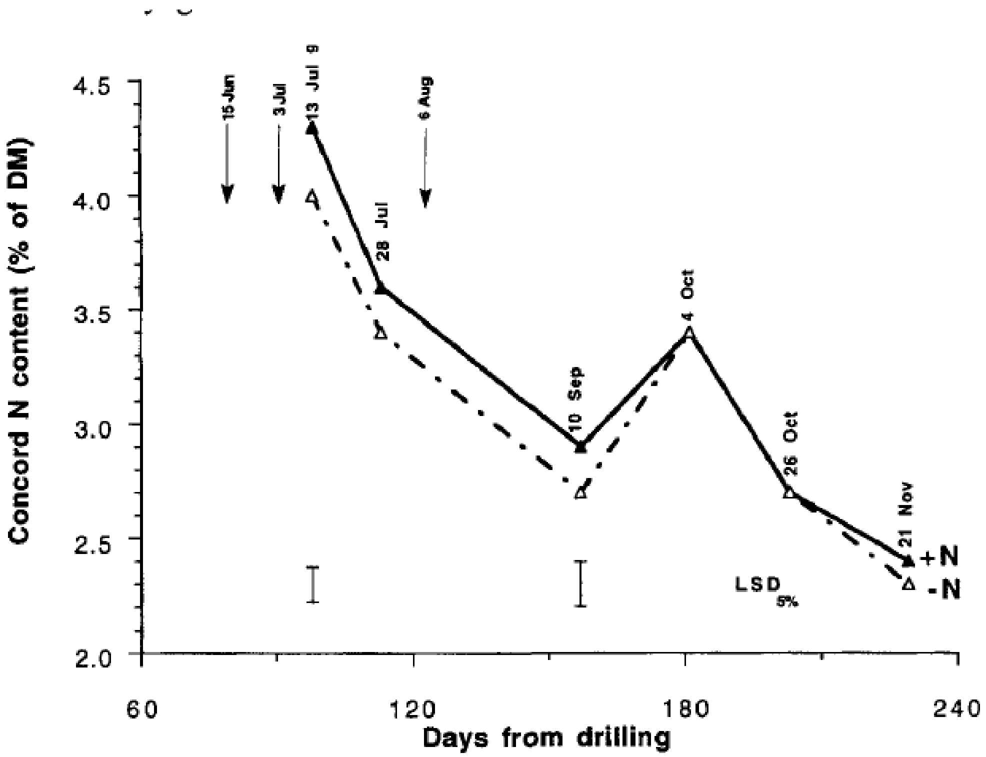

Figure 4.1: Nitrogen content (%) of autumn established Concord Italian ryegrass in winter and spring for plots receiving nitrogen fertiliser (+N) and for those that did not (-N). Arrows indicate when 25 kg N ha^{-1} was applied. (Thom and Prestidge 1996)

In both Italian and perennial ryegrass the CP content of stem is lower than for leaf tissue (Lowe et al. 1999a, Stockdale 1999a). The N content of leaf material in Italian ryegrass was generally higher than that of perennial ryegrass, whilst the N content in stem material was similar (Lowe et al. 1999a). Forage protein content of perennial ryegrass was found by Fulkerson et al. (1993b) to be negatively related to defoliation interval. A similar pattern is seen in Italian ryegrass, where nitrogen levels tend to decrease as the plant ages (Groot and Neuteboom 1997).

4.4.2 Energy and water soluble carbohydrates content

The metabolisable energy (ME) content of perennial and Italian ryegrass, as reported in the literature, varies between 7.15 and 11.8 MJ kg^{-1} DM (Table 4.7). Averaged over all seasons, the ME content of a perennial ryegrass based system (10.5 MJ kg^{-1}) was found by Tharmaraj et al. (2008) to be higher than that of an Italian ryegrass based system (10.3 MJ kg^{-1} DM). Although the ME levels of Italian and perennial ryegrass were reported to be similar during winter at between 11.0 and 11.4 MJ kg^{-1}DM, the

ME content of Italian ryegrass was lower than that of perennial ryegrass during spring (Fulkerson et al. 2007). This is in agreement with results from Fulkerson et al. (1998) who found that the ME content of Italian ryegrass remained relatively constant at 11.5 MJ kg^{-1} DM during winter, then declined rapidly to below 10.0 MJ kg^{-1} DM during spring (November) as most tillers became reproductive. The ME content of perennial ryegrass also declined from winter to summer, although in this case it was attributed to water stress rather than reproductive development (Fulkerson et al. 1998, Stockdale 1999a). Data from Lowe et al. (1999a) showed that the ME content of perennial and Italian ryegrass declined to concentrations as low as 7.35 and 7.15 MJ kg^{-1} DM respectively during in summer. Even under irrigation the low ME content of perennial ryegrass during the summer-early autumn period would limit the milk production from such pastures (Stockdale 1999a).

The ME content of perennial ryegrass tends to decline gradually from 11 MJ kg^{-1} DM when the first leaf emerges to approximately 9 MJ kg^{-1} DM at the four leaf stage (Fulkerson and Donaghy 2001). The ME content of perennial ryegrass is higher in leaf tissue than stem tissue (Stockdale 1999a), and the decline in ME as defoliation interval increases is associated with senescence and an increase in stem material after 3 ½ leaves/tiller had emerged.

Season and defoliation interval have been found to affect the concentration of water soluble carbohydrates (WSC) in ryegrass (Fulkerson et al. 1998, Fulkerson et al. 2007). Fulkerson et al. (1998) reported that the WSC content of perennial ryegrass increased from 5% to 28% from post-grazing to the 3 leaves/tiller stage during winter. During mid-spring the same response to defoliation interval was evident, but the increase in WSC was less pronounced, only increasing to 8% at the 3 leaves/tiller stage. The period when WSC accumulated most rapidly in perennial ryegrass coincided with the period when growth conditions were ideal for ryegrass growth, in this case during winter. This agrees with the results from Fulkerson et al. (2007) who found that the WSC content of perennial ryegrass, when defoliated at similar defoliation intervals, was highest during winter and declined to lowest concentrations during the summer-autumn period. The WSC content of Westerwolds ryegrass peaked during autumn, whilst for Italian ryegrass it peaked during spring. The effect of season on WSC has been linked to growth rates and climatic conditions during the respective seasons (Fulkerson and Donaghy 2001). The slower growth rates (such as those that occur during winter) lower the WSC requirement for ryegrass growth. This, accompanied by lower night temperatures, is believed to result in higher rates of WSC accumulation in perennial ryegrass during winter than during spring (Fulkerson and Donaghy 2001). In essence, the WSC content of ryegrass will increase more rapidly following defoliation during winter when growth conditions are ideal (Fulkerson et al. 1998).

Table 4.7: The metabolisable energy (ME) content (MJ kg^{-1} DM) of ryegrass

Reference	Species	Type	Cultivar	Season	ME
Lowe et al. 1999a	Annual	Italian	Concord	Summer 1	7.15
				Autumn 1	8.13
				Winter 1	10.5
				Spring 1	9.45
				Summer 2	8.13
				Winter 2	9.93
	Perennial	Yatsyn		Summer 1	7.35
				Autumn 1	7.90
				Winter 1	10.35
				Spring 1	9.58
				Summer 2	8.38
				Winter 2	9.83
Fulkerson et al. 2006	Annual	Italian	Concord	August-October	11.3
Meeske et al. 2006	Annual			Autumn	9.5
				Winter	10.8
				Spring	10.9
Lehmann et al. 2007	Annual	Westerwolds	Energa	August/September	11.3
Fulkerson et al. 2007	Annual	Italian	Concord	Autumn	11.0
				Winter	11.0
				Spring	9.7
	Annual	Westerwolds	Tetila	Autumn	11.0
				Winter	10.5
				Spring	10.4
	Perennial		Yatsyn	Autumn	10.0
				Winter	11.4
				Spring	11.1
				Summer	9.9

4.4.3 Neutral detergent fibre and acid detergent fibre

Figure 4.2 compares the dry matter (DM) content of Italian and perennial ryegrass dominant pastures, showing that the DM content of perennial ryegrass is generally higher than that of Italian ryegrass throughout the season (Thom and Bryant 1996). The authors attributed the lower milk yield obtained from Italian ryegrass during this study to the lower DM content of this pasture compared to that of the perennial ryegrass pasture.

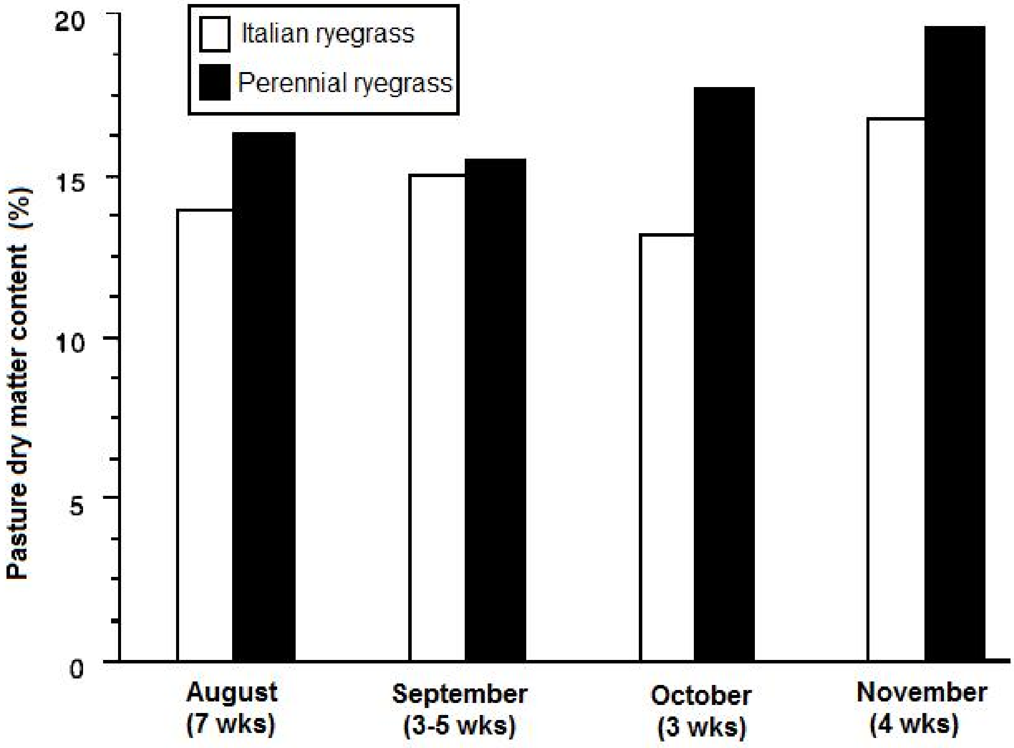

Figure 4.2: Dry matter content (%) of Italian or perennial ryegrass dominant pasture after 7, 3-5, 3 and 4 week re-growths sampled in August, September, October and November (Thom and Bryant 1996)

The ADF content of ryegrass, as cited in the literature, varies between 17 and 36 % (Table 4.8). The ADF content of Italian ryegrass has been reported to drop to concentrations as low as 17 % in winter months, with concentrations below 21% for perennial ryegrass systems also coinciding with this period (Fulkerson et al. 1998). The ADF content of Italian ryegrass during this period was thus below the 21% recommended for dairy cows producing 20 to 30 L day^{-1} (NRC 1989) and could negatively impact on production. The ADF content of Italian ryegrass tended to be lower than for perennial ryegrass during winter (Fulkerson et al. 1998, Lowe et al. 1999a). The ADF content of both Italian and perennial ryegrass underwent an increase from winter until maximum concentrations of 31.3 % were reached for perennial ryegrass during summer and 27% for Italian ryegrass during spring (Fulkerson et al. 2007). Lowe et al. (1999a) reported similar ADF concentrations for perennial ryegrass and Italian ryegrass during summer, but Italian ryegrass had a lower ADF content than perennial ryegrass during winter, spring and autumn.

Table 4.8: Neutral detergent fibre (NDF) and acid detergent fibre (ADF) content of ryegrass as reported in the literature

Reference	Species	Variety	Cultivar	Season	ADF	NDF
Reeves et al. 1996b	Perennial			June-October	17.7	39.5
Lowe et al. 1999a	Annual	Italian	Concord	Summer 1	29.2	51.1
				Autumn 1	30.6	50.5
				Winter 1	23.2	39.1
				Spring 1	27.6	46.2
				Summer 2	35.9	55.1
				Winter 2	22.1	37.6
	Perennial	Yatsyn		Summer 1	32.1	56.0
				Autumn 1	33.0	55.2
				Winter 1	24.9	41.4
				Spring 1	28.9	44.7
				Summer 2	34.2	51.4
				Winter 2	25.3	39.1
Fulkerson et al. 2006	Annual	Italian	Concord	August-October	22.1	44.4
Meeske et al. 2006	Annual			Autumn	29.0	51.0
				Winter	24.1	45.0
				Spring	28.0	49.0
Lehmann et al. 2007	Annual	Westerwolds	Energa	August/September		44.4
Fulkerson et al. 2007	Annual	Italian	Concord	Autumn	23.4	42.8
				Winter	23.6	42.2
				Spring	27.4	53.1
	Annual	Westerwolds	Tetila	Autumn	23.3	41.1
				Winter	24.1	45.9
				Spring	26.2	49.5
	Perennial		Yatsyn	Autumn	26.6	49.7
				Winter	23.2	48.9
				Spring	25.9	55.2
				Summer	31.3	51.5

The neutral detergent fibre (NDF) contents of Italian and perennial ryegrass are similar (Lowe et al. 1999a, Tharmaraj et al. 2008) and varies between 37.6% and 56.0% (Table 4.8). The NDF content of annual ryegrass peaks during the summer/autumn period and is lowest during winter (Fulkerson et al. 1998; Lowe et al. 1999a, Meeske et al. 2006). The low NDF content of annual ryegrass during winter could be problematic in terms of animal production, since it may lead to incidences of acidosis and "low milk-fat syndrome" in dairy cows (Fulkerson et al. 2007). The NDF content of perennial ryegrass also shows seasonality, and has been found to be lowest during winter and highest during spring, with autumn and summer concentrations being intermediate (Fulkerson et al. 2007). The NDF levels of annual ryegrass tend to increase from autumn-winter to highest levels spring, but are continuously lower than the values reported for perennial ryegrass (Fulkerson et al. 2007). In contrast Lowe et al. (1999a) reported that the NDF content of perennial ryegrass was highest during summer and autumn.

4.4.5 Digestibility

The digestibility of Italian ryegrass is similar to that of perennial ryegrass (Fulkerson et al. 1993a, Thom and Bryant 1996, Lowe et al. 1999a). The digestibility of perennial ryegrass during winter-early spring is 75-79% but declines to approximately 69% afterwards, when it enters the summer period (Fulkerson et al. 1993a). The digestibility of Italian ryegrass also shows a definite seasonal pattern, generally being highest during winter/early spring, then declining rapidly during late spring when Italian ryegrass enters a reproductive stage and the stem:leaf ratio increases (Thom and Prestidge 1996). The results from Thom and Bryant (1996) agree with this, where it was found that both Italian and perennial ryegrass decreased in digestibility from 82% during winter to a minimum level of 75% during summer. Lowe et al. (1999a) reported a similar trend, but in this case the decline was more extreme with *in vitro* DM digestibility of Italian and perennial ryegrass as low as 55.3 and 56.4 % respectively during summer. Although differences were not significant, the same data showed that the digestibility of Italian ryegrass was higher during autumn and winter than that of perennial ryegrass, but that during summer and spring perennial ryegrass had a higher digestibility. Seed set of Italian ryegrass during late spring and early summer has been implicated in this trend. As Italian ryegrass ages, the cell contents in its leaves tends to decrease, while cell wall constituents remain relatively constant, resulting in a decrease in *in vitro* digestibility of the leaves (Groot and Neuteboom 1997).

4.6 Mineral content of ryegrass

4.6.1 Calcium

The calcium (Ca) content of ryegrass, as reported in the literature, varies between 0.21% and 0.88% (Table 4.9), and has been found to be higher than the Ca content of tropical pasture species such as kikuyu (Reeves et al. 1996b).

The Ca content of annual ryegrass has been reported to be relatively high in September (spring), a period when the Ca content of perennial ryegrass was found to be deficient for dairy cows (Fulkerson et al. 1993a). The Ca content of Italian ryegrass declined rapidly from October (spring) onwards, with the decline associated with the reproductive development of the plant during this period (Fulkerson et al. 1998). Calcium concentration has been reported to show a linear increase in perennial ryegrass as it undergoes growth from the 1 to 3 leaves/tiller stage (Fulkerson et al. 1998, Fulkerson and Donaghy 2001).

Table 4.9: The mineral composition (%) of different ryegrass species as found in the literature

Reference	Species	Ca	P	Mg	Na	K
Beddows 1973	Annual ryegrass	0.5-0.9	0.21-0.41	0.08-0.36	0.009-0.14	1.2-4.5
Fulkerson et al. 1993a	Perennial ryegrass	0.21-0.39	0.19-0.23	0.25-0.45	-	2.0-4.0
Reeves et al. 1996b	Perennial ryegrass	0.35	0.38	0.24	0.15	3.1
Thom and Prestridge 1996	Italian ryegrass	0.41	0.36	0.19	0.27	3.50
Fulkerson et al. 1998	Perennial ryegrass-white clover	0.70	0.30	0.31	0.47	3.0
	Italian ryegrass	0.59	0.31	0.27	0.37	3.4
Dalley et al. 1999	Perennial ryegrass	0.44	0.35	0.22	0.44	3.12
	Italian ryegrass	0.59	0.31	0.27	0.37	3.4
Meeske et al. 2006	Annual ryegrass	0.67	0.36	0.36	0.89	3.4
	Perennial ryegrass-white clover	0.88	0.40	0.44	0.65	3.0
Lehmann et al. 2007	Annual ryegrass	0.50	0.50	-	-	-

4.6.2 Phosphorous

The phosphorous (P) content of annual and perennial ryegrass, as cited in the literature varies between 0.19 % and 0.50 % (Table 4.9). The P concentration of annual ryegrass is lower than that of perennial ryegrass (Fulkerson et al. 1993a). Phosphorous levels of perennial ryegrass tended to drop with an increase in re-growth period (Fulkerson et al. 1998). Season has a marked effect on the P content of both Italian and perennial ryegrass, with concentrations generally remaining high from winter until flowering and seed set during spring/summer, when concentrations decrease (Fulkerson et al. 1993a, Fulkerson et al. 1998).

4.6.3 Calcium: Phosphorous ratio

The Calcium:Phosphorous (Ca:P) ratio is slightly lower in Italian ryegrass than in perennial ryegrass, but is still adequate for dairy cows at 1.9:1 (Fulkerson et al. 1998). Due to the fact that Ca concentrations in perennial ryegrass tend to increase and P concentrations tend to decrease with increased defoliation intervals, the Ca: P ratio shows a marked change with re-growth, tending to increase from 1:1 to 2.2:1 from the 1 to 3 leaves/tiller stage, an almost two-fold increase (Fulkerson et al. 1998). The Ca:P ratio in Italian ryegrass declines dramatically during spring when the plants begin to enter the reproductive stage (Fulkerson et al. 1998).

4.6.4 Magnesium

Fulkerson et al. (1998) did not find any significant changes in the Magnesium (Mg) content of perennial ryegrass with re-growth, but did report slight seasonal changes, with lower concentrations during winter than during spring. Magnesium levels in perennial ryegrass have been reported to show a linear increase as the leaf ages (Fulkerson and Donaghy 2001).

4.6.5 Sodium

The sodium (Na) concentration in ryegrass is generally adequate for animal production. Unlike kikuyu which is a natrophobe, perennial ryegrass is a natrophile that readily accumulates Na in its leaves (Tainton 2000). For this reason the Na content of ryegrass at 0.37% is appreciably higher than for kikuyu (Reeves et al. 1996b). Sodium increases in perennial ryegrass as the plant ages (Fulkerson and Donaghy 2001).

4.7 Management of ryegrass

Experience has shown that there are contrasting requirements for production and persistence of temperate species in the sub-tropics and tropics compared with temperate environments. The main reasons for this difference are higher temperatures and radiation levels during the cool season in these areas. Both these factors result in higher growth rates than reported in temperate environments, but also mean that temperate species are often subjected to greater stress, increased disease pressure, high mortality rates and competition from C_4 summer growing grasses (Fulkerson et al. 1993a).

4.7.1 Establishment of pure ryegrass swards

Ryegrass seed can either be broadcast or planted in rows. Under both circumstances a good, weed free seedbed should be prepared to minimize the competition between newly established ryegrass and weeds. Developing a seedbed by numerous cultivations over an extended period has been found to be beneficial in terms of perennial ryegrass establishment and persistence, primarily due to the suppression of summer (C_4) grasses (Fulkerson et al. 1994). Consideration should however be given to the negative impact extreme cultivation practices could have on soil structure and stability. The recommended seeding rates for ryegrass establishment in a pure sward are given by Dickenson et al. (2004) and Tainton (2000) as:

- Perennial ryegrass in rows: 20 kg ha^{-1}
- Perennial ryegrass broadcasted: 25 kg ha^{-1}
- Annual diploid ryegrass in rows: 20 kg ha^{-1}
- Annual diploid ryegrass broadcasted: 25 kg ha^{-1}
- Annual tetraploid ryegrass in rows: 25 kg ha^{-1}
- Annual tetraploid ryegrass broadcasted: 30 kg ha^{-1}

The recommended establishment dates for annual ryegrass under South African conditions are indicated in Table 4.10 (Dickenson et al. 2004). This table illustrates that the correct timing of ryegrass establishment will be dependent on both environmental factors and the specific fodder flow requirements of the producer. An earlier planting date during autumn will ensure that feed is available earlier, but possibly at the expense of winter production.

Table 4.10: Sowing times and utilization periods of ryegrass in different regions in South Africa (Dickenson et al. 2004)

Region	Establishment Date	End of growth season	Length of growth season
Cold winters, heavy frost	Mid February	Mid December	10 months
Moderate winters, light frost	Mid March	Mid November	8 months
Warm winters, frost free	April	Mid Oct	6 months

Table 4.11 shows the effect of different planting dates on the yield of Italian ryegrass (Goodenough et al. 1984). As planting date was delayed from February to May the average yield of pasture increased. A possible negative impact was, however, that the period between planting date and the date when pasture could be utilized for the first time also increased. Of importance is to note that, although the DM yield of ryegrass planted during the winter months June and July is higher than the swards established in early autumn, the sward will only be ready to be grazed during spring. As result these pastures will not assist in alleviating the winter feed shortfall often experienced in South Africa. In

Australia it is recommended that seedbed preparation be started as early as March if annual ryegrass is expected to be ready for grazing by May (Fulkerson et al. 1993a).

Table 4.11: Influence of the planting date on the first utilization date and dry matter production from the first cut of Italian ryegrass at Cedara (Goodenough et al. 1984)

Planting date	Average first utilization date	Days after planting	Average DM yield (kg ha^{-1})
7 February	6 April	58	1569
7 March	3 May	57	1538
7 April	17 June	71	1602
7 May	17 August	102	1792
7 June	18 September	103	1626
8 July	1 October	86	1714

4.7.2 Grazing management

Figure 4.3 illustrates the process that a ryegrass plant undergoes after defoliation (Donaghy 1988). During the immediate post grazing period, root growth ceases, as the development of new photosynthetic tissue in regard to leaf development takes priority. The result of this is that the more frequently plants are grazed, the poorer root growth, with the end result that plants tend to be more sensitive to adverse environmental conditions such as hot or dry conditions (Fulkerson and Donaghy 2001). Ryegrass is termed a “three-leaf plant” as each tiller maintains about three leaves. Once the fourth leaf starts to emerge, the oldest leaf will start to senesce (Fulkerson and Donaghy 2001). The grazing of young re-growth shoots due to an extended grazing duration would have the same effect on the grass plants as when imposing frequent grazing intervals, due to removal of plant reserves (Fulkerson and Donaghy 2001). Frequent defoliation in winter will reduce growth, which will both reduce the ability of ryegrass to recover, but could also increase the incidence of sod pulling by grazing animals (Donaghy et al. 1997). It has also been found that defoliating perennial ryegrass at the 1 leaf/tiller stage during spring resulted in plants entering the summer period with smaller root systems than when defoliated at the 3 leaves/tiller stage. A secondary effect of this was that the plants defoliated at 1leaf/tiller had a greater number of individual plants pulled from the soil by grazing stock (Donaghy and Fulkerson 2002).

The different growth forms of annual and perennial ryegrass leads to the fact that they will react differently under similar cutting/grazing regimes, largely due to variation in heading behaviour and, as such, persistency (Cooper and Saeed 1949). The erect growth form of annual ryegrass results in many of its nodes and new tillers being situated above ground level, thus a 25 mm cutting height could potentially remove most of the photosynthetic tissue and some reserves (Cooper and Saeed 1949). Research from Fulkerson and Slack (1994) indicated that defoliating perennial ryegrass to a height of 120 mm, rather than 60 mm, reduced both ryegrass plant density, total edible DM yield and halved utilization of DM, but had no effect on the ingress of summer grasses. In perennial ryegrass the growth habit tends to be more prostrate with most nodes and vegetative tillers forming at ground level, thus even at low cutting regimes photosynthetic tissue and carbohydrate reserves will remain, lending to the improved persistence and greater recovery after heading of perennial ryegrass (Cooper and Saeed 1949).

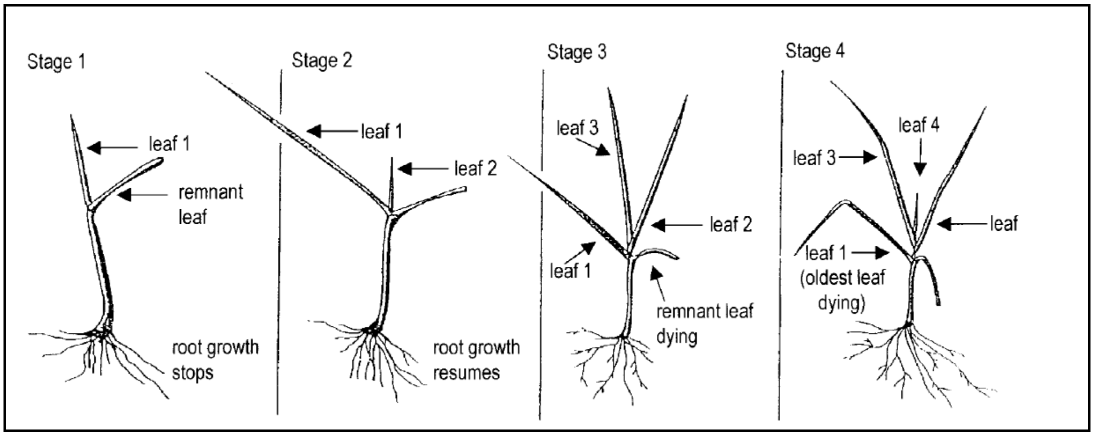

Figure 4.3: Re-growth of a ryegrass tiller following defoliation (Donaghy 1998)

Cooper and Saeed (1949) indicated that an 11 day grazing interval would result in exhaustion of the carbohydrate reserves in both stubble and roots, recommending an interval of between 28 and 30 days to maintain these storage reserves. Fulkerson and Donaghy (2001) stated that while replenishment of WSC reserves sets the standard for shortest grazing interval to ensure plant re-growth and survival, the decline in nutrient quality as the oldest leaves senesce sets the upper limit. According to these authors, in order to accumulate reasonable levels of minerals important for milk production, magnesium and calcium, and to minimize the potassium and N concentration in ryegrass, the correct time for grazing is at approximately 3 leaves/tiller. Grazing at 3 leaves/ tiller during winter and spring has also been found to improve the survival of perennial ryegrass into the summer and reduce the ingress of tropical grass species (Donaghy et al. 1997). These results were similar to those of Fulkerson et al. (1993b) who found that fewer ryegrass plants survived into summer and more summer grasses invaded ryegrass plots when defoliating at two weeks rather than at four weeks. There is some indication that a "closed" canopy during summer can reduce summer grass invasion (Fulkerson et al. 1993a).

The DM production of perennial ryegrass has been reported to be higher when less frequently grazed, but intensity (defoliation height) did not have an effect (McKenzie 1996). The production rate of perennial ryegrass has been improved by as much as 41% when grazed at a four week, rather than two week intervals (Fulkerson et al. 1993b). Of interest is that the greatest production rates were achieved when grazing interval was based on tiller number (3 leaves/tiller) rather than on fixed intervals. The results of Dale et al. (2008) reported a similar response, with the annual DM yield of perennial ryegrass grazed at 20 day intervals during winter higher than when grazed at eight to 12 day intervals. More lenient or less frequent grazing intervals can reduce the ingress of summer grasses and increase ryegrass survivability (Fulkerson et al. 1993, Donaghy et al. 1997, Donaghy and Fulkerson 2002), while also improving vigour of perennial ryegrass (McKenzie 1997). Infrequent grazing, irrespective of intensity, should be considered to improve the persistence of perennial ryegrass pastures (McKenzie 1997).

Frequent defoliation of Italian ryegrass during the period when it is setting seed (spring/summer) has been found to inhibit seed head formation, but not stem elongation. The impact of this was that seedling recruitment in the following autumn was greater for Italian ryegrass defoliated at longer intervals during this period (Donaghy et al. 1997). A decision will thus have to be made whether Italian ryegrass pastures will not be grazed during spring/summer to allow seed set and self-regeneration of the pasture during the second year, or whether pastures will simply be re-established in the second year by over-sowing (Donaghy et al. 1997).

4.7.3 Fertilisation and irrigation

Miles (1991) recommended that between 200 and 400 kg N ha^{-1} annum^{-1} was required to obtain maximum yields from ryegrass in South Africa, whilst Beyers (1994) recommended a rate of 400-600 N ha^{-1} annum^{-1} for ryegrass under irrigation. It has also been recommended that nitrogen be applied in split dressings in order to provide for the direct nitrogen requirements of the pasture plant (four to six weeks) (Labuschagne 2007).

Nitrogen fertilisation of ryegrass has been found to increase the number of ryegrass plants surviving into the summer under cutting, but it was concluded that this may not be the case under grazing (Fulkerson et al. 1993b). The application of N to perennial ryegrass pastures restricts root development to the soil surface, resulting in sod pulling by grazing livestock and nullifying the potential positive impact of N fertilizer on DM yield (Fulkerson et al. 1993a, Fulkerson et al. 1993b). A further complication of high N fertiliser rates of perennial ryegrass pastures during the summer months is that it promotes the growth of tropical weed grasses that commonly invade perennial ryegrass pastures (Donaghy and Fulkerson 2002).

Liming can improve DM production rate and survival of ryegrass pastures (Fulkerson et al. 1993b). Miles (1991) also reported that Italian ryegrass responded well to liming, possibly due to the species' sensitivity to acidic soil conditions (pH KCl <5.0).

Continued irrigation of annual ryegrass pastures during summer increased the DM yield of pastures compared to no irrigation (Donaghy et al. 1997). However, the increased DM yield under irrigation also resulted in a greater ingress of summer grasses and weeds. Irrigation has been found to have a positive effect on the DM yield potential of perennial ryegrass summer, autumn and winter (Fulkerson et al. 1994, Donaghy et al. 1997), while also improving the survival of ryegrass plants during summer (Fulkerson and Slack 1994).

5. Over-sowing kikuyu with ryegrass

5.1 Production potential

The pasture availability graph for a typical dairy farm in New South Wales is illustrated in Figure 5.1 (Fulkerson et al. 1993a). According to this graph, the DM production of kikuyu, annual ryegrass and perennial ryegrass all show a seasonal pattern, with each reaching its peak and lowest production at different times during the growing season. Under the specific conditions in this area, kikuyu showed relatively high growth rates from January to March, after which production rates declined to negligible levels from June until October. During October the DM production rate of kikuyu had started to recover by gradually increasing. The decline in DM production from March to June is also accompanied by a decline in quality (the "autumn slump" as mentioned in Section 3.3.2). The DM production of annual and perennial ryegrass, according to Figure 5.1, is comparatively high during the months when kikuyu growth is below requirements of this specific herd (March until December). The cause of this pattern is that temperatures in the sub-tropics and tropics lie within the optimum range for temperate species during the winter-spring period, making this period well suited to the growth of these species (Fulkerson et al. 1993a). It has been recommended that the seasonality of kikuyu production be matched with species that grow at lower temperatures such as annual ryegrass (Minson et al. 1993). Establishment of annual ryegrass during autumn months by conventional methods is often problematic for farmers, primarily because early establishment is required to obtain early winter feed from such pastures. The reluctance of farmers to employ such a system is related to the loss of the growth potential of summer grasses during autumn. Minimum tillage practices, where temperate species (such as ryegrass) are over-sown into kikuyu during autumn, have been identified as a possible solution to the above problems (Fulkerson et al. 1993a). In addition, it has been found that, under South African conditions, kikuyu over-sown with perennial or annual ryegrass had higher DM production rates than pure perennial ryegrass swards (Botha and Gerber 2008).

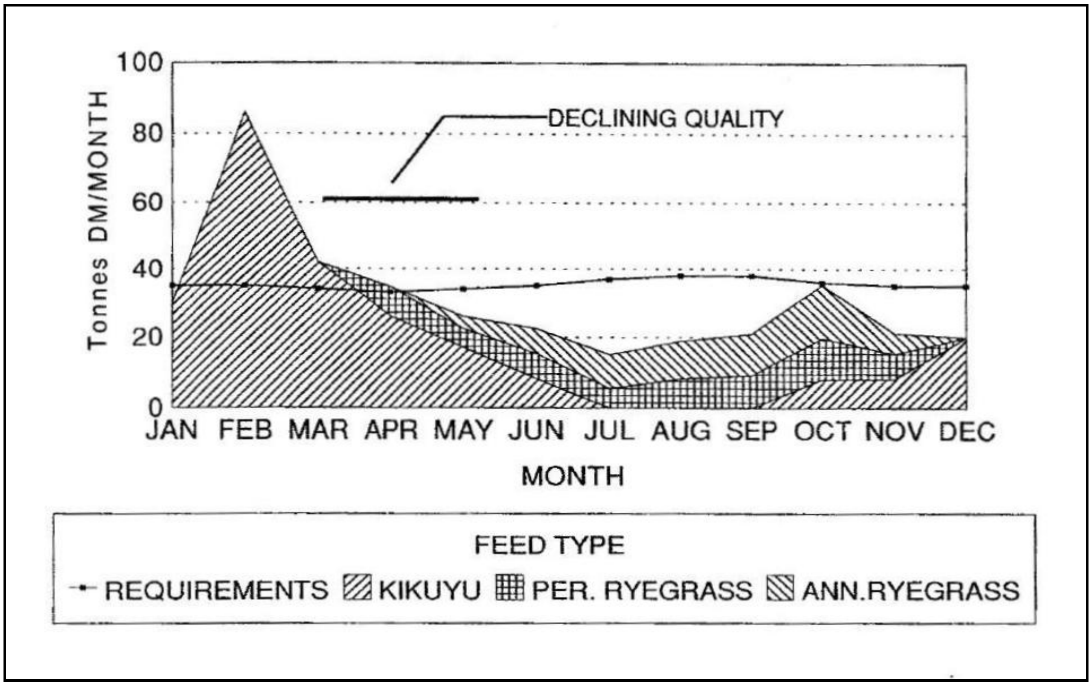

Figure 5.1: Pasture availability and requirements (t DM/month) on a typical farm in New South Wales (Australia) comprising 14 ha of ryegrass and 50 ha of summer growing grass (usually kikuyu) under irrigation. Requirements are for 77 milkers and 45 replacements. (Fulkerson et al. 1993)

Temperate species such as ryegrass (*Lolium* spp.), fescue (*Festuca arundinace* Schreb), clovers (*Trifolium* spp.) and Praire grass (*Bromus catharticus*) have been successfully over-sown into kikuyu to improve the DM production. The DM production from such pastures is shown in Table 5.1. Harris and Bartholomew (1991) reported that over-sowing kikuyu with Westerwolds or Italian ryegrass was found to improve the DM yield during winter and spring, compared to pure kikuyu swards. Clover and ryegrass was also successfully introduced into existing grass pastures by Goodchild et al. (1981) to improve the seasonality of production often experienced with tropical grass species. Differences in the DM production potential of these over-sown pastures have been reported, with kikuyu over-sown with ryegrass found to out-yield kikuyu over-sown with white (*T. repens*) and red (*T. pratense*) clover (Botha et al. 2008). In addition, kikuyu over-sown with ryegrass showed better sustainability when compared to pastures over-sown with Praire grass or Tall fescue (Hill 1985).

Table 5.1: The dry matter yield (t ha^{-1}) of kikuyu over-sown with various temperate pasture species

Reference	Pasture type	Description	DM yield
Betteridge 1985	Kikuyu-annual ryegrass	Annual	14.60
	Kikuyu-perennial ryegrass	Annual	15.10
	Kikuyu-praire grass	Annual	15.10
	Kikuyu	Annual	13.10
Hill 1985	Kikuyu-annual ryegrass	May	1.25
		July	0.66
		October	2.57
	Kikuyu-praire grass	May	1.31
		July	0.69
		October	1.99
	Kikuyu-tall fescue	May	0.90
		July	0.52
		October	-
Harris and Bartholomew 1991	Kikuyu-Italian ryegrass	Annual	17.65
	Kikuyu-Westerwolds ryegrass	Annual	17.36
Davison et al. 1997	Kikuyu-white clover	February	3.84
		May	2.69
		August	3.96
		November	3.74
Botha et al. 2008a	Kikuyu	Annual	13.80
	Kikuyu-annual ryegrass	Annual	15.70
	Kikuyu-white and red clover	Annual	14.50

In an effort to not only improve the seasonal DM production of kikuyu, but to lower the nitrogen requirement in such kikuyu based systems, kikuyu has also been successfully over-sown with various clover species (Davison et al. 1997, Botha et al. 2008a). The clover yield on such pastures has been reported to be relatively low, with clover levels of only 10 to 23% of the total yield in kikuyu-clover pastures recorded by Davison et al. (1997). Similar results were reported by Botha et al. (2008a), where the proportion of clover in a kikuyu over-sown with clover showed a decline from establishment onwards. However, unlike Davison et al. (1997), Botha et al. (2008a) reported that the proportion of clover in the pasture remained above 30% during the second year after establishment. The fact that animals often impose high selection pressures on clover in such pastures has been identified as a possible reason for the decline in clover content in kikuyu-clover pastures over time (Davison et al. 1997).

Annual ryegrass over-sown into kikuyu has been reported to increase the annual and seasonal DM production of pastures compared to pure kikuyu pastures (Harris and Bartholomew 1991, Botha et al. 2008a). The kikuyu-ryegrass pastures had a significantly higher grazing capacity than the pure kikuyu pasture, whereas pastures based on kikuyu over-sown with clover did not (Botha et al. 2008b). In addition, the kikuyu-ryegrass pastures were found to provide a more evenly distributed seasonal fodder availability when compared to kikuyu or kikuyu-clover pastures. The milk production per unit land area was higher in the kikuyu-ryegrass pastures, while production per animal increased as the proportion of clover in the kikuyu based pastures increased. These results indicate that that including temperate grasses and legumes in kikuyu pasture can improve animal production. Aside from the research by Betteridge (1985), which showed that perennial ryegrass over-sown into kikuyu improved the DM production of kikuyu, no data could be found on the production potential (pasture DM and milk production) of perennial ryegrass-kikuyu pastures.

5.2 Sward dynamics in over-sown pastures

There are two periods of importance in systems based on over-sowing kikuyu with temperate species, the first being autumn and the second spring. Autumn coincides with the period when the newly established temperate species will have to compete with the kikuyu, while spring coincides with the period when newly emerging kikuyu will have to compete with the temperate species to start its growth season (Willis 1995).

Careful consideration should be given to the cultivar choice when over-sowing kikuyu, primarily because the persistence of the temperate species into summer could negatively impact on the summer re-growth of kikuyu (Harris 1999). Over-seeding temperate species such as tall fescue or perennial ryegrass into kikuyu was found by Elmore et al. (1997) to reduce the percent cover of kikuyu compared to kikuyu that had not been over-seeded. The species planted will grow rapidly (higher rate of tillering) during the period when kikuyu is dormant, with denser canopies being able to reduce the invasion of kikuyu, whilst an open turf will allow stolon penetration (Elmore et al. 1997). Tropical grasses will often rapidly colonize the bare soil left by frequently cut ryegrass pastures as light penetration of the sward increases (Donaghy et al. 1997).

Harris and Bartholomew (1991) found that Westerwolds ryegrass varieties tended to die back earlier than the Italian ryegrass varieties, allowing greater re-growth of the kikuyu during summer (February), whilst the high production of the Italian ryegrass varieties during spring resulted in significantly lower yields during summer (January) of the kikuyu in these plots. By autumn, the kikuyu had fully recovered and the yields of both the Italian and Westerwolds plots were similar. Lawson and Kelly (2007), while investigating the effect of over-sowing Italian or perennial ryegrass into paspalum-perennial ryegrass pastures, found that the increase in pasture DM yield and consumption from the established grasses occurred mainly in winter and spring, with very high increases seen during spring in the Italian ryegrass treatment. Callow et al. (2005) reported that the production benefit gained from renovating degraded perennial ryegrass pastures depended on the density of the existing ryegrass sward, the environment and the climatic characteristics of the region.

Goodchild et al. (1982), while investigating Pangola/couch grass pastures over-sown with ryegrass, found that by November (spring) a substantial proportion of the pasture DM yield was contributed by the tropical species, rather than the ryegrass. Harris (1999), however, stated that the spring re-growth of kikuyu may be delayed when over-sown with ryegrass during autumn and that correct management can reduce this effect. Harris (1999) for instance recommended that a 28- day grazing cycle be followed in winter and autumn, whilst a shorter cycle with harder grazing be followed during late spring to prevent the ryegrass setting seed and in order to allow the kikuyu to come away as fast as possible during spring.

5.3 Quality

The quality of temperate grass species over-sown into tropical species has been reported to decrease from winter to summer, but was still higher than the pure stands of tropical species during winter (Goodchild et al. 1982). Lawson and Kelly (2007) investigated the effect of over-sowing Paspalum-perennial ryegrass pasture with either Italian or perennial ryegrass and indicated that the benefit from these pastures was related to increased pasture consumption rather than an improvement in nutritional quality. The quality of over-sown pastures, in turn, tended to be lower than that found in pure swards of temperate species, but higher than for pure swards of tropical species (Goodchild et al. 1982).

Bredon (1980) listed the incorporation of clovers into kikuyu as an alternative to improving the nutritive quality of pastures, stating that this was a possible system to reduce the “autumn slump” often experienced on kikuyu pasture. Davison et al. (1997) found that even if clover contributed very little to the total DM yield from kikuyu-clover pastures, it played a major role in improving nutritive quality and milk yield of animals grazing such pastures. Furthermore, the inclusion of clovers in kikuyu could alleviate the calcium (Ca) deficiency of these pastures, while clovers and ryegrasses can also relieve the sodium deficiency often found on pure kikuyu swards (Miles et al. 1995). Data from Davison et al.

(1997) has, however, indicated that kikuyu-clover pastures were still deficient in Ca and Magnesium during February and May (autumn).

The nutritional composition of kikuyu over-sown with white-and red-clovers or ryegrass, compared with a pure kikuyu sward is shown in Table 5.2 (Botha 2003). This study showed that, in terms of nutrient quality, kikuyu-clover pastures were superior to kikuyu and kikuyu-ryegrass systems in terms of a higher metabolisable energy (ME), crude protein (CP) and Ca contents, while clover dominant pastures also had lower neutral detergent fibre (NDF) concentrations. Although the inclusion of ryegrass also increased the Ca:P ratio and ME content, compared to that of pure kikuyu pastures, the increase was lower than in kikuyu-clover pastures.

Table 5.2: The mean annual nutritional composition of kikuyu over-sown with clover (KC), ryegrass (KR) and pure kikuyu (K) during the first year of establishment. ^{a}Means within rows with no common superscript differed significantly ($P<0.05$) (Adapted from Botha 2003)

Nutrient	KC	KR	K
Metabolisable energy (MJ kg^{-1} DM)	11.29^a	9.28^b	8.55^c
Crude protein content (%)	27.9^a	23.6^b	23.4^b
Neutral detergent fibre (%)	39.1^b	60.9^a	63.7^a
Calcium (%)	0.87^a	0.30^b	0.34^b
Phosphorous (%)	0.40^b	0.41^b	0.54^a
Calcium:phosphorous ratio	2.81:1	0.73:1	0.63:1

5.4 *Planting methods to over-sow ryegrass into kikuyu*

Betteridge (1985) advises that when sowing another species into kikuyu during autumn the bulk of stolon and leaf material must first be removed, to prevent it from interfering with drilling machinery and inhibiting seed-soil contact. When kikuyu is set back severely during the over-seeding of ryegrass, the improved access to light has been found to benefit the ryegrass seedlings (Hill 1985, Harris 1999). Some farmers establish ryegrass by first grazing the pasture short then either broadcasting or drilling the seed into the kikuyu after it has been mown and excess material removed (Willis 1995). Vertical mowing will reduce kikuyu grass into a network of surface stolons and rhizomes (Elmore et al. 1997), meaning that the kikuyu is still present when planting commences. As result, mulching of the kikuyu during ryegrass establishment has largely replaced mowing. The mulcher differs from the mower in that it has vertically swinging blades that cut the horizontal growing stolons of kikuyu to ground level, compared to the mower which cuts kikuyu to a minimum height of 30 mm with horizontally swinging blades. There are two ways of using the mulcher for over-sowing kikuyu with ryegrass. Firstly ryegrass can be broadcasted onto the well grazed kikuyu stubble and then mulched, or alternatively the kikuyu can be mulched and then ryegrass drilled in using an appropriate planter (Willis 1995, Botha 2003).

For annual ryegrass, direct drilling, rather than broadcasting, is recommended. Direct drilling results in improved establishment, growth and ryegrass content compared to broadcasting (Betteridge 1985). Broadcasting has, however, also been found to be a successful method of establishment, even though it may lead to higher rates of seedling mortality (Harris 1999).

Goodchild et al. (1982) compared two systems where temperate species such as ryegrass and clover were planted into existing tropical pastures (Pongola grass and couch grass) by either slashing or burning existing pasture, or by slashing, burning and using a rotary hoe. The uncultivated plots (no rotary hoe) displayed a higher increase in yield after establishment than the plots that were cultivated with a rotary hoe, indicating that temperate species can be successfully established into existing pastures with a no-tillage system. The main disadvantage of ryegrass establishment using rotavation is that this drastic method is relatively expensive and sets back the kikuyu severely, which could negatively impact on kikuyu production in the following summer (Willis 1995). Goodchild et al. (1982) did, however, emphasize that some cultivation during establishment could improve the quality of the pastures due to the lower proportion of kikuyu re-growth found in cultivated plots. Kunelius et al. (2004) noted that no-till establishment of ryegrass, compared to cultivation of soil, allowed for fast seeding and can reduce the risk of soil erosion. Thus, although ryegrass tends to establish at a lower rate with no-till establishment methods, yield can still match that of cultivation methods.

The spraying of kikuyu with herbicide has been found to increase the plant density of temperate species when over-sown into kikuyu compared to slashed plots. The degree of this effect is, however, dependent on the sowing date, generally declining as the planting date is extended from January to May (Hill 1985). Although spraying of kikuyu with herbicides may have a beneficial effect on ryegrass establishment, the negative effect on kikuyu re-establishment during spring must be considered (Betteridge 1985), as well as the reduction in yield during early winter that may accompany spraying (Thom and Prestidge 1996). Spraying of plots prior to establishment of Italian ryegrass into an existing sward, has been reported to result in higher DM yields during the late winter/early spring period, compared to unsprayed plots. However, by summer/autumn differences between sprayed and unsprayed treatments were no longer evident (Thom and Prestidge 1996). Certain authors adopted a practice whereby the plots where temperate species are planted into kikuyu were mown to a height of 50 mm (and cuttings removed) every week after planting. The aim of this practice is to reduce competition and the suppressive effect that the kikuyu has on the establishing seedlings (Harris and Bartholomew 1991, Elmore et al. 1997).

Table 5.3 compares different methods for establishing ryegrass in an existing stand of kikuyu (Botha 2003). Although there were no significant differences in the total annual or seasonal DM production, Botha (2003) recommended method number five. This method, where seed was broadcasted and pasture mulched afterwards, did not require expensive implements and was identified as the most economic option.

Table 5.3: The total seasonal and annual dry matter production (kg DM ha^{-1}) of a pure kikuyu sward and four different kikuyu-ryegrass systems based on different establishment methods during May. Means with no common superscript differed significantly. LSD (0.05) compares over and between rows (Botha, 2003).

Establishment method	Winter	Spring	Summer	Autumn	Annual
Graze to 50mm Kikuyu	1465^{fgh}	1465^{fgh}	3598^{de}	5288^{abcd}	12456^{a}
Graze to 50mm Mulcher Rotavator Disc Broadcast seed Landroller	996^{gh}	2630^{efg}	4608^{cd}	5638^{abc}	13872^{a}
Graze to 50 mm Spray Glyphosphate Mulcher Moore planter	444^{h}	2630^{efg}	4608^{cd}	5638^{abc}	11956^{a}
Graze to 50 mm Mulcher Moore planter	938^{gh}	2302^{efg}	3684^{de}	6929^{a}	13858^{a}
Graze to 50 mm Broadcast seed Mulcher Landroller	1012^{gh}	2114^{efgh}	3811^{de}	6393^{ab}	13265^{a}
LSD (005)			1706.8^{1}		3120^{2}

LSD^{1}: compares over seasons and treatments

LSD^{2}: compares annual production

Westerwolds and Italian ryegrasses can be successfully sown directly into summer grasses at high seeding rates (between 25 and 40 kg ha^{-1}) during March and April (Fulkerson et al., 1993a). The standard recommendation for the seeding rate when establishing annual ryegrass into kikuyu pastures is 25 kg ha^{-1} for diploid varieties and 30 kg ha^{-1} for tetraploid varieties (Harris and Bartholomew 1991). Higher seeding rates have resulted in lower kikuyu grass density and cover than lower seeding rates, especially shortly after the establishment period (Elmore et al. 1997). Very low seeding rates (20 kg ha^{-1}), when over-sowing annual ryegrass into kikuyu, have also been reported to result in poor establishment and lower DM yields compared to higher seeding rates (Harris and Bartholomew 1991). Minimum tillage is not widely applied to establish perennial ryegrass pastures, since herbicide treatment gives insufficient long-term control of competitive summer grasses (Fulkerson et al. 1993a).

5.5 *Planting date*

The optimum planting date for over-sowing kikuyu with temperate species will be dependent on the seedling vigour of the species involved and the pattern of temperatures in the area. The best planting date will generally coincide with optimum temperatures for establishment and the period when kikuyu competition is lowest for the seedlings (Hill 1985). Bredon (1980) recommended that, where possible, ryegrass should be established as soon as possible during autumn to minimize the autumn grazing period of kikuyu. Later planting in autumn will result in lower competition for the seedlings from kikuyu, whilst earlier planting could ensure that the winter feed gap is shortened because pastures are ready to be grazed earlier (Willis 1995).

Betteridge (1985) reported that an April sowing resulted in the highest DM production and ryegrass tiller density. Sowing earlier allows the kikuyu to recover more rapidly (mostly due to high temperatures) which can potentially suppress the establishment and growth of seedlings (Betteridge 1985, Kaiser et al. 1993). Work done by Hill (1985), on planting dates for the establishment of Italian ryegrass into slashed kikuyu, indicated that sowing during late autumn (April/May) resulted in higher plant densities of the ryegrass than over-sowing during summer (January/February) while kikuyu was still actively growing. Harris (1999) and Hill (1985) reported that over-sowing annual ryegrass into kikuyu during March, April or May did not significantly impact on total yield, but that the time of planting did influence the time till first harvest and the yield of first harvest. Later sowings were found to take longer to mature to the stage where it could be cut. Sowing later (in autumn) also resulted in a lower proportion of kikuyu and higher ryegrass proportion than early sowing (Hill 1985).

It has been recommended that temperate species should be replanted into the tropical species on annual basis to achieve the highest possible DM production from the high cost inputs of irrigation and fertiliser required on such pastures (Goodchild et al. 1982)

6. Determination of pasture yield using the rising plate meter

6.1 The importance of correct pasture measurement

Accurate determination of pasture yield plays a vital role in dairy pasture management and pasture based research.

Accurate budgeting and management of forage in grazing systems requires frequent assessment of forage mass and growth of pastures (Gabriëls and Van den Berg 1993, Sanderson et al. 2001). Knowledge on the available herbage mass can assist in taking the right management decisions at the right time (Gabriëls and Van den Berg 1993), as well as in the identification of pastures that need improvement and tracking of pasture condition (Sanderson et al. 2001). From a research point of view accurate pasture mass estimations could allow researchers to better understand the interactions of plants and animals in grazing trials. It is, therefore, necessary to have some measure of production; availability and consumption of forage (Bransby et al. 1977), whilst assisting to determine optimum stocking rates (Ganguli et al. 2000) and intake of experimental animals (Stockdale 1984).

The standard method for assessing forage mass is to clip and weigh the forage. This method is generally very accurate but requires great effort, labour and expense in order to collect enough samples to accurately represent a pasture, with farmers generally not willing to make this effort in the day-to-day management of pastures (Sanderson et al. 2001). Symons and Jones (1971) described various situations where clipping is not desirable or practical, such as when:

- veld or pasture is evaluated on a large scale where cutting of herbage is time consuming and impractical,
- a high intensity of sampling is necessary for accurate results, so that factors of time, expense and labour may preclude harvesting of herbage,
- research involves growing plants which require regular and continuous estimates of herbage present at successive growth stages. Here it is clearly undesirable to destroy the herbage by cutting,
- cutting, although not a factor being studied in an experiment can, itself, become a significant treatment,
- the use of grazing animals in pasture management studies increases the difficulty of estimating pasture yield by sample cutting techniques. Under grazing researchers will require many samples due to the very variable nature of grazed swards, but too many samples may significantly reduce available herbage, thus becoming a treatment in itself.

An alternative to such destructive sampling is the use of indirect methods that are based on visual assessment, height and density measurements or measurements of non-vegetative attributes such as capacitance (Crosbie et al. 1987). Most indirect methods are based on a double sampling procedure i.e. two overlapping methods are used. Standards are generally cut and used to develop a relationship between the indirect method, after which a larger number of measurements are taken with the indirect method and "plugged into" the calibration equation (`t Mannetjie 2000). Double sampling requires some destructive sampling to develop the predictive relationship, but once this relationship has been developed, less emphasis can be placed on clipping, using it only for calibration and validation within the trial (Ganguli et al. 2000). The major advantage of utilizing some form of double sampling is the marked reduction in time spent cutting herbage (Stockdale 1984).

`t Mannetjie (2000) highlighted the fact that although indirect methods are less accurate on a per sample basis than destructive cutting methods, they are less time consuming, laborious and allow for a larger number of measurements to be taken at a time, and in so doing could indirectly improve the accuracy of such methods. Symons and Jones (1971) and Tucker (1980) were however of the opinion that an indirect method could only be used if it met some criteria such as:

- Accuracy: the estimates of herbage yield must correlate well with actual herbage yield over the whole range of possible weights encountered.
- Sensitivity: the method should be capable of measuring differences which are meaningful to the worker.
- Reliability: consistent estimates of herbage yield are essential. Readings should not be influenced by inconsistent errors in the method itself.
- Specificity: differences in measurements should be due to herbage mass alone and should not be affected by other properties of the herbage such as moisture content or by non-herbage factors such the presence of the operator or even his temperament at the time of measurement. In addition to this, the apparatus should be relatively unaffected by environmental circumstances such as dew, wind, clouds, varying irradiation conditions and uneven micro-topography.
- Apparatus: any apparatus should be robust, reliable, lightweight, inexpensive, easily transportable and simple to operate.
- Operator friendly: the method should be easy and quick to utilize and calibrate. The method should also be simple enough for a person of average intelligence to be able to use it.

6.2 Comparison of the rising plate meter with other indirect methods

Piggot (1986) found virtually no differences between the pasture disc meter and capacitance probe in accuracy, with similar findings reported by Stockdale and Kelly (1984). Murphy et al. (1995) reported that the capacitance probe displayed less variability than the rising plate meter, whilst Fulkerson and Slack (1993) found that with tropical pasture species the rising plate meter was more accurate in estimating pasture mass than the capacitance probe. Martin et al. (2005) indicated that although the visual estimation method gave accurate estimations (indicated by a straight line and high R^2 values), the results were more variable between sampling dates than with the rising plate meter. Stockdale (1984) also found that the rising plate meter was more accurate than the visual assessment method in estimating herbage yields, especially pre-grazing.

Compared to the capacitance meter the rising plate meter does not experience certain problems, especially in regard to calibration, because it is not sensitive to drift due to battery power, environmental conditions and is more robust (Earle and McGowan 1979). Compared to both the visual estimation method and capacitance meter, the pasture meter requires appreciably less expertise and training for use. Furthermore, the disc meter does not have to be calibrated on a daily basis like the capacitance probe (`t Mannetjie 2000). Michell (1982) concluded that one of the greatest advantages of the pasture disc meter was the stability of the calibration relationship of this method across years, season and paddocks of similar pasture composition.

In post grazing swards most authors report that the capacitance meter is better suited to determining post-grazing herbage mass (Stockdale and Kelly 1984, Stockdale 1984). These results have been ascribed to the effect that the remaining stubble have on the pasture disc measurements when it is very hard (tipping) or that the plate could have on stubble when it is very young and soft (crushing) (Stockdale and Kelly 1984).

The scale, as it relates to size (plots, paddocks or whole farm), on which the pasture estimation is to occur is of primary importance when selecting the indirect method, since this will influence the amount of time and labour that can be expended on measurement (`t Mannetjie 2000). Martin et al. (2005) concluded that the rising plate meter was more operator friendly in terms of simplicity and ease than the visual estimation method. The RPM is generally also more convenient and less expensive to use than the capacitance meters currently available (Fulkerson and Slack 1993).

A positive attribute of the disc meter, especially the rising plate meter, is the ability to take a large number of readings in a short period of time (up to 100 readings in 5 minutes) at an appreciably faster rate than with the capacitance meter (Earle and McGowan 1979). The main attributes that favour the use of the pasture meter for the determination of pasture yield are its simplicity, rapidity, low cost and the robust character of the apparatus, which also requires little maintenance and repair (Douglas and Crawford 1994).

6.3 Development and description of the rising plate meter

Forage disk meters are used to estimate forage biomass by the height that some form of plate reaches when it is positioned on the pasture canopy, which is a function of canopy resistance or the ability of the vegetation to repel compaction or compression when a force is placed upon it (Harmoney et al. 1997). In effect, pasture meters measure not only height, but also height in relation to density (Fulkerson and Slack 1993) and “compressibility” (Bransby et al. 1977), which is often referred to as bulk height or bulk density (Bransby et al. 1977, Sanderson et al. 2001).

Initial pasture meters, referred to as “falling plate meters”, were based on dropping the plate from a height above the canopy and then simply measuring the settling height on a pole inserted through the centre of the plate (Douglas and Crawford 1994). Harmoney et al. (1997) pointed out the fact that certain inaccuracies could occur with such plates due to the fact that the plates were not always dropped from the same height, nor were they always of the same weight, which resulted in the plate being dropped and settling on the forage at varying velocities. Bransby and Tainton (1977) recommended that the plate be dropped from a constant height from the ground, but that this could only be applied if the sward was relatively dense and resistant to compression. Regardless of this, the falling distances, and thus force with which the plate hits the canopy, may still vary due to variation in the height of the sward itself (Bransby et al. 1977).

A large variety of materials have been used to construct the various plate meters used in literature cited, ranging from plastic, metal, plywood and cardboard (Bransby et al. 1977, Gabriëls and van den Berg 1993). Bransby et al. (1977), however, concluded that the material and weight of the disc material did not significantly affect estimation accuracy, as long as the calibration equation used for each was constructed using the specific plate.

Earle and McGowan (1979) developed an automated rising plate meter (RPM) that was an improvement upon the previous falling plate meter for various reasons. The RPM differs from the falling plate meter in that the pole is placed into the sward until it touches the ground. The resistance expressed by the canopy forces the plate to rise and rest at the height at which the force exerted by the canopy is equal to that exerted by the plate (Harmoney et al. 1997). The RPM developed by Earle and McGowan (1979) also does not require the observer to measure and record pasture height at each measuring point, but rather gives a cumulative measure of height recorded on the counter. Stockdale

(1984) reported that the rising plate meter was more accurate in estimating herbage yield than previous disc meters.

The main attributes that favour the use of the pasture meter for the determination of pasture yield are its simplicity, rapidity, low cost and the robust character of the apparatus, which also requires little maintenance and repair (Douglas and Crawford 1994).

6.4 Calibration

Calibration of meter readings to dry matter yield per area is undertaken by recording the height and dry matter yield of a number of qaudrats of pasture and correlating one with the other. Dry matter yield (Y kg ha^{-1}) is related to meter height (H cm) by the linear model: Y= a + bH (Earle and McGowan 1979). The relationship between pasture disc height and yield has been found to be mostly linear (Bransby and Tainton 1977, Earle and McGowan 1979, Michell 1982, Martin et al. 2005). Douglas and Crawford (1994), however, indicated that the relationship was better described as curvilinear or two separate straight line relationships with markedly different slopes. Bransby et al. (1977), on the other hand, did not find any significant improvement in calibration accuracy when the data was examined for curvilinearity.

The weighted disk meter has been found to have different seasonal calibrations, which have been attributed to a variation in species composition and dry matter percentage of pastures with season (Bransby et al. 1977, Bransby and Tainton 1977, Tucker 1980, Michell 1982). Fulkerson and Slack (1993) found similar results and stated that due to the accumulation of dry material, especially in tropical grass species, from early to late season, separate calibration equations should be developed as the growth season progresses. Earle and McGowan (1979) recommended that pooled calibration equations may be of greater value than individual calibration equations due to the greater number of data points used in the former, granted there weren't any extreme variations in species composition. It should be noted, however, that these recommendations were based on calibrations obtained from relatively homogenous pastures. Stockdale (1984) attempted to create pooled regressions that included data from many different periods, but found large coefficients of variation, especially in ryegrass-clover and annual pastures. Stockdale (1984) concluded that dry matter content and composition of the pasture, the way in which time of year influenced growth and physiological state, and the condition of the soil, including evenness and moisture content, could all have contributed to the above variation. As result, pooled regressions consisting of data over seasons and species were deemed unpractical for research purposes, although it may hold some value for farmers. Aiken and Bransby (1992) were also of the opinion that due to variation in the manner that operators calibrate and use the meter, care should be taken in comparing accuracy and results from different experiments in literature.

As mentioned earlier, the growth stage may affect the ability of a pasture meter to measure forage mass. Although Douglas and Crawford (1994) were of the opinion that separate calibration equations should be used during different growth stages, they highlighted the difficulty in objectively deciding when to use such different calibration equations.

Fulkerson and Slack (1993) found that by calibrating the disc meter to determine shoot DM, rather than total DM, greatly improved its accuracy. With this approach the samples for calibration are cut at a height of 50 mm, rather than to ground level. Michell (1982) also reported a difference in calibration equations when cutting to ground level or at a certain height above it. His results indicated that by not cutting to ground level, accumulated material would be excluded from pasture yield estimates, leading to a possible underestimation of yield, but pointed out that cutting to ground level may not give an appropriate indication of available herbage yield (pasture actually grazed by animals). Bransby and Tainton (1977) recommended that for swards of a tufted nature calibrations should be cut to 30 mm, whilst for swards of a creeping nature (e.g. clover) calibrations should be cut to ground level.

It is best to develop a standard calibration where the calibration measurements are done over as wide a range of pasture disc heights as possible (Trollope and Potgieter 1986). Bransby et al. (1977) reported an improvement in the R^2 value of the regression equation when the range of readings increased.

6.5 Factors that affect accuracy and use

6.5.1 Pasture characteristics

Tucker (1980) stated that any variables that affect the vegetation compression-biomass relationship within a sward would affect the calibration equation of pasture meters and in turn the accuracy of the method.

The pasture meter is capable of integrating uneven pasture distribution under the plate and can, as such, be used to measure swards with an uneven height distribution (Martin et al. 2005). Michell (1982) is of the opinion that the pasture disc meter is capable of overcoming the problems of accurately estimating pasture height in plots or paddocks that are variable in height.

Douglas and Crawford (1994) drew attention to the poor ability of pasture meters to measure lodged and overgrown pastures. They found that once grass started reaching the stage where it was falling over, the plate meter’s settling height often did not increase proportionally with the increase in forage biomass and at certain points even showed a decline in settling height, regardless of the fact that pasture was still actively growing.

Campbell and Arnold (1973) found that satisfactory calibration equations for the pasture meter could only be obtained if pasture mass exceeded a certain level, in this case 1000 kg DM ha^{-1}. Douglas and Crawford (1994) similarly found that the pasture meter underestimates forage biomass at low heights, attributing it to the pasture not having sufficient strength to resist the impact or support the weight of the plate when it is still young or when re-growth is short. Douglas and Crawford (1994) also found that at extremely high dry matter values there was marked variability in meter estimates, possibly due to the effect of lodging as mentioned.

In addition, Campell and Arnold (1973) found that large variations in botanical composition within and between plots reduced the accuracy of pasture meter estimates. This observation is supported by Earle and McGowan (1979) and Bransby et al. (1977), who recommend that separate calibration equations be developed for different types of pasture that vary in botanical composition. Harmoney et al. (1997) indicated that the disc meter may require more frequent calibration when used for the measurement of robust and jointing warm season grasses and low growing legume species like birdsfoot trefoil (*Lotus corniculatus* L.). Work done on Setaria (*Setaria ancepts*) and kikuyu grass by Fulkerson and Slack (1993) indicated that the accuracy of the disc meter was up to half as much in these tropical species compared to temperate pastures. The increase in error was attributed to a greater rate of dry matter accumulation and poor removal of said herbage by grazing. Fulkerson and Slack (1993) hypothesized that a pasture meter with a heavier plate of 40 kg m^{-2} versus the regular plate of 4.5 kg m^{-2} may improve the ability of the plate to measure tropical pastures.

The pasture meter has been reported by various authors to give poor estimations of biomass in post grazing swards, with post grazing estimation using the pasture disc meter generally less accurate than pre-grazing estimates (Stockdale 1984). Martin et al. (2005) attributed this to the fact that ungrazed stalks in, for example naturalized, un-mowed pastures could cause the pasture meter to tip and give inaccurate estimates. Murphy et al. (1995) also found that the plate of a pasture meter may be too heavy to be supported by post grazing stubble, resulting in poor correlations between post grazing meter height and forage biomass. Harmoney et al. (1997) also attributed the poor accuracy of the disc meter in estimating post-grazing herbage mass to the effect that hoof indentations may have on readings, whilst Stockdale (1984) drew attention to the negative impact that treading could have on accuracy of estimations on post-grazing swards with the disc pasture meter. Stockdale (1984) also found that calibration equations for pre-and post-grazing measurements differed, and recommended that separate equations should be used for these estimates under these low situations.

Growth stage of pasture grasses has also been found to influence the ability and accuracy of pasture meters in measuring forage biomass. When grasses reach a reproductive stage and ear-emerge starts to occur, the plate of a pasture meter may "sit up" on the hard stems rather than measuring the average height of the canopy (Douglas and Crawford 1994). Michell (1982) reported a change in the slope of the pasture disc meter calibration equation once ryegrass-clover swards started entering the flowering stage, which supports the theory that growth stage affects the estimation obtained from a pasture disc meter. Bransby et al. (1977) reports similar results, with the calibration equation of the pasture disc meter undergoing noticeable changes once tall fescue (*Festuca arundinaceae*) changed from the reproductive growth to vegetative growth.

Bransby and Tainton (1977) recommended that due to the large number of variables that can influence regression relationships, adequate notes should be taken during each calibration session on pasture type and condition, morphological stage of growth, treatment at the time of calibration and prior treatment, as well as the purpose for which the pasture is used.

6.5.2 Operator variability

Aiken and Bransby (1992) did extensive work to determine the effect that observer variability had on the accuracy of estimation of pasture yield with the pasture meter. They found differences between observers in terms of the calibration curves developed, as well as yield estimations. The variability between observers was attributed to differences between observers in choosing and clipping calibration sites, as well as an inadequate number of calibration cuts. An investigation by Earle and McGowan (1979) on factors that could lead to observer variability supports these findings. Their results indicated that differences in the technique operators employed in utilizing the apparatus, for example some operators put the plate down softly whilst other put it down harshly, could affect the compression of herbage and thus measured height. Secondly, variations and inaccuracies can occur if the operator uses the pasture disc meter as a walking stick rather than keeping the shaft vertical.

Michell (1982) pointed out the fact that poor cutting and calibration procedures of the pasture disc meter could easily be identified in erratic behaviour of the y- intercept. Both Aiken and Brainsby (1973) and Earle and McGowan (1979) recommended that a single operator should do calibrations and take measurements within an experiment or that operators should be trained in correct use of the pasture disc meter. Fulkerson and Slack (1993) also stated that between-operator variability could be reduced if the operating procedures for the pasture disc meter were followed correctly.

7. Conclusions and study aims

The preceding literature review makes it clear that, as a pasture specie, kikuyu has certain positive and negative attributes. In terms of dry matter production, kikuyu can achieve high growth rates and DM production during summer and autumn, but winter and spring production is comparatively low. Compared to most temperate pasture species, such as ryegrass, kikuyu has certain inherent nutritional deficiencies as a pasture species when grazed by high producing dairy cows which include an inadequate intake of metabolisable energy and marginal concentration of calcium, zinc and copper, whilst it is also prone to various Ca:P and K:Ca + Mg imbalances. In addition, kikuyu possesses certain anti-quality factors such as high concentrations of oxalate and periods when nitrate levels could impact negatively on animal production. Thus, kikuyu can support high stocking rates, but due to the low forage quality, production per cow is relatively low. The "autumn slump" experienced in production was also identified as a major concern within a dairy system based on kikuyu.

Although supplementation of animals with high energy concentrates was shown in this literature study to improve the milk production obtainable from kikuyu, it was realised that as well as being expensive, this did not improve the seasonality of kikuyu production. Fulkerson et al. (1993a) correctly identified temperate pastures as the least expensive and most common forage source that could fill the winter-spring feed gap in the sub-tropics and tropics, with the additional benefit that it could supplement the declining quality of summer grass pastures during autumn. The literature showed that various authors had successfully over-sown temperate species such as fescue, clovers, praire grass and ryegrass into kikuyu during autumn and that the species or cultivar utilised in such system would affect kikuyu production.

This preceding literature review, however, also pointed to the fact that limited scientific data is available on the pasture production potential, forage quality and milk production potential of kikuyu over-sown with different ryegrass species and varieties. The aim of the study was thus to quantify the dry matter yield, growth rate, forage quality, change in botanical composition, grazing capacity and milk production potential of kikuyu over-sown with Westerwolds ryegrass (WR), Italian ryegrass (IR) or perennial ryegrass (PR). The study also evaluated the use of the rising plate meter for measurement of ryegrass-kikuyu pastures and developed appropriate regression equations for such pastures in the Western Cape Province of South Africa.

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CHAPTER 2

Kikuyu over-sown with Italian, Westerwolds or perennial ryegrass: dry matter production, botanical composition and nutritional value

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Kikuyu (*Pennisetum clandestinum*) is highly productive during summer and autumn but the winter and spring production is low, while forage quality, and consequently milk production per cow, is low compared to temperate grass species. The aim of this study was to determine the dry matter yield, botanical composition and nutritional value of irrigated kikuyu over-sown with Italian ryegrass (*Lolium multiflorum* var. *italicum*), Westerwolds ryegrass (*Lolium multiflorum* var. *westerwoldicum*) or perennial ryegrass (*Lolium perenne*) being intensively grazed by dairy cows. The three kikuyu based pasture systems reached their peak growth rates during different months and seasons. Lowest growth rates for all treatments occurred during winter, while peak growth rates occurred during spring for the Italian ryegrass treatment; summer for the Westerwolds ryegrass treatment and late spring/early summer for the perennial ryegrass treatment. All three treatments had similar total annual dry matter yields (kg DM ha^{-1}) during year 1, but the perennial ryegrass treatment achieved a higher annual DM yield during year 2. As the kikuyu component increased in kikuyu-ryegrass pastures from winter to summer, the DM and NDF content increased, while the ME content decreased. All three treatments were deficient in Ca throughout the experimental period and deficient in P during summer and autumn for high producing dairy cows. The Ca:P ratio of all treatments was also below the recommended ratio of 1.6:1 for high producing dairy cows throughout the experimental period.

Keywords: kikuyu, ryegrass, over-sow, pasture production, botanical composition, forage quality

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1. Introduction

Kikuyu comprises the greater part of summer and autumn pasturage (Botha et al. 2008b) on predominately pasture based dairy systems in the Southern Cape region of South Africa (Meeske et al.

2006). Kikuyu is well adapted to the environmental conditions of the main milk producing areas in the Western Cape Province of South Africa (Botha 2003), achieving high dry matter (DM) yields during summer and autumn, but winter and spring DM production is low. Although kikuyu can support high stocking rates and milk production per ha (Colman and Kaiser 1974, Reeves 1997), production per cow is low due to its low forage quality (Marais 2001).

The primary reason for the low milk production from animals grazing kikuyu, is an inadequate intake of metabolisable energy (Joyce 1974, Reeves et al. 1996a). Kikuyu is deficient in calcium (Ca) and sodium (Na), whilst also being prone to Ca: phosphorous (P) and potassium (K): Ca + magnesium (Mg) imbalances (Fulkerson et al. 1993, Miles et al. 1995, Fulkerson et al. 1998, Marais 2001).

Energy supplementation is a possible way of improving the milk production of animals grazing kikuyu, but this is expensive and requires skills to implement successfully (Marais 2001). Temperate pasture species provide the least expensive forage source to fill the winter-feed gap characteristic of tropical species and can supplement the declining quality of summer grass pastures during the summer (Fulkerson et al. 1993). The strategic incorporation of temperate grasses such as annual and perennial ryegrass has been shown to improve the seasonal DM production and quality of kikuyu pasture (Botha 2003). The choice of specie over-sown into kikuyu has been found to influence the production of kikuyu during spring and summer (Elmore et al. 1997, Harris 1999, Botha 2008, Botha 2009), and careful consideration should be given to the selection of specie to over-sow into kikuyu and how it will affect fodder flow and availability.

The aim of this study was to quantify the dry matter yield, growth rate, change in botanical composition and forage quality of kikuyu over-sown with Westerwolds, Italian or perennial ryegrass.

2. Materials and methods

2.1 Experimental site

The study was carried out over a period of two years on the Outeniqua Research Farm (altitude 201 m, 33°58’38” S and 22°25’16”E) in the Western Cape Province of South Africa. The mean annual rainfall (30 year average) in this area is 725 mm, with mean minimum and maximum temperatures ranging between 7-15°C and 18-25°C respectively (ARC 2010). Winter during the experimental period 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).

2.2 Experimental layout

The study was conducted on approximately nine hectares of existing kikuyu pasture under permanent sprinkler irrigation. The experimental area is characterised by an Estcourt soil type (Soil Classification Work group 1991) and was divided into eight blocks which served as replicates. Each block was divided into three experimental paddocks, to which one of the three treatments was randomly allocated, resulting in a total of 24 experimental paddocks and eight experimental paddocks per treatment. Pasture measurements such as the rising plate meter calibrations; determination of botanical composition and all pasture quality analyses were only done on "monitor camps". Figure 1 illustrates the experimental layout, the allocation of paddocks to treatments and the monitor camps used during the study.

2.3 Treatments

The treatments consisted of three different ryegrass types over-sown into kikuyu. The ryegrass varieties that were evaluated included annual Italian ryegrass (*Lolium multiflorum* var. *italicum*), annual Westerwolds ryegrass (*Lolium multiflorum* var. *westerwoldicum*) and perennial ryegrass (*Lolium perenne*). The treatments, scientific names, abbreviations and cultivars used during the study are listed in Table 1.

Table 1: Treatments, scientific names, abbreviations and cultivars used during the study

Treatment	Scientific name	Abbreviation	Cultivar (*cv*)
Italian ryegrass	*Lolium multiflorum* var. *italicum*	IR	Jeanne
Westerwolds ryegrass	*Lolium multiflorum* var. *westerwoldicum*	WR	Jivet
Perennial ryegrass	*Lolium perenne*	PR	Bronsyn

2.4 Establishment methods

All kikuyu was grazed to a height of 50 mm prior to the commencement of ryegrass establishment during autumn. Italian ryegrass was planted at 25 kg ha^{-1} into kikuyu using an Aitchison seeder (2.4m Aitchison 3116C seedmatic with 16 rows) after the kikuyu had been mulched to ground level (1.6 meter Nobili with 24 blades) during March (Botha et al. 2008a). Westerwolds ryegrass was planted into kikuyu during March by broadcasting the seed at 25 kg ha^{-1} and then mulching the kikuyu stubble (Botha 2003). Perennial ryegrass was planted into mulched kikuyu at 20 kg ha^{-1} during April with an Aitchison seeder. All the treatments were rolled with a 2.33 m Cambridge type roller after planting. All treatments were re-established using the same methods during year 2. The perennial ryegrass was re-established due to its poor persistence into the second year after establishment, as is common to this region (Botha et al. 2008c). The treatments, seeding densities and over-sowing methods used to over-sow Italian, Westerwolds and perennial ryegrass into kikuyu are summarized in Table 2.

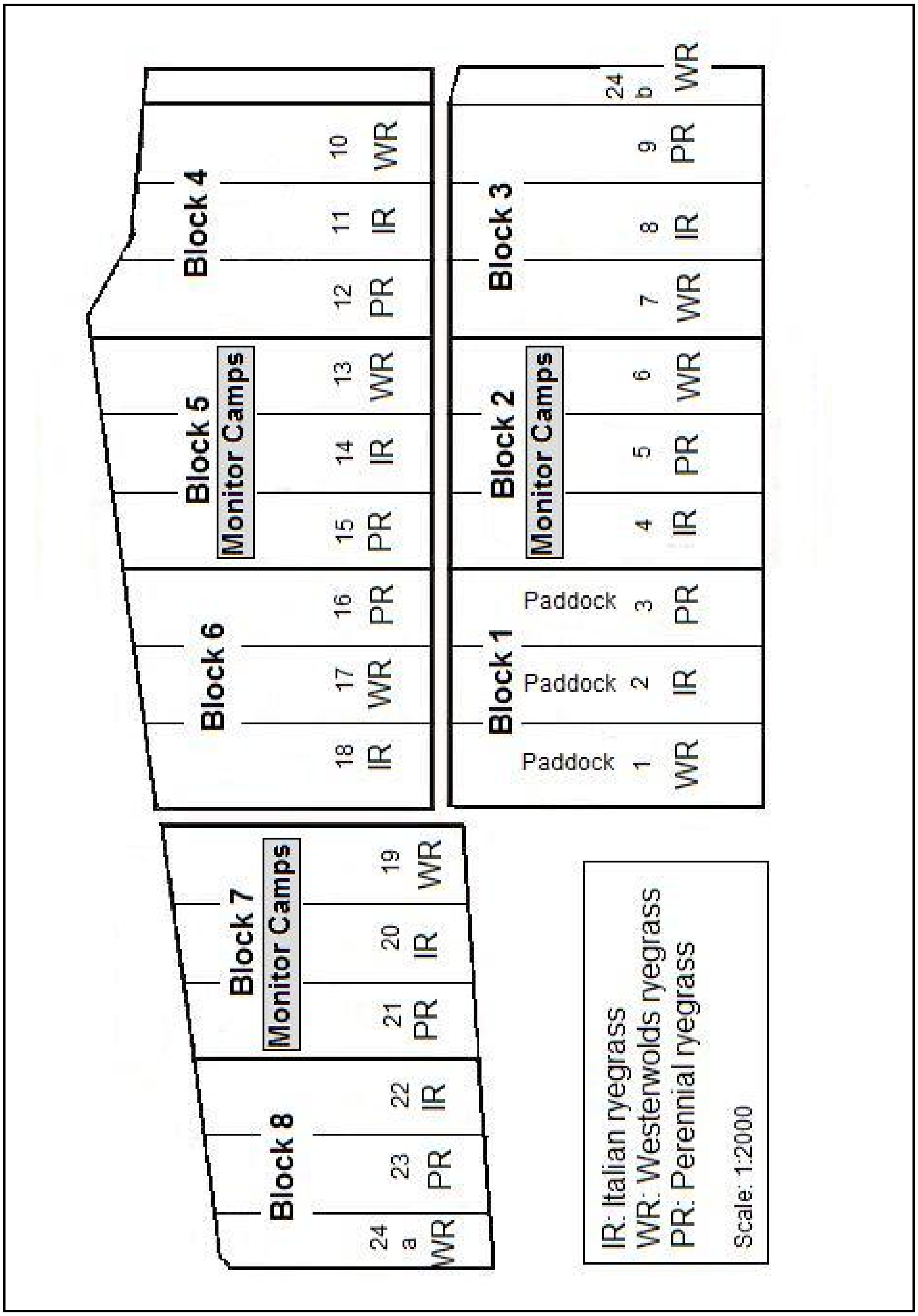

Figure 1: The experimental layout, allocation of paddocks to treatments and the monitor camps used during the study

2.5 Irrigation

Irrigation was scheduled by means of tensiometers placed at strategic locations throughout the experimental area at a depth of 150 mm. Daily tensiometer readings were taken in the mornings at approximately 08:00am. 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 2), accompanied by a low availability of irrigation water, resulted in irrigation below optimum levels during January and February of year 2.

2.6 Fertilisation

Each year before planting commenced, soil samples were taken using a beater type soil sampler to a depth of 100 mm (Miles 1997) and analysed for Ca, Mg, Na, K, P, Cu, Zn, Mn, B, S, and C levels. Fertiliser was applied according to the soil analysis to raise soil P (citric acid method) level to 35 mg kg^{-1}, K level to 80 mg kg^{-1} and pH (KCl) to 5.5 (Beyers 1973). All the treatments were with limestone ammonium nitrate (LAN) top dressed at a rate of 55kg N ha^{-1} on a monthly basis (Marais 2001, Botha 2003).

Table 2: The treatments, seeding rates and over-sowing methods used to over-sow Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass into kikuyu

Treatment	Seeding rate (kg ha^{-1})*	Over-sowing method	
IR	25	1.	Graze to 50 mm
		2.	Mulcher
		3.	Seeder
		4.	Land roller
WR	25	1.	Graze to 50 mm
		2.	Broadcast seed
		3.	Mulcher
		4.	Land roller
PR	20	1.	Graze to 50 mm
		2.	Mulcher
		3.	Seeder
		4.	Land roller

*According to recommendations by Dickenson *et al*. (2004)

2.7 Data collection

2.7.1 Dry matter production, pasture availability and degree of utilisation

Dry matter production of the pasture treatments was estimated using the rising plate meter (Stockdale 1984, Fulkerson 1997). Dry matter yield (Y kg ha^{-1}) is related to meter height by the linear model (Earle and McGowan 1979):

$$Y = mH + b$$

$$\text{Where } m = \text{gradient; } H = \text{mean rising plate meter height and } b = \text{intercept value}$$

The rising plate meter (RPM) was thus calibrated by developing a linear regression that relates the RPM height of the pasture to herbage dry matter (DM) yield per unit area. During this particular study, the height of the pasture was measured with the RPM at a specific point, a ring of the same size as the RPM plate (0.098m^2) placed over the RPM and all DM within the ring borders cut (t'Mannetjie 2000). The pasture samples were cut at a height of 30 mm, rather than at ground level (Fulkerson and Slack 1993, Botha 2003). Three samples were cut at a height estimated by the operator as low, medium and high, respectively, within each of the two grazing strips. A total of 18 calibration samples were thus cut per treatment (paddock) at each calibration. The RPM was calibrated three times per treatment during the grazing cycle, or approximately every 10 days. Pre-grazing calibrations were cut the day before animals entered a paddock. Data from each cutting within a season was utilised 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 then used to estimate the average DM available per paddock and hectare. Pasture readings were taken the day before animals entered a new grazing strip and the day animals had moved to a new grazing strip.

The measurement of pasture parameters was initiated once the pasture was ready to be grazed after establishment. During year 1, IR and WR pasture production was measured for the first time in June 2007 (established March 2007) and PR in July 2007 (established in April 2007). During year 2, pasture measurement commenced two months after establishment, namely May 2008 for IR and WR and June 2008 for PR.

2.7.2 Botanical Composition

Botanical composition was estimated by placing six 0.25 m^2 quadrats randomly within an experimental paddock and cutting samples to a height of 30 mm. The six samples were pooled, 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 (all species not part of the treatment). The samples were dried at 60ºC for 72 hours, weighed and the percentage contribution of each fraction calculated on a DM basis (Fenthum-Vermeulen et al. 2009).

2.7.3 Nutritive value

Samples for quality analyses were collected at the same time as the calibration clippings i.e. three times per grazing cycle at approximately 10-day intervals. A total of six samples (of 0.098 m^2 each) were cut at a height of 30 mm per treatment at each sampling date. Samples were dried at 60ºC for 72 hours to a constant mass and weighed to determine the DM content (%). The six samples of each treatment were pooled and milled (SWC Hammer mill, 1mm sieve), with a total of 33 pooled samples collected per treatment over a one year period (three samples per grazing cycle x 11 grazing cycles). Samples were then 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), calcium (Ca) (Giron 1973), phosphorous (P) (AOAC 2000b) and magnesium (Mg) (Giron 1973) content. Metabolisable energy (MJ kg^{-1} DM) was calculated from the IVOMD (ME = 18.4 X IVOMD% x 0.81) (ARC 1984, MAFF, 1984).

2.8 Grazing management

Jersey cows were used to strip graze pasture treatments. Experimental paddocks were divided into two grazing strips (with identical pasture treatments) by means of a permanent one-meter high fence. The grazing strips were divided into four blocks using a temporary mobile electrical wire. A fresh block of grazing was allocated to the cows after each milking. Each grazing strip was grazed for two consecutive days and each paddock for four days. Cows could graze back for a maximum of two days, after which the strip was closed up. Cows were on the experimental area for a total of 32 days at a time. Thus, the grazing cycle during the experimental period was 32 days. However, while one block was being grazed, the other seven were rested, resulting in a 28 day period of abscence from each block and a 30 day period of abscence from each grazing strip. The number of cows per paddock was adjusted daily to ensure that animals received 4.5 kg DM pasture cow^{-1} $grazing^{-1}$ or 9 kg DM cow^{-1} day^{-1}. The experimental animals received 2 kg of dairy concentrate during milking in addition to pasture and were milked twice daily (4 kg dairy concentrate cow^{-1} day^{-1}). The milk production data of the cows that grazed the three kikuyu based pastures can be found in Van der Colf et al. (2010).

2.9 Statistical design and analysis

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

3. Results and discussion

3.1 Climate

The mean monthly minimum and maximum temperature and total monthly rainfall that occurred during year 1 and year 2, compared to the 30 year long term average (LTA) is shown in Figure 2.

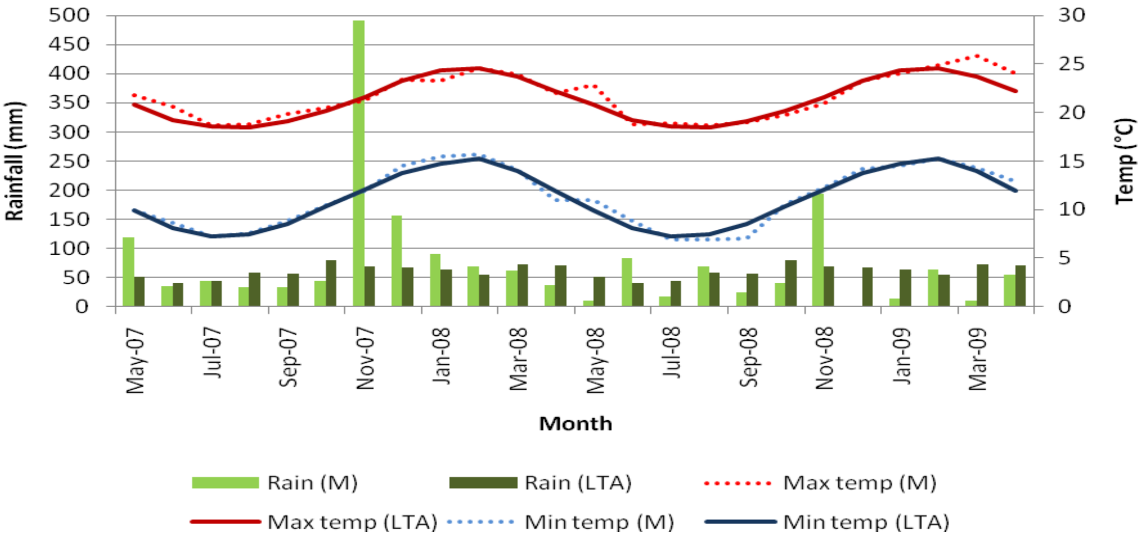

Figure 2: The mean monthly maximum temperature (max temp) minimum temperature (min temp) and total rainfall (mm) on the Outeniqua Research Farm during year 1 (2007/2008) and year 2 (2008/2009) in comparison to the long term (30 years) average (LA)

During November in year 1 (2007) a large amount of rain fell over a short period of time (318.7 mm in three days) which resulted in a monthly rainfall figure well above (422 mm) the LTA. During year 2 (2008) another excessive amount of rain fell within a short period of time (172.8 mm in 4 days) during November. During December, January and March of year 2 (2008/2009) rainfall was lower than the long term average by 64.6, 59.9 and 61.1 mm, respectively.

3.2 Growth and dry matter production

3.2.1 Mean monthly pasture growth rate

The mean monthly pasture growth rate (kg DM ha^{-1} day^{-1}) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial ryegrass (PR) during year 1 and year 2 is presented in Table 3 and Table 4, respectively.

The highest growth rate for IR during year 1 occurred during October, with similar ($P>0.05$) growth rates during November, December and February. The growth rates of IR during May, June, July and August were lower ($P<0.05$) than during the other months for this treatment in year 1. The highest ($P<0.05$) growth rates for WR in year 1 occurred during January and February. The lowest ($P<0.05$) growth rate for WR during year 1 occurred during July, with all other months higher ($P<0.05$), except June and May, when it was similar ($P>0.05$). The PR treatment experienced its highest ($P<0.05$) growth rates during December, January and February in year 1. The growth rate of PR was lower ($P<0.05$) during July than for all other months within this treatment.

The growth rate IR during June in year 2 was lower than all the other months for the IR treatment, except for July when it was similar ($P>0.05$). In the same year the growth rate of IR was higher ($P<0.05$) during October than the rest of the months. During year 2 the highest ($P<0.05$) growth rates for WR occurred during December and January, with the growth rate during March not significantly lower ($P>0.05$). The lowest ($P<0.05$) growth rates during year 2 for WR occurred during June and July. The PR treatment achieved its highest ($P<0.05$) growth rates from October to December ($P<0.05$). The growth rate of PR was higher ($P<0.05$) from August to March than during June, July and April within the same treatment.

Table 3: Mean monthly growth rate (kg DM ha^{-1} day^{-1}) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1.$^{abc..}$Means with no common superscript differed significantly ($P<0.05$). LSD (0.05) compares over treatments and months.

Month	IR	WR	PR
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}	61.03^{klm}	65.4^{ijklm}
November	77.1^{efgh}	57.05^{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^{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 4: Mean monthly growth rate (kg DM ha^{-1} day^{-1}) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 2. $^{abc..}$Means with no common superscript differed significantly ($P<0.05$). LSD (0.05) compares over treatments and months

Month	IR	WR	PR
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	

3.2.2 Total seasonal dry matter production

Table 5 shows the total seasonal dry matter (DM) production (kg DM ha^{-1}) of the three kikuyu based systems during year 1 and year 2.

During year 1 the highest ($P<0.05$) seasonal DM production was for WR and PR during summer (7412 and 7380 kg DM ha^{-1} respectively) and the lowest ($P<0.05$) for PR in winter (2084 kg DM ha^{-1}). The low DM production of PR during winter in year 1 was due to the fact that the PR treatment had a month shorter production period than IR and WR (Table 3), primarily because it was established a month later. The highest ($P<0.05$) seasonal DM production in year 2 was for PR during spring (5610 kg DM ha^{-1}), with the seasonal DM production of PR and WR in summer, and IR in spring not significantly lower ($P>0.05$). The IR treatment had the lowest ($P<0.05$) seasonal production during autumn (1428 kg DM ha^{-1}) in year 2, with WR autumn production not significantly higher ($P>0.05$). Both the IR and WR treatment had a month shorter production period than PR during autumn in year 2 to allow for the re-establishment of pastures during March (Table 4).

Table 5: The total seasonal dry matter (DM) production (kg DM ha^{-1}) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1 and year 2. $^{abc...}$Means with no common superscript differed significantly ($P<0.05$). LSD (0.05) compares over season within year

Year		IR	WR	PR
Year 1	Winter	3512^{d}	3422^{d}	2084^{e}
	Spring	6073^{b}	4774^{c}	5117^{c}
	Summer	6161^{b}	7412^{a}	7380^{a}
	Autumn	3022^{d}	3272^{d}	3502^{d}
LSD (0.05) = 780				
Year 2	Winter	2864^{de}	2958^{de}	3273^{d}
	Spring	4980^{ab}	4149^{c}	5610^{a}
	Summer	4385^{bc}	5516^{a}	5044^{ab}
	Autumn	1428^{g}	1621^{fg}	2275^{ef}
LSD (0.05) = 687				

The IR treatment out-yielded ($P<0.05$) WR in spring of year 1 and 2, while WR had a higher ($P<0.05$) summer production in both years than IR. This was because IR tended to experience its peak growth rate during the spring month of October (Table 3 and 4), whilst the WR treatment reached its growth peak in the summer months of December/January (Table 3 and 4). The PR treatments' peak in growth rate, thus highest seasonal DM production, occurred during summer in year 1 and spring in year 2. The high spring and low summer production of IR compared to WR are in agreement with the results of Harris and Bartholomew (1991) who found that the high production of Italian ryegrass during spring, when planted into kikuyu, lowered the production of kikuyu during summer, whereas Westerwolds varieties died back earlier and kikuyu yield during summer was unaffected. In pure swards of ryegrass, Italian ryegrass cultivars have also been found to have higher DM production rates during spring than Westerwolds ryegrass cultivars (Botha et al. 2008c).

3.2.3 Total annual dry matter production

The total annual DM production (kg DM ha^{-1}) of the IR, WR and PR treatments is shown in Table 6. All treatments had similar ($P>0.05$) total annual DM yields during year 1 (between 18083 and 18880 kg DM ha^{-1} annum^{-1}), but the PR treatment had a higher ($P<0.05$) annual DM production than both the IR and WR treatments during year 2. The higher annual DM yield of PR during year 2 was due to PR's higher ($P<0.05$) seasonal DM production than WR during spring as well as a higher ($P<0.05$) seasonal DM production than IR during summer and autumn (Table 5).

Table 6: The total annual dry matter production (kg DM ha^{-1}) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass for year 1 and year 2. ^{ab}Means with no common superscript differed significantly ($P<0.05$). LSD (0.05) compares over treatments within year

	IR	WR	PR	LSD (0.05)
Year 1	18768^{a}	18880^{a}	18083^{a}	819
Year 2	13479^{b}	14040^{b}	16202^{a}	713

3.3 Botanical composition

The seasonal changes that occurred in the botanical composition of IR, PR or WR, in terms of the percentage kikuyu, ryegrass and other species during year 1 and year 2 are presented in Table 7. The kikuyu component increased for all treatments (except IR in year 1) from spring to autumn, while the ryegrass component decreased.

The kikuyu component was similar ($P>0.05$) for the IR, WR and PR treatments during winter and spring for both years. During year 1 the IR treatment had a lower ($P<0.05$) kikuyu component than WR in summer and a higher ($P<0.05$) ryegrass component than PR and WR during autumn. During summer of year 2, PR had a lower ($P<0.05$) kikuyu and higher ($P<0.05$) ryegrass component than WR. The ryegrass percentage of the PR treatment was higher ($P<0.05$) during autumn than both the WR and IR treatment during year 2. The contribution of other species was similar ($P>0.05$) for all treatments within seasons during year 1. During year 2 other species present in the sward were lower (P<0.05) in spring for IR compared to the other two treatments, due to the high growth rate of the predominately ryegrass based pasture during this season. The other species component was similar for IR, WR and PR during winter, summer and autumn in year 2.

Table 7: The mean seasonal proportions of kikuyu, ryegrass and other species (all species not included in treatment) component (%) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1 and year 2. $^{abc..}$Means with no common superscript differed significantly (P<0.05). LSD (0.05) compares over seasons and treatments within component. NA = not available

		Year 1			Year 2		
Treatment	Season	Kikuyu	Ryegrass	Other	Kikuyu	Ryegrass	Other
IR	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}	1.86^{f}	3.1^{d}
WR	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}
PR	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

3.4 Nutritive value

3.4.1 Dry matter content

The dry matter (DM) content (%) of IR, WR and PR during year 1 and year 2 is given in Table 8. The DM content of the PR treatment during summer was the highest (P<0.05) for all the treatments over the seasons in year 1. The DM content for IR, WR and PR was similar (P>0.05) within all seasons for year 1, except during summer, when PR had a higher (P<0.05) DM content than IR and WR. During year 2 the DM content of all treatments were higher (P<0.05) during a summer and autumn than during winter and spring.

Table 8: The mean seasonal dry matter (DM) content (%) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1 and year 2. $^{abc\ldots}$Means with no common superscript differed significantly (P<0.05). LSD (0.05) compares over treatments and seasons within year

Year	Season	IR	WR	PR
Year 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			
Year 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			

The DM content of all treatments increased as the growth season progressed, to where it was higher (P<0.05) during summer than during winter for both years. 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.

3.4.2 Crude protein content

The mean seasonal crude protein (CP) content (%) of the three kikuyu based systems during year 1 and year 2 is shown in table 9. The CP content of IR and WR was higher (P<0.05) than for PR during winter in year 1. 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 differences during the other seasons not significant (P>0.05). The IR treatment had a higher (P<0.05) CP content than PR during autumn of year 1, but did not differ (P>0.05) from WR. The CP content of PR during summer was the lowest (P<0.05) of all treatments and seasons in year 1, but it was not lower (P>0.05) than IR and WR in summer. During year 2 the CP content of WR during winter was higher than any other treatment during spring, summer and autumn, but did not differ (P>0.05) from IR and PR during winter.

The CP content of all treatments was similar (P>0.05) within the seasons of spring and summer in year 1. During year 2 the CP content of IR, WR and PR did not differ (P>0.05) from each other within seasons. This agrees with the findings by Fulkerson et al. (1993) and Tharmaraj et al. (2008) that annual and perennial ryegrasses have similar CP contents, while during summer and autumn pastures were based on predominately kikuyu (Table 7).

Table 9: The mean seasonal crude protein content (%) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1 and year 2. $^{abc...}$Means with no common superscript differed significantly ($P<0.05$). LSD (0.05) compares over treatments and seasons within year

Year	Season	IR	WR	PR
Year 1	Winter	30.4^{a}	32.4^{a}	25.1^{bc}
	Spring	22.7^{cde}	22.5^{cde}	22.0^{def}
	Summer	19.8^{efg}	19.3^{fg}	17.9^{g}
	Autumn	26.7^{b}	24.9^{bcd}	23.7^{cd}
LSD (0.05) = 3.06				
Year 2	Winter	26.6^{ab}	29.6^{a}	27.2^{abc}
	Spring	25.4^{cd}	25.8^{bcd}	25.7^{bcd}
	Summer	22.6^{d}	23.1^{d}	23.2^{d}
	Autumn	22.7^{d}	22.6^{d}	23.6^{d}
LSD (0.05) = 3.26				

The CP contents of all treatments were higher ($P<0.05$) in winter than summer and autumn during both years. The CP content of all pasture treatments tended to decrease from winter to summer as the kikuyu component increased (Table 7) and pastures reached their peak growth rates. These findings are similar to Botha et al. (2008a) who reported that the CP content of kikuyu-ryegrass pastures was higher in spring than in summer and autumn.

3.4.3 Neutral detergent fiber content

The mean seasonal neutral detergent fibre (NDF) content (%) of the three kikuyu based systems during year 1 and year 2 is shown in Table 10. The NDF content of the IR and WR treatments increased ($P<0.05$) from winter to spring, and increased ($P<0.05$) from spring to summer during year 1 and year 2. These results compare favourably with those of Botha et al. (2008a) who also reported an increase in the NDF content of annual ryegrass-kikuyu pastures from spring to summer. The NDF content of the PR treatment increased ($P<0.05$) from winter to spring during year 1, but not ($P>0.05$) during year 2, while it increased ($P<0.05$) from spring to summer during both year 1 and year 2. Summer and autumn NDF contents were similar ($P>0.05$) within treatments during year 1 and year 2. The higher ($P<0.05$) NDF content observed within all treatments during summer and autumn, compared to spring and winter, was associated with the increase ($P<0.05$) in the kikuyu component from spring to autumn for all treatments (Table 7).

During year 1 the NDF content of IR, WR and PR were similar ($P>0.05$) during winter, spring and autumn when compared within season (within rows). The NDF content of WR was higher ($P<0.05$) during summer of year 1 than for IR, which coincided with a period when the kikuyu component in WR was higher ($P<0.05$) than in IR (Table 7). During year 2 a similar trend was seen, with the NDF content of IR lower ($P<0.05$) than that of WR during spring, when the ryegrass component of IR pastures was higher ($P>0.05$) than in WR pastures (Table 7). The NDF content of temperate species, such as perennial ryegrass, have been found to be lower than for kikuyu (Reeves et al. 1996), thus it can be concluded that if ryegrass is maintained in kikuyu pastures for longer, it will reduce the NDF content of these mixed pastures. The NDF content of all pastures remained below values of 62.6 to 64.7% reported by Botha et al. (2008a) for pure kikuyu pastures during summer and autumn. The NDF content of IR and WR were similar to those reported by Fulkerson et al. (2007) for annual ryegrass during winter (42.4 to 45.9%) and spring (49.5 to 53.1%). The NDF content of PR during winter and spring were also similar to concentrations of between 39.1 to 44.7% reported for perennial ryegrass during this period in the literature (Lowe et al. 1999a)

Table 10: The mean seasonal neutral detergent fibre (NDF) content (%) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1 and year 2. $^{abc..}$Means with no common superscript differ significantly ($P<0.05$). LSD (0.05) compares over treatments and seasons within year

Year	Season	IR	WR	PR
Year 1	Winter	37.9^{e}	37.4^{e}	41.5^{e}
	Spring	45.9^{d}	48.9^{d}	48.7^{d}
	Summer	56.8^{bc}	61.9^{a}	59.1^{ab}
	Autumn	54.5^{c}	58.0^{abc}	56.9^{bc}
LSD (0.05) = 4.34				
Year 2	Winter	41.3^{e}	44.5^{e}	46.3^{de}
	Spring	44.9^{de}	51.9^{bc}	50.3^{cd}
	Summer	55.8^{ab}	59.2^{a}	57.0^{ab}
	Autumn	57.8^{a}	61.0^{a}	57.8^{a}
LSD (0.05) = 5.42				

3.4.5 Metabolisable energy content

The mean seasonal metabolisable energy (ME) content (MJ kg^{-1} DM) of the IR, WR and PR treatments during year 1 and year 2 is shown in Table 11. The ME content of IR, WR and PR decreased ($P<0.05$) from winter to spring and from spring to summer during year 1. During year 2 the ME content of all three treatments decreased ($P<0.05$) from winter to summer and from summer to autumn. The ME content of WR and PR decreased below 10.0 MJ kg DM^{-1} during summer and autumn during year 1, while it was below this concentration for the IR and WR during summer and autumn in year 2. The ME content of IR remained above 10 MJ kg^{-1} DM during all seasons in year 1, while PR maintained an ME content above 10 MJ kg^{-1} DM during winter, spring and summer during year 2.

When compared within seasons and years (same rows), the ME content of IR, WR and PR were similar ($P>0.05$) during winter and spring of year 1 and year 2. During year 1 the IR treatment had a higher ($P<0.05$) ME content than WR and PR during autumn, which coincided with the period when the ryegrass component in IR was higher ($P<0.05$) than in WR and PR (Table 7). During autumn in year 2 the higher ryegrass component (Table 7) in PR than in IR and WR resulted in the PR treatment also having the highest ($P<0.05$) ME content during this period. The change in ME content of IR, WR and PR followed an opposite pattern to that of NDF content, with the ME content decreasing when the NDF content increased (from winter to summer/autumn).

The ME content of IR, WR and PR 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 IR and WR had very low ME contents (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 (Table 7), 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 sub-tropics (Lowe et al. 1999).

Table 11: The mean seasonal metabolisable energy (MJ kg^{-1} DM) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1 and year 2. $^{abc..}$Means with no common superscript differed significantly (P<0.05). LSD (0.05) compares over treatments and seasons within year

Year	Season	IR	WR	PR
Year 1	Winter	12.0^{a}	12.0^{a}	11.9^{a}
	Spring	11.0^{b}	10.6^{bc}	10.9^{b}
	Summer	10.0^{cd}	9.40^{de}	9.24^{e}
	Autumn	10.3^{bc}	9.22^{e}	9.39^{de}
LSD (0.05) =	0.74			
Year 2	Winter	12.4^{a}	12.2^{a}	11.8^{a}
	Spring	12.4^{a}	11.9^{a}	12.2^{a}
	Summer	9.78^{bc}	9.31^{c}	10.5^{b}
	Autumn	7.94^{d}	8.19^{d}	9.62^{c}
LSD (0.05) =	0.473			

3.4.6 Mineral content

The mean seasonal calcium (Ca) content (%) of the IR, WR and PR treatments during year 1 and year 2 is shown in Table 12. The Ca content of all treatments was similar (P>0.05) within season during spring and summer of year 1. During autumn of year 1, however, PR had a higher (P<0.05) Ca content than WR, but did not differ (P>0.05) from IR. There were no differences (P>0.05) between the three treatments for seasonal Ca content in year 2. The Ca content of the pasture treatments ranged between 0.36 and 0.43 % during the study, which is lower than the Ca requirement of 0.67% for dairy cows (NRC 2001).

During winter, when pastures were comprised of mainly ryegrass, the Ca content of WR and IR compared favourably with values of 0.41% reported for annual ryegrass (Thom and Prestridge 1996), but the Ca content of PR was higher than the range of 0.21-0.39 % reported by Fulkerson et al. (1993). Compared to a pure kikuyu sward, Botha et al. (2008a) did not achieve an improvement in the Ca content of pastures during summer and autumn by planting annual ryegrass into kikuyu during autumn. The Ca content of the pastures investigated here were however higher than reported for kikuyu during spring (0.26%), summer (0.25%) and winter-autumn (0.24%) by Fulkerson et al. (1999). 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.

Table 12: The mean seasonal calcium content (%) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass for years 1 and year 2. $^{abc...}$Means with no common superscript differed significantly ($P<0.05$). LSD (0.05) compares over treatments and seasons within year

Year	Season	IR	WR	PR
Year 1	Winter	0.36^{cde}	0.39^{abc}	0.41^{ab}
	Spring	0.41^{ab}	0.42^{a}	0.41^{ab}
	Summer	0.34^{de}	0.33^{e}	0.37^{bcde}
	Autumn	0.38^{abcd}	0.36^{cde}	0.41^{ab}
LSD (0.05) = 0.044				
Year 2	Winter	0.43^{a}	0.38^{a}	0.41^{a}
	Spring	0.39^{a}	0.40^{a}	0.40^{a}
	Summer	0.38^{a}	0.37^{a}	0.40^{a}
	Autumn	0.41^{a}	0.39^{a}	0.37^{a}
LSD (0.05) = 0.061				

The mean seasonal phosphorous (P) content (%) for the three kikuyu based pasture based systems during year 1 and year 2 is shown in Table 13. During year 1 the P content did not show ($P>0.05$) any seasonal changes for IR and PR, but WR had a lower ($P<0.05$) P content during summer than during winter. The PR and IR treatments had lower ($P<0.05$) P contents during autumn than during winter or spring during year 2, while the P content of WR during was lower ($P<0.05$) during summer and autumn than during winter. The decrease in the P content of the kikuyu-ryegrass based pasture systems from winter to summer/autumn was due to the higher kikuyu component during summer/autumn than winter (Table 7). The P content of all treatments were similar ($P>0.05$) within seasons during year 1 and year 2.

The P content of IR, PR and WR during autumn and winter (0.30 to 0.45%) was above the levels of 0.27% reported for kikuyu during autumn-winter by Fulkerson et al. (1999). This indicates that the inclusion of ryegrass increases the winter-autumn P content of kikuyu. The P contents recorded during summer (0.33 to 0.37%) of the experimental period compared favourably the levels of Fulkerson et al. (1999) for kikuyu during summer (0.33%). The P content of IR, WR and PR during winter (0.39 to 0.45%), when the treatments consisted mainly of ryegrass (Table 7), was above the cocentrations of 0.36% reported for annual ryegrass (Thom and Prestridge 1996, Meeske et al. 2006) and 0.38% for perennial ryegrass (Reeves et al. 1996).

The P content was above or equal to the recommended level for dairy cows of 0.38 % (NRC, 1989) during winter and spring for all treatments, but was below this concentration for PR and WR during summer and IR during autumn in year 1. During year 2 the P content of all treatments was below 0.38% during summer and autumn, due to the increasing contribution of kikuyu to the sward (Table 7).

Table 13: The mean seasonal phosphorous content (%) of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1 and year 2. ^{abc}Means with no common superscript differed significantly ($P<0.05$). LSD (0.05) = compares over treatment and season within year

Year	Season	IR	WR	PR
Year 1	Winter	0.42^{ab}	0.45^{a}	0.42^{ab}
	Spring	0.39^{ab}	0.38^{ab}	0.40^{ab}
	Summer	0.38^{ab}	0.35^{b}	0.37^{b}
	Autumn	0.36^{b}	0.40^{ab}	0.39^{ab}
LSD (0.05) = 0.074				
Year 2	Winter	0.39^{ab}	0.42^{a}	0.39^{ab}
	Spring	0.38^{ab}	0.39^{ab}	0.38^{ab}
	Summer	0.33^{bc}	0.34^{bc}	0.33^{bc}
	Autumn	0.30^{c}	0.35^{bc}	0.30^{c}
LSD (0.05) = 0.070				

The mean seasonal calcium: phosphorous (Ca:P) ratio of kikuyu over-sown with Italian, Westerwolds or perennial ryegrass during year 1 and year 2 is presented in Table 14. All treatments had a low Ca:P ratio throughout the period because they were based solely on grasses, with only the PR treatment maintaining a Ca:P ratio above or at the recommended 1:1 ratio for grazing animals in order to prevent a negative impact on Ca and P absorption (NRC 2001). Kikuyu is well known for its inverse Ca:P ratio, since it often contains more P than Ca (Miles et al. 1995). The continued presence of a ryegrass component throughout the growth season in the PR treatment (Table 7) and the higher Ca:P ratios of perennial ryegrass than annual ryegrass (Fulkerson et al. 1998) are possible reasons for the ability of the PR treatment to maintain a ratio above or at 1:1 throughout the growth season.

The Ca:P ratio of IR and PR did not undergo any significant changes ($P>0.05$) from winter to autumn during year 1, but Ca:P of WR was lower ($P<0.05$) during autumn than during spring. During year 2 the Ca:P ratio of IR, WR and PR increased from winter to autumn regardless of an increase in the kikuyu component. The was most likely due to the relatively low growth rates of pastures during summer and autumn of year 2 as result of the drought and irrigation below optimum levels. There were no differences ($P>0.05$) between the three treatments within seasons during year 1 or 2, except during autumn in year 2 when the Ca:P ratio of PR was higher ($P<0.05$) than WR, but did not differ ($P>0.05$) from IR.

The Ca:P ratio of the three kikuyu-ryegrass pasture treatments were higher than the values obtained by Botha et al. (2008a) for kikuyu-annual ryegrass pasture during summer (0.77:1), autumn (0.74:1) and winter (0.70:1). The summer Ca:P content of the kikuyu-ryegrass pastures remained well above the 0.5:1 reported by Miles et al. (1995) for pure kikuyu pastures during summer. Thus, similar to findings from Botha et al. (2008a), the inclusion of ryegrass improved the Ca:P ratio compared to pure kikuyu swards.

Table 14: Mean seasonal calcium: phosphorous ratio of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1 and year 2. $^{abc..}$Means with no common superscript differed significantly (P<0.05). LSD (0.05) compares over treatment and season within year

Year	Season	IR	WR	PR
Year 1	Winter	0.90:1^{b}	0.93:1^{ab}	1.00:1^{ab}
	Spring	1.10:1^{ab}	1.16:1^{a}	1.10:1^{ab}
	Summer	0.91:1^{b}	0.96:1^{ab}	1.02:1^{ab}
	Autumn	1.02:1^{ab}	0.92:1^{b}	1.09:1^{ab}
LSD (0.05) = 0.243				
Year 2	Winter	0.98:1^{ed}	0.89:1^{e}	1.07:1^{cde}
	Spring	1.08:1^{bcd}	1.05:1^{cde}	1.09:1^{bcde}
	Summer	1.13:1^{bcd}	1.14:1^{bcd}	1.23:1^{abc}
	Autumn	1.32:1^{ab}	1.19:1^{bcd}	1.44:1^{a}
LSD (0.05) = 0.244				

The mean seasonal magnesium (Mg) content (%) of all three treatments during year 1 and year 2 is shown in Table 15. 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 IR, WR and PR during year 2 was higher (P<0.05) during autumn than during winter and spring within treatments. The Mg content of all three treatments were similar (P>0.05) within all seasons during year 1 and year 2, except during winter of year 1 when PR had a lower (P<0.05) Mg content than WR and IR.

No data could be found on the Mg content of kikuyu-ryegrass pastures in the literature, but similar to what occured during this experiment, the Mg content of kikuyu is reported to increase from early to late season (Reeves et al. 1996b) and to be higher during autumn than during summer (Miles et al. 1995). The Mg content of all treatments during winter of year 1 was high compared to the levels of 0.36% reported for annual ryegrass by Meeske et al. (2006) and 0.25-0.40% reported for perennial ryegrass by Fulkerson et al. (1993). The Mg content of all treatments were, however, lower and closer to these values during year 2.

Table 15: The mean seasonal magnesium content of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1 and year 2. $^{abc..}$Means with no common superscript differed significantly (P<0.05). LSD (0.05) compares over treatment and season within year

Year	Season	IR	WR	PR
Year 1	Winter	0.57^{a}	0.59^{a}	0.51^{b}
	Spring	0.30^{d}	0.30^{d}	0.30^{d}
	Summer	0.31^{d}	0.32^{d}	0.31^{d}
	Autumn	0.38^{c}	0.41^{c}	0.38^{c}
LSD (0.05) = 0.053				
Year 2	Winter	0.39^{bcde}	0.37^{cde}	0.35^{de}
	Spring	0.35^{de}	0.34^{de}	0.33^{e}
	Summer	0.39^{bcd}	0.40^{bcd}	0.37^{cde}
	Autumn	0.49^{a}	0.45^{ab}	0.42^{abc}
LSD (0.05) = 0.065				

4. Conclusions

The growth rate of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass varied over months, with the three kikuyu based pastures reaching their peak growth rates during different months and seasons. Winter growth rates were low compared to other seasons and the IR treatment experienced its highest growth rates during spring, the WR treatment during summer and the PR treatment during late spring/early summer.

The lower growth rate of the WR treatment during spring, compared to the IR treatment, resulted in a higher kikuyu component in the WR treatment during spring, summer and autumn. The high growth rate of the IR treatment during spring (primarily attributable to the ryegrass component) impacted negatively on the summer DM production of the IR treatment. During year 2 the PR treatment had a higher seasonal DM production than WR during spring and IR during summer and autumn. The ability of the PR treatment to maintain DM production during periods when the other treatments underwent a dip in production (WR during spring and IR during summer) enabled it to achieve a higher annual DM production than IR and WR 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 in the kikuyu-based pastures during summer and autumn (as for the IR treatment during year 1 and the PR 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. Therefor, 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. The Ca:P ratio of IR, WR and PR was below the recommended ratio of 1.6:1 for dairy cows (NRC 1989).

It is thus concluded that 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 the forage quality of kikuyu pastures.

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CHAPTER 3

Kikuyu over-sown with Italian, Westerwolds or perennial ryegrass: grazing capacity, milk production and milk composition

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Kikuyu (*Pennisetum clandestinum*) is a highly productive pasture specie capable of supporting high stocking rates and milk production per ha, but production per cow is low due to its low forage quality. The aim of this study was to determine the grazing capacity, milk production and milk composition of dairy cows grazing irrigated kikuyu over-sown with Italian (*Lolium multiflorum* var. *italicum*), Westerwolds (*Lolium multiflorum* var. *westerwoldicum*) or perennial ryegrass (*Lolium perenne*) during autumn. The grazing capacity of all three kikuyu-ryegrass systems was lower during winter and autumn than during spring and summer, with the seasonal grazing capacity of the perennial ryegrass treatment more evenly distributed than that of the Italian and Westerwolds ryegrass treatments. The perennial ryegrass treatment had a lower butterfat and milk production per lactation than the Italian and Westerwolds ryegrass treatments during both years, but had the highest milk solids and fat corrected milk production per ha. The latter was a result of the higher annual grazing capacity achieved by the perennial ryegrass treatment. It was thus concluded that because kikuyu over-sown with perennial ryegrass supported a higher number of animals and had a more evenly distributed fodder-flow, it achieved higher animal production per ha than kikuyu over-sown with annual ryegrass varieties such as Italian and Westerwolds ryegrass.

Keywords: kikuyu, ryegrass, grazing capacity, milk production, milk composition

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1. Introduction

Kikuyu (*Pennisetum clandestinum*) is a highly productive pasture specie that is well adapted to the main milk producing areas of the Southern Cape (Botha et al. 2008b). Although kikuyu can support high stocking rates and milk production per ha (Colman and Kaiser 1974, Reeves 1997), production per cow is low due to its low forage quality (Marais 2001). Supplementation with concentrates is a possible means of improving the milk production of dairy cows grazing kikuyu (Reeves et al. 1996). The diminishing return on concentrate feeding as the level of concentrate feeding increases (Meeske et al. 2006), decreased intake of pastures at high rates of supplementation (Caton and Dhuyvetter 1997) and decreased efficiency of roughage utilisation (Fulkerson et al. 2006), however, limit the degree to which supplementation can be utilised in pasture based systems.

An alternative to supplementation would be to maintain high pasture utilisation and pasture quality (Van Houtert and Sykes 1999) of kikuyu pastures. The over-sowing of established kikuyu pastures with temperate grass species can provide more even seasonal fodder availability and, as result, less variation in seasonal milk production and grazing capacity than pure kikuyu based pastures (Botha et al. 2008b).

There is currently limited scientific data available in the literature comparing the grazing capacity, milk production and milk composition of systems based on kikuyu over-sown with different ryegrass species and varieties. The aim of this study was to compare the grazing capacity, milk production potential and milk composition of Jersey cows grazing kikuyu over-sown with Italian (*Lolium multiflorum* var. *italicum*), Westerwolds (*Lolium multiflorum* var. *westerwoldicum*) or perennial ryegrass (*Lolium perenne*).

2. Materials and methods

2.1 Experimental site and layout

The study was conducted over a period of two years (2007 to 2009) on the Outeniqua Research Farm (altitude 201 m, 33°58’38” S and 22°25’16”E) near George in the Western Cape Province of South Africa. Approximately nine hectares of an Estcourt soil type (Soil Classification Workgroup, 1991), under permanent overhead sprinkler irrigation and consisting of well established kikuyu pastures, was utilised as the experimental area.

The experimental area was divided into 24 experimental paddocks (approximately 0.38 ha/paddock), which were in turn divided into eight blocks, each consisting of three paddocks apiece.

The three experimental paddocks within a block were randomly allocated to one of the three pasture treatments under investigation, resulting in a total number of eight experimental paddocks per treatment.

2.2 *Treatments and establishment methods*

The three treatments consisted of kikuyu over-sown with Italian ryegrass, kikuyu over-sown with Westerwolds ryegrass and kikuyu over-sown with perennial ryegrass. The Italian and perennial ryegrass was established once the kikuyu had been grazed down to 50 mm, followed by mulching (1.6 meter Nobili with 24 blades) the remaining stubble and then planting the ryegrass with an Aitchison Seeder (2.4 m Aitchison 3116C seedmatic with 16 rows) (Botha et al. 2008a). The Italian ryegrass and perennial ryegrass were planted at seeding rates of 25 and 20 kg ha^{-1}, respectively. The Westerwolds ryegrass was established by grazing kikuyu to 50 mm, broadcasting the seed at a rate of 25 kg ha^{-1} and mulching the pasture to ground level (Botha 2003). All pasture treatments were rolled with a 2.33 m Cambridge roller after planting was completed. The annual ryegrass varieties were over-sown during March and the perennial ryegrass a month later, during April. All treatments were re-established according to the same methods during year 2. The perennial ryegrass was re-established due to its poor persistence into the second year after establishment as is common to this region (Botha et al. 2008c). The species, cultivars, scientific names, seeding rates, abbreviations and over-sowing methods used during the study are shown in Table 1.

Table 1: The species, cultivars, scientific names, seeding rates (kg ha^{-1}), abbreviations and over-sowing methods used during the study

Specie and cultivar	Scientific name	Seeding rate	Abbreviation	Over-sowing method
Italian ryegrass cv. Jeanne	*Lolium multiflorum* var. *italicum*	25	IR	1. Graze to 50 mm 2. Mulch to ground level 3. Seeder 4. Land roller
Westerwolds ryegrass cv. Jivet	*Lolium multiflorum* var. *westerwoldicum*	25	WR	1. Graze to 50 mm 2. Broadcast seed 3. Mulch to ground level 4. Roller
Perennial ryegrass cv. Bronsyn	*Lolium perenne*	20	PR	1. Graze to 50 mm 2. Mulch to ground level 3. Seeder 4. Land roller

2.3 Pasture management and measurement

Irrigation scheduling was conducted using tensiometer readings which were taken daily at 08:00 in the morning. The tensiometers were located at strategic points throughout the experimental area at a depth of 150 mm. Irrigation commenced at a tensiometer reading of –25 kPa and was terminated at a reading of -10 kPa (Botha 2002). Lower than average rainfall during December and January in year 2 (Figure 2), accompanied by a shortage of available irrigation water availability, resulted in irrigation below optimum levels during January and February.

Soil samples were taken before the commencement of pasture establishment at a depth of 100 mm (Miles 1997) using a Beater Type soil sampler during both years. The soil samples were analysed for Ca, Mg, Na, K, P, Zn, Mn, B, S, and C levels. Fertiliser was applied according to the results of the soil analysis to raise soil P level (citric acid method) to 35 mg kg^{-1}, K level to 80 mg kg^{-1} and the pH (KCl) to 5.5 (Beyers 1973). All the treatments were top dressed at a rate of 55 kg N ha^{-1} month^{-1} with limestone ammonium nitrate (Marais 2001, Botha 2003).

Dry matter (DM) production was estimated using a rising plate meter (Stockdale 1984, Fulkerson 1997). A detailed description on how the rising plate meter was calibrated and used, the monthly growth rates, seasonal DM production, annual DM production and nutritive value for the treatments during the two year experimental period are reported in Van der Colf et al. (2010).

2.4 Experimental animals

Forty-five multiparous Jersey cows from the Outeniqua Research Farm herd, used during the experimental period, were blocked according to calving date, lactation number and 4 % FCM production for the previous lactation (see blocking of cows in Appendix A). Cows within blocks were randomly allocated to the three pasture treatments, resulting in 15 cows per treatment. Cows grazed the same treatment for the duration of a full lactation (305 days), with new cows allocated to each treatment during the second year of the study.

Cows were inseminated when on heat 50 days after calving and dried off 60 days before the expected calving date. For the IR and WR treatments, the experimental animals were on the study from June 2007 up until March 2008, while the animals for the PR treatment were on the study from July 2007 up until April 2008. The animals on the PR treatment calved a month later than the animals on the WR and IR pasture treatments. The reason for this was that the PR pastures were established a month later than IR and WR pastures, and as result, they were only ready for grazing a month later. During year 2, grazing was ready a month earlier for all treatments, but the selected experimental animals had not yet calved, resulting in pasture being grazed by other animals, whereafter the animal production study commenced from June 2008 for IR and WR treatments, and July 2008 for PR treatment. The study was completed by the end of March 2009 for IR and WR treatments, and April 2009 for PR treatment.

2.5 Grazing management and determination of grazing capacity

The cows grazed the pasture treatments according to a "put and take system" (Bransby and Tainton 1977). This system consisted of adding additional cows to groups when pasture production exceeded demand and removing cows when pasture demand exceeded pasture production. Experimental animals that could not be accommodated on the experimental area where kept on similar pastures until pasture production was such as to permit their return to the experimental area. Such a system allowed for the determination of grazing capacity of each treatment. Pasture was allocated according to dry matter production per grazing strip (determined with the RPM) at a pasture allowance of 9 kg DM pasture per day or 4.5 kg DM pasture per grazing above 30 mm. In addition to roughage provided through pasture, animals received 4 kg (as is) of concentrate supplementation, which was fed at a rate of 2 kg per milking. The concentrate was sampled weekly, pooled monthly and analyzed in a similar manner to pasture samples (Van der Colf et al., 2010).

The division of the experimental area into paddocks, grazing strips and grazing blocks is shown in Figure 1. Each treatment consisted of eight experimental paddocks that were divided into two grazing strips by a permanent one-meter high fence. Grazing strips were separated into four blocks by a temporary electric fence. After each milking, or twice daily, animals received a fresh block of pasture.

Animals grazed each grazing strip for two consecutive days and each experimental paddock for four days. Cows were on the experimental area for a total of 32 days. Thus, the grazing cycle during the experimental period was 32 days. However, while one block was being grazed, the other seven were rested, resulting in a 28 day period of abscence from each block and a 30 day period of abscence from each grazing strip. Cows could graze back for a maximum of two days, after which the strip was closed up after they had moved to the new strip. The number of animals was adjusted according to available dry matter every second day, or the morning before they entered the new grazing strip.

2.6 Milk production and milk composition

Cows were milked twice daily at, 07:30 and 15:00, utilising a 20 point Dairy Master swing over milk machine (Total Pipeline Industries, 33 Van Riebeeck Street, Heidelberg, 6665). The machine was fully automated with weigh-all electronic milk meters that allowed daily milk production of each individual cow to be measured.

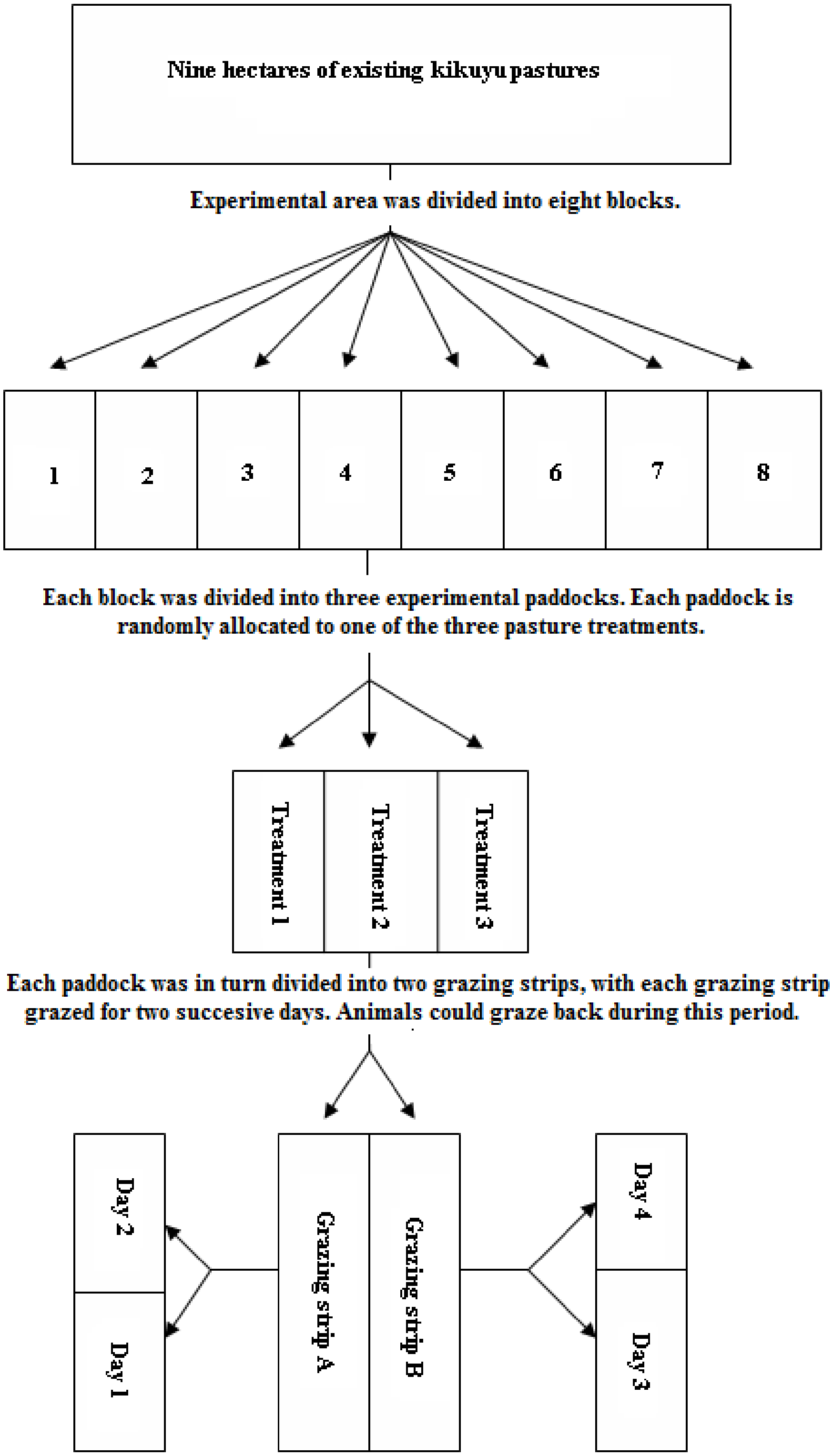

Figure 1 The division of the experimental area into paddocks, grazing strips and grazing blocks

From the daily milk production data collected, the 305-day milk production of each cow was calculated upon completion of the study. If a cow did not achieve a complete 305-day lactation (because she was dried off or the trial had ended), the milk production for the remaining days was calculated from a polynomial equation developed from her milk production data up to that point. The polynomial equation, $y = ax^2 + bx + c$, related daily milk production to days in lactation for a specific cow, where y = daily milk yield (kg cow^{-1}), x= days in lactation, a = factor 1, b= factor 2 and c=constant. Unique values for a, b and c were developed for each individual cow (see appendix B).

Milk composition was determined on a monthly basis from a 24 mL composite morning and afternoon milk sample of 16 mL and 8 mL, respectively. The volume to be taken was calculated according the milking interval of 16 hours for the morning milking and 8 hours for the afternoon milking. Analysis was done a maximum of two days after sampling, before which samples were preserved in sodium dichromate. The protein, butterfat (BF), lactose and milk urea nitrogen (MUN) content of the milk was determined according to the IDF standard 141B (IDF 1996) with a Milkoscan FT 6000 analyzer (Foss Electric, Denmark). Samples were also analyzed for somatic cell count by means of cytometry using a Fossmatic 5000 (Foss Electric, Denmark).

The 305-day lactation data and butterfat percentage of each cow was used to calculate fat corrected milk production (FCM) by means of the equation FCM = (0.4*305 day milk production) + (15*305 day milk production*BF). The yield of butterfat (kg BF cow^{-1}), protein (kg protein cow^{-1}) and milk solids (kg MS cow^{-1}) was calculated for the 305-day lactation of each cow and the mean production per treatment determined. In addition, the daily yield and daily stocking rates recorded throughout the experimental period allowed for the determination of milk production, FCM production and milk solids production per ha of all three treatments.

2.7 Body weight and body condition score

Cows were weighed and condition scored at calving, and on a monthly basis thereafter, after the morning milking. Condition scoring was done by the same individual throughout the trail period according to a five point body condition scoring system (Roche et al. 2004). Animals were also weighed and condition scored at the end of the study or when a specific cow was dried off. The start and end data was used to calculate the mean change in bodyweight and body condition score (BCS) of the treatments at the end of the study.

2.8 Statistical design

The experiment was a complete block design with the three treatments randomly allocated within each of the experimental blocks. The block replicates of the treatments cannot be viewed as independent of each other because the blocks were grazed successively (Wilkens et al. 1995). A factorial analysis of variance (AOV) was preformed with seasons, months or years included as factors. The milk production data was adjusted for each cow and cows were used as replication in analysis (Wilkens et al. 1995). Student's t-LSD (least significant difference) was calculated at a 5% significance level to compare treatment means. The "STATS" module of SAS version 9.12 was used to analyze data (SAS 1999).

3. Results and Discussion

3.1 Climatic data

The mean monthly minimum and maximum temperature and total monthly rainfall that occurred during year 1 and year 2, compared to the 30 year long term average (LTA) is shown in Figure 2.

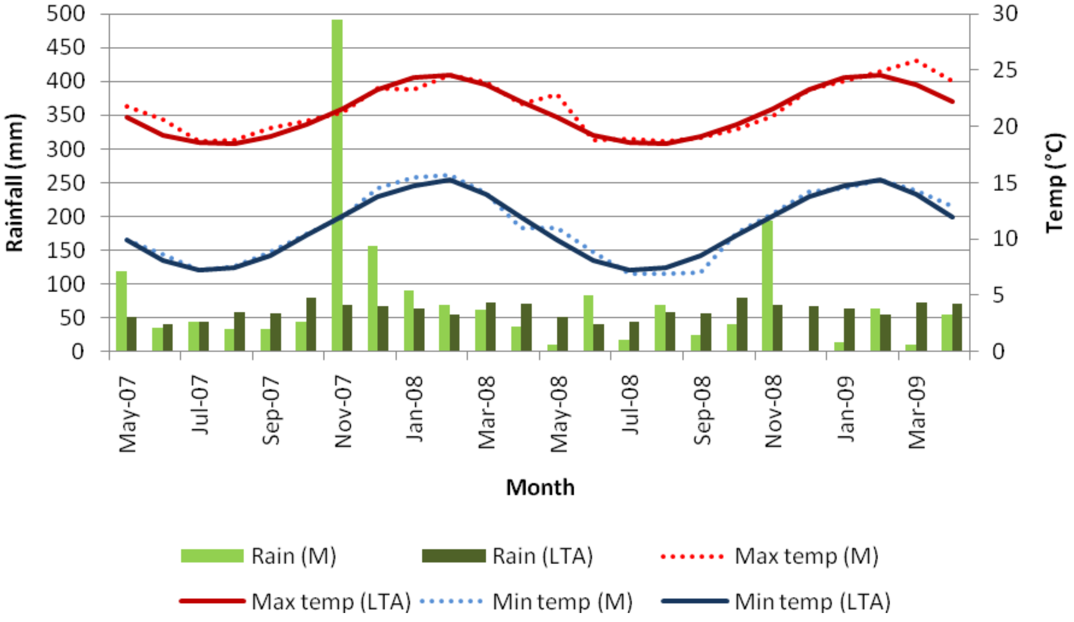

Figure 2: The mean monthly maximum temperature (max temp) minimum temperature (min temp) and total rainfall (mm) on the Outeniqua Research Farm during the study in comparison to the long term (30 years) average (LA)

During November in year 1, a large amount of rain fell over a short period of time (319 mm within three days) which resulted in a monthly rainfall figure well above (422 mm) the LTA. During year 2, another excessive amount of rain fell within a short period of time (173 mm within four days) during November. During both these periods animals had to be removed from the experiemental area for approximately three days or until the paddocks had dried off sufficiently to allow grazing to continue without damaging the pastures due to treading. Animals were placed on pastures of a similar quality and botanical composition during these periods. During December, January and March of year 2, rainfall was lower than the long term average by 64.6, 59.9 and 61.1 mm, respectively. This, along with a shortage in the availibilty of irrigation water, impacted negatively on pasture dry matter production during January and February (Van der Colf et al. 2010).

3.2 Monthly grazing capacity

The monthly grazing capacity of IR, WR and PR during year 1 is shown in Table 2. During the period after establishment, when animals could not graze pastures, stocking rates were recorded as zero. The highest ($P<0.05$) grazing capacity for the IR treatment occurred during October (8.17 cows ha^{-1}), with the grazing capacities from November to February similar ($P>0.05$). The WR treatment's highest ($P<0.05$) grazing capacity during year 1 occurred during February (10.29 cows ha^{-1}), with the grazing capacity not significantly lower ($P>0.05$) during January. The highest grazing capacity for the PR treatment occurred during February (9.51 cows ha^{-1}), with a similar ($P>0.05$) number of cows ha^{-1} supported by PR during December and January. The lowest ($P<0.05$) grazing capacities for the PR and WR treatments occurred during July (2.65 and 3.16 cows ha^{-1} respectively). The IR treatment carried its lowest ($P<0.05$) cows ha^{-1} during July (3.09 cows ha^{-1}), with the grazing capacity during August not significantly higher ($P>0.05$).

The grazing capacities of all three treatments were similar ($P>0.05$) within the months July, August and September during year 1. During June 2007 and May 2008 there were no cows grazing the PR treatment, whilst the grazing capacities of IR and WR did not differ ($P>0.05$) during these months. The grazing capacity of IR was lower ($P<0.05$) than PR and WR within months during January and February, but was higher ($P<0.05$) than both other treatments during October. The WR treatment carried fewer ($P<0.05$) cows ha^{-1} during November than IR and PR.

Table 2: The monthly grazing capacity (cows ha^{-1}) of kikuyu over-sown with Italian (IR), Westerwolds (WR) and perennial (PR) ryegrass for year 1. ^{abc}Means with no common superscript differed significantly at $P < 0.05$. LSD (0.05) compares over treatments and months.

	IR	WR	PR
June	6.10^{ghijk}	5.71^{hijkl}	0^{q}
July	3.09^{op}	2.65^{p}	3.16^{op}
August	3.88^{no}	4.07^{mno}	4.49^{lmn}
September	6.29^{fghij}	5.64^{hijkl}	5.42^{ijkl}
October	8.17^{cd}	6.42^{fghij}	6.75^{efgh}
November	7.47^{def}	5.52^{ijkl}	7.05^{defg}
December	7.77^{cde}	7.49^{def}	8.93^{bc}
January	7.02^{defg}	9.45^{ab}	8.71^{bc}
February	7.90^{cde}	10.29^{a}	9.51^{ab}
March	6.54^{fghi}	7.78^{cde}	7.39^{def}
April	0^{q}	0^{q}	6.04^{ghijkl}
May	5.06^{klmn}	5.21^{jklm}	0^{q}
LSD (0.05)		1.22	

The monthly grazing capacity of the three kikuyu-based systems for year 2 is shown in Table 3. The highest ($P<0.05$) grazing capacity for the IR treatment occurred during October (7.41 cows ha^{-1}). The lowest ($P<0.05$) grazing capacity for IR occurred during June (3.22 cows ha^{-1}), but the grazing capacity during July did not differ ($P>0.05$). The highest ($P<0.05$) grazing capacity for the WR treatment occurred during January (7.83 cow/ha), with similar ($P>0.05$) grazing capacities achieved by this treatment during December and March. The PR treatment's highest ($P<0.05$) grazing capacity occurred during October (7.41 cows ha^{-1}), with similar ($P>0.05$) grazing capacities during November and December.

The grazing capacities of all three treatments were similar ($P>0.05$) within the months of June and August during year 2. During October and November the grazing capacity of WR was lower ($P<0.05$) than IR and PR within months. The IR treatment carried fewer ($P<0.05$) cows ha^{-1} than WR and PR during December and January when compared within months.

Table 3: The monthly grazing capacity (cows ha^{-1}) of kikuyu over-sown with Italian (IR), Westerwolds (WR) and perennial (PR) ryegrass for year 2. ^{abc}Means with no common superscripts differed significantly at P <0.05. LSD (0.05) compares over treatments and months.

	IR	WR	PR
June	3.22^{op}	3.20^{op}	3.96^{lmno}
July	3.79^{mno}	3.46^{nop}	2.88^{p}
August	4.37^{klm}	4.40^{jklm}	4.92^{hijk}
September	5.21^{ghij}	4.64^{ijkl}	5.86^{efg}
October	7.41^{ab}	5.28^{ghi}	7.62^{a}
November	6.55^{cde}	5.64^{fgh}	7.46^{ab}
December	5.99^{defg}	7.65^{a}	7.53^{ab}
January	5.66^{fgh}	7.83^{a}	6.74^{bcd}
February	5.36^{ghi}	6.46^{cdef}	5.89^{efg}
March	6.36^{cdef}	7.18^{abc}	6.32^{def}
April	0^{q}	0^{q}	4.22^{klmn}
LSD (0.05)		0.829	

3.3 Seasonal grazing capacity

The mean seasonal grazing capacity of IR, WR and PR during year 1 and year 2 is shown in Table 4. In order to calculate seasonal grazing capacity, stocking rates were recorded as zero during periods when pastures were not being grazed. These periods coincided with the time when animals could not graze pastures after ryegrass had been established during autumn (see Table 2 and Table 3).

The highest (P>0.05) seasonal grazing capacities during year 1 was for the WR and PR treatments during summer. During year 2 the highest (P<0.05) seasonal grazing capacity occurred for the WR treatment during summer, with similar (P>0.05) grazing capacities achieved by the PR treatment during spring and summer. The grazing capacities of all treatments were lower (P<0.05) during winter and autumn than during spring and summer during both years.

The PR treatment was grazed for a month shorter during winter in year 1 (Table 3) because it was established a month later, and as a result, had a lower (P<0.05) grazing capacity than WR and IR during this season. The IR treatment had a higher (P>0.05) grazing capacity than WR and PR during spring, but lower (P<0.05) during summer. This pattern in grazing capacity coincided with high growth rates of the ryegrass component of the IR treatment during spring and lower growth rates of the kikuyu component during summer (Van der Colf et al. 2010). The three treatments had similar

(P>0.05) grazing capacities during autumn of year 1 and winter of year 2. Within season the grazing capacities of IR and WR were lower (P<0.05) than PR during spring and autumn in year 2. During summer the grazing capacities of PR and WR were higher (P<0.05) than IR. Except for winter in year 1, the PR treatment did not have the numerically lowest grazing capacity within any season, indicating a more evenly distributed seasonal grazing capacity than IR and WR. This is in agreement with the findings of Van der Colf et al. (2010) that showed that during year 2 the ability of the PR treatment to maintain DM production during periods when the other treatments underwent a dip in production (WR during spring and IR during summer). This resulted in improved seasonal and annual DM production of this treatment compared to kikuyu-annual ryegrass treatments, and in turn enabled it to support higher seasonal grazing capacities during various seasons.

Table 4: Mean seasonal grazing capacity (cows ha^{-1}) of kikuyu over-sown with Italian (IR), Westerwolds (WR) and perennial ryegrass (PR) during year 1 and 2. LSD (0.05) compares over season and treatment within year. ^{abc}Means with no common superscripts differed significantly at P <0.05.

Year	Season	IR	WR	PR	LSD (0.05)
1	Winter	4.37^{d}	4.11^{d}	2.36^{e}	0.704
	Spring	7.43^{b}	5.90^{c}	6.44^{c}	
	Summer	7.59^{b}	9.10^{a}	9.09^{a}	
	Autumn	3.95^{d}	4.34^{d}	4.34^{d}	
2	Winter	3.75^{ef}	3.64^{ef}	3.87^{e}	0.699
	Spring	6.34^{bc}	5.18^{d}	6.94^{ab}	
	Summer	5.68^{cd}	7.38^{a}	6.75^{ab}	
	Autumn	2.72^{g}	3.08^{fg}	5.23^{d}	

3.4 *Milk production per animal*

The milk production, milk composition, live weight change and body condition score change of cows grazing kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass during year 1 and year 2 is shown in Table 5 and Table 6 respectively.

The three kikuyu based pasture systems had an average daily milk production between 15.9 and 16.1 kg cow^{-1} during year 1 and between 16.1 and 17.7 kg cow^{-1} during year 2. These values compare favourably with those of Botha (2003) of between 14 and 17.2 kg cow^{-1} day^{-1} for Jersey cows grazing annual ryegrass-kikuyu pastures. The daily milk production of cows grazing kikuyu over-sown with Italian, Westerwolds or perennial ryegrass was also similar to the daily milk production (17.2 to 18.7 kg cow^{-1} day^{-1}) of dairy cows grazing pure ryegrass stands in the same region (Meeske et al. 2009).

The latter is unexpected, since the milk production per cow from kikuyu is notoriously low (Marais 2001) and the pastures contained an appreciable kikuyu component from spring onwards (Van der Colf et al. 2010). The daily milk yield and 305-day milk production of cows grazing IR, WR and PR did not differ ($P>0.05$) from each other during year 1. During year 2 the 305-day milk production of PR was lower ($P<0.05$) than for IR and WR. The 305-day FCM milk production of PR was lower ($P<0.05$) than IR during year 1 and lower ($P<0.05$) than IR and WR during year 2. Although Lowe et al. (1999) reported that there were no significant differences between the 300-day milk production of cows grazing pure swards based on perennial or Italian ryegrass, daily milk yield from the cows grazing Italian ryegrass pastures was almost 2 L lower per cow per day than for cows grazing perennial ryegrass pastures.

Although the butterfat (BF) percentage of the three treatments did not differ ($P>0.05$) during year 1 or year 2, the PR treatment did have a lower ($P<0.05$) production of BF per lactation (kg BF cow^{-1}) than IR and WR during both years. Studies based on pure stands of Italian or perennial ryegrass also did not report differences in the BF content of dairy cows grazing these two pasture types (Lowe et al. 1999). The BF contents of all three treatments (between 4.63% and 4.94% during year 1 and between 4.40% and 4.47% during year 2) were above values for BF (3.89%) recorded for supplemented Holsteins grazing kikuyu (Reeves et al. 1996). The BF contents were also higher than the 3.6 % BF reported for unsupplemented Holsteins grazing kikuyu at 30 day grazing intervals (Henning et al. 1995). The lower BF percentages reported by these authors is most likely a result of breed differences, since Jerseys cows produce milk with a higher BF content (4.43%) than Holsteins (3.54%) (De Villiers 2000). The only data that could be found in the literature for similar pastures grazed by Jersey cows were those of Botha et al. (2008b). The BF content of IR, WR and PR were similar to values of between 4.13% and 4.79% reported during this study by Botha et al. (2008b).

The milk protein content (%) of PR was lower ($P<0.05$) than IR during year 1. The higher 305-day milk production of PR during year 1, however, cancelled out the effect of a lower protein content and, as such, kg protein lactation^{-1} was similar ($P>0.05$) for all treatments during year 1. During year 2 the opposite occurred, with the lower ($P<0.05$) 305-day milk production of the PR treatment resulting in lower ($P<0.05$) kg protein lactation^{-1} produced by the PR treatment than by the IR and WR treatments, regardless of protein content being similar ($P<0.05$) for all three treatments. The protein content (between 3.55% and 3.88%) of the three kikuyu based systems was similar or slightly higher to those recorded by Henning et al. (1995) for cows grazing kikuyu (3.6%). Only the IR treatment during year 1 reached similar protein percentages of 3.82 and 3.85% for Italian and perennial ryegrass based pastures respectively (Lowe et al. 1999). All treatments achieved similar or higher protein contents of between 3.42% and 3.59% reported for annual ryegrass-kikuyu pastures in the same region (Botha 2003).

The lactose content (%) of IR, WR and PR did not differ ($P>0.05$) between treatments during year 1 or year 2. Milk lactose content is the least variable milk component and is essentially constant 4.85 % of milk, varying only slightly with breed and milk protein concentration (NRC 2001). The somatic cell contents (SCC) of all treatments were similar during year 1 and year 2, and were below the value of >300 cells mL^{-1} considered as abnormal for cows' milk (De Villiers et al. 2000).

The milk solids production of PR was lower ($P<0.05$) than for IR and WR during year 1 and year 2. Milk solids content tends to decrease with lowered protein and energy intake, as well as increased fibre intake (De Villiers et al. 2000). This is unlikely to be the reason for the lower milk solids production observed for the PR treatment, since the pasture treatments did not differ in terms of seasonal crude protein (CP) content, except during winter and autumn in year 1, when PR had a lower ($P<0.05$) CP content than IR. Additionaly, the neutral detergent fiber content of PR was similar ($P>0.05$) to IR and WR throughout the study. The only contributing factor could thus have been metabolisable energy (ME) content, with the ME content of PR lower ($P<0.05$) than that of IR during summer and autumn during year 1. This trend was, however, not repeated during year 2 (Van der Colf et al. 2010).

The milk urea nitrogen (MUN) content (mg dL^{-1}) of IR, WR and PR was between 12.9 and 14.1 mg dL^{-1} during year 1 and fell within the range of 12 to 18 mg dL^{-1} recommended by Harris (1996) for cows achieving a milk protein content above 3.2%. According to Harris (1996), this indicates that animals received a diet with a balanced amino acid and carbohydrate content. During year 2, the MUN contents of all three treatments were above the recommended levels (between 18.3 and 19.5 mg dL^{-1}), indicating that the protein intake of the experimental animals was in excess of requirements, or that there was a deficient level of energy in the diet (Harris 1996). Trevaskis and Fulkerson (1999) hypothesised that the high Nitrogen/Water soluble carbohydrate (N/WSC) ratio often found in kikuyu may increase MUN levels, primarily because cows are unable to metabolise the large pool of ammonia that accumulates under certain circumstances of grazing. Since WSC content was not measured during this study, it could not be determined if this was the case here. The very low ME content of all pasture treatments during summer and autumn in year 2 could, however, have been a contributing factor.

Cows grazing IR, WR and IR pasture treatments had similar ($P>0.05$) start and end body weights and did not differ ($P>0.05$) in terms of body weight change during either year 1 or year 2. Cows on all the treatments gained weight from calving up until the end of the experimental period/drying off during both years. During year 1 the cows grazing the PR treatment started their lactation at a higher ($P<0.05$) body condition score (BCS) than the IR and WR treatments, but all treatments had similar

($P>0.05$) BCS at the end of the lactation. As a result, the PR treatment had a lower ($P<0.05$) gain in BCS than the IR and WR treatments. Although a higher BCS at calving has been linked to higher 4% FCM yields, the BCS of PR was not high enough to elicit this response, since the increase is most marked at a BCS of 3 (Roche et al. 2007). During year 2 all three treatments had similar ($P>0.05$) BCS at the end and start of the experiemental period, with no differences ($P>0.05$) between treatments in terms of BCS change during lactation.

Table 5: Milk production, milk composition, live weight change and body condition score[1] change of cows grazing kikuyu over-sown with Italian (IR), Westerwolds (WR) and perennial (PR) ryegrass for year 1. ^{ab}Means in the same row with different superscripts differed significantly at $P<0.05$. LSD (0.05) compares within row over treatments.

		Treatments			
Parameter	Unit	IR	WR	PR	LSD (0.05)
Daily milk production	kg cow^{-1} day^{-1}	15.9^{a}	16.0^{a}	16.1^{a}	1.02
305-day milk production	kg cow^{-1}	4864^{a}	4864^{a}	4905^{a}	311.2
305-day 4% FCM[2] production	kg cow^{-1}	5551^{ab}	5670^{a}	5352^{b}	276.7
Butterfat production	kg cow^{-1}	241^{a}	247^{a}	226^{b}	14.0
Butterfat content	%	4.94^{a}	4.97^{a}	4.63^{a}	0.384
Protein production	kg cow^{-1}	185^{a}	186^{a}	178^{a}	9.9
Protein content	%	3.84^{a}	3.75^{ab}	3.64^{b}	0.167
Milk solids production	kg cow^{-1}	427^{a}	433^{a}	404^{b}	21.6
Lactose content	%	4.64^{a}	4.66^{a}	4.66^{a}	0.063
MUN[3]	mg dL^{-1}	13.1^{ab}	12.9^{b}	14.1^{a}	1.27
SCC[4]	1000 mL^{-1}	215^{a}	225^{a}	213^{a}	120.3
BW[5] $_{\text{start}}$	kg	353^{a}	378^{a}	357^{a}	33.5
BW $_{\text{end}}$	kg	396^{a}	423^{a}	408^{a}	30.5
BW $_{\text{change}}$	kg	42.6^{a}	45.2^{a}	51.1^{a}	21.82
BCS[6] $_{\text{start}}$		2.22^{b}	2.18^{b}	2.45^{a}	0.229
BCS $_{\text{end}}$		2.55^{a}	2.58^{a}	2.46^{a}	0.316
BCS $_{\text{change}}$		0.33^{a}	0.40^{a}	0.02^{b}	0.293

[1] Five point system where 1 is thin and 5 is fat

[2] Fat corrected milk [3] Milk urea nitrogen [4] Somatic cell count [5] Body weight [6] Body condition score

Table 6: Milk production, milk composition, live weight change and body condition score[1] change of cows grazing kikuyu over-sown with Italian (IR), Westerwolds (WR) and perennial (PR) ryegrass for year 2. ^{ab}Means in the same row with different superscripts differed significantly at $P<0.05$. LSD (0.05) compares within row over treatments.

		Treatments			
Parameter	Unit	IR	WR	IR	LSD (0.05)
Daily milk production	kg cow^{-1} day^{-1}	17.7^{a}	17.1^{ab}	16.1^{b}	1.26
305-day milk production	kg cow^{-1}	5394^{a}	5206^{a}	4913^{b}	383.7
305-day 4% FCM[2] production	kg cow^{-1}	5773^{a}	5769^{a}	5182^{b}	358.0
Butterfat production	kg cow^{-1}	241^{a}	246^{a}	214^{b}	17.9
Butterfat content	%	4.50^{a}	4.47^{a}	4.40^{a}	0.380
Protein production	kg cow^{-1}	191^{a}	187^{a}	173^{b}	13.0
Protein content	%	3.54^{a}	3.61^{a}	3.53^{a}	0.146
Milk solids production	kg cow^{-1}	432^{a}	433^{a}	387^{b}	27.5
Lactose content	%	4.61^{a}	4.63^{a}	4.67^{a}	0.080
MUN[3]	mg dL^{-1}	19.5^{a}	19.5^{a}	18.3^{b}	1.234
SCC[4]	1000 mL^{-1}	230^{a}	242^{a}	250^{a}	128.4
BW[5] $_{\text{start}}$	kg	383^{a}	402^{a}	368^{a}	39.61
BW $_{\text{end}}$	kg	414^{a}	424^{a}	383^{a}	30.8
BW $_{\text{change}}$	kg	31.0^{a}	22.2^{a}	15.0^{a}	38.2
BCS[6] $_{\text{start}}$		2.12^{a}	2.17^{a}	2.10^{a}	0.194
BCS $_{\text{end}}$		2.43^{a}	2.48^{a}	2.22^{a}	0.314
BCS $_{\text{change}}$		0.32^{a}	0.32^{a}	0.12^{a}	0.391

[1] Five point system where 1 is thin and 5 is fat

[2] Fat corrected milk [3] Milk urea nitrogen [4] Somatic cell count [5] Body weight [6] Body condition score

3.5 Milk production per hectare

The mean annual grazing capacity, milk production and milk solids production per ha of kikuyu over-sown with Italian (IR), Westerwolds (WR) and perennial ryegrass (PR) during year 1 and year 2 is shown in Table 7.

The PR treatment had a higher ($P<0.05$) mean annual grazing capacity and milk production ha^{-1} than WR and IR during year 1 and year 2. The FCM production ha^{-1} and milk solids ha^{-1} of PR was higher ($P<0.05$) than for IR and WR during year 2, but was similar ($P>0.05$) for all treatments during year 1. The mean annual grazing capacities of all treatments were lower than annual grazing capacities of 6.67 to 9.01 cows ha^{-1} reported by Botha et al. (2008b) for annual ryegrass-kikuyu pastures. However, the pastures during the study by Botha et al. (2008b) were grazed for a shorter period than reported here. The milk production per hectare of all three ryegrass-kikuyu systems compared favourably with production rates of between 25953 and 38406 kg milk ha^{-1} found in other studies where dairy cows grazed annual ryegrass-kikuyu pastures (Botha et al. 2008b).

Table 7: Mean annual grazing capacity^{1}, milk production and milk solids per ha for kikuyu over-sown with Italian (IR), Westerwolds (WR) and perennial ryegrass (PR) during year 1 and year 2. ^{ab}Means in the same row with different superscripts differed significantly at P<0.05. LSD (0.05) compares within row across treatments

			Treatments			LSD
Year	Parameter	Units	IR	WR	PR	(0.05)
1	Grazing capacity^{1}	Cows ha^{-1}	6.44^{b}	6.49^{b}	6.93^{a}	0.273
	Milk production per ha	kg ha^{-1}	30446^{b}	29761^{b}	32288^{a}	1539.9
	4% FCM^{2} production per ha	kg FCM/ha	34556^{a}	34057^{a}	35268^{a}	1698.9
	Milk solids production per ha	kg MS/ha	2627^{a}	2566^{a}	2639^{a}	128.5
2	Grazing capacity^{1}	Cows ha^{-1}	5.34^{b}	5.52^{b}	5.96^{a}	0.350
	Milk production per ha	kg ha^{-1}	28073^{b}	27032^{b}	31385^{a}	1253.4
	4% FCM^{2} production per ha	kg FCM/ha	30087^{b}	30052^{b}	33086^{a}	1425.9
	Milk solids production per ha	kg MS/ha	2247^{b}	2258^{b}	2457^{a}	106.6

^{1}For the 10 month period when experimental animals were on the experimental area

^{2}Fat corrected milk

4. Conclusions

The grazing capacities of the three kikuyu based pasture systems varied over months and seasons, with the grazing capacity of all three treatments lower during winter and autumn than during spring and summer. Kikuyu over-sown with perennial ryegrass (PR) had more evenly distributed seasonal grazing capacities than kikuyu over-sown with Italian (IR) or Westerwolds ryegrass (WR).

The PR treatment had a lower 305-day FCM production than the WR treatment during year 1 and year 2. In addition, the PR treatment had a lower butterfat and milk solids production per lactation than the IR and WR treatments during both years. However, due to the higher annual grazing capacity achieved by the PR treatment during year 1 and year 2, it achieved a higher milk production ha^{-1} during both years than IR and WR. During year 2 the PR treatment had a higher milk solids and FCM production per ha than the other treatments.

It is thus concluded that the PR treatment provided a more even fodder-flow availability and achieved higher animal production per ha, primarily because it supported more animals per ha than the WR and IR treatments during both years. An economical analysis and comparison is, however, recommended to identify the most profitable kikuyu-ryegrass system in order to give consideration to the input costs required for and income generated by each system.

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CHAPTER 4

Kikuyu over-sown with Italian, Westerwolds or perennial ryegrass: Calibration of the rising plate meter for pasture yield determination

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The rising plate meter (RPM) has been used widely by researchers and farmers to estimate the DM production of pastures grazed by dairy cows. There is currently limited data available for the calibration of the RPM for kikuyu over-sown with ryegrass and grazed by dairy cows in the Western Cape Province of South Africa. The aim of this study was to evaluate the calibrations developed for the RPM during a two year systems trial conducted on the production potential of kikuyu over-sown with Italian (*Lolium multiflorum* var. *italicum*), Westerwolds (*Lolium multiflorum* var. *westerwoldicum*) or perennial ryegrass (*Lolium perenne*) at the Outeniqua Research Farm in the Western Cape Province of South Africa. Pastures were under permanent irrigation and intensively strip grazed by dairy cows. The pre-grazing and post-grazing regressions developed for all three kikuyu-ryegrass treatments differed over seasons and years, primarily due to the change in botanical composition from ryegrass-based pastures during winter to kikuyu-based pastures during summer. The post-grazing regressions developed during the study did not have a lower degree of accuracy (R^2 values) than the pre-grazing regressions. The generalised RPM regression equations developed for kikuyu-ryegrass pastures (consisting of large data sets pooled over treatments and years) could be of use to farmers in the surrounding area with similar pastures and management practices, but are not recommended for research purposes.

Keywords: kikuyu, over-sown, ryegrass, pasture measurement, rising plate meter

1. Introduction

Accurate determination of pasture yield plays a vital role in dairy pasture management and pasture based research.

Accurate budgeting and management of forage in grazing systems requires frequent assessment of forage mass and growth of pastures (Gabriëls and Van den Berg 1993, Sanderson et al. 2001). Knowledge on the available herbage mass can assist in taking the correct management decisions at the correct time (Gabriëls and Van den Berg 1993), in the identification of pastures that need improvement and allow the tracking of pasture condition (Sanderson et al. 2001). From a research point of view, accurate pasture mass estimations could allow researchers to better understand the interactions between plants and animals in grazing trials. It is, therefore, necessary to have some measure of production, availability and consumption of forage (Bransby et al. 1977). In addition, knowledge on available pasture mass can assist in determining optimum stocking rates (Ganguli et al. 2000) and intake of experimental animals (Stockdale 1984) during grazing trials.

The rising plate meter (RPM) developed by Earle and McGowan (1979) has been used widely by researchers and farmers to estimate the DM production of pastures grazed by dairy cows. The advantages associated with using the RPM for the estimation of pasture DM yield include its robustness, relatively low cost, ease of use, low sensitivity to environmental conditions, the stability of calibration equations across years and seasons (if pasture composition remains similar) and the fact that it is relatively operator friendly, allowing a large number of readings to be taken in a short period of time (Earle and McGowan 1979, Michel 1982, Fulkerson and Slack 1993, Douglas and Crawford 1994, Martin et al. 2005). An additional advantage of using the RPM is that it has been found to be more accurate in estimating the forage DM yield (kg DM ha^{-1}) of tropical grass species, such as kikuyu, than the capacitance probe (Fulkerson and Slack 1993).

The accuracy of pasture yield determination with pasture disc meters has been found to be lower in ryegrass when grazed, than when ungrazed (Bransby and Tainton, 1977, Michell 1982). This necessitates an evaluation of RPM calibrations under grazing situations. Additionally, the development of region specific calibration equations for the RPM has been advocated in the literature (Sanderson et al. 2001).

There is currently limited data available for the calibration of the RPM for kikuyu pastures over-sown with ryegrass that is grazed by dairy cows in the Western Cape Province of South Africa. The aim of this study was to evaluate the calibrations developed for the RPM during a two year systems trial conducted on the production potential of kikuyu over-sown with Italian (*Lolium multiflorum* var. *italicum*), Westerwolds (*Lolium multiflorum* var. *westerwoldicum*) or perennial ryegrass (*Lolium* *perenne*) at the Outeniqua Research Farm in the Western Cape Province of South Africa. An attempt was also made to develop standard calibrations for irrigated ryegrass-kikuyu pastures being intensively stripgrazed by dairy cows in the region, which could be used by farmers to evaluate pasture production of these systems.

2. Materials and methods

2.1 Experimental site

The study was carried out on the Outeniqua Research Farm (altitude 201 m, 33°58'38" S and 22°25'16"E) in the Western Cape Province of South Africa. The mean annual rainfall (30 year average) in this area is 725 mm, with mean minimum and maximum temperatures ranging between 7-15°C and 18-25°C respectively (ARC, 2010). The study was conducted over a two year a period, with year 1 consisting of the period from June 2007 until May 2008, and year 2 from June 2008 until May 2009. Winter during the study 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.

2.2 Treatments and Experimental layout

Three kikuyu based pasture treatments were evaluated during the study. The three treatments consisted of kikuyu over-sown with annual Italian ryegrass (*Lolium multiflorum* var. *italicum*), annual Westerwolds ryegrass (*Lolium multiflorum* var. *westerwoldicum*) and perennial ryegrass (*Lolium perenne*). The treatments, scientific names, abbreviations and cultivars utilised during the study are listed in Table 1.

Table 1: Treatments, scientific names, abbreviations and cultivars used during the study

Treatment	Scientific name	Abbreviation	Cultivar (*cv*)
Italian ryegrass	*Lolium multiflorum* var. *italicum*	IR	Jeanne
Westerwolds ryegrass	*Lolium multiflorum* var. *westerwoldicum*	WR	Jivet
Perennial ryegrass	*Lolium perenne*	PR	Bronsyn

The study was conducted on existing kikuyu pastures under permanent sprinkler irrigation and characterised by an Estcourt type soil (Soil Classification Work Group 1991). The nine hectare experimental area was divided into eight blocks that acted as replicates, with each block divided into three experimental paddocks to which one of the three treatments was randomly allocated. There were a total of 24 experimental paddocks, with eight experimental paddocks allocated per treatment. The rising plate meter (RPM) calibrations were only developed on "monitor camps". The experimental layout, the allocation of paddocks to treatments, the monitor camps and size of paddocks used during the study are illustrated in Figure 1.

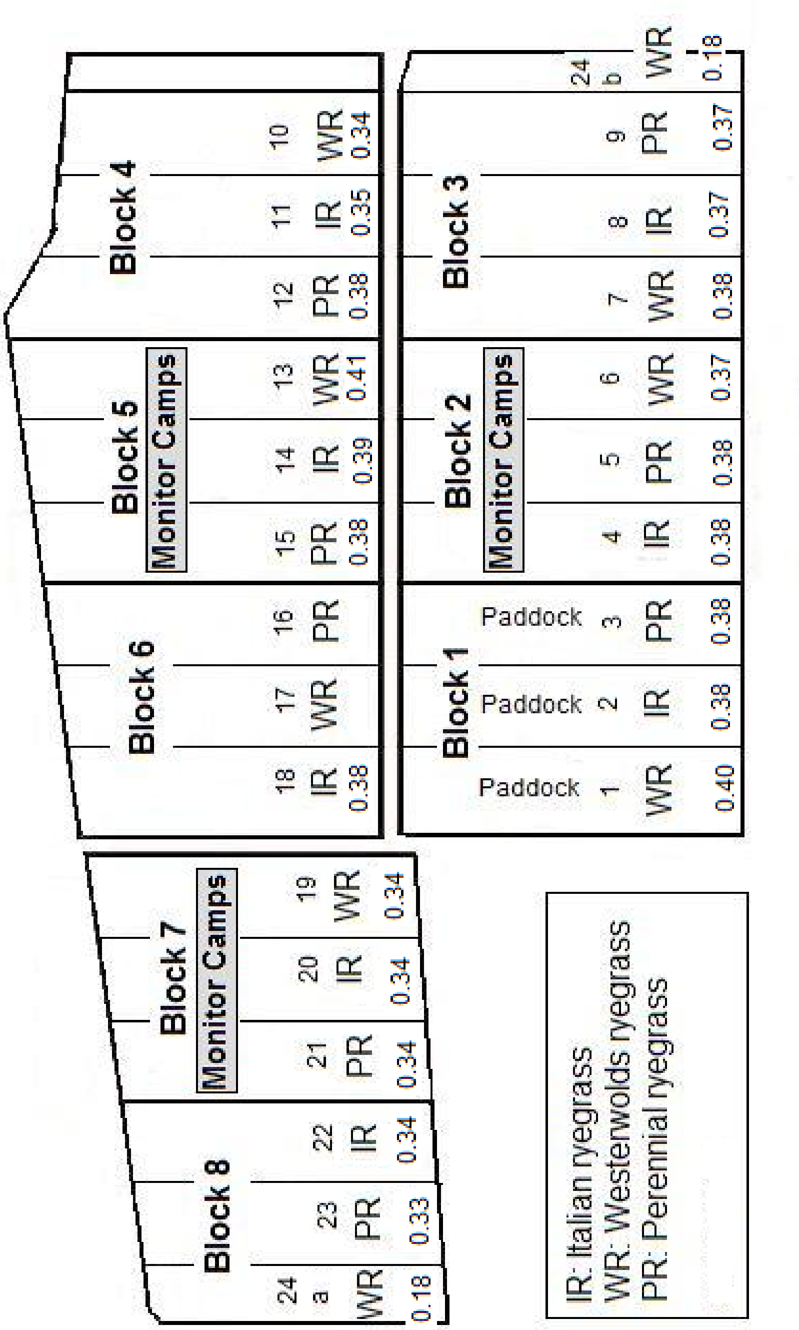

Figure 1: The experimental layout, allocation of paddocks to treatments, monitor camps and size of paddocks (ha) used during the study

2.3 Establishment methods

All kikuyu was grazed to a height of 50 mm prior to the commencement of ryegrass establishment during autumn. Italian ryegrass was planted at 25 kg ha^{-1} into kikuyu during March using an Aitchison seeder (2.4m Aitchison 3116C seedmatic with 16 rows) after the kikuyu had been mulched to ground level (1.6 meter Nobili with 24 blades) (Botha et al. 2008a). Westerwolds ryegrass was planted into kikuyu during March by broadcasting the seed at a rate of 25 kg ha^{-1} and then mulching the remaining kikuyu stubble (Botha, 2003). Perennial ryegrass was planted into mulched kikuyu at 20 kg ha^{-1} during April with an Aitchison seeder. All treatments were rolled with a 2.33 m Cambridge type roller after planting had been completed. All treatments were re-established, using to the same methods described, during year 2. The perennial ryegrass was re-established due to its poor persistence into the second year after establishment, as is common to this region (Botha et al. 2008b). The treatments, seeding rates and over-sowing methods used to over-sow Italian, Westerwolds and perennial ryegrass into kikuyu are summarized in Table 2.

Table 2: The treatments, seeding rates and over-sowing methods used to over-sow Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass into kikuyu

Treatment	Seeding rate (kg ha^{-1})^{a}	Over-sowing method
IR	25	1. Graze to 50 mm
		2. Mulcher
		3. Seeder
		4. Land roller
WR	25	1. Graze to 50 mm
		2. Broadcast seed
		3. Mulcher
		4. Land roller
PR	20	1. Graze to 50 mm
		2. Mulcher
		3. Seeder
		4. Land roller

[a] According to recommendations by Dickenson *et al*. (2004)

2.4 Pasture management

Pastures were irrigated according to tensiometer readings taken daily at 08:00 in the mornings. The tensiometers were 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 during year 2 (Figure 3), accompanied by a shortage in availability of irrigation water, resulted in irrigation below optimum levels during January and February of year 2.

Before planting commenced each year soil samples were taken using a beater type soil sampler to a depth of 100 mm, using the sampling methodology described by Miles (1997). Soils samples were analysed for Ca, Mg, Na, K, P, Cu, Zn, Mn, B, S, and C levels. Fertiliser was applied according to the results of the soil analyses in order to raise soil P level (citric acid method) to 35 mg kg^{-1}, K level to 80 mg kg^{-1} and pH (KCl) to 5.5 (Beyers 1973). All the treatments were top dressed with limestone ammonium nitrate at a rate of 55kg N ha^{-1} on a monthly basis (Marais 2001, Botha 2003).

All pasture treatments were strip grazed by Jersey cows. Experimental paddocks were divided into two grazing strips (with identical pasture treatments) by means of a permanent one-meter high fence. The grazing strips were divided into four blocks using a temporary mobile electrical wire. A fresh block of grazing was allocated to the cows after each milking. Each grazing strip was grazed for two consecutive days and each paddock for four days. Cows could graze back the pasture for a maximum of two days, after which the strip was closed up. Cows were on the experimental area for a total of 32 days. Thus, the grazing cycle during the experimental period was 32 days. However, while one block was being grazed, the other seven were rested, resulting in a 28 day period of abscence from each block and a 30 day period of abscence from each grazing strip. The number of cows per paddock was adjusted daily according to available DM production with 4.5 kg DM pasture allocated per cow per grazing or 9 kg DM cow^{-1} day^{-1}. Grazing management was aimed at maintaining a post-grazing height on the RPM of 10 (50 mm) throughout all seasons for all pasture treatments.

2.5 Sampling procedure

Calibration of meter readings to dry matter yield per unit area is undertaken by recording the height and dry matter yield of a number of quadrats of pasture and correlating one with the other. Dry matter yield (Y kg ha^{-1}) is then related to meter height by the linear model (Earle and McGowan 1979):

$$Y = mH + b$$

Where m = gradient; H = mean rising plate meter height and b = intercept value

Separate calibrations were developed pre- and post-grazing, since it has been found that both the gradient and intercept value will differ for RPM regressions developed for pre-and post grazing swards (Stockdale 1984).

During this particular study, the height of the pasture was measured with the RPM at a specific point, a ring of the same size as the RPM plate (0.098m^{2}) placed over the RPM and all DM within the ring borders cut (t'Mannetjie 2000). The pasture samples were cut at a height of 30 mm, rather than at ground level (Bransby and Tainton 1977, Fulkerson and Slack 1993, Botha 2003). During post-grazing calibrations no samples were cut if the RPM height was 6 (30 mm) or below, but the height was recorded and DM yield entered as “zero” in the dataset. Samples were dried at 60ºC (1400 L SWC forced convection oven) for 72 hours to determine the dry matter (DM) yield, within the 0.098 m^2 area, at the specific height.

In order to improve the accuracy of the calibrations, an attempt was made to cut samples over as wide a range of sward heights as possible (Bransby et al. 1977, Earle and McGowan 1979, Trollope and Potgieter 1986). In order to achieve the above metioned, three samples were cut at a height estimated by the operator as low, medium and high, respectively, within each of the two grazing strips. A total of 18 calibration samples were thus cut per treatment (paddock) at each calibration. The RPM was calibrated three times per treatment during the grazing cycle, or approximately every 10 days, both pre-and post-grazing. Pre-grazing calibrations were cut the day before animals entered a paddock, after a 28 day period of abscence. Post-grazing calibrations were cut the day animals were moved to a new paddock following a short (four day) period of occupation.

From the collected data, a linear regression ($y = mx + b$) relating meter reading to herbage DM mass was developed, where y = yield (kg DM ha^{-1}), m = gradient, x = mean RPM height and b = intercept value.

Pre-grazing pasture height of each paddock was estimated by taking 200 RPM measurements per paddock in a zigzag pattern. A total of 105 post-grazing readings were taken the day after animals had moved to a new grazing strip, therefore a total of 210 readings were taken per paddock. The majority of RPM readings were taken by one operator during the entire experimental period to reduce the effect of operator variability on accuracy of calibrations and readings (Aiken and Bransby 1992).

In addition to pasture yield measurements, botanical composition of each pasture type was determined on a monthly basis. The details and data relating to the change in botanical composition of the three pasture treatments over seasons can be found in Van der Colf et al. (2010).

2.6 *Statistical analysis*

All statistical analyses were completed using Excel for Microsoft Vista (Microsoft Corporation 2007). Data was analysed to determine the R^2 value. The coefficient of determination, or R^2, is a scale free, one number summary of the strength of the relationship between y_i and x_i in the data (Weisberg 2005). For example, if the R^2 value within a calibration equation (in this case) is equal to 0.758, it would indicate that 75.8% of the variability in yield (y) is explained by RPM height (Bransby and Tainton 1977). For the purposes of this study, a R^2 of 0.70 or above was viewed as “high”, 0.50 or below as “low” and between 0.50 and 0.70 as “acceptable” (Marde Booyse, pers. comm.). The error associated with estimating dry matter was expressed as the standard error of estimate (SE_y) (Fulkerson and Slack 1993).

It has been noted that calibration equations for pasture disc meters differs between seasons (Bransby et al. 1977, Bransby and Tainton 1977, Tucker 1980, Michell 1982, Stockdale 1984, Fulkerson and Slack 1993). An attempt was thus made to determine whether this was the case for the different pasture treatments evaluated during this study. The various seasonal regressions for each treatment were compared within a year in terms of DM yield predicted by each seasonal regression at RPM heights between 10 and 60, for pre-grazing regressions, and 5 and 20 for post-grazing regressions. The aim of this was to identify the effect that seasonal variations in gradient (m) and intercept (b) values would have on DM yield determination. Additionaly, the regressions of a specific treatment within a season developed during the two year study were compared with each other (i.e. year 1 and year 2 winter regressions for treatment 1 compared with each other). All pre-and post-grazing regressions were tested for curvilinearity.

Although pooled calibration equations, consisting of data pooled over seasons and species, have been deemed unpractical for research purposes, it could be of some value to farmers (Stockdale 1984). For this reason, “generalised regressions” were developed by pooling data over seasons and treatments to evaluate the practical value of such regressions.

3. Results and Discussion

3.1 Climatic data

The mean monthly minimum and maximum temperature and total monthly rainfall that occurred during year 1 and year 2, compared to the 30 year long term average (LTA) is shown in Figure 2. During November in year 1 (2007) a large amount of rain fell over a short period of time (319 mm in three days) which resulted in a monthly rainfall figure well above (422 mm) the LTA. During year 2 (2008) another excessive amount of rain fell within a short period of time (173 mm in 4 days) during November. During December, January and March of year 2 (2008/2009) rainfall was lower than the long term average by 64.6, 59.9 and 61.1 mm, respectively. This, along with a shortage in the availibilty of irrigation water, impacted negatively on pasture dry matter production during January and February 2009 (Van der Colf et al. 2010).

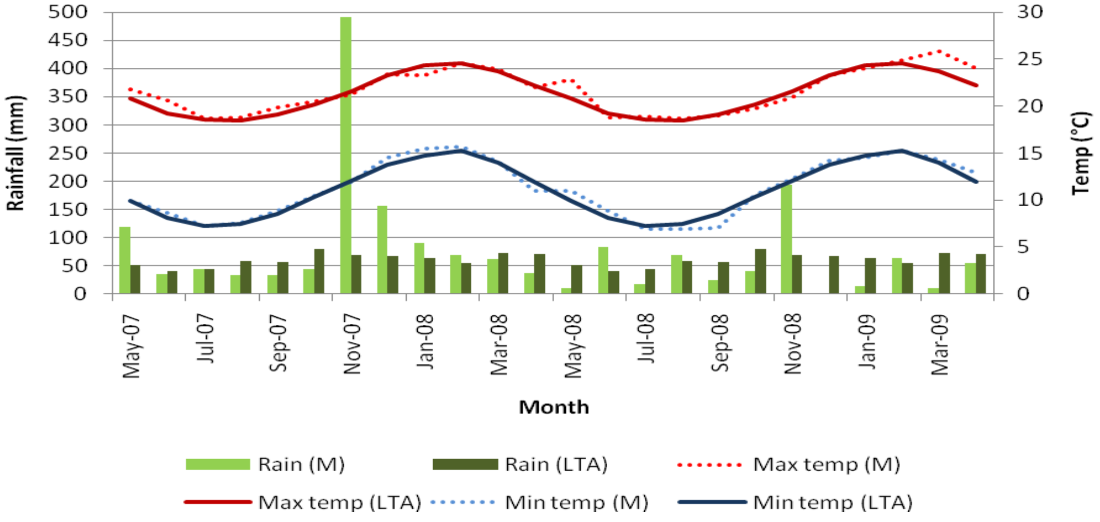

Figure 2: The mean monthly maximum temperature (max temp) minimum temperature (min temp) and total rainfall (mm) on the Outeniqua Research Farm during the study in comparison to the long term (30 years) average (LTA)

3.2 Comparison of pre-grazing seasonal calibrations within treatments

The mean measured RPM height, range in measured height, number of paddocks measured and number of readings taken pre-grazing for kikuyu over-sown with Italian ryegrass (IR) during respective seasons in year 1 and year 2 are shown in Table 3. During year 1 the measured pre-grazing height of IR increased from 20.8 during winter to its highest value of 37.2 during summer. During year 2 the mean measured height was again lowest in winter (23.3) and increased to its highest during spring (33.5). There were fewer readings taken during autumn than other seasons, since pastures were re-established during March and no readings could be taken during April and May.

Table 3: The mean measured RPM height, range in measured height*, number of paddocks measured and number of readings taken pre-grazing for kikuyu over-sown with Italian ryegrass (IR) during year 1 and year 2

Year	Season	Mean height	Range height	Paddocks	Readings
1	Winter	20.8	11-44	47	4700
	Spring	34.6	19-50	45	4500
	Summer	37.2	25-47	45	4500
	Autumn	33.5	24-42	15	1500
2	Winter	23.3	15-46	65	6500
	Spring	33.5	22-46	46	4600
	Summer	28.0	17-40	45	4500
	Autumn	30.1	22-38	12	1200

* Range of mean heights calculated from readings at each sampling

Details for the seasonal pre-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with Italian ryegrass (IR) during year 1 and year 2 are presented in Table 4.

Table 4: Details for the seasonal pre-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with Italian ryegrass (IR) during year 1 and year 2

								RPM height	
Treatment	Year	Season	*n	m	b	R^2	SE_Y	Range	Mean
IR	1	Winter	162	90.1	-692	0.89	401	6-64	23
		Spring	142	63.8	-484	0.73	588	9-76	34
		Summer	144	66.9	-325	0.65	636	9-68	35
		Autumn	36	66.5	-363	0.68	522	15-62	37
	2	Winter	234	65.2	-341	0.81	344	6-63	24
		Spring	144	50.6	-36	0.71	490	9-76	32
		Summer	162	69.9	-169	0.61	681	8-69	30
		Autumn	18	50.7	325	0.66	526	15-57	35

n= number of samples, m=gradient, b=intercept, R^2=coefficient of variation, SE_Y=standard error of estimate

The R^2 for the seasonal regressions of the IR treatment decreased from its highest value of 0.89 during winter, to its lowest value of 0.65 during summer in year 1. During year 2 the R^2 again decreased from its highest value of 0.81 during winter to its lowest value of 0.61 during summer. The R^2 values for the IR treatment were high during winter and spring (>0.70), and remained above 0.60 during summer and autumn (>0.50) for both year 1 and year 2.

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with Italian ryegrass (IR), as predicted by the seasonal pre-grazing calibration equations developed for the RPM during year 1, is shown in Figure 3. Up to a RPM height of 20, there would have been small differences between DM yields predicted by the different seasonal regression equations developed during year 1. The winter regression had a higher gradient (*m*) value than the other seasonal regression equations during year 1 (Table 4). This would have resulted in the DM yield predicted by the winter regression increasing at a greater rate per unit RPM reading than during other seasons and, as such, higher DM yields than the other seasonal regressions, especially at RPM heights above 20. In contrast, the spring regression equation had the lowest gradient (*m*) value during year 1 (Table 4), which would have resulted in it predicting lower DM yields than the other seasonal regression equations when compared at the same RPM height. Similar DM yields would have been predicted by the summer and autumn regressions, primarily because the gradient (*m*) and intercept (*b*) values during these two seasons were similar (Table 4).

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with Italian ryegrass (IR), as predicted by the seasonal pre-grazing calibration equations developed for the RPM during year 2, is shown in Figure 4. The winter and spring regressions during year 2 would have predicted similar DM yields between RPM heights of 23 and 34. The mean measured pre-grazing heights during winter (23.3) and spring (33.5) of year 2 fell within this range (Table 3). The positive intercept (*b*) value for the autumn regression of IR during year 2 at +325, compared to the negative intercept (*b*) values during all other seasons (Table 4), indicates that this regression equation would have predicted higher DM yields at low RPM heights than the regressions of other seasons (Figure 4).

The dry matter yield (kg DM ha^{-1}), as predicted by the seasonal pre-grazing calibration equations developed during year 1 and year 2 for kikuyu over-sown with Italian ryegrass (IR), compared within season, is shown in Figure 5.

The winter regressions developed for IR during year 1 and year 2 predicted similar DM yields between RPM heights of 10 and 15. From this point onwards the higher gradient (*m*) value of the winter regression during year 1 (Table 4) would have resulted in a greater rate of increase in DM yield than during year 2 as the RPM height increased (Figure 5a). Although there were differences between the spring regressions developed during year 1 and year 2 in terms of both gradient (*m*) and intercept (*b*) values (Table 4), both predicted similar DM yields at RPM heights between 30 and 40 (Figure 5b). The mean measured RPM heights during spring of year 1 (34.6) and year 2 (33.5) fell within this range (Table 3). The similar gradient (*m*) values for summer regressions developed during year 1 (66.9) and year 2 (69.9) (Table 4) would have resulted in DM yield increasing at a similar rate with an increase in RPM height during both years. However, the higher intercept (*b*) value of the summer regression developed during year 2 (-169 *vs*. -325 during year 1) would have resulted in higher predicted DM yields at all RPM heights between 10 and 60, compared to the summer regression developed during year 1 (Figure 5c). The autumn regressions developed for IR during year 1 and year 2 differed greatly in terms of gradient (*m*) and intercept (*b*) values (Table 4). Regardless of this, differences in predicted DM would have been small (lower than 500 kg DM ha^{-1}) at all RPM heights, with differences particularly small at RPM heights between 30 and 60 (Figure 5d). Thus the effect of the differences in gradient and intercept values between the autumn regressions would have been small at the mean measured RPM heights of 33.5 and 30.1 during autumn for year1 or year 2, respectively.

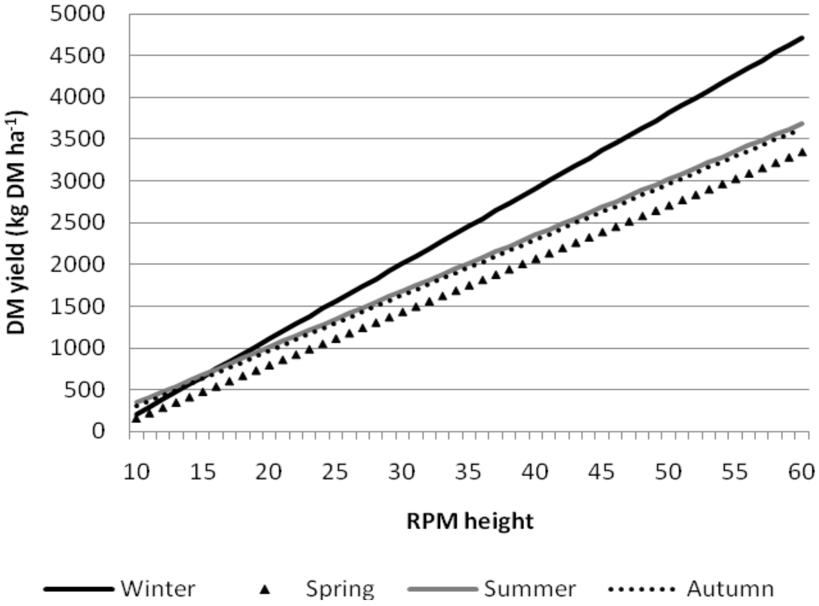

Figure 3: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal pre-grazing calibration equations developed for the RPM of kikuyu over-sown with Italian ryegrass (IR) during year 1

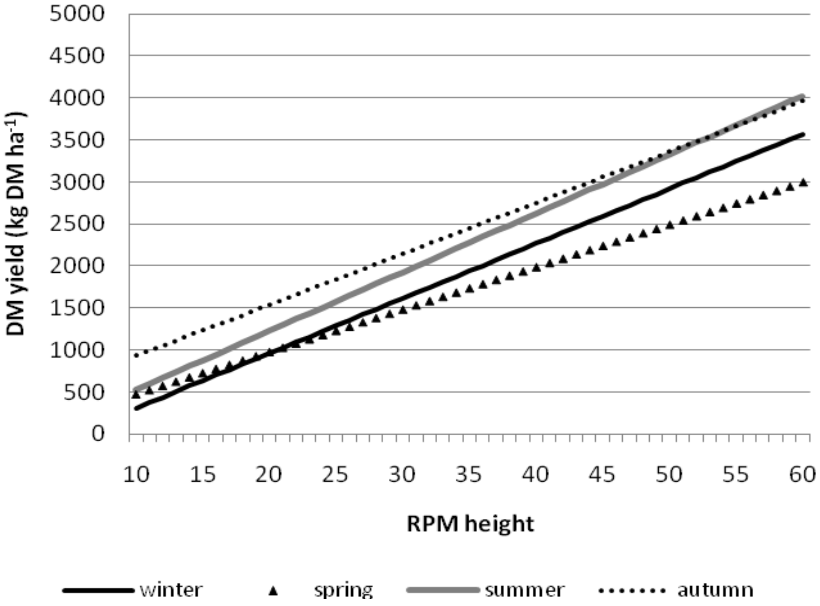

Figure 4: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal pre-grazing calibration equations developed for the RPM of kikuyu over-sown with Italian ryegrass (IR) during year 2

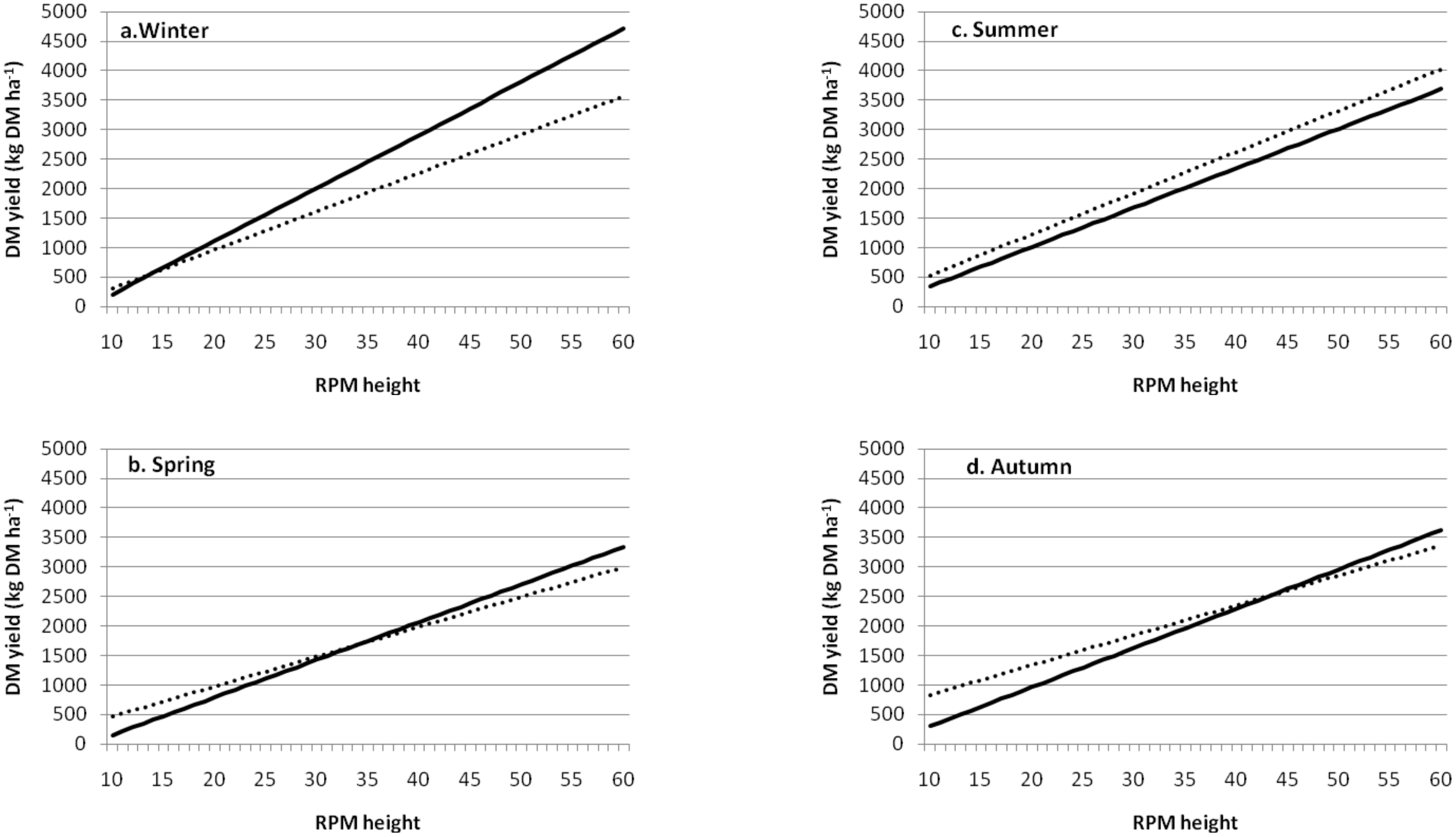

Figure 5: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal pre-grazing calibration equations for the RPM of kikuyu over-sown with Italian ryegrass (IR) during a) winter; b) spring; c) summer and d) autumn for year 1 (-) and year 2 (----)

The mean measured RPM height, range in measured height, number of paddocks measured and number of readings taken pre-grazing for kikuyu over-sown with Westerwolds ryegrass (WR) during respective seasons in year 1 and year 2 is shown in Table 5. During year 1 the measured pre-grazing height of WR increased from 20.7 during winter to its highest value of 41.4 during summer. During year 2 the mean measured height was also lowest during winter (23.1) and increased to its highest during summer (34.6). Since pastures were re-established during March, and no readings could be taken during April and May, fewer RPM meter readings were taken during autumn than during other seasons.

Table 5: The mean measured RPM height, range* in measured height, number of paddocks measured and number of readings taken pre-grazing for kikuyu over-sown with Westerwolds ryegrass (WR) during respective seasons during year 1 and year 2

Year	Season	Mean height	Range height	Paddocks	Readings
1	Winter	20.7	11-37	48	4800
	Spring	28.3	20-39	45	4500
	Summer	41.4	21-56	45	4500
	Autumn	34.6	24-43	15	1500
2	Winter	23.1	15-47	65	6500
	Spring	27.9	18-43	46	4600
	Summer	34.6	24-54	45	4500
	Autumn	32.1	26-49	12	1200

* Range of mean heights calculated from readings at each sampling

Details for the seasonal pre-grazing regressions ($Y = mH + b$), relating herbage mass Y (kg DM ha-1) and meter reading (H), developed for kikuyu over-sown with Westerwolds ryegrass (WR) during year 1 and year 2 is shown in Table 6.

The R^2 of the seasonal pre-grazing regressions developed for the WR treatment during year 1 decreased from its highest value of 0.84 during winter, to its lowest value of 0.57 during summer. During year 2, the R^2 value remained between 0.74 and 0.75 from winter to summer, but then decreased drastically to 0.44 during autumn. This decrease in the R^2 value during autumn of year 2 was, however, not associated with a dramatic increase in the standard error (SE_Y) associated with the regression estimation compared to the summer regression.

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with Westerwolds ryegrass (WR), as predicted by the seasonal pre-grazing calibration equations developed for the RPM during year 1, is shown in Figure 6. The winter regression had the highest gradient (*m*) value of the seasonal regressions developed for WR during year 1 (Table 6). As result, the DM predicted by the winter regression would have increased at a greater rate with an increase in RPM height than with the other seasonal regressions. At RPM heights between 10 and 25, the regressions developed for spring, summer and autumn during year 1, would have predicted similar DM yields. Beyond this point, the lower gradient (*m*) value of the spring regression (Table 6) would have resulted in it predicting lower DM yields than other seasonal regressions developed during year 1. The summer and autumn regressions for WR during year 1 had similar gradient (*m*) values, but differed in regard of intercept (*b*) values (Table 6). Although the summer regression, which had a higher intercept (*b)* value, would have predicted higher DM yields than the autumn regressions at all heights, the differences would have been relatively small.

Table 6: Details for the seasonal pre-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with Westerwolds ryegrass (WR) during year 1 and year 2

								RPM readings	
Treatment	Year	Season	n	m	b	R^2	SE_y	Range	Mean
WR	1	Winter	160	97.4	-920	0.84	612	6-72	24
		Spring	143	64.1	-441	0.68	667	6-75	37
		Summer	143	72.2	-270	0.57	970	15-81	41
		Autumn	36	74.6	-519	0.69	659	18-69	40
	2	Winter	234	55.7	-128	0.74	407	6-64	25
		Spring	143	60.3	-162	0.74	500	5-69	30
		Summer	162	75.1	-268	0.75	677	12-73	35
		Autumn	18	35.2	1192	0.44	663	17-68	39

n= number of samples, m=gradient, b=intercept, R^2=coefficient of variation, SE_Y=standard error of estimate

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with Westerwolds ryegrass (WR), as predicted by the seasonal pre-grazing calibration equations developed for the RPM during year 2, is shown in Figure 7. The spring and winter pre-grazing regressions developed for WR during year 2 had similar gradient (*m*) and intercept (*b*) values (Table 6). As result the DM yield predicted by the winter and spring regressions would have been similar between RPM heights of 10 and 60. The summer regression had the highest gradient (*m*) value of the pre-grazing seasonal regressions developed during year 2 (Table 6) for the WR treatment. This would have resulted in a greater rate of increase in predicted DM yield as the RPM height increased when compared to other seasonal regressions developed during year 2 for the WR treatment. The high positive intercept (*b*) value (+1192) of the autumn regression (Table 6) would have resulted in this regression predicting high DM yields at low

RPM heights when compared to other seasonal regressions developed during year 2. However, due to the low gradient (*m*) value of the autumn regression compared to the other seasonal regressions (Table 6), the rate at which predicted DM yield increased would have been lower than for other seasonal regressions developed for WR during year 2.

The dry matter yield (kg DM ha^{-1}), as predicted by the seasonal pre-grazing calibration equations developed during year 1 and year 2 for kikuyu over-sown with Westerwolds ryegrass (WR), compared within season, is shown in Figure 8. Between the mean measured pre-grazing RPM heights of the WR treatment for winter during year 1 and year 2 (20.7 and 23.1, respectively, as shown in Table 5), the differences in DM yield predicted by the winter regressions developed during the two years would have been small (Figure 8a). The higher gradient (*m*) value of the winter regression during year 1 (Table 6) would, however, have resulted in it predicting higher DM yields than that of the winter regression during year 2, as the RPM height increased from 20 to 60. At RPM heights between 10 and 60, the spring regressions for year 1 and year 2 would have predicted similar DM yields (Figure 8b). The slightly higher DM yields predicted by the spring regression developed during year 2, were a result of the lower intercept (*b*) value of the spring regression during year 2 than during year 1 (Table 6). A similar trend was seen for the summer regressions, with the DM yield predicted by the regressions during year 1 and year 2 similar (Figure 8c). This can be attributed to the similarity in the gradient (*m*) and intercept (*b*) values for the summer regressions during year 1 and year 2 (Table 6). Due to the great differences in the gradient (*m*) and intercept (*b*) values of the autumn regressions developed for WR during year 1 and year 2 (Table 6), the DM yield predicted by the two regression equations also differed greatly (Figure 8d). The high differences in predicted DM yield (up to 1000 kg DM ha^{-1}) at low RPM heights, can be attributed to the large differences in intercept (*b*) values for the autumn regressions during year 1 (-519) and year 2 (+1192). However, as the RPM height increased, the difference between the DM yield predicted by the two equations decreased, primarily due to the lower gradient (*m*) value of the regression during year 2 (35.2) compared to year 1 (74.6) (Table 6).

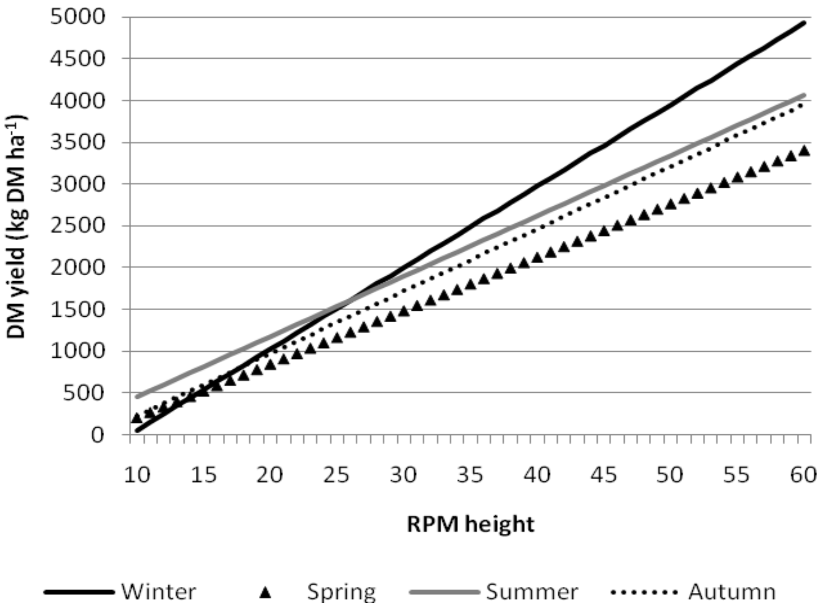

Figure 6: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal pre-grazing calibration equations developed for the RPM of kikuyu over-sown with Westerwolds ryegrass (WR) during year 1

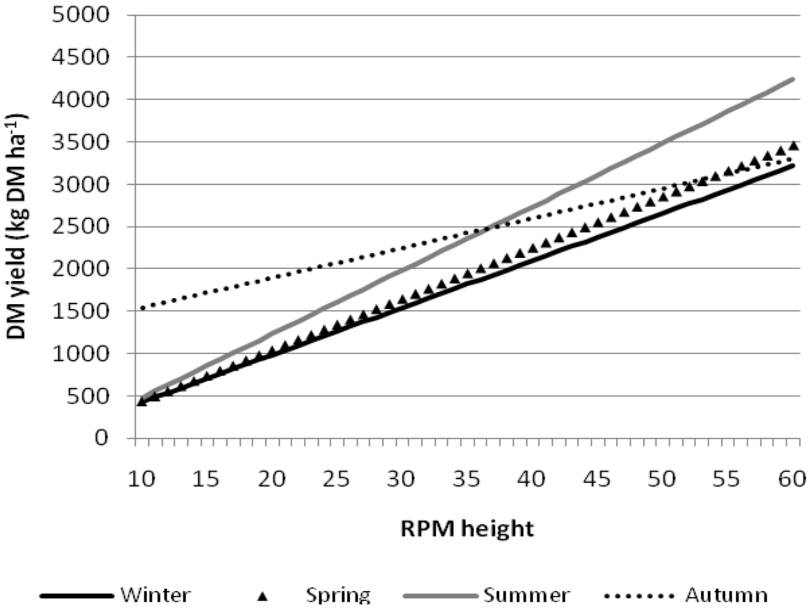

Figure 7: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal pre-grazing calibration equations developed for the RPM of kikuyu over-sown with Westerwolds ryegrass (WR) during year 2

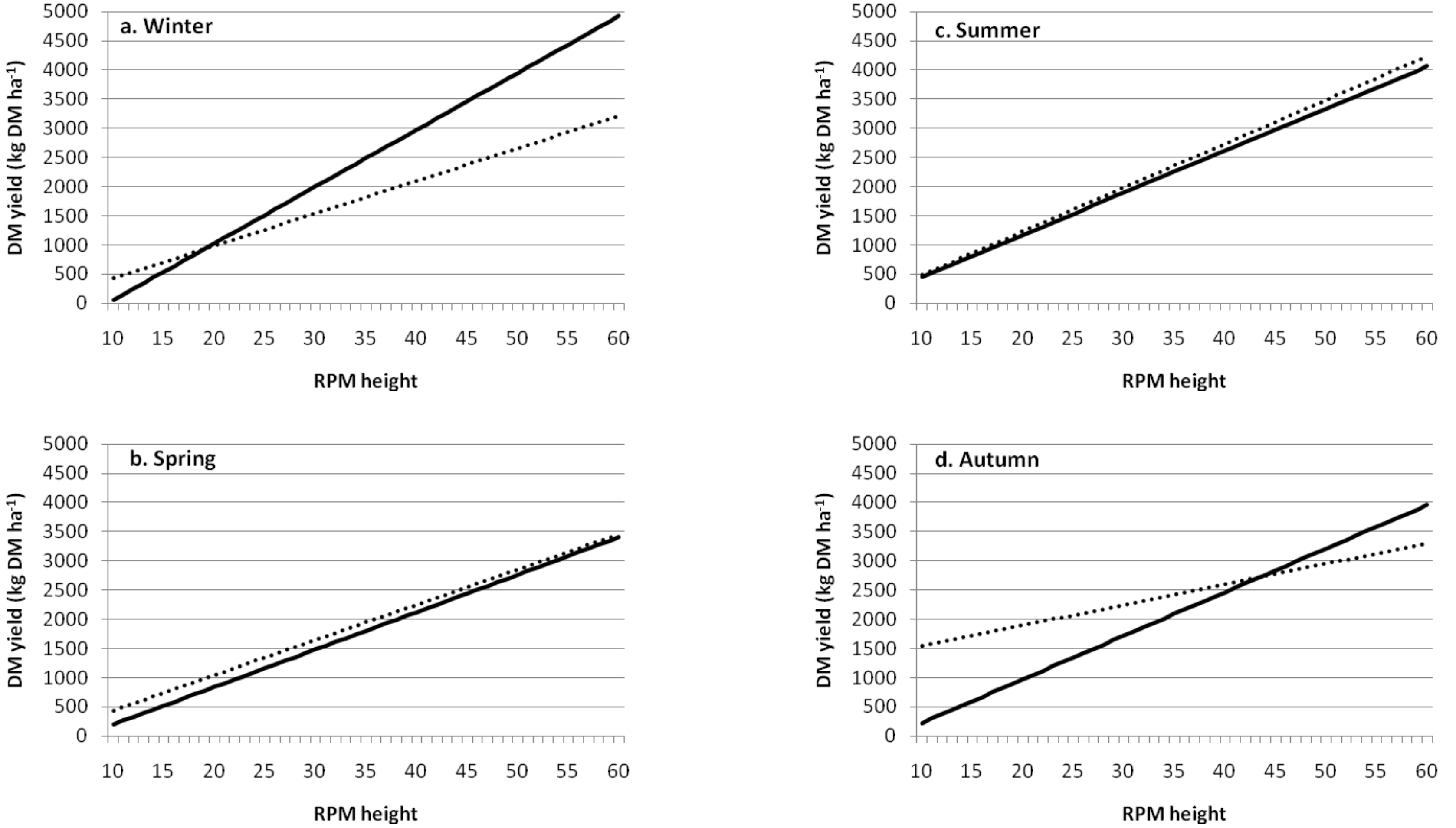

Figure 8: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal pre-grazing calibration equations for the RPM of kikuyu over-sown with Westerwolds ryegrass (WR) during a) winter; b) spring; c) summer and d) autumn for year 1 (-) and year 2 (----)

The mean measured RPM height, range in measured height, number of paddocks measured and number of readings taken pre-grazing for kikuyu over-sown with perennial ryegrass (PR) during respective seasons during year 1 and year 2, is shown in Table 7. During year 1 the measured pre-grazing height of PR increased from 20.3 during winter to its highest value of 39.6 during summer. During year 2 the mean measured height was lowest during autumn (21.8) and highest during spring (30.7).

Table 7: The mean measured RPM height, range* in measured height, number of paddocks measured and number of readings taken pre-grazing for kikuyu over-sown with perennial ryegrass (PR) during respective seasons during year 1 and year 2

Year	Season	Mean height	Range height	Paddocks	Readings
1	Winter	20.3	15-31	28	2800
	Spring	30.5	19-45	45	4500
	Summer	39.6	28-48	45	4500
	Autumn	31.2	22-40	31	3100
2	Winter	22.8	15-33	49	4900
	Spring	30.7	22-38	46	4600
	Summer	29.2	20-38	45	4500
	Autumn	21.8	14-33	28	2800

* Range of mean heights calculated from readings at each sampling

Details for the seasonal pre-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with perennial ryegrass (PR) during year 1 and year 2 is shown in Table 8.

The R^2 value for the seasonal regression equations of the PR treatment during year 1 was highest during spring (0.76) and decreased to below 0.50 during summer (0.46) and autumn (0.36). During year 2 the R^2 of the seasonal regressions remained above 0.70 during winter, summer and autumn, with the lowest R^2 value of 0.64 occurring during spring.

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with perennial ryegrass (PR), as predicted by the seasonal pre-grazing calibration equations developed for the RPM during year 1, is shown in Figure 9. There were small differences in the DM yield predicted by the winter and summer regressions developed for PR during year 1 due to the similarity in gradient (*m*) and intercept (*b*) values between the two regressions (Table 7). The spring regression equation had the lowest intercept (*b*) value of all seasonal regressions developed during year 1 (Table 7) and, as a result, predicted the lowest DM yields at RPM heights up to approximately 35. The autumn regression was the only regression developed for PR during year 1 with a positive intercept value (*b*) (Table 8). The implication of this was that it predicted higher DM yields up to RPM heights of 20 than the other seasonal regressions during year 1. Due to the low gradient (*m*) value of the autumn regression (Table 7), however, the predicted DM yield increased at a lower rate with an increase in RPM height, and once RPM height exceeded 40, it predicted lower DM yields than all other seasonal regressions developed during year 1.

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with perennial ryegrass (PR), as predicted by the seasonal pre-grazing calibration equations developed for the RPM during year 2, is shown in Figure 10. During year 2 the difference in DM yield predicted by the various seasonal regressions developed for the PR treatment remained relatively small up to a RPM height of 30. This was regardless of the large variation in gradient (*m*) and intercept (*b*) values over seasons. Beyond this point the summer regression predicted higher DM yields than the other seasons, primarily because it had the highest gradient (*m*) value (Table 8).

Table 8: Details for the seasonal pre-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with perennial ryegrass (PR) during year 1 and year 2

								RPM readings	
Treatment	Year	Season	*n	m	b	R^2	SE_y	Range	Mean
PR	1	Winter	89	81.7	-516	0.73	464	6-46	21
		Spring	144	78.6	-662	0.76	589	12-80	34
		Summer	144	71.8	-209	0.46	1016	14-74	35
		Autumn	90	54.6	187	0.36	1000	10-63	29
	2	Winter	162	81.0	-565	0.79	378	8-44	22
		Spring	144	76.9	-402	0.64	561	8-54	28
		Summer	162	87.8	-519	0.71	607	10-58	28
		Autumn	72	69.4	-113	0.71	606	8-67	27

* n= number of samples, m=gradient, b=intercept, R^2=coefficient of variation, SE_Y=standard error of estimate

The dry matter yield (kg DM ha^{-1}), as predicted by the seasonal pre-grazing calibration equations developed during year 1 and year 2 for kikuyu over-sown with perennial ryegrass (PR), compared within season, is shown Figure 11. Due to the similar gradient (*m*) and intercept (*b*) values for the winter regression equations developed for PR during year 1 and year 2 (Table 8), the DM yields predicted by the two equations were similar at all RPM heights (Figure 11a). The spring regression developed for the PR treatment during year 1 predicted lower DM yields than that of the spring regression developed during year 2 (Figure 11b). Although differences were small (less than 500 kg DM ha^{-1}), they were the result of the lower intercept (*b*) value for the spring regression during year 1 than during year 2 (Table 8). During summer and autumn the regression equations developed during year 1 and year 2 predicted similar DM yields up to a RPM height of approximately 25, after which the DM yields predicted by the regressions developed during year 2 were higher than that of year 1 (Figure 11c and Figure 11d). The primary reason for this was the higher gradient values (*m*) for the summer and autumn regressions during year 2 than during year 1 (Table 8).

All regression equations differed in terms of gradient (*m*) and intercept (*b*) values during different seasons and years. This is in agreement with findings in the literature that calibration equations for the pasture disc meters differed between seasons (Bransby et al. 1977, Bransby and Tainton 1977, Tucker 1980, Michell 1982, Stockdale 1984, Fulkerson and Slack 1993). Even within a mixed sward, changes in botanical composition were found to change the regression relationship for the pasture disc meter (Bransby et al. 1977). The change in botanical composition is thus the most likely reason for the different regression equations found within the same treatment during different seasons. All pastures investigated during this study changed from ryegrass dominant pastures during winter to kikuyu dominant pastures during summer and autumn (Van der Colf et al. 2010). These results are in agreement with the findings of Earle and McGowan (1979) that a change in botanical composition could play a large role in the change in regression equations.

In addition, Fulkerson and Slack (1993) reported that the regression equations for tropical species, such as kikuyu, differed significantly ($P<0.05$) for early season (November-March) and late season (March-May). This trend has been attributed to the buildup of a dead stoloniferous mat as the growth season of kikuyu progresses (Fulkerson and Slack 1993), while the development of a kikuyu mat has also been found to reduce the gradient and intercept value of regressions (Reeves et al. 1996). Although a decrease in the gradient of regression equations from summer to autumn was observed for all treatments during year 2, this was not the case during year 1. The high grazing pressures maintained during the study, particularly aimed at preventing kikuyu mat formation, could have been a contributing factor to these results. The post-grazing heights achieved during the study for the IR, WR and PR treatment are given in Tables 9, 11 and 13 respectively.

From the results found during this study it would appear that there was less variation between different seasonal regressions developed for the PR treatment (Figure 9 and Figure 10) than for the WR and IR treatments. Annual ryegrass pastures have been found to show more variation in regression relationships during different seasons. The primary reason for these findings was reported to be due to the fact that, in contrast to perennial ryegrass that does not undergo reproductive development and continues growth into the summer, annual ryegrass will undergo reproductive development during spring and die off during summer (Stockdale 1984).

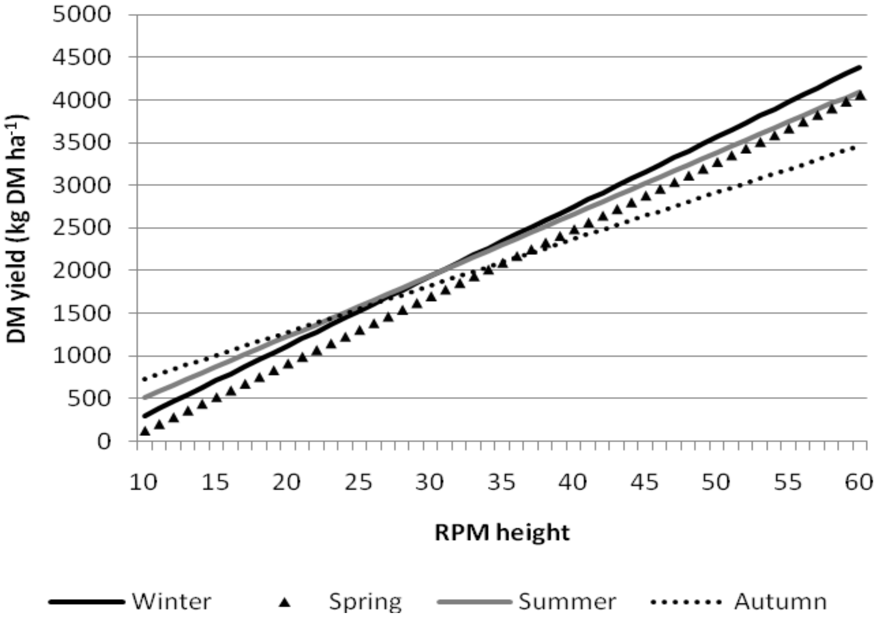

Figure 9: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal pre-grazing calibration equations developed for the RPM of kikuyu over-sown with perennial ryegrass (PR) during year 1

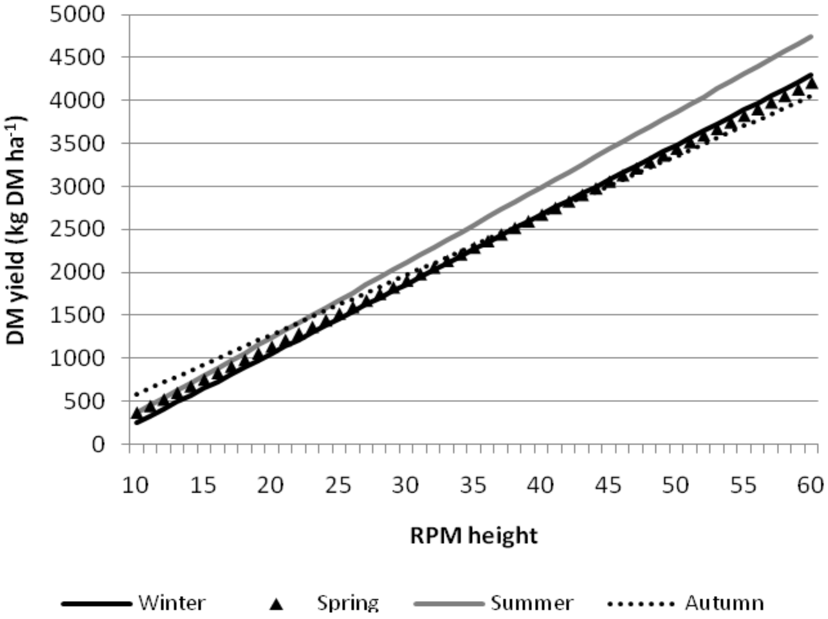

Figure 10: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal pre-grazing calibration equations developed for the RPM of kikuyu over-sown with perennial ryegrass (PR) during year 2

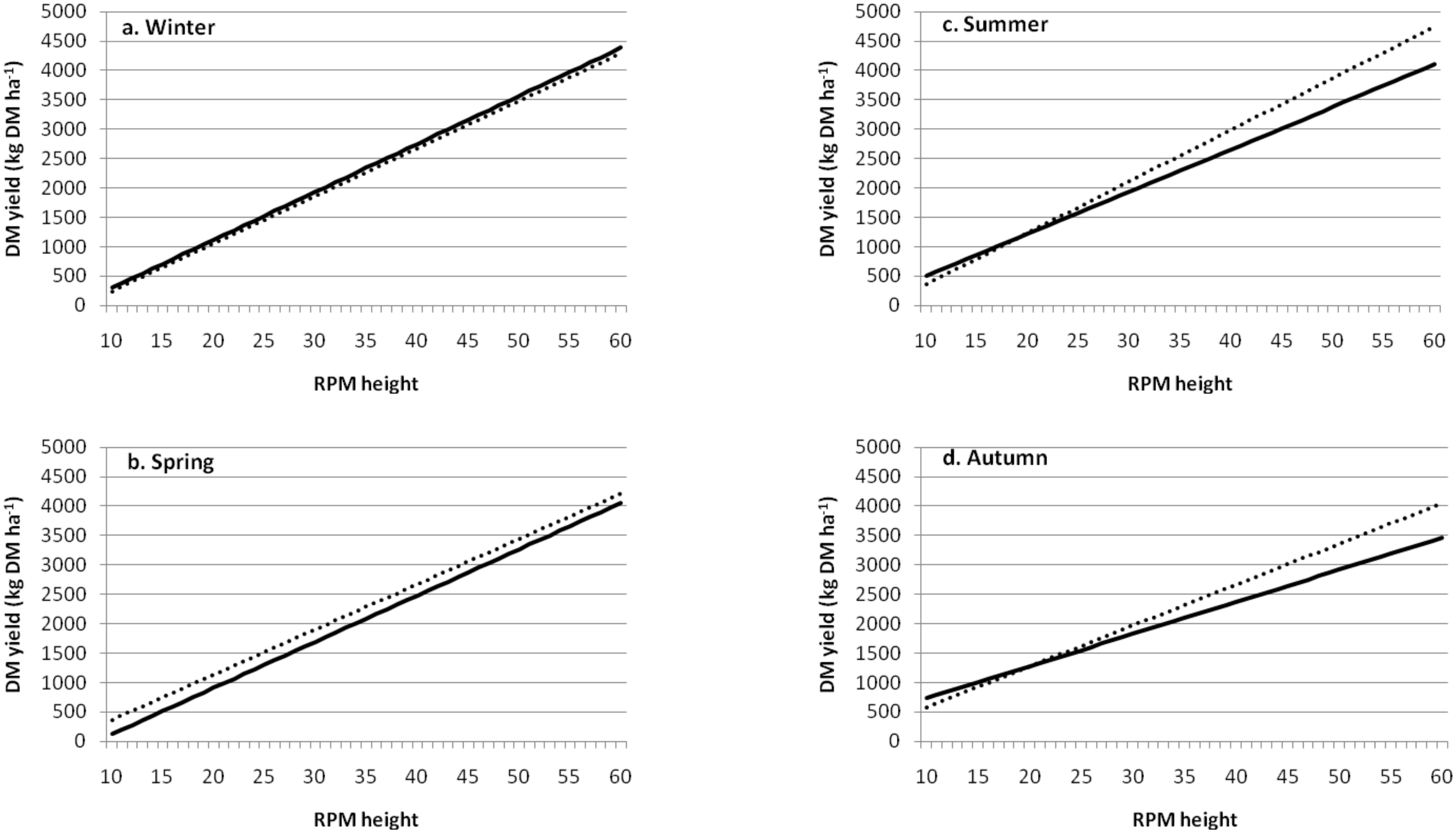

Figure 11: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal pre-grazing calibration equations for the RPM of kikuyu over-sown with perennial ryegrass (PR) during a) winter; b) spring; c) summer and d) autumn for year 1 (**-**) and year 2 (----)

The results from this study showed that the gradient (*m*) value of all treatments, except WR during year 2, decreased from winter to spring, and then increased again during summer. These results are similar to those of Michell (1982), who reported that as ryegrass becomes more erect at about ear emergence (seed set) during spring, the gradient of the regression equation decreased slightly, after which it increased again during summer. The decrease in the density of the pasture treatments during spring, when setting seed, could thus have been associated with the lower gradient (*m*) values, since the gradient (*m*) value of a regression equation is determined by the density of a sward (t'Mannetjie 2000). These results support the findings of Martin et al. (2005) that separate equations should be developed for different pasture types. Pasture structure, as it relates to for example stem:leaf ratio and growth habit, should thus also be considered when developing calibration equations for the RPM.

The R^2 value of all treatments tended to decrease from winter onwards. It has been found that the error associated with pasture yield determination is up to twice as high in pastures based on sub-tropical species compared to those based on temperate species (Fulkerson and Slack 1993). The reduction in accuracy (in terms of R^2) could thus have been due to the change in botanical composition of the pastures from primarily temperate ryegrass-based pastures during winter and spring, to primarily sub-tropical kikuyu-based pastures in summer and autumn (Van der Colf et al. 2010). Excessive stem material present in the sward has also been found to reduce accuracy of pasture yield measurement (Fulkerson and Slack 1993). Consideration should be given to the trend for mean measured height to increase from winter to summer for all pasture treatments investigated during the study. The higher mean measured RPM heights occurred during the peak growth period of kikuyu (summer) when high amounts of DM accumulated over short periods of time (Van der Colf et al. 2010). It has been shown that at very high pasture masses the error associated with pasture measurement using a RPM increases, due to the effect of lodging (Douglas and Crawford 1994). Since the accuracy of regressions has been found to increase as the number of samples taken increases upto 50 (Bransby et al. 1977), increasing the number of calibration samples taken for WR and IR during autumn to at least 50 could possibly have increased the accuracy of autumn regression equations.

3.3 Comparison of post-grazing seasonal calibrations within treatments

The mean measured RPM height, range in measured height, number of paddocks measured and number of readings taken post-grazing for kikuyu over-sown with Italian ryegrass (IR) during year 1 and year 2 is shown in Table 9. The mean measured post-grazing height of the IR treatment increased from winter to autumn during year 1 and from spring to autumn during year 2.

Table 9: The mean measured RPM height, range* in measured height, number of paddocks measured and number of readings taken post-grazing for kikuyu over-sown with Italian ryegrass (IR) during respective seasons during year 1 and year 2

Year	Season	Mean height	Range height	Paddocks	Readings
1	Winter	9.14	4-13	46	4830
	Spring	11.2	9-14	47	4830
	Summer	11.6	7-16	45	4725
	Autumn	12.2	10-15	16	1680
2	Winter	9.94	8-12	63	6615
	Spring	9.88	8-13	44	4620
	Summer	11.8	9-17	47	4935
	Autumn	13.3	11-16	14	1470

* Range of mean heights calculated from readings at each sampling

Details for the seasonal post-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with Italian ryegrass (IR) during year 1 and year 2 is shown in Table 10. During year 1 the R^2 values associated with the post-grazing regressions of IR were lowest during winter at 0.63, and highest during summer and autumn at 0.74. During year 2 the R^2 value remained at or above 0.70 during all seasons.

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with Italian ryegrass (IR), as predicted by the seasonal post-grazing calibration equations developed for the RPM during year 1, is shown in Figure 12. At a RPM height of 10 (the desired post grazing height during this study) the winter and spring regression equations predicted similar yields, while the summer and autumn regression equations also predicted similar DM yields at all RPM heights between 5 and 20. The summer and autumn regressions had similar gradient (*m*) and intercept (*b*) values (Table 10) and predicted higher DM yields than the winter and autumn regressions at a RPM height of 10, primarily because the intercept (*b*) values of these two regressions were higher than that of the winter and spring regressions during year 1 (Table 10).

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with Italian ryegrass (IR), as predicted by the seasonal post-grazing calibration equations developed for the RPM during year 2, is shown in Figure 13. At a RPM height of 10 all the seasonal post-grazing regressions developed during year 2 predicted similar DM yields. However, as the RPM height increased beyond this point, the summer and autumn regressions predicted higher DM yields than the winter and spring equations when compared at the same RPM height. This was due to the higher gradient (*m*) values of the summer and autumn regressions than the winter and spring regressions during year 2 (Table 10).

The dry matter yield (kg DM ha^{-1}), as predicted by the seasonal post-grazing calibration equations developed during year 1 and year 2 for kikuyu over-sown with Italian ryegrass (IR), compared within season is shown in Figure 14. During winter the DM yield predicted by the seasonal regressions for the IR treatment during year 1 and year 2 would have been similar at all RPM heights between 10 and 20, with the difference never exceeding 250 kg DM ha^{-1} (Figure 14a). The spring regression developed for IR during year 1 had a higher gradient (*m*) value than that of year 2 (Table 10), thus the rate of increase in DM yield with increased RPM height would have been greater during year 1. Regardless of this, the DM yield predicted by the two spring regressions would not have differed by more than 250 kg DM ha^{-1} at RPM heights between 5 and 20 (Figure 14b). During summer, the DM yields predicted by the regression equations developed during year 1 and year 2 would have been similar at a RPM height of 10. After this point the summer regression developed during year 2 would have predicted higher DM yields than that of year 1 due to the higher gradient (*m*) value of the summer regression developed during year 2 (Table 10). The difference in predicted DM yield between the two regressions did not, however, exceed 250 kg DM ha^{-1} up to a RPM height of 20 (Figure 14c). The autumn post-grazing regressions developed for the IR treatment during year 1 and year 2 differed greatly in terms of gradient (*m*) and intercept (*b*) values (Table 10). Regardless of this, both the equations predicted similar DM yields at a RPM height of 10 (Figure 14d). Since the measured post grazing height during autumn was 12.2 during year 1 and 13.3 during year 2 (Table 9), consideration should however be given to the trend where the DM yield predicted by the autumn regression during year 2 increased at a higher rate (due to a higher gradient (*m*) value) than during year 1 (Table 10).

Table 10: Details for the seasonal post-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with Italian ryegrass (IR) during year 1 and year 2

								RPM readings	
Treatment	Year	Season	n	m	b	R^2	SE_y	Range	Mean
IR	1	Winter	161	87.4	-602	0.63	442	4-34	14
		Spring	125	71.5	-468	0.66	378	4-35	15
		Summer	144	75.7	-385	0.74	349	2-38	14
		Autumn	54	74.8	-387	0.74	337	4-34	15
	2	Winter	198	74.1	-405	0.77	261	2-44	12
		Spring	126	78.4	-476	0.70	324	2-30	15
		Summer	153	92.9	-638	0.78	440	4-44	15
		Autumn	54	129.4	-884	0.74	594	4-31	15

n= number of samples, m=gradient, b=intercept, R^2=coefficient of variation, SE_Y=standard error of estimate

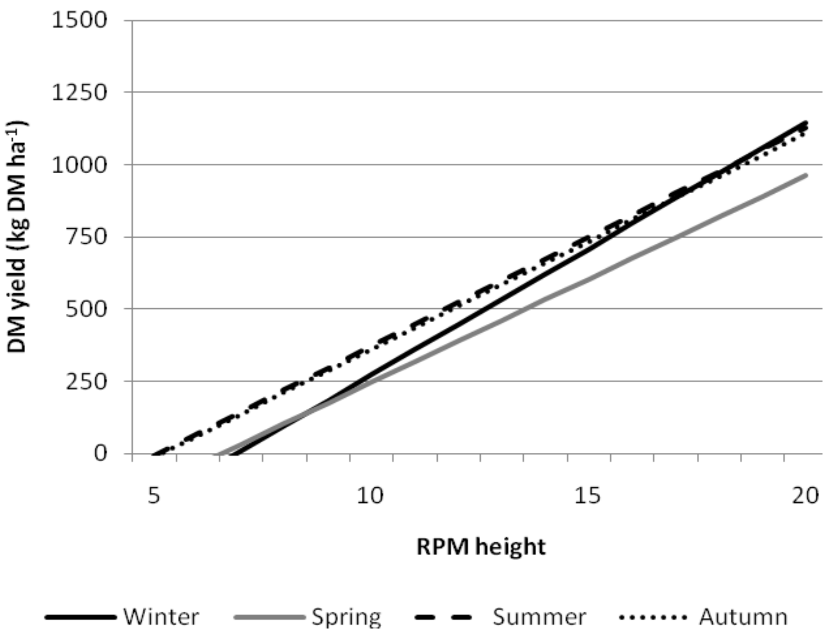

Figure 12: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal post-grazing calibration equations for the RPM of kikuyu over-sown with Italian ryegrass during year 1

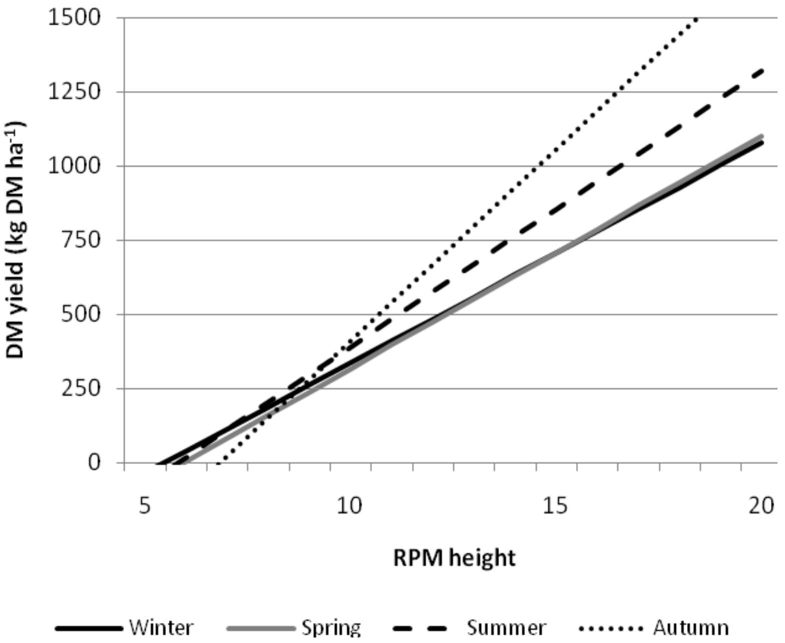

Figure 13: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal post-grazing calibration equations for the RPM of kikuyu over-sown with Italian ryegrass during year 2

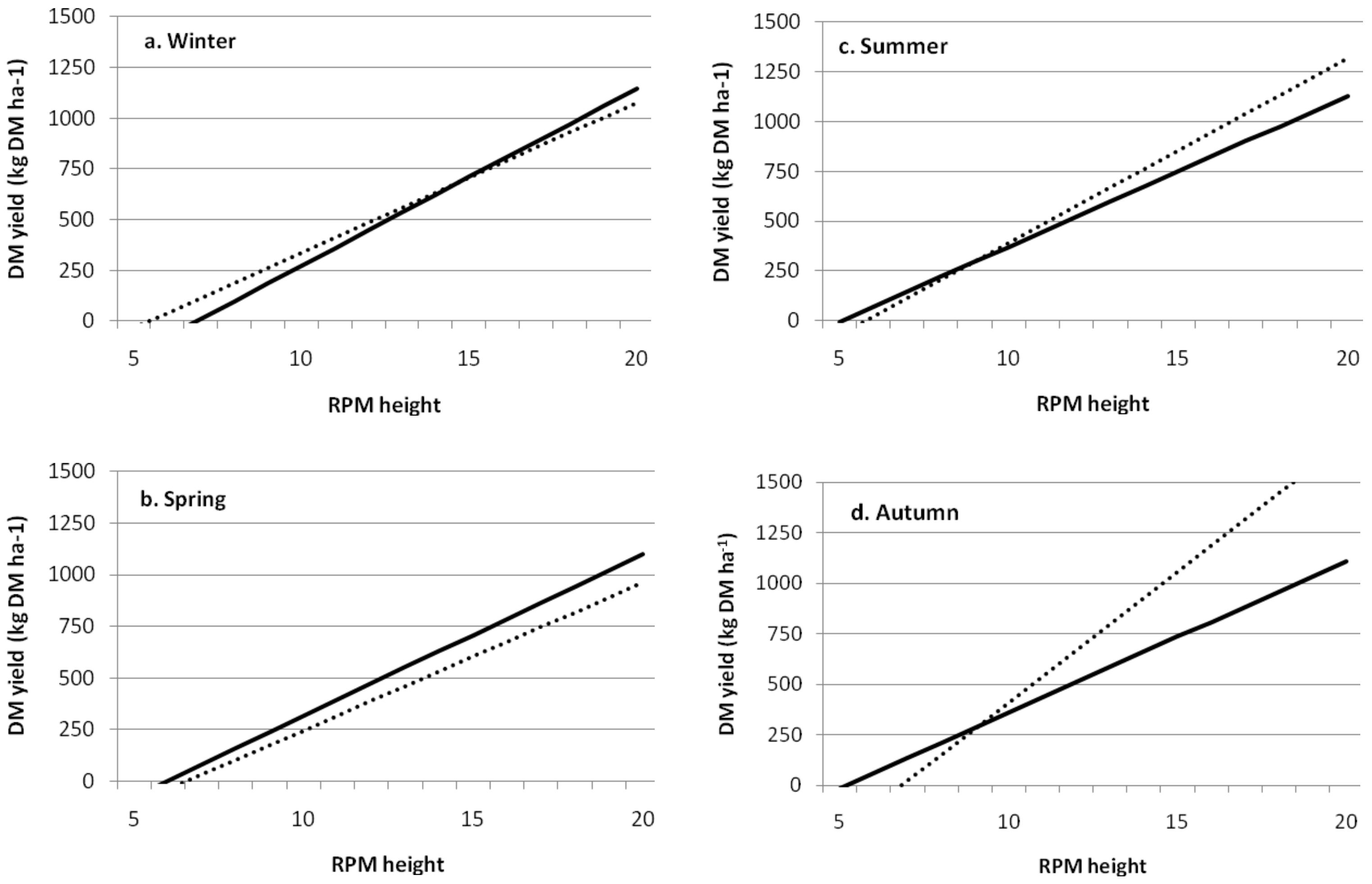

Figure 14: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal post-grazing calibration equations of kikuyu over-sown with Italian ryegrass for the RPM during a) winter; b) spring; c) summer and d) autumn for year 1 (−) and year 2 (----)

The mean measured RPM height, range in measured height, number of paddocks measured and number of readings taken post grazing for kikuyu over-sown with Westerwolds ryegrass (WR) during year 1 and year 2 is shown in Table 11. During year 1 the mean measured post-grazing RPM height increased from its lowest value of 9.35 during winter to its highest value of 13.2 during summer. During year 2 the lowest mean post-grazing height again occurred during winter, with the height increasing to its highest value of 14.3 during autumn.

Table 11: The mean measured RPM height, range* in measured height, number of paddocks measured and number of readings taken post-grazing for kikuyu over-sown with Westerwolds ryegrass (WR) during respective seasons during year 1 and year 2

Year	Season	Mean height	Range height	Paddocks	Readings
1	Winter	9.35	4-13	46	4830
	Spring	11.3	8-14	47	4830
	Summer	13.2	9-21	45	4725
	Autumn	12.0	10-15	16	1680
2	Winter	9.87	8-14	63	6615
	Spring	10.3	8-20	44	4620
	Summer	13.5	10-20	47	4935
	Autumn	14.3	12-17	14	1470

* Range of mean heights calculated from readings at each sampling

Details for the seasonal post-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with Westerwolds ryegrass (WR) during year 1 and year 2 is shown in Table 12.

During year 1 the R^2 value for seasonal post-grazing regression of WR was lowest at 0.63 during winter, but remained above 0.70 during spring, summer and autumn. During year 2 the R^2 value remained at or above 0.70 from spring to autumn and was lowest during winter at 0.64.

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with Westerwolds ryegrass (WR), as predicted by the seasonal post-grazing calibration equations developed for the RPM during year 1, is shown in Figure 15. The similar gradient (*m*) and intercept (*b*) values of the winter and spring regressions (Table 12) resulted in these two equations predicting similar DM yields at all RPM heights between 5 and 20 during year 1. The higher gradient values (*m*) of the summer and autumn regressions than the winter and spring regressions (Table 12) resulted in higher predicted DM yields by the former when compared at the same RPM height.

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with Westerwolds ryegrass (WR), as predicted by the seasonal post-grazing calibration equations developed for the RPM during year 2, is shown in Figure 16. During year 2 the DM yield predicted by the seasonal post-grazing regressions was similar at a RPM height of 10. Beyond this point, the summer and autumn regressions predicted higher DM yields than the winter and spring regressions. This was due to the higher gradient (*m*) values of the summer and autumn regressions than the winter and spring regressions during year 2 (Table 12).

Table 12: Details for the seasonal post-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with Westerwolds ryegrass (WR) during year 1 and year 2

								RPM readings	
Treatment	Year	Season	*n	m	b	R^2	SE_y	Range	Mean
WR	1	Winter	160	80.3	-573	0.63	376	3-37	13
		Spring	123	83.2	-578	0.73	415	3-41	16
		Summer	144	101.0	-599	0.70	581	2-57	16
		Autumn	54	116.2	-785	0.73	511	3-35	15
	2	Winter	198	73.5	-432	0.64	357	3-34	13
		Spring	126	74.3	-385	0.76	307	2-30	14
		Summer	153	99.3	-652	0.70	585	3-46	17
		Autumn	54	115.8	-840	0.74	646	5-36	18

n= number of samples, m=gradient, b=intercept, R^2=coefficient of variation, SE_Y=standard error of estimate

The dry matter yield (kg DM ha^{-1}), as predicted by the seasonal post-grazing calibration equations developed during year 1 and year 2 for kikuyu over-sown with Westerwolds ryegrass (WR), compared within season, is shown Figure 17. The difference in the DM yield predicted by the post-grazing winter regression equations developed for WR during year 1 and 2 was below 250 kg DM ha^{-1} at all RPM heights, with the difference decreasing as the RPM height increased from 5 to 20 (Figure 17a). The spring post-grazing regression developed during year 2 for WR would have predicted higher DM yields than the spring regression developed during year 2, especially at low RPM heights (Figure 17b). This was because the spring regression during year 2 had a higher intercept (*b*) value than the regression developed during year 1 (Table 12). During both summer and autumn the regression equations developed during year 1 would have predicted higher DM yields than the regressions developed during year 2, although differences would have been lower than 250 kg DM ha^{-1} (Figure 17c and 17d). This was because both the summer and autumn regressions had intercept values (*b*) that were higher during year 1 than during year 2, while gradient values (*m*) were similar (Table 12).

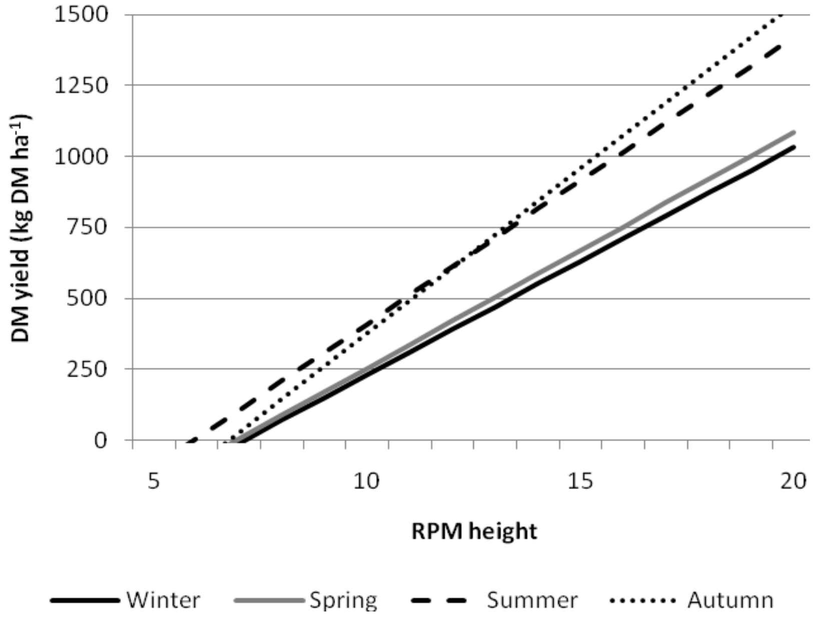

Figure 15: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal post-grazing calibration equations for the RPM of kikuyu over-sown with Westerwolds ryegrass (WR) during year 1

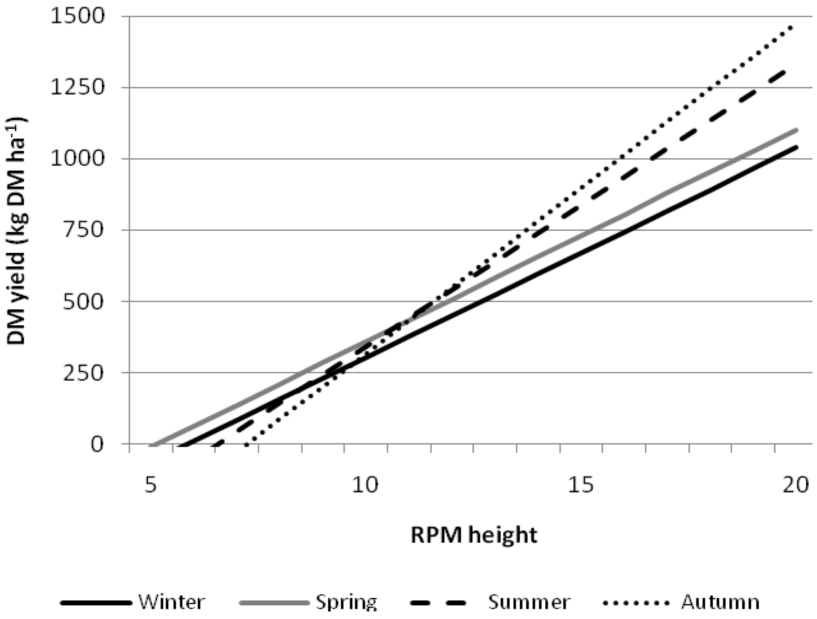

Figure 16: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal post-grazing calibration equations for the RPM of kikuyu over-sown with Westerwolds ryegrass (WR) during year 2

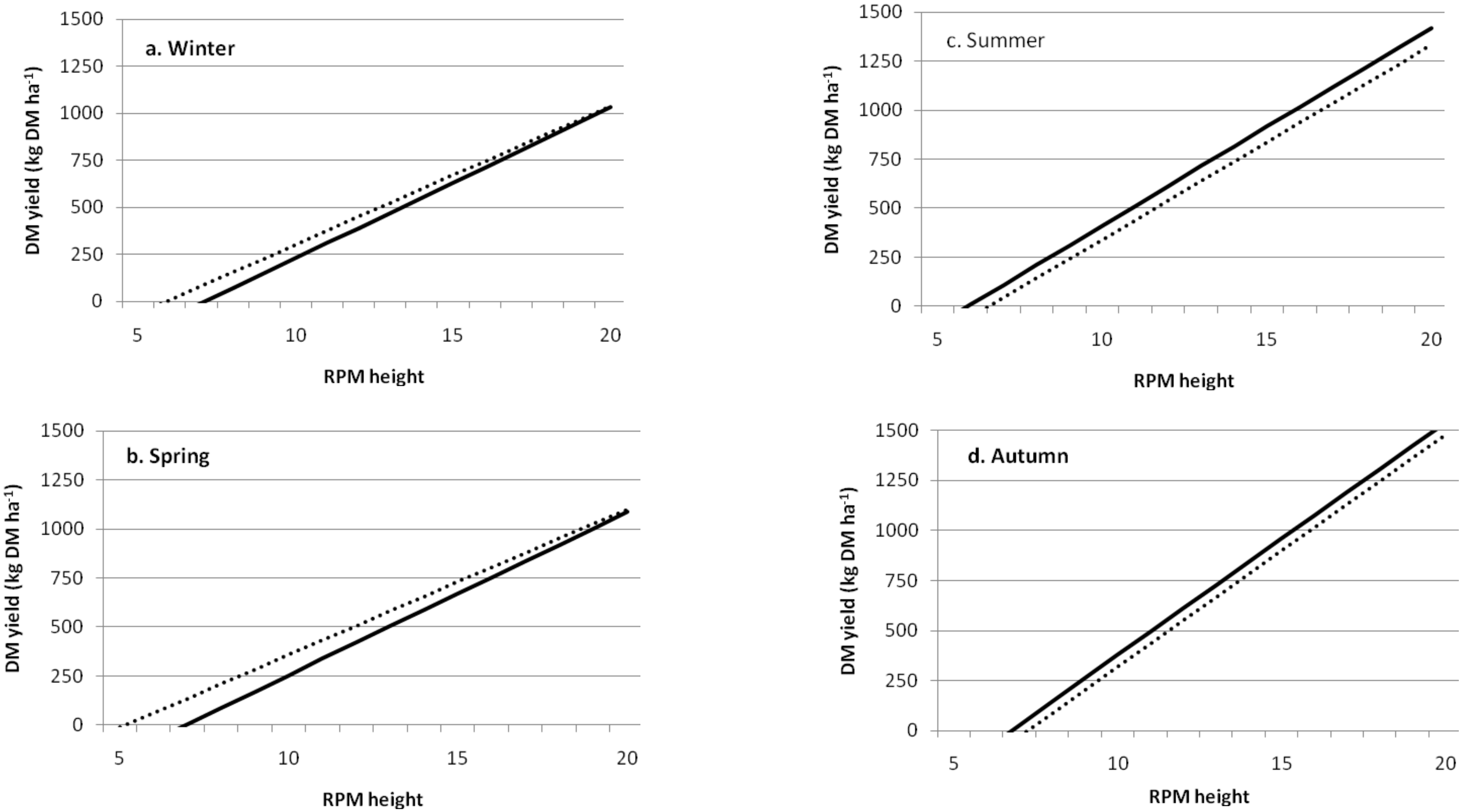

Figure 17: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal post-grazing calibration equations for the RPM during a) winter; b) spring; c) summer and d) autumn for year 1 (**-**) and year 2 (----) for kikuyu over-sown with Westerwolds ryegrass (WR)

The mean measured RPM height, range in measured height, number of paddocks measured and number of readings taken post-grazing for kikuyu over-sown with perennial ryegrass (PR) is shown in Table 13. The lowest mean post-grazing heights during year 1 and year 2 occurred during winter. The highest mean post-grazing height within years occurred during spring in year 1 and during summer in year 2.

Table 13: The mean measured RPM height, range* in measured height, number of paddocks measured and number of readings taken post-grazing for kikuyu over-sown with perennial ryegrass (PR) during respective seasons during year 1 and year 2

Year	Season	Mean height	Range height	Paddocks	Readings
1	Winter	10.4	9-12	25	2625
	Spring	12.2	10-14	47	4830
	Summer	11.4	8-15	45	4725
	Autumn	10.6	8-14	34	3570
2	Winter	10.6	8-16	47	4935
	Spring	11.0	8-16	44	4620
	Summer	11.7	10-16	47	4935
	Autumn	10.9	8-15	30	3150

* Range of mean heights calculated from readings at each sampling

Details for the seasonal post-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with perennial ryegrass (PR) during year 1 and year 2 are shown in Table 14. During year 1 the R^2 value of the post-grazing seasonal regressions developed for PR remained at or above 0.70 during winter, spring and autumn, but decreased to 0.66 during summer. During year 2 the R^2 value was highest during winter and spring at 0.69 and lowest during summer at 0.46.

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with perennial ryegrass (PR), as predicted by the seasonal post-grazing calibration equations developed for the RPM during year 1, is shown in Figure 18. The DM yields predicted by the winter and spring post-grazing regressions developed for the PR treatment during year 1 would have been similar at all RPM heights between 5 and 20, with differences in DM yield never exceeding 250 kg DM ha^{-1}. The summer regression had the highest gradient (*m*) value during year 1 (Table 14), and as result, the DM yield predicted by the summer regression would have increased at a greater rate with an increase in RPM height than during the other seasons.

The dry matter yield (kg DM ha^{-1}) of kikuyu over-sown with perennial ryegrass (PR), as predicted by the seasonal post-grazing calibration equations developed for the RPM during year 2, is shown in

Figure 19. The various seasonal post-grazing regressions developed for the PR treatment during year 2 differed in terms of gradient (*m*) and intercept (*b*) values (Table 14). However, at a RPM height of 10, the differences in predicted DM yields would have been small between the winter and spring regressions as well as between the summer and autumn regressions. At a RPM height below 10, the high intercept (*b)* value of the summer regression (Table 14) would have resulted in it predicting higher DM yields than, especially, the winter and spring regressions. The low gradient (*m*) value of the summer regression would, however, have resulted in this effect declining as the RPM height increased beyond 10.

Table 14: Details for the seasonal post-grazing regressions (Y = mH + b), relating herbage mass Y (kg DM ha^{-1}) and meter reading (H), developed for kikuyu over-sown with perennial ryegrass (PR) during year 1 and year 2

								RPM readings	
Treatment	Year	Season	n	m	b	R^2	SE_y	Range	Mean
PR	1	Winter	71	86.0	-616	0.70	291	5-27	13
		Spring	143	99.8	-800	0.72	470	5-34	16
		Summer	124	118.4	-634	0.66	614	1-31	14
		Autumn	124	95.4	-517	0.71	437	1-31	14
	2	Winter	125	63.9	-292	0.69	318	4-42	14
		Spring	126	82.9	-435	0.69	407	3-47	14
		Summer	153	65.8	-162	0.46	599	3-68	15
		Autumn	89	98.6	-423	0.56	474	3-29	13

n= number of samples, m=gradient, b=intercept, R^2=coefficient of variation, SE_Y=standard error of estimate

The dry matter yield (kg DM ha^{-1}), as predicted by the seasonal post-grazing calibration equations developed during year 1 and year 2 for kikuyu over-sown with perennial ryegrass (PR), compared within season, is shown Figure 20. Up to a RPM height of 10, the winter post-grazing regression developed during year 2 would have predicted higher DM yields than the winter regression developed during year 1 (Figure 20a). This can be attributed to the higher intercept (*b*) value of the winter regression during year 2 (Table 14). A similar trend occurred during spring, with the higher intercept (*b*) value for the regression equation during year 2 (Table 14) resulting in higher DM yields predicted by this equation than that of year 1, especially at low heights (Figure 20b). During summer the post-grazing regressions developed for PR during year 1 and year 2 would have predicted similar yields at a RPM height of 10 (Figure 20b). However, because of the higher gradient (*m*) value of the summer regression developed during year 1 (Table 14), the DM yield predicted by this regression would have been higher than that of year 2 at RPM heights above 10 (Figure 20c). Although the autumn post-grazing regressions for PR had similar gradient (*m*) values, the slightly higher intercept (*b*) value of the regression developed during year 2 (Table 14) would have predicted higher DM yields than the regression developed during year 1 at all RPM heights between 5 and 20 (Figure 20d).

In contrast to the findings of Stockdale (1984), the post-grazing regressions developed for the various sward types during this study did not have a lower precision than pre-grazing regressions, maintaining R^2 values above 0.60 in all but two instances (PR treatment during autumn and summer in year 2). These findings are in agreement with those of Reeves et al. (1996), who achieved the same accuracy for pre-and post grazing regressions developed for kikuyu. Martin et al. (2005) found that inaccurate post grazing estimates could be attributed to ungrazed stalks, in for example naturalized, un-mowed pastures, which could cause the pasture meter to tip. Thus, a possible reason for the high R^2 values obtained during this study could have been the low post-grazing heights achieved for all treatments during the entire experimental period.

Relatively little data and information could be found in the literature on the influence that season and sward type has on post-grazing regressions for the RPM. It would stand to reason that pastures exposed to heavy grazing pressures and that are grazed to low heights (as is the case here), would be relatively homogenous across seasons in terms of post-grazing height. Consideration should, however, be given to the effect that the transition of the pastures from a tufted temperate pasture specie (ryegrass) to a creeping sub-tropical species (kikuyu) (Van der Colf et al. 2010) could have had on the seasonal variation of regressions. The trend whereby the gradient (*m*) value of the IR and WR treatments increased from winter and spring to summer and autumn could have been an indication of the accumulation of material in the form of a stolonferous mat during the growth period of kikuyu.

The greater variation and lower accuracy found for the PR treatment over seasons and years, compared to the IR and WR treatments, could have been the result of the inherent morphology of the perennial ryegrass plant. The canopy that results when perennial ryegrass undergoes rapid growth, can cause the crown of the plant to become elevated (Beddows 1967). It is thus hypothesised that at certain stages during the year, especially if there are older ryegrass plants in a sward, the operators cutting calibration samples may cut into the dense perennial ryegrass tuft, removing high amounts of plant material that is high in stem tissue. This could in turn negatively impact on the accuracy of the regression. This will, however, require further investigation.

Results indicate that with post-grazing regressions developed on heavily grazed dairy pastures, the intercept value (*b*), rather than gradient (*m*) value, determined the difference in DM yield predicted by different regression equations. This was primarily because the mean measured RPM heights were low (9.1 to 14.3) in post grazing swards (Table 9, 11 and 13). Thus the post-grazing height achieved on a specific farm or during a research project will determine the regression equation that should be used.

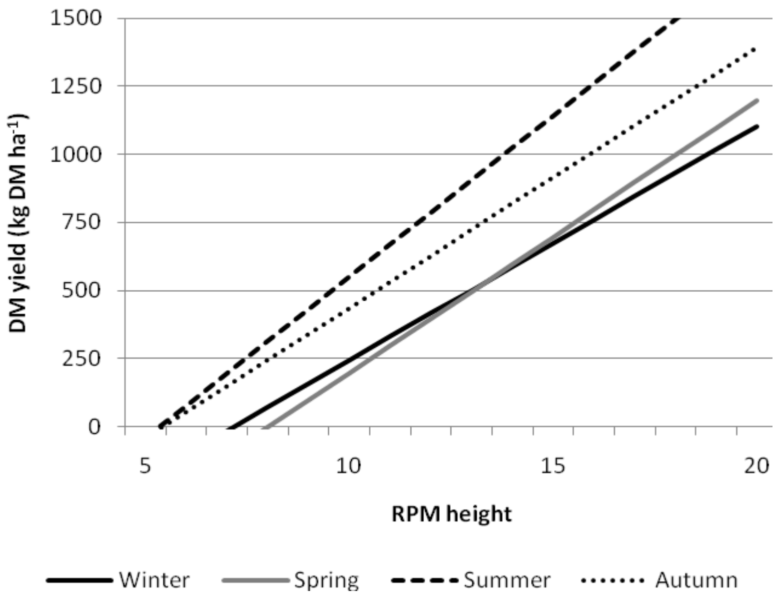

Figure 18: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal post-grazing calibration equations for the RPM of kikuyu over-sown with perennial ryegrass (PR) during year 1

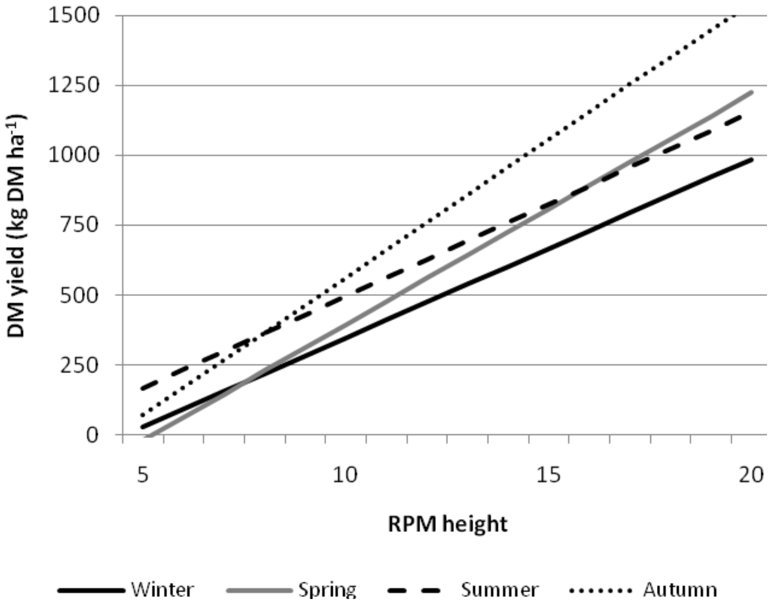

Figure 19: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal post-grazing calibration equations for the RPM of kikuyu over-sown with perennial ryegrass (PR) during year 2

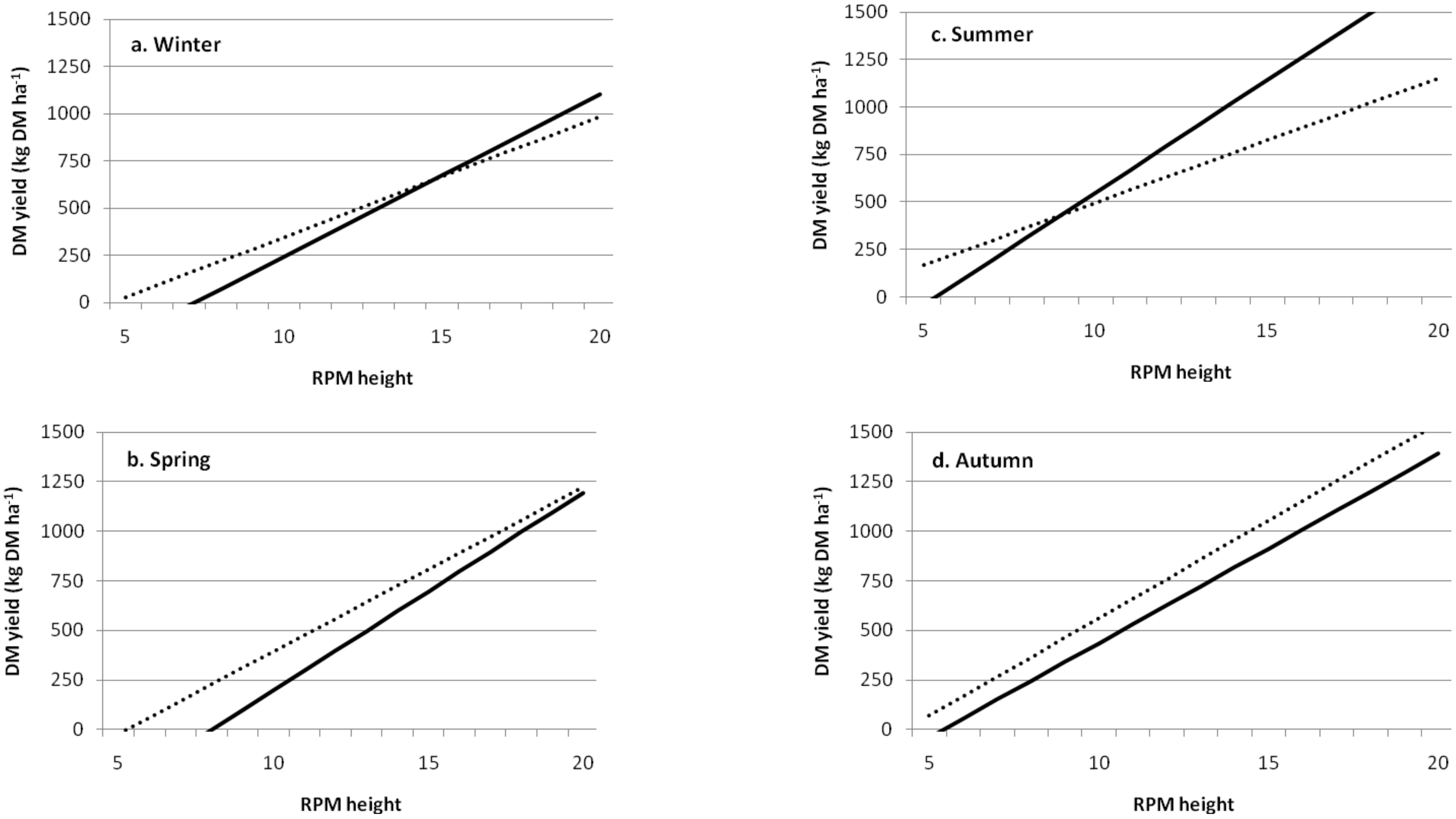

Figure 20: The dry matter yield (kg DM ha^{-1}) as predicted by the seasonal post-grazing calibration equations for the RPM during a) winter; b) spring; c) summer and d) autumn for year 1 (**-**) and year 2 (----) for kikuyu over-sown with perennial ryegrass (PR)

3.4 Testing the linearity of the regression relationship

In order to test whether a curvilinear model would be more appropriate to describe the relationship between RPM height and DM yield, the data from the seasonal pre- and post-grazing regressions were re-analysed by a multiple regression according to the model:

$$Y = aH + bH^2 + c$$

Where a = constant 1; b = constant 2; c = interept and H = mean RPM height

The second degree polynomial equations for seasonal pre-grazing data during year 1 and year 2 and the R^2 value for the polynomial regression and the linear regression is shown in Table 15. A polynomial regression improved the R^2 value in 54% (13 out of the 24) of the pre-grazing regressions investigated, indicating that under certain circumstances a curvilinear relationship could more accurately describe the relationship between RPM height and DM yield. This may be particularly relevant for kikuyu-ryegrass based pastures during autumn, since a polynomial equation improved the R^2 value of autumn regressions for all three treatments during both years. The most likely reason for this trend was the high amount of dry material that accumulates in kikuyu pastures in the form a “mat” during this season, which would result in high DM yields at low RPM heights, but not necessarily at high RPM heights.

The second degree polynomial equations for seasonal post-grazing data during year 1 and year 2 and the R^2 value for the polynomial regression and the linear regression is shown in Table 16. A polynomial regression improved the R^2 value in 46% (11 out of the 24) of the post-grazing regressions investigated, although differences were relatively small in most instances. It should be noted that it also resulted in a decrease in the R^2 value of the winter post-grazing regression for the PR treatment during year 2. It is thus unlikely that the relationship between post grazing RPM height and yield is curvilinear.

The practical importance of these findings is, however, not clear, since Michell (1982) concluded that the inclusion of a quadratic term was only warranted where dealing with swards of widely varying yields, while Bransby et al. (1977) found no significant improvement when curvilinearity was investigated relative to linear regressions. In addition, it has been stated that a linear regression equation between an indirect pasture measurement (such as RPM height) and DM yield would be more useful to farmers than a quadratic equation for predicting DM yield. The primary reason for this is that with a linear relationship the change in the predicted DM yield per unit change in the measurement is the same for low, as well as high, values of measurement (Martin et al. 2005). If the relationship is, however, curvilinear, pasture yield would increase rapidly with an increase in pasture height initially, but the rate of increase would decline as pasture height increased beyond a certain point.

Table 15: The second degree polynomial equations for seasonal pre-grazing data during year 1 and year 2 and the R^2 value obtained for the linear regression obtained using the same data

			Polynomial		Linear
Treatment	Year	Season	Equation	R^2	R^2
IR	1	Winter*	$y = 0.41x^2 + 65.3x - 404$	0.90	0.89
		Spring	$y = 0.02x^2 + 62.1x - 457$	0.73	0.73
		Summer*	$y = -0.26x^2 + 86.5x - 645$	0.66	0.65
		Autumn*	$y = 0.49x^2 + 28.8x + 297$	0.69	0.68
	2	Winter	$y = -0.07x^2 + 69.1x - 385$	0.81	0.81
		Spring	$y = -0.32x^2 + 74.2x - 393$	0.71	0.71
		Summer*	$y = -0.48x^2 + 102x - 619$	0.62	0.61
		Autumn*	$y = -1.35x^2 + 149x - 1230$	0.73	0.66
WR	1	Winter*	$y = 1.06x^2 + 29.7x - 111$	0.87	0.84
		Spring	$y = -0.08x^2 + 70.3x - 534$	0.68	0.68
		Summer*	$y = -0.56x^2 + 122x - 1254$	0.58	0.57
		Autumn*	$y = -0.95x^2 + 151x - 1884$	0.71	0.69
	2	Winter*	$y = -0.42x^2 + 80.7x - 428$	0.75	0.74
		Spring	$y = 0.08x^2 + 54.6x - 77.1$	0.74	0.74
		Summer	$y = -0.03x^2 + 77.5x - 308$	0.75	0.75
		Autumn*	$y = -1.46x^2 + 158x - 1033$	0.60	0.44
PR	1	Winter**	$y = -0.73x^2 + 117x - 873$	0.73	0.76
		Spring	$y = -0.27x^2 + 99.9x - 1029$	0.76	0.76
		Summer*	$y = -1.33x^2 + 174x - 1925$	0.51	0.46
		Autumn*	$y = -0.76x^2 + 105x - 494$	0.37	0.36
	2	Winter	$y = -0.01x^2 + 81.6x - 571$	0.79	0.79
		Spring	$y = -0.01x^2 + 77.2x - 406$	0.64	0.64
		Summer	$y = 0.15x^2 + 78.9x - 402$	0.71	0.71
		Autumn*	$y = -0.43x^2 + 97.5x - 479$	0.72	0.71

*Instances where a polynomial transformation achieved a higher R^2 value than a linear transformation

**Instances where a linear transformation achieved a higher R^2 value than a polynomial transformation

Table 16: The second degree polynomial equations for seasonal post-grazing data during year 1 and year 2 and the R^2 value obtained for the linear regression obtained using the same data

			Polynomial		Linear
Treatment	Year	Season	Equation	R^2	R^2
IR	1	Winter	$y = -0.003x^2 + 87.5x - 603$	0.63	0.63
		Spring *	$y = 0.86x^2 + 42.8x - 277$	0.67	0.66
		Summer	$y = 0.20x^2 + 68.9x - 341$	0.74	0.74
		Autumn	$y = -0.17x^2 + 80.6x - 426$	0.74	0.74
	2	Winter	$y = 0.78x^2 + 51.8x - 281$	0.77	0.77
		Spring *	$y = 1.29x^2 + 43.0x - 285$	0.71	0.70
		Summer	$y = 0.63x^2 + 67.7x - 446$	0.78	0.78
		Autumn	$y = 1.12x^2 + 93.0x - 654$	0.74	0.74
WR	1	Winter*	$y = 1.41x^2 + 40.5x - 324$	0.66	0.63
		Spring	$y = 1.15x^2 + 40.1x - 281$	0.73	0.73
		Summer*	$y = -0.95x^2 + 140x - 904$	0.72	0.70
		Autumn*	$y = 1.91x^2 + 53.5x - 370$	0.75	0.73
	2	Winter	$y = 0.39x^2 + 62.2x - 367$	0.64	0.64
		Spring	$y = 0.06x^2 + 72.5x - 374$	0.76	0.76
		Summer*	$y = -0.49x^2 + 119x – 807$	0.71	0.70
		Autumn	$y = 0.13x^2 + 111x - 802$	0.74	0.74
PR	1	Winter**	$y = -2.74x^2 + 160x - 1056$	0.64	0.70
		Spring *	$y = 1.02x^2 + 60.4x - 483$	0.73	0.72
		Summer	$y = 0.43x^2 + 105x - 559$	0.66	0.66
		Autumn*	$y = 1.49x^2 + 48.3x - 242$	0.72	0.71
	2	Winter*	$y = -1.47x^2 + 116x - 653$	0.73	0.69
		Spring *	$y = -1.36x^2 + 131x - 756$	0.72	0.69
		Summer*	$y = 1.43x^2 + 51.2x - 288$	0.72	0.46
		Autumn	$y = 1.13x^2 + 68.9x - 269$	0.56	0.56

*Instances where a polynomial transformation achieved a higher R^2 value than a linear transformation

**Instances where a linear transformation achieved a higher R^2 value than a polynomial transformation

3.5 *Combining data to obtain generalised regressions*

The calibration equations employed by dairy farmers in the Western Cape Province of South Africa are often based on data and research from other countries. The development of region specific calibration equations for the RPM has been advocated in the literature (Sanderson et al. 2001). Additionally, the use of regressions for either ryegrass or kikuyu throughout the year would most likely not be adequate due to the difference in growth and morphology of these two species, while thes the finding during this study that regression equations show variation within these specific pasture systems over different seasons should also be considered. In an attempt to develop generalized regressions for kikuyu over-sown with ryegrass, that could be utilized as a practical tool by farmers in the Western Cape Province of South Africa, data obtained during this two year study on kikuyu based pasture systems was combined in the following manner:

- All data collected for a specific season (e.g. winter) and treatment (e.g. IR) over the two year period was pooled to develop a "generalised seasonal regression" for each pasture type, namely kikuyu over-sown with Italian ryegrass (IR), Westerwolds ryegrass (WR) and perennial ryegrass (PR).
- All data collected for a specific treatment during the 2 year period was pooled to develop a "generalised annual regression" for each treatment (IR, WR and PR).
- The data collected for the two systems based on annual ryegrass species, namely IR and WR, were pooled to develop generalised regressions for kikuyu over-sown with annual ryegrass (AR).
- The data collected for the IR, WR and PR treatments were pooled to develop generalised regressions for kikuyu-ryegrass pastures (KR).

Details for the generalised pre-grazing seasonal regressions developed for kikuyu over-sown with Italian ryegrass (IR), Westerwolds ryegrass (WR), perennial ryegrass (PR), annual ryegrass (AR) and ryegrass (KR) are shown in Table 17. The R^2 value of generalized seasonal pre-grazing regressions for the IR, WR, PR and AR treatments were above or equal to 0.70 during winter and spring, but decreased to below 0.70 during summer and autumn. All the R^2 values for generalized pre-grazing regressions were above 0.50, with the exception of the PR treatment's autumn regression, which had a R^2 value of 0.49.

There were seasonal differences in terms of gradient (*m*) and intercept (*b*) values for all the pasture treatments. For the IR, WR, AR and KR treatments the gradient (*m*) value decreased from winter to spring, increased from spring to summer, then decreased again from summer to autumn. For the PR treatment the gradient (*m*) value of the generalised pre-grazing regressions decreased from winter to autumn. The intercept (*b*) value of the generalised pre-grazing seasonal regressions decreased from winter to autumn for IR, WR, PR, AR and KR.

Although the annual generalised regressions of IR, WR, PR and AR had R^2 values above 0.70, the seasonal differences observed for regression equations during this study should be kept in mind. Invariably, a generalised regression consisting of large pooled data sets will underestimate DM yield during certain periods in the growing season and overestimate it during others. Combining the data from the PR and AR treatments did not alter the generalised seasonal or annual pre-grazing regressions to a great extent in terms of gradient (*m*) or intercept (*b*) values. The data set used to construct the pre-grazing generalised annual regression for the KR treatment, is illustrated in Figure 21. This figure illustrates that, regardless of the relatively high R^2 value of 0.69 obtained from the regression created by pooling this large data set, there was a wide variation in DM yields recorded at specific RPM heights.

Table 17: Details for generalised pre-grazing seasonal regressions developed for kikuyu over-sown with Italian ryegrass (IR), Westerwolds ryegrass (WR), perennial ryegrass (PR), annual ryegrass (AR) and ryegrass (KR)

Treatment	Season	n	m	b	SE_y	R^2
IR	Winter	396	77.1	-530	413	0.83
	Spring	286	57.2	-252	548	0.71
	Summer	306	66.5	-180	671	0.62
	Autumn	54	59.4	-60	524	0.66
	Annual	1042	64.9	-281	570	0.71
WR	Winter	394	75.3	-520	582	0.74
	Spring	287	61.9	-291	592	0.70
	Summer	305	73.1	-249	827	0.66
	Autumn	54	57.4	+218	706	0.56
	All data	1040	72.2	-419	694	0.72
PR	Winter	251	81.1	-544	410	0.76
	Spring	288	76.3	-484	583	0.71
	Summer	306	76.8	-287	834	0.56
	Autumn	162	60.8	+56	851	0.49
	All data	1007	74.8	-350	691	0.64
AR	Winter	790	76.0	-521	504	0.78
	Spring	573	59.2	-263	574	0.70
	Summer	611	71.5	-266	757	0.65
	Autumn	108	59.2	+48	625	0.61
	Annual	2082	69.1	-364	638	0.72
KR	Winter	1041	76.5	-510	485	0.77
	Spring	861	62.9	-277	603	0.68
	Summer	917	72.2	-242	786	0.62
	Autumn	270	59.4	+72	766	0.55
	Annual	3089	70.1	-338	662	0.69

n= number of samples, m=gradient, b=intercept, R^2=coefficient of variation, SE_Y=standard error of estimate

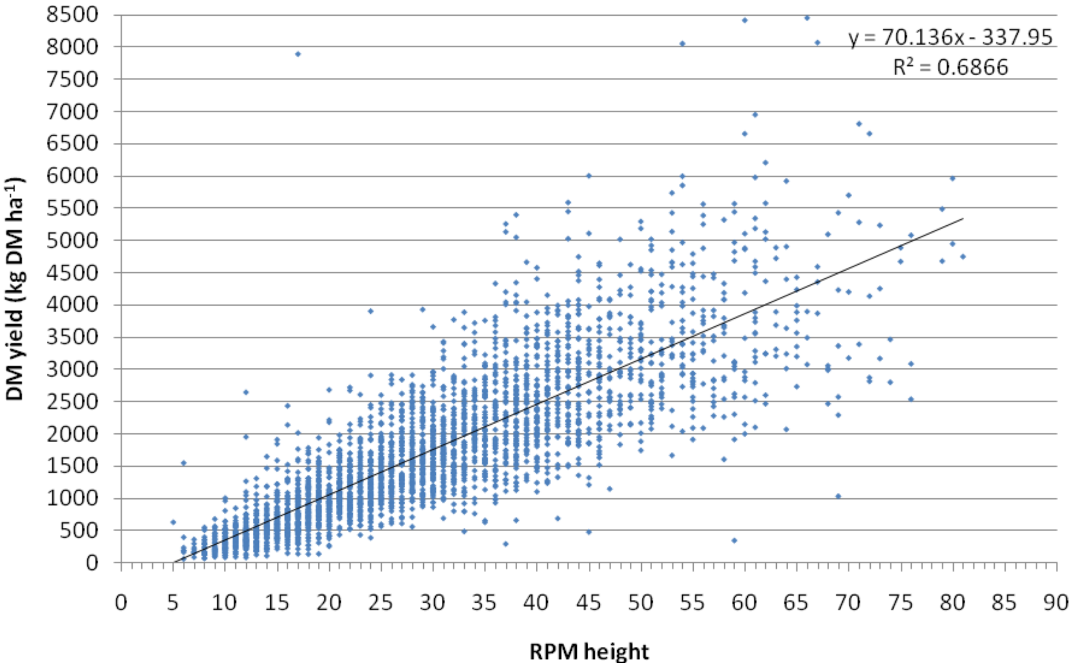

Figure 21: The data set used to construct the generalised annual pre-grazing regression for the kikuyu-ryegrass (KR) treatment

Details for the generalised post-grazing seasonal regressions developed for kikuyu over-sown with Italian ryegrass (IR), Westerwolds ryegrass (WR), perennial ryegrass (PR) and annual ryegrass (AR) is shown in Table 18.

The generalised seasonal and annual post-grazing regressions developed for IR, WR, PR, AR and KR all had a R^2 value above 0.60. In contrast to pre-grazing seasonal regressions, where the intercept value increased from winter to autumn, the intercept value of the generalised post-grazing regressions of IR, WR, AR and KR tended to decrease from winter to autumn. The intercept value of the PR treatment was the exception, with its intercept value increasing slightly from spring to autumn. As with the pre-grazing regressions the pooling of data over seasons, the generalised annual post-grazing regression would have resulted in the regression under-predicting DM yield during certain periods of the growing season and over-predicting DM yield during others. The dataset used to construct the annual post-grazing regression is shown in Figure 22. This figure indicates a similar trend to that shown with the pre-grazing regression, in that although the R^2 value was acceptable (0.67), there was large variation in the DM yield recorded at a specific RPM height.

Table 18: Details for generalised post-grazing seasonal regressions developed for kikuyu over-sown with Italian ryegrass (IR), Westerwolds ryegrass (WR), perennial ryegrass (PR), annual ryegrass (AR) or ryegrass (KR)

Treatment	Season	n	m	b	SE_y	R^2
IR	Winter	359	80.0	-487	356	0.68
	Spring	251	73.3	-453	354	0.67
	Summer	297	85.8	-528	403	0.76
	Autumn	108	103.5	-646	545	0.67
	All data	1015	84.0	-523	403	0.70
WR	Winter	340	78.2	-507	369	0.63
	Spring	267	77.1	-466	364	0.73
	Summer	297	99.8	-621	582	0.70
	Autumn	108	115.3	-801	578	0.74
	All data	1012	93.6	-623	487	0.70
PR	Winter	178	66.78	-343	316	0.67
	Spring	287	90.9	-607	438	0.70
	Summer	277	104.7	-578	543	0.66
	Autumn	197	96.0	-463	506	0.64
	All data	939	91.3	-516	491	0.64
AR	Winter	699	79.1	-497	362	0.66
	Spring	518	75.6	-464	359	0.71
	Summer	594	94.0	-588	508	0.72
	Autumn	216	110	-732	561	0.71
	All data	2027	89.3	-578	449	0.70
KR	Winter	877	76.4	-464	355	0.66
	Spring	805	81.3	-517	394	0.70
	Summer	871	95.6	-562	525	0.70
	Autumn	413	103.7	-597	538	0.69
	All data	2966	89.8	-556	464	0.68

n= number of samples, m=gradient, b=intercept, R^2=coefficient of variation, SE_Y=standard error of estimate

Pooling calibration data for a range of swards over a time period that produces a high precision regression, would allow operators to utilise a standard calibration equation over a large range of situations (Michell 1982). Pooled regressions have, however, been found to show large co-efficients of variation, regardless of acceptable R^2 values, due to the large deviation of certain points from the curve as result of variation in DM content and pasture composition during the year (Stockdale 1984). The findings during these study thus agree with those of Stockdale (1984) that year round pooled regressions are unsuitable for research purposes, but that such regressions could be of value to farmers and their advisors. Sward uniformity has been identified as a possible reason for the high precision of pooled regressions used for perennial ryegrass-white clover pastures (Fulkerson and Slack 1993). It is thus concluded that the generalised regression equations presented here could be valuable to farmers and extension officers in the immediate area, but holds little value for research purposes.

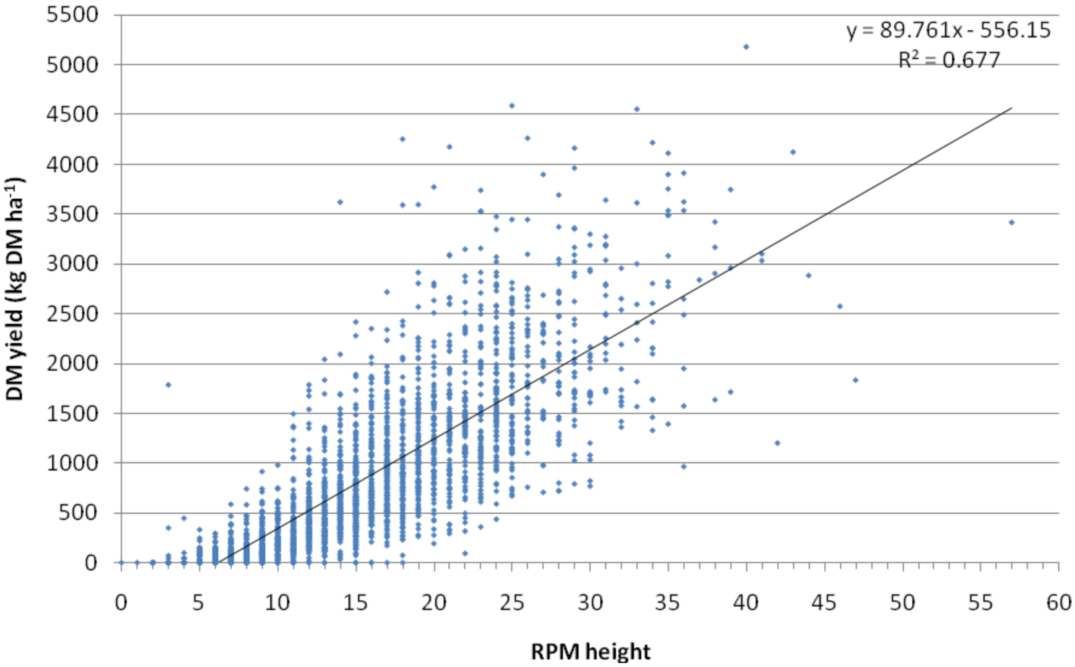

Figure 22: The data set used to construct the generalised annual post-grazing regression for the kikuyu-ryegrass (KR) treatment

4. Conclusions

Due to a change in botanical composition from ryegrass dominant pastures during winter to kikuyu dominant pastures during summer and the accompanying change in pasture structure of IR, WR and PR, all pre-grazing regressions developed during this study differed in terms of gradient and intercept values during different seasons and years for the respective treatments. The gradient values of regressions developed for IR and WR decreased from winter to spring as result of the annual Italian and annual Westerwolds ryegrass undergoing reproductive development and becoming more erect in growth form during spring, after which the ryegrass died off. The PR treatment, which did not undergo reproductive development and continued growth into summer, showed less variation in regression equations with season. The R^2 value of the seasonal pre-grazing regressions decreased from winter onwards as the pastures changed from temperate ryegrass based pastures to sub-tropical kikuyu based pastures. The high pasture yields and excessive stem material associated with kikuyu pastures during summer and autumn, resulted in the decreased accuracy of regressions during summer and autumn.

The post-grazing regressions developed for the pastures evaluated during this study did not have a lower precision than pre-grazing regressions, partially due to the low mean post-grazing height achieved for all pasture treatments throughout the experiemental period. The seasonal variation observed in the post-regression equations was most likely due to a change from pastures based on tufted ryegrass during winter and spring, to pastures based on creeping kikuyu during summer and autumn. The accumulation of a stoloniferous mat during the growth period of kikuyu resulted in an increase in the gradient value of regressions developed for IR and WR from winter/spring to summer/autumn.

The relationship developed between DM yield and RPM was adequately described by a linear regression, except for the pre-grazing regressions during autumn. The accumulation of large amounts of material in a stoloniferous mat during autumn would have resulted in DM yield increasing at a greater rate with increased RPM height at low heights, but at a lower rate at higher heights. This would have resulted in a curvilinear relationship between DM yield and RPM height during autumn.

The generalised RPM regressions (consisting of large pooled datasets) developed for kikuyu-ryegrass pastures during this study could be of use to farmers in the area, granted that pasture type and management practices are similar, management is optimal and post-grazing RPM heights are maintained at approximately 10 (50mm) throughout the growing season. Due to the large error associated with regressions pooled across pasture types and seasons, use of these regressions is not recommended for research purposes on kikuyu over-sown with ryegrass.

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CHAPTER 5

General Conclusions and Recommendations

The successful integration of kikuyu (*Pennisetum clandestinum*) as a pasture base into a pasture system holds specific challenges for the dairy producer. The most challenging aspects are the improvement of the seasonality of production and overall forage quality of the kikuyu in an economical and sustainable manner.

The strategic incorporation of different species and varieties of temperate C_3 grasses, such as annual ryegrass (*Lolium multiflorum*) and perennial ryegrass (*Lolium perenne*), into kikuyu pasture is a possible means of improving the seasonal DM production and forage quality of the pasture. There is, however, limited data available in the literature on the impact of the ryegrass species or variety on these aspects.

From this research the effect that over-sowing kikuyu with Italian (*Lolium multiflorum* var. *italicum*), Westerwolds (*Lolium multiflorum* var. *westerwoldicum*) or perennial ryegrass (*Lolium perenne*) has on the seasonal growth rate, annual DM yield, forage quality, grazing capacity, milk composition and milk yield was determined. In addition to this, calibration equations for the rising plate meter for irrigated kikuyu-ryegrass pasture systems, that were are intensively grazed by dairy cows in the Western Cape Province of South Africa, were developed that could assist farmers to determine pasture mass and growth rate more accurately.

The growth rate of different kikuyu-ryegrass pasture types varied greatly over months, with the lowest growth rates generally occurring during winter (June, July and August) and highest growth rates during spring or summer. Consideration should thus be given to the effect of varied growth rates within a kikuyu-ryegrass pasture system on the seasonal fodder flow program and pasture availability for the dairy herd. Nevertheless, the three different kikuyu-ryegrass pastures reached their peak growth rates and peak seasonal DM yields (kg DM ha^{-1}) during different seasons. The highest seasonal DM yield of kikuyu over-sown with Italian ryegrass (IR) occurred during spring, kikuyu over-sown with Westerwolds ryegrass (WR) produced its highest seasonal DM yield during summer and kikuyu over-sown with perennial ryegrass (PR) produced its highest seasonal DM yield during late spring/summer. The growth rate of each treatment during spring, predominately characterized by ryegrass growth, was found to affect the growth of kikuyu in the summer. The lower growth rate of the WR treatment during spring, compared to the IR treatment, resulted in higher seasonal DM yields of the WR treatment during summer as well as a higher kikuyu component (%). The relatively low growth rate of the

Westerwolds ryegrass during spring allowed higher amounts of sunlight to reach the growth points of the kikuyu that was recovering from winter dormancy, allowing rapid recovery and growth of the kikuyu. The high growth rate of the IR treatment during spring impacted negatively on the growth rate of the kikuyu component during summer due to the negative impact that the ryegrass would have on kikuyu recovery during spring via the effect of over-shadowing.

The annual DM production of all three treatments was similar during year 1. However, during year 2 the PR treatment had a higher annual DM production than IR and WR treatments. This was due to the trend whereby the seasonal DM yield of the PR treatment was either highest (winter and autumn) or similar to that of the highest producing treatments (spring and summer) during all seasons of year 2. The ability of the PR treatment to maintain DM production during periods when the other treatments underwent a dip in production (WR during spring and IR during summer) thus enabled the PR treatment to maintain a higher annual DM production during year 2 than the systems based on annual ryegrass species.

The seasonal change in the nutritional composition of the various kikuyu-ryegrass systems evaluated during this study, was found to coincide with the changes in botanical composition from ryegrass dominant pastures during winter and spring, to kikuyu dominant pastures during summer and autumn. As the kikuyu component increased from winter to summer, the dry matter (DM) and neutral detergent fiber (NDF) content of all pasture treatments increased, while the metabolisable energy (ME) content decreased. The crude protein (CP) content of all three treatments remained above 20% during all seasons, except during the summer of year 1, which coincided with the period when seasonal DM production was at its highest throughout the study. In addition to the above, the CP content of all three treatments was higher during winter than during summer and autumn during both years. During this particular research it was found that if ryegrass was maintained at higher levels in pastures during summer and autumn (which was the case with the perennial ryegrass-kikuyu system), forage quality of the kikuyu base could be improved. All pastures were deficient in terms of calcium (Ca) for high producing dairy cows throughout the study, thus dairy cows grazing kikuyu over-sown with ryegrass should be supplemented with Ca. In addition, the Ca:P ratio of all pastures was below 1.6:1 for dairy cows and pastures were also deficient in P during summer and autumn.

The grazing capacity of the three kikuyu ryegrass pasture systems showed the same seasonal variation as pasture growth rate, with the grazing capacities of all treatments higher during spring and summer than during winter and autumn. The highest grazing capacities occurred during summer for the WR treatment; summer/spring for the IR treatment and during summer/spring for the PR treatment.

Kikuyu over-sown with perennial ryegrass achieved a higher mean annual grazing capacity than the other two treatments during both years. Additonally, the study showed that kikuyu over-sown with perennial ryegrass was capable of achieving a more evenly distributed grazing capacity (with less difference between highest and lowest grazing capacities) than kikuyu over-sown with Italian or Westerwolds ryegrass. Regardless of the higher annual grazing capacity achieved by the PR treatment, it should be noted that grazing capacity still varied greatly during the growth season. As a result, fodderflow programs should still allow for periods when feed my fall short of animal requirements or when feed may exceed animal requirements within any kikuyu-ryegrass system.

The average daily milk production of the three kikuyu-ryegrass pasture systems varied between 15.9 and 16.1 kg cow^{-1} day^{-1} during year 1 and between 16.1 and 16.1 and 17.7 kg cow^{-1} day^{-1} during year 2. The 305-day milk yield of all treatments was similar during year 1, while PR had a lower 305-day milk yield than WR and IR during year 2. The 305-day fat corrected milk production of PR was lower than WR during year 1 and lower than IR and WR during year 2. The butterfat content (%) of the three treatments did not differ during year 1 or year 2, but the PR treatment had a lower butterfat production per lactation (kg BF lactation^{-1}) than IR and WR during both years. The milk protein content (%) of PR was lower than that of IR during year 1, while the protein production per lactation of PR was lower than that of IR during year 2. When compared in terms of total milk solids production per lactation, PR had the lowest production during year 1 and year 2.

Regardless of the above, the PR treatment had a higher mean annual grazing capacity and milk production per ha than the IR and WR treatments during year 1 and year 2. The FCM per ha and milk solids production per ha of the PR treatment was higher than that of the IR and WR treatment during year 2. It was thus concluded that because the number of animals supported by the PR treatment was higher and showed less variation, this treatment achieved higher animal production per ha during both years, regardless of it not achieving the highest production per animal.

The change in botanical composition from ryegrass dominant pastures during winter to kikuyu dominant pastures during summer for all pasture treatments and the associated change in pasture structure (density and leaf:stem ratio), was found to be an important determining factor of the gradient and intercept values of pre-grazing regressions developed during the study. For example, the gradient value of the pre-grazing regressions of the IR and WR treatments decreased from winter to spring as the two annual ryegrass species (Italian and Westerwolds ryegrass) underwent reproductive development and adopted a more erect growth-form during spring. In contrast, the perennial ryegrass in the PR treatment remained vegetative and continued growth into the summer, with the resultant effect that the regression equations for the PR treatment showed less seasonal variation than the other two kikuyu-ryegrass treatments.

In contrast to various other studies found in the literature, the post-grazing regressions developed during the study did not have a lower precision (lower R^2 values) than the pre-grazing regressions. This was most likely due to the high grazing pressures and low post-grazing heights achieved for all treatments throughout the study. In a similar trend as displayed in the pre-grazing regressions, the post-grazing regressions of all three treatments showed seasonal variation. This variation was attributed to the accumulation of a stoloniferous mat during the summer, which resulted in an increase on the gradient value of the post-grazing regression during this period.

The generalized rising plate meter (RPM) regressions developed for kikuyu-ryegrass pastures during this study, based on large datasets pooled over treatments, seasons and years, could be of use to farmers in the Western Cape region of South Africa. It is, however, important to ensure that pasture type and management practices of the pastures to be measured are similar to those described during this study. The use of these regressions by researchers is, however, not advisable. Due to the large errors associated with such pooled regressions, it is recommended that researchers should develop separate seasonal regressions for different pasture types under the specific climatic and management conditions applicable to the study they are undertaking.

Three important conclusions can be made from this study. Firstly that the duration of the growth season and the overshadowing effect of the different ryegrass species would affect the production of the kikuyu component during the following summer and autumn. Secondly, the change in botanical composition from a ryegrass dominant pasture during winter/spring to a kikuyu dominant pasture during summer/autumn resulted in a change in the forage quality of pastures, with the continued presence of ryegrass in pastures during summer and autumn holding the potential to improve the forage quality of the kikuyu-base. Finally, it was concluded that the grazing capacity, in terms of cows ha^{-1}, rather than milk production per cow, was the determining factor in the milk production per ha achievable from ryegrass-kikuyu systems.

Although the PR treatment achieved the highest dry matter, milk and fat corrected milk production per ha during year 2, the three kikuyu-ryegrass pasture systems must also be compared on an economic basis. Furthermore, the choice of which one of the three systems to use on a specific farm must be made according to the specific conditions prevalent on that farm and the fodder-flow requirements of the system. Possibly a combination of the three systems could be used to fill specific feed gaps for example 1) perennial ryegrass-kikuyu (planted during April/May) to provide food during late autumn, when annual ryegrass pastures is being over-sown into kikuyu, 2) Westerwolds ryegrass-kikuyu to provide high summer production of kikuyu and 3) Italian ryegrass-kikuyu to fill the spring feed-gap when Westerwolds ryegrass-kikuyu systems undergo a “dip” in production.

This data could therefor assist farmers and extension officers to identify the system which would be most appropriate for a specific farm, whilst also allowing for better fodder-flow planning. Further research, aimed at identifying other temperate species that are better adapted to the climatic conditions of the Southern Cape, which could reduce fertilizer and irrigation inputs and that are still capable of successfully growing and competing within a kikuyu based pasture, needs to be undertaken. This research is required to improve the profitability and sustainability of these kikuyu based pasture systems.

SUMMARY

Milk production in the Southern Cape region is based mainly on pastures, with most pastures consisting of a kikuyu (*Pennisetum clandestinum*)-base. Although pasture production of kikuyu is high during summer and autumn, with these pastures capable of supporting high stocking rates, kikuyu has certain shortcomings as a pasture specie. The greatest negative attributes of kikuyu pastures are; that winter and spring production is low, metabolisable energy intake on these pastures is low, it is deficient in a number of minerals, it is prone to mineral imbalances and milk production per animal is low. The strategic incorporation of temperate grass species, such as ryegrass (*Lolium* spp.), into kikuyu pastures during autumn is an inexpensive and effective method of filling the winter/spring feedgap and improving the forage quality of the pasture. However, farmers still need to make a decision on which species (annual or perennial) and which variety (Westerwolds or Italian) of ryegrass to over-sow into kikuyu. From and extensive study of the literature, it was found that there is currently limited data available on the pasture and milk production potential of kikuyu over-sown with Italian ryegrass (*L. multiflorum* var. *italicum*), Westerwolds ryegrass (*L. multiflorum* var. *westerwoldicum*) or perennial ryegrass (*L. perenne*).

The aim of this study was to quantify the growth rate, annual pasture production, seasonal botanical composition, forage quality, grazing capacity and milk production potential of kikuyu over-sown with Italian (IR), Westerwolds (WR) or perennial (PR) ryegrass. The study also evaluated the rising plate meter (RPM) for measurement of kikuyu-ryegrass pastures and developed appropriate calibration equations for such pastures in the Western Cape Province of South Africa.

The study consisted of a two year system trial conducted on nine hectares of existing kikuyu under permanent sprinkler irrigation. Pastures were intensively strip-grazed by Jersey cows in a put and take system. Growth rate (kg DM ha^{-1} day^{-1}), total seasonal dry matter production (kg DM ha^{-1}), total annual dry matter production (kg DM ha^{-1} $year^{-1}$), seasonal botanical composition, seasonal forage quality, grazing capacity, milk composition, milk production per cow per lactation and milk production per ha was determined. The pre-and post-grazing regressions developed for the RPM during the study included seasonal regressions for each treatment and combined regressions consisting of data pooled across treatments, seasons and years.

The growth rate of IR, WR and PR varied over months, with the three treatments reaching peak growth rates during different months and seasons. The IR treatment experienced its highest growth rate during spring, WR during summer and PR during spring/summer. The growth rates of all three treatments were lower during winter than during other seasons. The duration of ryegrass growth into

spring, and the effect of over-shadowing during this period, determined the summer and autumn growth potential of kikuyu. The IR treatment had high spring (ryegrass) growth rates but, low summer (kikuyu) growth rates. The WR treatment had low spring (ryegrass) growth rates and high summer (kikuyu) growth rates. The PR treatment was intermediate between the IR and WR treatments in terms of spring growth. The ability of the PR treatment to maintain DM production during periods when the other treatments underwent a dip in production (WR during spring and IR during summer) thus enabled the PR treatment to maintain a higher annual DM production during year 2 than the systems based on annual ryegrass species.

The botanical composition of all three treatments changed from ryegrass dominant pastures during winter and spring, to kikuyu dominant pastures during summer and autumn. As a result, the metabolisable energy (ME) and crude protein (CP) content of the kikuyu-ryegrass pasture decreased from winter to summer, whilst the neutral detergent fiber (NDF) content increased. All pasture treatments were deficient in terms of calcium (Ca) for high producing dairy cows throughout the study, with pastures also deficient in phosphorous (P) during summer and autumn. The Ca:P ratio of IR, WR and PR was below the recommended ratio of 1.6:1 for dairy cows during all seasons. The study also found that if ryegrass is maintained at a greater proportion in kikuyu-ryegrass pastures during summer and autumn, the forage quality of the pastures remained higher than when pastures consisted of only kikuyu.

The grazing capacity of IR, WR and PR varied over months and seasons, with the grazing capacity higher during summer and autumn than during winter and spring for all treatments. The seasonal grazing capacities of PR were found to be more evenly distributed than that IR and WR. In addition, the PR treatment had a higher mean annual grazing capacity than IR and PR. Although the PR treatment had a lower 305-day fat corrected milk (FCM) production than WR during both years and lower butter butterfat and milk solids production per lactation than IR and WR, it still achieved the highest milk production per ha during both years. Thus grazing capacity, rather than milk production per cow, was shown to be the determining factor for milk production achievable per ha from the various kikuyu-ryegrass systems.

An economical analysis of the different systems, accompanied by a description of the specific fodder-flow program of a particular farm, would be required to make further recommendations as to which system is the best system for a specific farm. Furthermore, a combination of the three systems, rather than one system alone, would most likely provide a better seasonal fodderflow.

The seasonal changes that occur in the botanical composition and pasture structure of kikuyu-ryegrass pastures resulted in seasonal variations of the gradient and intercept values of regressions developed for the RPM. The pre-grazing regressions of the two annual ryegrass species (Italian and Westerwolds ryegrass), which underwent reproductive development during spring, had shown more seasonal variation than that of the PR treatment. The development of a stoloniferous kikuyu mat during summer and autumn was identified as the most likely reason for the seasonal changes observed in the post-grazing regressions and decreasing accuracy from winter to summer/autumn. The accuracy of the post-grazing regressions developed for the PR treatment was also found to be negatively affected by the dense tuft that forms during the growth season of perennial ryegrass. The generalised RPM regressions (consisting of large pooled data sets) developed during the study could be of value to farmers in the area, especially to improve the accuracy of pasture growth rate and DM production. It is, however, important to ensure that pasture type and management practices of the pastures to be measured are similar to those described during this study. Such calibrations should not be used by researchers due to the large error associated with these pooled regressions.

APPENDIX A:

BLOCKING OF COWS FOR STUDY

Table A.1: List of cows, lactation number, butterfat production from previous lactation and fat corrected milk production for the cows as blocked for each treatment during year 1

Cow number	Treatment	LN	BF	FCM	Cow number	Treatment	LN	BF	FCM
1	IR	3	4.88	5858	9	IR	6	4.88	7146
1	WR	2	4.98	5899	9	WR	5	5.31	6840
1	PR	4	5.08	6131	9	PR	6	5.33	6537
2	IR	1	4.81	5117	10	IR	2	5.33	5756
2	WR	2	4.89	4802	10	WR	3	5.16	5729
2	PR	1	4.64	5055	10	PR	2	4.91	5668
3	IR	3	4.48	5383	11	IR	5	5.10	6512
3	WR	2	4.97	5635	11	WR	5	4.91	6360
3	PR	3	4.65	5388	11	PR	6	5.20	6443
4	IR	6	4.56	6306	12	IR	1	5.19	5032
4	WR	7	4.91	6303	12	WR	3	5.15	5367
4	PR	6	4.67	6490	12	PR	3	4.86	5442
5	IR	5	5.53	6806	13	IR	3	5.10	6935
5	WR	4	4.97	7262	13	WR	3	5.03	7283
5	PR	2	4.95	6470	13	PR	2	4.84	6639
6	IR	2	5.20	5281	14	IR	5	4.99	6721
6	WR	1	5.23	5108	14	WR	4	5.40	6086
6	PR	1	5.45	5554	14	PR	5	4.39	6389
7	IR	4	5.53	6059	15	IR	4	4.89	6670
7	WR	2	4.75	6374	15	WR	3	5.83	6694
7	PR	3	5.07	6158	15	PR	4	4.88	6636
8	IR	3	4.99	5364					
8	WR	5	4.60	5489					
8	PR	3	4.89	5595					

Table A.2: The mean butterfat content (%) and fat corrected milk production (kg milk cow^{-1}) from the previous lactation for cows used during year 1

Treatment	Butterfat content	305-day Fat corrected milk production
IR	5.03^{a}	6063^{a}
WR	5.07^{a}	6082^{a}
PR	4.92^{a}	6040^{a}
LSD (0.05)	0.216	495.5

Table A.3: List of cows, lactation number, butterfat production from previous lactation and fat corrected milk production for the cows as blocked for each treatment during year 2

Cow number	Treatment	LN	BF	FCM	Cow number	Treatment	LN	BF	FCM
1	IR	7	4.84	6627	9	IR	4	5.25	5379
1	WR	7	4.87	6622	9	WR	6	4.51	5753
1	PR	6	5.16	6296	9	PR	2	5.06	5975
2	IR	3	5.35	6182	10	IR	6	5.29	5631
2	WR	3	5.13	6415	10	WR	5	5.36	5543
2	PR	4	5.17	6450	10	PR	4	4.82	5213
3	IR	4	4.85	6693	11	IR	2	4.91	5412
3	WR	4	4.65	6764	11	WR	1	4.86	5503
3	PR	3	5.63	6259	11	PR	1	5.36	5056
4	IR	4	4.48	6109	12	IR	1	4.61	4996
4	WR	5	5.15	6125	12	WR	1	4.68	4631
4	PR	3	5.08	6076	12	PR	4	4.96	5425
5	IR	6	4.70	6237	13	IR	4	4.85	5309
5	WR	8	4.94	5838	13	WR	4	5.43	5259
5	PR	6	5.13	6265	13	PR	3	5.14	5162
6	IR	2	4.53	5915	14	IR	1	5.19	5302
6	WR	1	4.85	6083	14	WR	2	5.11	5096
6	PR	2	4.35	6047	14	PR	2	5.27	4937
7	IR	4	4.92	6055	15	IR	2	4.60	4495
7	WR	3	5.55	5775	15	WR	1	4.80	4584
7	PR	3	4.93	5956	15	PR	1	4.81	4774
8	IR	2	5.41	5661					
8	WR	1	5.33	5466					
8	PR	1	4.77	5660					

Table A.4: The mean butterfat content (%) and fat corrected milk production (kg milk cow-1) from the previous lactation for cows used during year 2

Treatment	Butterfat content	305-day Fat corrected milk production
IR	4.92^a	5734^a
WR	5.01^a	5697^a
PR	5.04^a	5703^a
LSD (0.05)	0.225	447.1

APPENDIX B:

EQUATIONS FOR PREDICTION OF LACTATION YIELD

Table B.1: **Equations used for the prediction of missing milk data for cows grazing kikuyu over-sown with Italian ryegrass (IR), Westerwolds ryegrass (WR) and perennial ryegrass during year 1**

Treatment	Cow	Equation	R²	Days predicted
IR	1	$y = 5E\text{-}06x^2 - 0.0388x + 21.81$	0.69	30
IR	4	$y = -8E\text{-}05x^2 - 0.0086x + 22.16$	0.70	3
IR	5	$y = -0.0001x^2 - 0.0017x + 18.91$	0.79	31
IR	6	$y = -0.0002x^2 + 0.0339x + 18.20$	0.81	7
IR	7	$y = -5E\text{-}05x^2 - 0.015x + 18.87$	0.73	6
IR	10	$y = -0.0001x^2 + 0.022x + 16.91$	0.48	12
IR	11	$y = -0.0002x^2 + 0.0265x + 19.79$	0.47	20
IR	14	$y = -0.0003x^2 + 0.0456x + 17.45$	0.43	55
IR	15	$y = -0.0002x^2 + 0.0221x + 16.57$	0.74	3
WR	1	$y = -0.0002x^2 + 0.0171x + 18.85$	0.70	12
WR	2	$y = -0.0002x^2 + 0.021x + 16.53$	0.67	40
WR	3	$y = -0.0002x^2 + 0.0236x + 17.26$	0.73	6
WR	4	$y = -0.0003x^2 + 0.0694x + 16.42$	0.76	6
WR	6	$y = -0.0001x^2 + 0.0059x + 18.40$	0.71	25
WR	8	$y = -0.0003x^2 + 0.0486x + 15.44$	0.72	6
WR	12	$y = -0.0003x^2 + 0.0625x + 16.83$	0.78	6
WR	13	$y = -0.0002x^2 + 0.0232x + 18.66$	0.46	6
WR	14	$y = -0.0002x^2 + 0.0153x + 20.19$	0.72	10
WR	15	$y = -0.0002x^2 + 0.0108x + 17.60$	0.68	9
PR	1	$y = -0.0001x^2 - 0.0009x + 21.09$	0.67	4
PR	4	$y = -0.0002x^2 - 0.0201x + 26.17$	0.82	12
PR	5	$y = 2E\text{-}05x^2 - 0.0474x + 20.53$	0.79	12
PR	6	$y = 7E\text{-}05x^2 - 0.0542x + 21.41$	0.71	9
PR	7	$y = -0.0001x^2 - 0.0033x + 21.57$	0.73	9
PR	8	$y = -2E\text{-}05x^2 - 0.0434x + 23.05$	0.80	24
PR	9	$y = -1E\text{-}04x^2 - 0.0314x + 23.36$	0.81	6
PR	10	$y = -5E\text{-}05x^2 - 0.0226x + 19.60$	0.76	4
PR	11	$y = -7E\text{-}06x^2 - 0.0397x + 24.78$	0.62	14
PR	12	$y = -1E\text{-}05x^2 - 0.0194x + 18.54$	0.51	9
PR	13	$y = -3E\text{-}05x^2 - 0.016x + 19.40$	0.41	19
PR	14	$y = -0.0003x^2 + 0.0677x + 15.30$	0.48	21

Table B.2: Equations used for the prediction of missing milk data for cows grazing kikuyu over-sown with Italian ryegrass (IR), Westerwolds ryegrass (WR) and perennial ryegrass during year 2

Treatment	Cow	Equation	R²	Days predicted
IR	2	$y = -0.0003x^2 + 0.0477x + 19.72$	0.79	34
IR	3	$y = -0.0002x^2 + 0.0069x + 22.71$	0.81	13
IR	7	$y = -0.0003x^2 + 0.0349x + 20.76$	0.80	24
IR	11	$y = -0.0003x^2 + 0.0322x + 23.11$	0.79	21
IR	13	$y = -0.0003x^2 + 0.0688x + 16.92$	0.66	30
IR	14	$y = -0.0002x^2 + 0.0278x + 18.06$	0.73	38
WR	1	$Y2 = -0.0002x^2 + 0.0194x + 24.89$	0.84	6
WR	2	$y = -0.0001x^2 + 0.0062x + 21.08$	0.73	19
WR	3	$y = -0.0002x^2 + 0.0085x + 22.64$	0.77	39
WR	4	$y = -0.0002x^2 + 0.0217x + 17.61$	0.72	22
WR	7	$y = -0.0003x^2 + 0.06x + 18.25$	0.80	13
WR	8	$y = -0.0002x^2 + 0.0202x + 22.42$	0.82	33
WR	9	$y = -0.0001x^2 + 0.0132x + 17.37$	0.63	12
WR	11	$y = -0.0002x^2 + 0.021x + 19.51$	0.77	16
WR	13	$y = -0.0002x^2 + 0.029x + 15.25$	0.64	8
WR	14	$y = -0.0003x^2 + 0.0526x + 15.62$	0.75	20
PR	2	$y = -0.0002x^2 + 0.0168x + 21.02$	0.79	25
PR	4	$y = -7E-05x^2 - 0.0188x + 21.12$	0.67	3
PR	5	$y = -0.0002x^2 + 0.0252x + 20.32$	0.63	31
PR	6	$y = -0.0002x^2 - 0.0178x + 27.94$	0.77	33
PR	7	$y = -0.0002x^2 + 0.0189x + 21.34$	0.65	8
PR	8	$y = -0.0002x^2 + 0.0206x + 20.94$	0.62	20
PR	10	$y = 4E-05x^2 - 0.0496x + 20.06$	0.80	26
PR	11	$y = -0.0001x^2 - 0.0126x + 22.62$	0.70	31
PR	12	$y = -0.0001x^2 - 0.0054x + 20.88$	0.70	12
PR	13	$y = -0.0001x^2 + 6E-05x + 18.54$	0.76	12
PR	14	$y = -0.0002x^2 + 0.0284x + 15.30$	0.39	20
PR	15	$y = -0.0002x^2 + 0.0455x + 16.50$	0.70	9